PROGRAM MANAGER
FOR ROCKY MOUNTAIN ARSENAL

U.S. ARMY
MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

Final Corrective Action Management Unit Designation Document Rocky Mountain Arsenal Commerce City, Colorado

Volume I of II

Harding Lawson Associates

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Final Corrective Action Management Unit Designation Document, Rocky Mountain Arsenal Commerce City, Colorado

Volume I of II

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THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

June 12, 1996

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PREFACE

On March 15, 1996, the U S Department of the Army (Army) submitted the Draft Final Corrective Action Management Unit (CAMU) Designation Document (Draft Final CDD) to the Colorado Department of Public Health and Environment (CDPHE) The Draft Final CDD was submitted by the Army to allow CDPHE to designate a CAMU at the Rocky Mountain Arsenal in accordance with Section 264 552 (a) of 6 CCR 1007-3 under the authority granted by the Hazardous Waste Management Act In response to the Army's CAMU application, CDPHE and the Army entered into a Compliance Order on Consent No 96-06-07-01 (the Order) on June 7, 1996

Paragraph 17 of the Order states

> "By this order on consent, the Department approves the Draft Final CAMU Designation Document as a corrective measure plan and the designation of a CAMU subject to the findings and conditions set forth in Attachment A, which is hereby incorporated into this Order on Consent "

The sole purpose of this Final CDD is to incorporate the modifications requested by CDPHE in Attachment A of the Order Appendix S of this document includes a complete list of the modifications

1.0 INTRODUCTION

This Corrective Action Management Unit (CAMU) Designation Document (CDD) has been prepared in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 (CRS) The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

The CDD has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0-007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Site Background

RMA is located northeast of Denver, Colorado, and is on more than 17,000 acres (27 square miles) (Figure 1) It is located about 10 miles from downtown Denver just north of the former Stapleton International Airport and west of Denver International Airport

1.1.1 Site History

RMA was built in 1942 to manufacture chemical weapons in support of World War II Chemical weapons such as mustard gas, white phosphorus, and napalm were manufactured at RMA. The Army continued with the manufacturing of these munitions until 1969 RMA was then used as a site to destroy these chemical munitions until the 1970s The Army leased RMA facilities to Shell Oil

Company (Shell) and its predecessors from 1952 to 1989 for manufacturing herbicides and pesticides A variety of methods was used for treating and disposing of wastes generated by manufacturing and munitions activities during the production years at RMA Disposal methods included chemical neutralization, incineration, evaporation, and offsite disposal Due to some of the disposal practices that existed during the manufacturing period, contamination of the soil, groundwater, surface water, and structures occurred

Offsite groundwater contamination was first discovered in the mid-1950s on agricultural land north of RMA In an attempt to contain the waste and prevent further offsite migration, the Army built a 93-acre, asphalt-lined storage pond (Basin F) A 12,500-foot deep injection well was also constructed to increase waste disposal capacity Despite these efforts, a significant cleanup action remained to be accomplished The Army began a systematic investigation into the contamination problem in 1984 in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) RMA was placed on the CERCLA National Priorities List for environmental cleanup in 1985 The Army's first and foremost goal was to contain the pollution and prevent additional offpost migration The Installation Restoration Program was created by the Army to address environmental issues at RMA Since 1985, the sole mission at RMA has been remediation of the contamination

1.1.2 Conceptual Remedy

In June 1995, an Agreement for a Conceptual Remedy (the Conceptual Remedy) for the Cleanup of RMA among the State, U S Environmental Protection Agency (EPA), the Army, Shell, and the U S Fish and Wildlife Service (FWS) was signed The Conceptual Remedy represents agreement by the parties relative to specific components of the remedy for the final cleanup of RMA These components of the remedy are included in the (1) Proposed Plan for the RMA Onpost Operable Unit and (2) Final Detailed Analysis of Alternatives Report (DAA) (Foster Wheeler, 1995) The Conceptual Remedy, the Proposed Plan for the Onpost Operable Unit, and the DAA are documents prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) The Conceptual Remedy calls for the construction and operation of a new onsite hazardous waste landfill for disposal of principal threat and human health exceedance soil and debris as those categories of contamination are defined in the DAA.

1.2 Summary of Regulatory Requirements

In the Onpost Operable Unit Detailed Analysis of Alternative Dispute Resolution Agreement dated October 16, 1995 (Dispute Resolution), the State, EPA, Army, Shell, and FWS agreed that a CAMU incorporating the future hazardous waste landfill, the Basin F Waste Pile drying unit, and the appropriate waste staging and/or management area(s) would be designated The Dispute Resolution was developed in accordance with the Federal Facility Agreement (FFA), which exists under CERCLA

The requirements for CAMUs are provided in 6 CCR 1007-3, Subpart S Section 264 552 This regulation provides the basis for designation of a CAMU and outlines the requirements for the CAMU that are to be specified as part of the designation In addition, Section 264 552(a)(3) specifies that where remediation waste placed into a CAMU is hazardous waste, the CAMU shall comply with Part 265, Subparts B,C,D, and E of 6 CCR 1007-3 (Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities [TSDFs]) When such remediation waste are to remain in place after closure, Section 264 552 (a)(3) also requires compliance with the siting requirements for hazardous waste disposal sites, which are found in 6 CCR 1007-2, Part 2 These regulatory requirements are listed below

- Part 265 Subpart B refers to general facility standards for owners and operators of hazardous waste TSDFs
- Part 265 Subpart C refers to preparedness and prevention requirements for TSDFs
- Part 265 Subpart D refers to contingency plan and emergency plan requirements for TSDFs
- Part 265 Subpart E refers to manifest system, record-keeping, and reporting requirements for TSDFs
- Requirements for siting and design of hazardous waste disposal sites which are found in 6 CCR 1007-2, Part 2

Section 4 0 provides a cross-reference of where CAMU related regulatory requirements and/or guidance is located within the CDD

1.3 Overview of the CDD

This CDD will be submitted to the CDPHE in response to Section 264 552(d) of 6 CCR 1007-3 As required in Section 264 552(d), the CDD includes information to enable CDPHE to designate the CAMU The basis or criteria for designation of a CAMU are specified in Section 264 552(c) of 6 CCR 1007 3 The corrective action order incorporating the designation of the CAMU will summarize requirements for design and operation, groundwater monitoring, closure and post-closure, as well as identify remediation wastes to be placed in the landfill These requirements are specified in 264 552(e)

Section 2 0 of this CDD contains a discussion of the basis and justification for the proposed designation of the RMA CAMU Section 3 0 addresses the operational, monitoring, closure, and post-closure requirements that will be developed in detail following designation of the CAMU Section 4 0 provides a cross-reference of regulatory requirements and/or guidance applicable to the CAMU and the location within the CDD where these requirements and/or guidance are addressed Section 5 0 presents a schedule of CAMU waste management activities Section 6 0 provides conclusions to the CDD Section 7 0 provides a list of acronyms used in the CDD Section 8 0 provides the references used to produce the CDD The appendixes to the CDD contain additional information, which is responsive to the design and/or operational requirements for a CAMU specified in 264 552(a)(3) and 264 552(e) The following appendixes are included with the CDD

- **Appendix A.** Part 2 Siting Criteria Compliance Demonstration
- **Appendix B** Design Narrative
- **Appendix C** Guidelines for the Development of an Operations Narrative
- **Appendix D** Guidelines for Development of a Waste Analysis Plan
- **Appendix I** Conceptual Test Fill Work Plan

- **Appendix K.** Guidelines for the Development of a Groundwater Monitoring Plan
- **Appendix L** Guidelines for the Development of a Closure and Post-Closure Plan
- **Appendix P** Preliminary Specifications
- **Appendix R** Final Landfill Site Feasibility Report

Included within Section 5 0 of this document is an outline for various engineering analysis work plans, plan products, and design drawings, which will be developed as part of the CAMU detailed design process Outlines of additional plans pertaining to construction and operation of the CAMU are presented in the Appendixes listed below The design and operational related work plans and products will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of this document The CDPHE review process may include a public comment period (see Section 5 0)

- **Appendix E** Security Plan Outline
- **Appendix F** Personnel Training Plan Outline
- **Appendix G** Inspection Plan Outline
- **Appendix H.** Construction Quality Assurance Plan Outline
- **Appendix J** Operating Record System Plan Outline
- **Appendix N** Action Leakage Rate and Response Plan Outline
- **Appendix O.** Health and Safety Plan Outline
- **Appendix Q** Contingency Plan Outline

2.0 BASIS FOR DESIGNATION OF THE CAMU

The DAA presents a detailed evaluation of the alternatives for final remedy of the cleanup of RMA The evaluations within the DAA resulted in the selection of a preferred sitewide remedy for the final remediation of the contaminated soil media and structures at RMA The preferred remedy includes the designation of a CAMU by CDPHE The components of the preferred remedy for soil and structures that will be conducted as part of the CAMU are as follows

- Onpost land disposal
- Basin F Waste Pile drying unit
- Related waste staging and/or management areas

A description of the preferred sitewide soil remedy selected within the DAA is presented in Table 2 1 The components of the preferred remedy that will be part of the CAMU waste management activities are highlighted in bold in Table 2 1 In addition, drummed waste generated as a result of RI/FS activities and currently stored in warehouses at RMA may be disposed in the landfill

Section 264 552 (c) of 6 CCR 1007-3 specifies certain decision criteria that are applicable to the designation of a CAMU Each of these criteria are discussed below

2.1 Facilitation of the Remedy

Section 264 552(c)(1) of 6 CCR 1007-3 requires that the CAMU facilitate the implementation of a reliable, effective, protective, and cost-effective remedy

The preferred sitewide remedy for soils, selected by the DAA, includes the creation of an onsite landfill for containment of principal threat and human health exceedance contaminated soil The principal threat and human health exceedance categorization of soil derives from the application of CERCLA related guidance and are fully explained within the DAA The preferred remedy also includes the drying of certain Basin F Waste Pile soil prior to disposal in the landfill For structures, the preferred Alternative calls for debris from the dismantling of structures with significant contamination history and agent history to be placed in the onsite landfill. As was agreed to within the Dispute Resolution, the onsite landfill and Basin F Waste Pile drying unit are remediation waste management activities that will be connected as part of the CAMU.

In selecting the preferred remedy, the DAA utilized nine evaluation criteria. These criteria are derived from the provisions in the CERCLA Section 121 and are also set forth in the National Contingency Plan (NCP) (codified at 40 Code of Federal Regulations [CFR] 300.430[e][9][iii]). The CERCLA criteria consist of two threshold criteria, five primary balancing criteria, and two modifying criteria (EPA, 1990). One of the threshold criteria and three of the primary balancing criteria are similar to the decision criteria that are applicable to the CAMU under CHWMA. These analogous CERCLA criteria are identified in Table 2.2.

The conclusions within the DAA that support the DAA's determination that the remedy is reliable, effective, protective, and cost-effective can be summarized as follows

- The remedy protects humans and biota by treating some principal threats and providing a physical barrier to prevent exposure through capping and landfilling.
- Mobility of the contaminants is reduced by minimizing the amount of infiltration into contaminated soil below the caps or in the landfill.
- Placement of soil excavated from the Basin F Wastepile and **Former Basin F principal threat soil** in a triple-lined cell provides additional assurance of containment. This additional containment balances the moderate short-term risk during excavation, transportation, and landfilling with the effectiveness of the long-term containment.
- Treatment and/or placement of other contaminated soil such as agent contaminated soil, buried M-pits, hex pits, debris with significant contamination and agent history in double lined cells provides for assurance of containment.
- The consolidation of 1,200,000 BCY of contaminated soil in Basin A, Basin F, and the South Plants Central Processing Area prior to capping these sites lowers the cost of obtaining borrow materials and reduces the area disturbed for borrow.

- The overall effectiveness of the preferred remedy is high since the preferred remedy provides low long-term risk, which compensates for a moderate short-term risk during excavation The cost of this remedy is lower than other remedies that may have been as equally overall effective

The following summarize how the CAMU waste management activities facilitate the implementation of the preferred remedy

- Drying saturated Basin F Waste Pile soil achieves a performance standard of only landfilling material, which passes the EPA paint filter test
- The landfill interrupts exposure pathways and the landfill's containment systems minimize the potential for migration of contaminants to groundwater
- Incorporation of the landfill units into a CAMU provides the regulatory flexibility to construct an onpost landfill
- The CAMU allows for the application of standards that are more appropriate to remediation wastes than as-generated RCRA wastes
- The CAMU expedites the implementation of the preferred remedy by expediting the approval process for the landfill

In addition to the above, an analysis of the long-term containment ability of the contemplated landfill design is presented in Section 2 1 1 of Appendix A to this document. That analysis also indicates that the landfill can be designed in a manner that is protective of human health

2.2 Risks to Human Health and the Environment

Section 264 552(c)(2) requires that the waste management activities associated with the CAMU not create unacceptable risks to humans or to the environment resulting from exposure to hazardous wastes or hazardous constituents

The waste management activities associated with the CAMU will include landfilling and the long-term containment of contaminated soil and debris The CAMU activities will also include the operation of the Basin F Waste Pile drying unit Waste staging/sizing/handling activities related to the landfill and drying of the Basin F Waste Pile soil will also be included within the CAMU

In the context of the federal preambles and Colorado's Statement of Basis and Purpose for CAMUs, an evaluation of short-term effectiveness should be performed within the context of other factors such as the long-term effectiveness of the remedy The DAA evaluated the short-term risk associated with the preferred remedy This evaluation included an assessment relative to the related CERCLA criteria indicated in Table 2 2 The DAA characterized short-term risk associated with the landfill and other CAMU waste management activities as being moderate The DAA further indicates that one or more of the following measures will, to the extent necessary, be utilized to control the short-term risks to an acceptable level

- Temporary enclosures, if necessary, to control odors and emissions
- Use of water or other vapor-and-dust suppressing agents to reduce particulate-related emissions from the landfill
- Use of interim and/or daily covers as material is placed in the landfill
- Use of proper personal protection equipment.
- Use of emission control equipment for the Basin F Waste Pile drying unit

Given the above discussion and the assessments performed within the DAA, it can be concluded that the CAMU waste management activities can be performed in a manner that does not create unacceptable risks to humans or the environment as a result of exposure to hazardous waste or hazardous constituents The short-term risks that may be associated with the CAMU activities, when considered with the long-term effectiveness, do not preclude the implementation of a reliable, effective, and protective remedy

2.3 Justification of Inclusion of Uncontaminated Area

The proposed areal configuration of the CAMU is located in an area of RMA, which is delineated within the DAA as being contaminated This area was identified within the Final Landfill Site Feasibility Study (FS) Soils Support Program (HLA, 1995) as the most protective landfill site within the RMA. A primary consideration in the selection of the preferred site was the protection afforded by that site's geologic and hydrologic conditions, as compared with other parts of RMA. A summary of the basis of the selection for the site is presented below

The selection of the landfill location was based on landfill siting criteria that were developed through a review of previous landfill siting studies, geologic, hydrologic, and geotechnical data, pertinent regulatory requirements, and consideration of issues relevant to siting a landfill at RMA The criteria developed within the FS were used to screen potential landfill areas to identify an area that met applicable regulatory requirements and provided the most protective location for siting of an onsite landfill A summary of the screening criteria are presented in Table 2 4 RMA features relevant to the screening criteria (e g , groundwater elevations, floodplains) were integrated into maps using a Geographical Information System (GIS) format. The maps were used to identify areas that met the screening criteria In addition, secondary screening criteria were evaluated to further screen out potential landfill locations Based on the screening evaluations, an area occupying the western half of Section 25 and a portion of the eastern half of Section 26 was identified

After the screening analysis, a geological/geotechnical investigation was initiated in the western half of Section 25 to obtain additional information regarding the suitability of the proposed area The investigation results indicated that the area is conducive to the construction of the landfill

Thus, the area identified for the CAMU is the most appropriate location within RMA based on considerations of siting criteria, subsurface conditions, and the protectiveness of human health and the environment.

2.4 Containment of Remediation Waste Remaining After Closure

Section 264 553(a)(3) of 6 CCR 1007-3 requires that where remediation wastes placed into a CAMU are hazardous, and, when such remediation wastes will remain in place after closure of the CAMU, the CAMU shall comply with the requirements for siting of hazardous waste disposal sites, which can be found in 6 CCR 1007-2, Part 2 Basin F Waste Pile soils are hazardous waste Other RMA waste may also be hazardous. As applied to the proposed CAMU, Section 2.5.3 of Part 2 requires that the landfill be capable of isolating the wastes within the designated disposal area and away from natural environmental pathways that could expose the public for at least 1,000 years.

An analysis is presented m Section 2.1 of Appendix A that demonstrates that the contemplated siting and design of the landfill combined with the geological conditions underlying the landfill area will comply with the 1,000-year isolation requirements.

Appendix L of this document presents guidance for development of a detailed closure plan following design. The detailed closure plan will be submitted to CDPHE for review and approval in accordance with the schedule discussed m Section 5.0 of this document. The closure plan will include closure and post-closure activities that will minimize or eliminate post-closure escape of hazardous waste or hazardous waste decomposition products.

The portion of the proposed CAMU that incorporates the Basin F Waste Pile drying unit and related waste staging/consolidation area(s) will be closed in a manner such that no wastes associated with these CAMU activities will be left in place. **Principal threat soil removal** and capping activities will also take place in the Former Basin F. These Former Basin F activities will be conducted in accordance with a closure plan approved by CDPHE. This closure plan will be reviewed and approved by CDPHE in accordance with regulations promulgated under authority of the CHWMA. The closure plan for former Basin F is not part of the proposed CAMU. Even though a portion of the Former Basin F wastes may be located within the areal configuration of the CAMU, they are not part of the CAMU waste management activities. In addition, the Former Basin F wastes do not meet the definition of remediation wastes as defined in 260.10 of 6 CCR 1007-3 (i.e., these wastes are handled under a closure plan to be approved by CDPHE). Given the above discussion, the Former Basin F wastes are not a consideration relative to the CAMU designation decision criteria.

Given the above discussions, it can be concluded that the proposed CAMU waste management activities that result in remediation wastes remaining in place after closure (the landfill) will control, minimize, or eliminate future releases to the extent necessary to protect human health and the environment

2.5 Expedite Timing of Remedial Activity Implementation

In selecting the preferred alternative (which includes the CAMU waste management activities), the DAA balanced the timing of implementation of the remedial activities with the need to implement a reliable, effective, protective, and cost-effective remedy (Section 264 552[c][1]) The preferred remedy is also consistent with Section 264 552(c)(2) regarding not creating unacceptable risks to humans or the environment

The CAMU expedites implementation of the preferred remedy by expediting the regulatory approval process for the landfill component of that remedy The CAMU (including its timing) also facilitates compliance with the requirements of Section 264 552(c)(1) and (c)(2)

2.6 Application of Treatment Technologies

Section 264 552(c)(6) specifies that, where appropriate, the CAMU shall enable the use of treatment technologies to enhance the long-term effectiveness of remedial actions by reducing the toxicity, mobility, or volume of remediation wastes that will remain in place after closure

The preferred remedy includes treatment of some principal threat material The landfill portion of the CAMU provides for final containment of the treated material The landfill also provides for containment of approximately 1 5 million cubic yards of soil and debris that will be placed in the landfill pursuant to the CERCLA Conceptual Remedy As discussed in Section 2 1 above, the CAMU facilitates the implementation of the preferred remedy The preferred remedy utilizes treatment as well as containment to provide for long-term effectiveness

2.7 Minimization of Land Area Where Remediation Wastes Will Remain in Place

The areal configuration of that portion of the CAMU where remediation wastes will remain in place after closure (i e , the landfill) is shown in Figure 2 of this document. The areal configuration of this portion of the CAMU was selected and minimized taking into account the following considerations

- Sufficient area must be provided to allow for flexibility in the design of the individual landfill cell(s) layout In developing the CAMU areal configuration, the total landfill volumes (waste plus daily cover) contemplated within the DAA were considered, as well as the necessity for flexibility in phasing of the overall remedy The phasing may require that the waste would be contained in several individual landfill cells The area shown in Figure 2 was sized considering the scheduling and sequencing of waste excavation contemplated by the Army at the time that this document was developed

- A minimum of 20 feet will be provided between the bottom of the landfill cells and the groundwater (This separation was based on the analysis of the 1,000-year isolation discussed in Section 2 1 1 of Appendix A)

- A 100-foot separation between the edges of landfill cell covers will be provided

- Height of landfill cell(s) is not a limiting factor

- A contingency factor of 25 percent was included in the analysis to account for uncertainties that may arise in design or scheduling/sequencing of the remedy

Given the above considerations, the area of that portion of the CAMU where remediation wastes will remain in place after closure has been selected in a manner that optimizes compliance with the requirements in Section 264 552(c)(1) for an effective remedy and in Section 264.552(c)(2) for minimization of exposure To the extent possible, given other siting criteria, the CAMU minimizes the land area where remediation wastes will remain in place after closure

3.0 ATTAINMENT OF CAMU REQUIREMENTS

The basis for designation of a CAMU is specified in Section 264 552(c) As discussed in Section 2 0 above, each of the decision criteria for designating the CAMU is achieved for the proposed RMA CAMU The corrective action order incorporating the designation of the CAMU will summarize requirements for the CAMU in accordance with Section 264 552(e) The Section 264 552(e) requirements include the following

- Areal configuration of the CAMU
- Requirements for design, operation, and closure
- Requirements for groundwater monitoring
- Closure and post-closure requirements

In addition to the above, Section 264 552(a)(3) states that where the remediation wastes placed into a CAMU are hazardous, the CAMU shall comply with Subparts B, C, D, and E of Part 265 These subparts specify general operating requirements Implementation of these operating requirements results in the need for the following plans

- Subpart B
  - Waste Analysis Plan (265 13)
  - Personal Training Plan (265 16)
  - Inspection Plan (265 15)
  - Construction Quality Assurance Plan (265 19)
  - Security Plan (265 14)
- Subpart C
  - Health and Safety Plan
- Subpart D
  - Contingency Plan

- Subpart E
  - Operating Record System Plan

As the above items are requirements for the CAMU, it is anticipated that they will be specified in accordance with the same process that is used to respond to Section 264 552(e) The documents and outlines presented in the attached appendixes are intended as a means of facilitating the specification, by CDPHE, of requirements for the CAMU

The various components of the proposed CAMU's waste management activities have not yet been designed Accordingly, it is premature to develop all of the specific details associated with implementation of the CAMU. For those CAMU requirements that are dependent upon completion of design, it is envisioned that the documents contained within the appendixes will be used as a framework or guidance for development of the design and final specific plans The specific plans will be reviewed and approved by CDPHE as part of the design review process These plans will be submitted in accordance with the schedule discussed in Section 5 0

A discussion of the requirements of Section 264 552(e) is presented below

3.1 Areal Configuration of the CAMU

The proposed CAMU boundaries are shown in Figure 2 of this document. Two CAMU locations are proposed One location, which incorporates 50 acres, includes the Basin F Waste Pile drying unit and any related decontamination facilities and/or waste staging/consolidation area(s) that may occur during closure of the waste pile This location is in the vicinity of the Basin F Waste Pile because it is anticipated that the optimal location for the drying process will be near the point of excavation The second CAMU boundary, which incorporates 245 acres, includes the landfill area and any related decontamination facilities and/or waste staging/consolidation areas

The areal extent of the CAMU boundary for the Basin F Waste Pile drying unit has been selected to allow for flexibility in the final location of the CAMU activities to be conducted in this area None of these CAMU activities result in remediation waste that is placed into the CAMU being left in place after closure

The basis for the location and areal extent of that portion of the CAMU that incorporates the landfill are discussed in Sections 2 3 and 2 7 above

3.2 Waste Management Requirements

The requirements for waste management under Section 264 552(e)(2) are anticipated to incorporate the following

- Design of the landfill, Basin F Waste Pile drying unit and associated decontamination facilities and/or waste staging/consolidation area(s)
- Operation of the CAMU waste management facilities
- The requirements related to 265 Subpart B, C, D, and E, which will result in the development of the plans listed in Section 3 0 that are associated with these subparts

Various sections of and appendixes to this document provide guidance for development of the detailed plans that will govern the above waste management requirements A cross reference of the regulatory requirement and the location within the CDD document where the guidance can be found is included in Section 4 0 The detailed plans will be developed as part of the CAMU design process The plans will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0

3.2.1 Design Requirements

Appendix B presents a Design Narrative that provides requirements for design The design requirements are presented in terms of performance standards and/or design guidance The performance standards represent design objectives as opposed to specifying a specific design detail The performance standards are driven by a regulatory requirement and/or guidance, such as the broad requirements of 6 CCR 1007-2, Part 2, Section 2 4

The completion of the design and subsequent review and approval of the design by CDPHE will represent fulfillment of the Section 264 552(e)(2) requirements for design of the CAMU

3.2.2 Operation Requirements

The final details of the operation requirements cannot be effectively developed until after completion of the design Appendix C presents the framework for development of the final operation requirements relative to the CAMU waste management activities The specific operating details will be developed and approved by CDPHE prior to commencing the CAMU waste management activities

3.2.3 Subparts B, C, D, and E Requirements

Appendix D presents a framework for development of a Waste Analysis Plan (WAP) The WAP will address the waste characterizations necessary for operation of the landfill and Basin F Waste Pile drying unit In the absence of design, particularly for the Basin F Waste Pile drying unit, it is not practical to specify the details of the WAP Those details will be developed during the design and will be submitted to CDPHE for review and approval as part of the design review process

Outlines for the other plans that derive from the 265 Subparts B, C, D, and E requirements are also presented in the appendixes to this document The locations of these plan outlines are cross-referenced in Table 4 2 with the regulatory requirement and/or guidance, which is related to a given plan

3.3 Groundwater Monitoring

Appendix K presents the primary elements of the groundwater monitoring program that may be used as guidance for the development of more detailed and specific Groundwater Monitoring Plans It is anticipated that three Groundwater Monitoring Plans will be developed and implemented during the course of the CAMU's waste management activities

The Groundwater Monitoring Program in Appendix K presents the components of the Background Monitoring System The Operational Period Groundwater Monitoring Plan will be developed and submitted for CDPHE approval during the design review process This timing allows for the incorporation of the background data into the development of the operational plan The Post-Closure Period Groundwater Monitoring Plan will be developed and submitted for CDPHE approval just prior to closure

3.4 Closure and Post-Closure Requirements

Appendix L presents a framework for development of the Closure and Post-Closure Plan. Effective development of the details for closure cannot occur until design The specific plans will be developed and submitted for CDPHE approval during the design review process

4.0 CROSS-REFERENCE OF REGULATORY REQUIREMENTS AND/OR GUIDANCE VERSUS LOCATION OF REQUIRED INFORMATION

The regulations for designating a CAMU are given in 6 CCR 1007-3, Section 264 552. Section 264 552(d) of this regulation requires the owner/operator of the CAMU to provide sufficient information to enable CDPHE to designate the CAMU in accordance with the criteria specified in Section 264 552 The purpose of this section is to cross-reference where the required regulatory information is located within the CDD

The subsections below include tables with columns listing the applicable regulation and/or guidance, a brief description or title of the regulation, and the appendix or section of the CDD where the regulation is addressed

4.1 Regulatory Requirements Under 6 CCR 1007-2, Part 2

The remediation waste placed in the landfill portion of the CAMU will be left in place after closure and in some cases that waste will be hazardous Therefore, compliance with the siting requirements for hazardous waste landfills that are found in 6 CCR 1007-3, Part 2 will be applicable

Table 4 1 presents the location in the CDD text and appendixes where the applicable requirements and/or guidance of Part 2 are addressed

4.2 Regulatory Requirements Under 6 CCR 1007-3, Part 265

The remediation waste placed in the landfill portion of the CAMU will in some cases be hazardous Therefore, in addition to compliance with the requirements of Section 264 552 of 6 CCR 1007-3, this CDD will address compliance with Part 265 Subparts B, C, D, and E Part 264 Subpart N, Landfills, also offers guidance related to the design and operation of the landfill portion of the CAMU Table 4 2 presents the location in the CDD text and appendixes where these requirements and/or guidance are addressed

5.0 SCHEDULE OF CAMU ACTIVITIES

Table 5 1 presents an itemization of the various design studies, analyses, drawings, and reports that will be developed as part of the CAMU detailed design process An itemization of the currently contemplated specifications, construction and operational plans for the CAMU is also provided in Table 5 1 As indicated in Section 1 3 of this document, guidance and/or outlines for development of many of the specifications and plans are presented in appendixes to the CDD Table 5 1 also presents an estimated time frame for submission of the plans and design work products to CDPHE for review and approval A schedule of CAMU activities from CDD designation activities through landfill operations is presented in Figure 3 The schedule is preliminary and subject to change due to uncertainties associated with implementation of the remedy

In CAMU working sessions, it was agreed that one additional public comment period would be provided during the CAMU design to provide an opportunity for public comment on the development of the design and operational details of the CAMU The schedule and format for this public comment period will be set by mutual agreement of CDPHE and the Army It is anticipated that the public comment period will be at or after the 30 percent level of design so that the design and operational details will have been substantially developed In the event of significant schedule variations or significant modifications to work plans or designs that had previously been available for a public comment period, the Army and CDPHE will evaluate the need to provide additional opportunity for public comment

6.0 CONCLUSIONS

The proposed CAMU at RMA meets all of the regulatory decision criteria specified in Section 264 552(c) for designation of a CAMU The specific details associated with the requirements for the CAMU waste management activities will be developed and submitted to CDPHE for approval during the design review process A framework for development of the specific details is presented in the various appendixes to this document. Appendix B to this document presents a design narrative, which will be used for developing the design of the facilities associated with the CAMU's waste management activities The design narrative provides the flexibility necessary for the design to meet the intent of the CERCLA Conceptual Remedy, while specifying design parameters that are directly related to specific regulatory requirements for the CAMU under CHWMA

7.0 ACRONYMS

Army	U S Department of the Army
BCY	Bank cubic yards
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHWA	Colorado Hazardous Waste Act
Conceptual Remedy	Agreement for a Conceptual Remedy for the Cleanup of the Rocky Mountain Arsenal
CRS	Colorado Revised Statute
DAA	Detailed Analysis of Alternatives
Dispute Resolution	Onpost Operable Unit Detailed Analysis of Alternatives Dispute Resolution Agreement
EPA	U S Environmental Protection Agency
FFA	Federal Facilities Agreement
FS	Feasibility study
FWS	U S Fish and Wildlife Service
GIS	Geographical Information System
HLA	Harding Lawson Associates
NCP	National Contingency Plan
RI/FS	Remedial Investigation/Feasibility Study
RMA	Rocky Mountain Arsenal
Shell	Shell Oil Company
State	State of Colorado
SY	Square yards

TCLP	Toxicity Characteristic Leaching Procedure
TMV	Toxicity, Mobility, Volume
TSDF	Treatment, storage, and disposal facility
WAP	Waste Analysis Plan

8.0 REFERENCES

Agreement for a conceptual remedy for the cleanup of the Rocky Mountain Arsenal between the U S Department of the Army, Shell Oil Company, the State of Colorado, the U S Environmental Protection Agency, and the U S Fish and Wildlife Service 1995 June 13

Foster Wheeler Environmental Corporation 1995 *Final detail analysis of alternatives*, Version 4 1 Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colorado October

Onpost Operable Unit Detailed Analysis of Alternative Dispute Resolution Agreement between the U S Department of the Army, Shell Oil Company, the State of Colorado, the U S Environmental Protection Agency, the U S Fish and Wildlife Service 1995 October 16

Harding Lawson Associates 1995 *Final landfill site feasibility report*, Rocky Mountain Arsenal, Commerce City, Colorado July

U S Environmental Protection Agency 1990 *Guide to selecting superfund remedial actions* April EPA/9355 0-27/FS

Table 2.1: Description of Preferred Sitewide Soil Remedy*

Medium Groups/ Subgroups	Components of the Preferred Remedy with the CAMU Waste Management Activities in Bold
Munitions Testing	Munitions Screening; off post detonation of UXO; **Landfill debris and soil above TCLP (89,000 BCY)**. (Alternative U4a; Section 5.2.4). #
North Plants	**Landfill human health exceedance (220 BCY);** agent screening during excavation; caustic solution washing; cap/cover (soil cover) soil posing risk to biota and processing area footprint (160,000 SY). (Alternative A3; Section 6.2.3). #
Toxic Storage	**Landfill human health exceedance (2,700 BCY)**; utilize New Toxic Yards Storage Yard for borrow area; agent screening during site excavation and preparation, caustic washing. (Alternative A3; Section 6.5.3). #
Lake Sediments	**Landfill human health exceedances (19,000 BCY)** and consolidate soil posing risk to biota (19,000 BCY) (Upper Derby Lake); deferral to USFWS for aquatic sediment. (Alternative B5a; Section 7.2.4). #
Surficial soil	**Landfill human health exceedances (87,000 BCY)** consolidate soil posing risk to biota in Basin A/Former Basin F/South Plants (450,000 BCY); Parties to determine action in accordance with Conceptual Remedy for remainder of site. (Alternative B5a; Section 8.2.4). #
Ditches/Drainage Areas	Consolidate soil posing risk to biota in Basin A (52,000 BCY). (Alternative B5a; Section 9.2.4).
Basin A	Cap/cover (concrete/soil cap) principal threat and human health exceedances and soil posing risk to biota (670,000 SY); consolidate soil posing risk to biota (800,000 BCY); and structural debris (160,000 BCY) from other sites. (Alternative 6; Section 10.2.5).
Basin F Waste Pile	**Landfill entire waste pile principal threat exceedance (600,000 BCY) in triple lined cell (with vapor controls) after drying saturated materials.** (Alternative 3; Section 11.2.3). #
Former Basin F	**Landfill principal threat soil (165,000 BCY) in triple lined cell.** (RMA ROD Amendment 10/20/05); cap/cover (RCRA-Equivalent cover) entire site (446,000 SY).
Secondary Basins	**Landfill human health exceedances (32,000 BCY);** cap/cover (soil cover) soil posing risk to biota (500,000 SY). (Alternative 3b; Section 12.2.4). #
Sanitary/Process Water Sewers	Plug remaining manholes. (Alternative 2; Section 13.2.2).
Chemical Sewers	Plug sewer lines in South Plants Central Processing Area and Complex Trenches; **landfill remaining principal threat and human health exceedances (64,000 BCY)**. (Alternative 38; Section 13.5.7). #

Table 2.1 (continued)

Medium Groups/ Subgroups	Components of the Preferred Remedy with the CAMU Waste Management Activities in Bold
Complex Trenches	Cap/cover (concrete/soil RCRA-equivalent cap) principal threat and human health exceedances and soil posing risk to biota (390,000 SY) and install a slurry wall around disposal trenches. (Alternative 5, Section 14.2.2).
Shell Trenches	Modify existing cap/cover to be RCRA equivalent (32,000 SY) and modify existing slurry wall around trenches. (Alternative 5a, Section 14.5.3).
Hex Pit	Treatment technologies (including innovative technologies) to be reviewed and remedy to be determined prior to ROD **(3,300 BCY)**.
Sanitary Landfill	**Landfill human health exceedances (14,000 BCY)**; consolidate debris and soil posing risk to biota in Basin A (410,000 BCY). (Alternative 3f, Section 15.2.4).#
Section 36 Lime Basins	Construct in-situ slurry wall around basins; cap/cover (RCRA-Equivalent cover) entire site (63,000 SY). (RMA ROD Amendment 10/20/05)
Buried M-1 Pits	Solidification of principal threat and human health exceedances **(26,000 BCY)** and **Landfill (with vapor controls)**. (Alternative 10, Section 16.5.4). #
South Plants Central Processing	**Landfill principal threat and human health exceedances (110,000 BCY)**; cap/cover (soil cover) entire site including soil Area posing risk to biota (220,000 SY); consolidate soil posing risk to biota from other sites (380,000 BCY). (Alternative 3b, Section 17.2.3). #
South Plants Ditches	**Landfill principal threat and human health exceedances 33,000 BCY)**; consolidate soil posing risk to biota into excavated areas or South Plants Central Processing Area (23,000 BCY); cap/cover (soil cover) entire site (120,000 SY). (Alternative 3g, Section 17.5.5). #
South Plants Balance of Areas	**Landfill principal threat and human health exceedances (135,000 BCY)**; consolidate soil posing risk to biota into excavated areas or South Plants Central Processing Area (510,000 BCY); cap/cover (soil cover) entire site (1,700,000 SY). (Alternative 3g, Section 17.8.5). #
Buried Sediments	**Landfill human health exceedances (16,000 BCY).** (Alternative 3, Section 18.2.3). #
Sand Creek Lateral	**Landfill human health exceedances (55,000 BCY)**; consolidate soil posing risk to biota into Basin A (90,000 BCY). (Alternative 3f, Section 18.5.3).#
Section 36 Balance of Areas	**Landfill human health exceedances and debris (142,000 BCY)**; consolidate soil posing risk to biota into Basin A (200,000 BCY); cap/cover (soil cover) entire site (710,000 SY). (Alternative 3g, Section 19.2.4).#

Table 2.1 (continued)

Medium Groups/ Subgroups	Components of the Preferred Remedy with the CAMU Waste Management Activities in Bold
Burial Trenches	**Landfill human health exceedances and debris (85,000 BCY)** (Alternative 3, Section 19 5 2)

BCY Bank cubic yards
CAMU Corrective Action Management Unit
DAA Detailed Analysis of Alternatives
RCRA Resource Conservation and Recovery Act
ROD Record of Decision
SY Square yards
TCLP Toxicity characteristic leaching procedure
USFWS U S Fish and Wildlife Service
UXO Unexploded Ordnance

* This table was derived from Table ES4 3-1 of the Executive Summary (Vol I) of the Final detailed Analysis of Alternatives Report, Version 4 1, October 1995 As indicated on the DAA Preferred Alternative Mass Balance Diagram (October 29, 1995), some of the volume estimates presented in the above tables have been modified and other onsite materials, not included in the above table, will be placed in the landfill These other materials include

- Agent Structures Demolition (120,000 BCY)
- Significant Contaminated Structures (42,000 BCY)
- Caustic Agent Treatment Facility (10,000 BCY)
- Contingent Soil Volume (150,000 BCY)

\# Alternative designations and section references refer to the DAA.

Table 2.2: CERCLA Evaluation Criteria that are Analogous to Certain CAMU Decision Criteria

Threshold Criteria

- Overall Protection of Human Health and the Environment — This criterion addresses whether or not a remedy provides adequate protection and describes how risks posed through each exposure pathway (assuming reasonable maximum exposure) are eliminated, reduced, or controlled through treatment, engineering controls, or institutional controls — Relates to the CAMU decision criteria found at 6 CCR 1007 3 Part 264 552(c)(1)

Primary Balancing Criteria

- Long-term Effectiveness and Permanence — This criterion refers to the ability of a remedy to maintain reliable protection of human health and the environment over time once remediation goals have been met. — Relates to CAMU decision criterion found at 6 CCR 1007-3 Part 264 552(c)(1)

- Short-term Effectiveness — This criterion addresses the period of time needed to achieve protection and any adverse impacts on human health or the environment that may be posed during the construction and implementation period until remediation goals are achieved — Relates to the CAMU decision criteria found at 6 CCR 1007-3 Part 264 552(c)(1) and (c)(2)

Table 2.3: Summary of Analysis of Sitewide Soil Remedy Relative to Those CERCLA Criteria that are Similar to CAMU Designation Criteria

CERCLA Decision Criteria	Preferred Remedy
Overall protection of human health and the environment	Protective Exposures to humans and biota prevented by containing contaminated soil in place and by treating some of the principal threat volume
Long-term effectiveness and permanence	Minimal residual risk. Relies on treatment of some highly contaminated soil, groundwater controls, and capping/landfilling to prevent migration and exposure
Reduction in Toxicity, Mobility, or Volume	Toxicity, mobility, or volume of some highly contaminated soil reduced through treatment, relies on containment for most mobility reduction.
Short-term effectiveness	Moderate short-term risk. Some high-risk sites excavated and transported, potential for releases

Table 2.4: Summary of Rocky Mountain Arsenal Landfill Siting Criteria

Siting Criteria	Landfill Siting Criteria Regulations: Description	Landfill Siting Criteria Regulations: Citation	Regulatory Criteria Adopted HLA, 1994: Primary Siting Criteria Adopted	Regulatory Criteria Adopted HLA, 1994: Secondary Siting Criteria
Faults	>1,000 feet from a Holocene fault >200 feet from a Holocene fault	6 CCR 1007-3, 264 18(a) 6 CCR 1007 2, 3 1 3	>1,000 feet from a Holocene fault	
Floodplain	Outside 100-year floodplain Not located in "floodplain" as defined in regulation	6 CCR 1007-3, 264 18(b) 6 CCR 1007 2, 3 1 7	Outside 100 year floodplain	
Salt formations	Not within salt formations	6 CCR 1007-3, 264 18(c)	Not within salt formations	
Surface water/groundwater	No waste placed below or into surface water or groundwater No waste placed below or into surface water or groundwater	6 CCR 1007 3, 264 18(d) 6 CCR 1007 2, 3 1 9	No waste placed below or into surface water or groundwater	Maximize depth to groundwater
Airport safety	Notification if facility is within 5 miles of runway	6 CCR 1007 2, 3 1 1	Notification if facility is within 5 miles of runway	
Wetlands	Not located in wetlands	6 CCR 1007 2, 3 1 2	Not within wetland	
Seismic impact zone	Not located in seismic impact zone without demonstration	6 CCR 1007 2, 3 1 4	Not located in seismic impact zone without demonstration	
Unstable areas	Not within unstable area	6 CCR 1007-2, 3 1 5	Not within unstable area	
Topography	Maximize protection from wind and precipitation catchment area	6 CCR 1007-2, 3 1 6	Maximize protection from wind and precipitation catchment area	
Isolation	Isolate waste from public and environment	6 CCR 1007-2, 3 1 8 6 CCR 1007 2 4 1	Isolate waste from public and environment	
Hydrogeology	Reasonable assurance that waste isolated for 1,000 years	6 CCR 1007-2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1,000 years	Avoid saturated alluvium
Geology	Reasonable assurance that waste isolated for 1,000 years	6 CCR 1007-2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1,000 years	Minimize depth to bedrock

Table 2.4 (continued)

Siting Criteria	Landfill Siting Criteria Regulations: Description	Landfill Siting Criteria Regulations: Citation	Regulatory Criteria Adopted HLA, 1994: Primary Siting Criteria Adopted	Regulatory Criteria Adopted HLA, 1994: Secondary Siting Criteria
Location	Within distance controlled by Army to prevent adverse effects to public health	6 CCR 1007-2, Part 2, 2 5 6	Within distance controlled by Army to prevent adverse effects to public health	Centrally located within RMA boundary
Buffer Zone	Noise levels within limits	CRS Sections 25-12-101 to 108	Noise levels within limits	

CCR Code of Colorado Regulations
CRS Colorado Revised Statute
HLA Harding Lawson Associates
RMA Rocky Mountain Arsenal

Table 4.1: Cross-Reference of Regulatory Requirements and/or Guidance - Part 2

Regulatory Section	Requirement and/or Guidance	Where Addressed in CDD Appendix	Title	Section
2 4 1	Designed in a manner that the design performance will assure long term protection of human health and the environment	A	Part 2 Siting Compliance Demonstration	All
		B	Design Narrative	All
2 4 2	Designed to prevent long-term adverse effects on groundwater	A	Part 2 Siting Compliance Demonstration	3 1
2 4 3	Designed to prevent long-term adverse effects on surface-water quality	A	Part 2 Siting Compliance Demonstration	3 2
		B	Design Narrative	7 0
2 4 4	Designed to prevent long-term adverse effects on air quality	A	Part 2 Siting Compliance Demonstration	3 3
		B	Design Narrative	All
2 4 5	Designed to prevent long-term adverse effects on public health and the environment due to migration of waste constituents in the surface or subsurface environment	A	Part 2 Siting Compliance Demonstration	3 4
		B	Design Narrative	All
2 4 6	Protection of the function and physical integrity of any liner placed in a hazardous disposal site	A	Part 2 Siting Compliance Demonstration	3 5
		B	Design Narrative	All
		G	Inspection Plan	All
		H	Construction Quality Assurance Plan	All
		P	Specifications	All
		Q	Contingency Plan	All
2 4 7	Leachate and runoff control systems designed with sufficient capacity such that the design performance complies with Sections 2 4 1 through 2 4 5	A	Part 2 Siting Compliance Demonstration	3 6
		B	Design Narrative	5 0, 7 0
2 4 8	Design includes a method of closure that provides reasonable assurance of long-term compliance with Sections 2 4 1, 2 4 2, 2 4 4, 2 4 5, and 2 4 7	A	Part 2 Siting Compliance Demonstration	3 7
		B	Design Narrative	4 0
		L	Closure and Post-Closure Plan	All
2 4 9	Design includes systems for monitoring groundwater and surface water and providing quality control of materials in construction	A	Part 2 Siting Compliance Demonstration	3 8
		B	Design Narrative	All
		C	Operations Narrative	All
		G	Inspection Plan	All
		H	Construction Quality Assurance Plan	All
		I	Test Fill Work Plan	All
		K	Guidelines for the Development of a Groundwater Monitoring Plan	All
		P	Specifications	All
2 4 10	Design includes procedures to be followed during construction, including certification by a professional geologist or engineer to demonstrate that the facility is constructed in accordance with the design as approved	A	Part 2 Siting Compliance Demonstration	3 9
		H	Construction Quality Assurance Plan	All
		I	Conceptual Test Fill Work Plan	All
		P	Specifications	All

Table 4.1 (continued)

Regulatory Section	Requirement and/or Guidance	Where Addressed in CDD Appendix	Title	Section
2 5 1	Siting and design demonstrates that the minimum design performance criteria contained in Section 2 4 will be satisfied after site construction and implementation of the proposed design	A	Part 2 Siting Compliance Demonstration	All
		B	Design Narrative	All
		C	Operations Narrative	All
2 5 2	The proposed design, and design performance of a hazardous waste disposal site	C	Operations Narrative	All
2 5 3	Reasonable assurance is provided that hazardous wastes to be disposed will be isolated within the designated disposal area of the site and away from natural environmental pathways that could expose the public for 1,000 years	A	Part 2 Siting Compliance Demonstration	2 1
2 5 4	Design includes a liner whose performance complies with Sections 2 4 1, 2 4 2, 2 4 3, and 2 4 5	A	Part 2 Siting Compliance Demonstration	2 2
		B	Design Narrative	3 0
2 5 5	Design includes a leachate and runoff control system that will provide compliance with Section 2 4	A	Part 2 Siting Compliance Demonstration	2 3
		B	Design Narrative	3 0
2 5 6	The location for disposal and preparation for disposal of hazardous wastes will be within a distance controlled by the owner/operator by an acceptable means to prevent adverse effects on the public health should unexpected discharges of hazardous waste occur	A	Part 2 Siting Compliance Demonstration	2 4

CAMU Corrective Action Management Unit
CDD CAMU Designation Document
CCR Code of Colorado Regulations

Table 4.2: Cross-Reference of Regulatory Requirements and/or Guidance Subparts B, C, D, E, N, and S

Regulatory Section	Regulation and/or Guidance	Where Addressed in CDD Appendix	Title	Section
Subpart B - General Facility Standards				
265 12	Required Notices		Not Applicable	
265 13	General Waste Analysis	D	Guidelines for the Development of a Waste Analysis Plan	All
265 14	Security	E	Security Plan Outline	All
265 15	General Inspection Requirements	G	Inspection Plan Outline	All
265 16	Personnel Training	F	Personnel Training Plan Outline	All
	General Requirements for Ignitable Reactive or Incompatible Waste	C	Guidelines for the Development of an Operations Narrative	2 1 2
265 17		O	Health and Safety Plan Outline	All
265 18	Installation Standards	A	Part 2 Siting Compliance Demonstration	4 0
265 19	Construction Quality Assurance Program	H	Construction Quality Assurance Plan Outline	All
Subpart C - Preparedness and Prevention				
265 30 through 265 37		B	Design Narrative	All
		C	Guidelines for the Development of an Operations Narrative	8 0
		O	Health and Safety Plan Outline	All
		Q	Contingency Plan Outline	All
Subpart D Contingency Plan and Emergency Procedures				All
265 50 through 265 56		Q	Contingency Plan Outline	All
Subpart E Manifest System Record Keeping and Reporting				
265 70 through 265 73		J	Operating Record System Plan Outline	All
Subpart N Landfills				
264 300		B	Design Narrative	All
		C	Guidelines for the Development of an Operations Narrative	All
Subpart S - Corrective Action				
264 552	Corrective Action Management Units			
264 552 (c)(1)	Facilitation of the Remedy	N/A	CDD Text	2 1
264 552 (c)(2)	Risks to Human Health and Environment	N/A	CDD Text	2 2

Table 4.2 (continued)

Regulatory Section		Regulation and/or Guidance	Where Addressed in CDD		
			Appendix	Title	Section
264 552	(c)(3)	Justification for Inclusion of Uncontaminated Areas	N/A	CDD Text	2 3
264 552	(c)(4)	Containment of Remediation Wastes Remaining after Closure	N/A	CDD Text	2 4
264 552	(c)(5)	Timing of Remedial Action Implementation	N/A	CDD Text	2 5
264 552	(c)(6)	Application of Treatment Technologies	N/A	CDD Text	2 6
264 552	(c)(7)	Minimization of Land Area	N/A	CDD Text	2 7
264 552	(e)(1)	Areal Configuration of CAMU	N/A	CDD Text	2 8 1
264.552	(e)(2)	Waste Management Requirements	N/A	CDD Text	2 8 2
264 552	(e)(3)	Groundwater Monitoring	N/A	CDD Text	2 8 3
264 552	(e)(4)	Closure and Post-Closure Requirements	N/A	CDD Text	2 8 4

CAMU Corrective Action Management Unit
CCR Code of Colorado Regulations
CDD CAMU Designation Document
N/A Not applicable

Table 5.1: Preliminary Scope of Work and Schedule of Design Activities for the RMA CAMU

Task/Deliverable	Subtask	Time Frame for Preparation and Submission to CDPHE for Review and Approval[a]
1 0 Design Studies and Evaluations		
	Test Fill Program[b]	Third quarter 1996 through first quarter 1997
	Survey Landfill Area and Borrow Areas	Second quarter 1996 through first quarter 1997
	Waste Sampling and Analysis/Testing, as necessary	Second quarter 1996 through third quarter 1997
	Sampling and Evaluation of Onsite Materials, as necessary	Second quarter 1996 through third quarter 1997
	Sampling and Evaluation of Foundation Materials, as necessary	Second quarter 1996 through third quarter 1997
	Compatibility Evaluations and Testing	Second quarter 1996 through fourth quarter 1997
	Landfill Component Equivalency Evaluations (where applicable)	Second quarter 1996 through third quarter 1997
	Constructability and Cost Evaluations	Second quarter 1996 through fourth quarter 1997
	Value Engineering Analysis	Second quarter 1996 through fourth quarter 1997
2 0 Landfill Design Report		Second quarter 1996 through fourth quarter 1997
Design Basis and Calculations		
	Cell Construction	
	Cell Configuration and Sizing (Landfill Cell Layout Plan)	Second quarter 1996 through third quarter 1997
	Cut and Fill Volume Estimates	Second quarter 1996 through third quarter 1997
	Subgrade Stability, Bearing Capacity, Settlement, Hydrostatic Pressure, and Seismic Evaluations	Second quarter 1996 through third quarter 1997
	Liner System	
	Liner Materials Compatibility Evaluations and Testing	Second quarter 1996 through fourth quarter 1997
	Slope Stability, Bearing Capacity, Settlement, Hydrostatic Pressure, and Seismic Evaluations	Second quarter 1996 through third quarter 1997
	Material Equivalency Demonstration, if applicable	Second quarter 1996 through third quarter 1997
	Leachate Collection and Leak Detection Systems	
	Materials Compatibility Evaluations and Testing	Second quarter 1996 through fourth quarter 1997
	Flow Capacity and Head Buildup to Include HELP Modeling	Second quarter 1996 through third quarter 1997
	Pipe Selection and Sizing	Second quarter 1996 through third quarter 1997
	Sump Configuration and Sizing	Second quarter 1996 through third quarter 1997
	Pump Selection and Sizing	Second quarter 1996 through third quarter 1997
	Material Equivalency Demonstration, if applicable	Second quarter 1996 through third quarter 1997

Table 5.1 (continued)

Task/Deliverable	Subtask	Time Frame for Preparation and Submission to CDPHE for Review and Approval[a]
	Cover System	
	Slope Stability, Bearing Capacity, Settlement, Hydrostatic Pressure, and Seismic Evaluations	Second quarter 1996 through third quarter 1997
	Volume Estimates for Clay(if applicable), Drainage Layer, Biota Barrier, Vegetation Layer and Top Soil	Second quarter 1996 through third quarter 1997
	Infiltration Drainage System Flow Capacity to Include HELP Modeling	Second quarter 1996 through third quarter 1997
	Wind and Water Erosion	Second quarter 1996 through third quarter 1997
	Material Selection Evaluations	Second quarter 1996 through third quarter 1997
	Selection of Vegetation	Second quarter 1996 through third quarter 1997
	Gas Collection/Venting System	
	Gas Production Rates	Second quarter 1996 through third quarter 1997
	Gas Collection System Capacity, Sizing, and Vent Spacing	Second quarter 1996 through third quarter 1997
	Surface Water Drainage Systems	
	Drainage and Retention Structure Selection and Sizing	Second quarter 1996 through third quarter 1997
	Erosion Evaluation	Second quarter 1996 through third quarter 1997
Drawings		Third quarter 1996 through fourth quarter 1997
	Title Sheet	
	Index/List of Drawings	
	Legend, Symbols, Abbreviations, and General Notes	
	Site and Vicinity Maps	
	Existing Site Plans	
	Existing Exploration Plans	
	Limits of Construction and CAMU Boundary Plans	
	Disposal Cell Excavation and Grading Plans	
	Disposal Cell Liner Component Grading Plans	
	Leachate Collection and Leak Detection Piping and Grading Plans	
	Surface Water Collection and Removal Plans	
	Temporary Cover and Waste Grading Plans	
	Disposal Cell Final Grading Plans	
	Disposal Cell Sections and Details	
	Sumps and Pipe Plans, Sections, and Details	
	Sump Electrical Diagrams for Pumps and Connections	
	Borrow Area Excavation, Grading, and Reclamation Plans and Sections	
	Cell Development Sequence	
	Typical Cell Filling Plan, Sections, and Details	
	Access Ramp Details	
	Haul Traffic Control Plans	
	Construction Staging and Decontamination Plans, Sections, and Details	
	Ancillary Facility Plans, Sections, and Details	

Table 5.1 (continued)

Task/Deliverable	Subtask	Time Frame for Preparation and Submission to CDPHE for Review and Approval[a]
Specifications (Appendix P)[c]		Third quarter 1996 through fourth quarter 1997
	Summary of Work	
	Construction Controls	
	Environmental Controls	
	Traffic Regulations and Controls	
	Emission Controls	
	Storm, Surface Water and Erosion Controls	
	Control Measure Procedures	
	Demolition	
	Borrow Area Operations	
	Survey Services	
	Earthwork	
	Low Permeability Layer (Compacted Clay Liner)	
	Drainage Aggregate and Biotic Barrier Layer	
	Top Soil	
	Geotextiles	
	Geomembranes	
	Geosynthetic Clay Liners	
	Geonets	
	Erosion Control Materials	
	Waste Handling and Placement	
	Storm Water Structures and Controls	
	Construction Material Stockpile, Staging, and Treatment Areas	
	Daily Cover	
	Leachate Collection and Removal System Piping and Sump	
	Seeding	
	Pavement and Base Course Materials	
	Concrete	
	Miscellaneous Metals	
	Monitoring Wells	
	Fences	
	Pumps and Equipment	
	Piping	
	Electrical Work	
	Ancillary Facilities	

Table 5.1 (continued)

Task/Deliverable	Subtask	Time Frame for Preparation and Submission to CDPHE for Review and Approval[a]
3 0 Construction and Operational Plans		
	Construction Cost Estimate and Schedule	Second quarter 1996 through fourth quarter 1997
	Construction Quality Assurance Plan (Appendix H)[c,d]	Second quarter 1996 through first quarter 1998
	Operation Plan (Appendix C)[c,d]	First quarter 1997 through first quarter 1998
	Air Monitoring Plan	First quarter 1997 through third quarter 1997
	Groundwater Monitoring Plan (Appendix K)[c,d]	First quarter 1997 through third quarter 1997
	Closure Plan (Appendix L)[c,d]	First quarter 1997 through first quarter 1998
	Post Closure Plan (Appendix L)[c,d]	First quarter 1997 through first quarter 1998
	Action Leakage Rate/Response Action Plan (Appendix N)[c,d]	Second quarter 1996 through first quarter 1998
	Inspection Plan (Appendix G)[c,d]	Second quarter 1996 through first quarter 1998
	Personnel Training Plan (Appendix F)[c d]	Second quarter 1996 through first quarter 1998
	Operating Record System Plan (Appendix J)[c d]	Second quarter 1996 through first quarter 1998
	Health and Safety Plan (Appendix O)[c,d]	Second quarter 1996 through first quarter 1998
	Contingency Plan (Appendix Q)[c,d]	Second quarter 1996 through first quarter 1998
	Security Plan (Appendix E)[c,d]	Second quarter 1996 through first quarter 1998
	Waste Analysis Plan (Appendix D)[c,d]	Second quarter 1996 through first quarter 1998

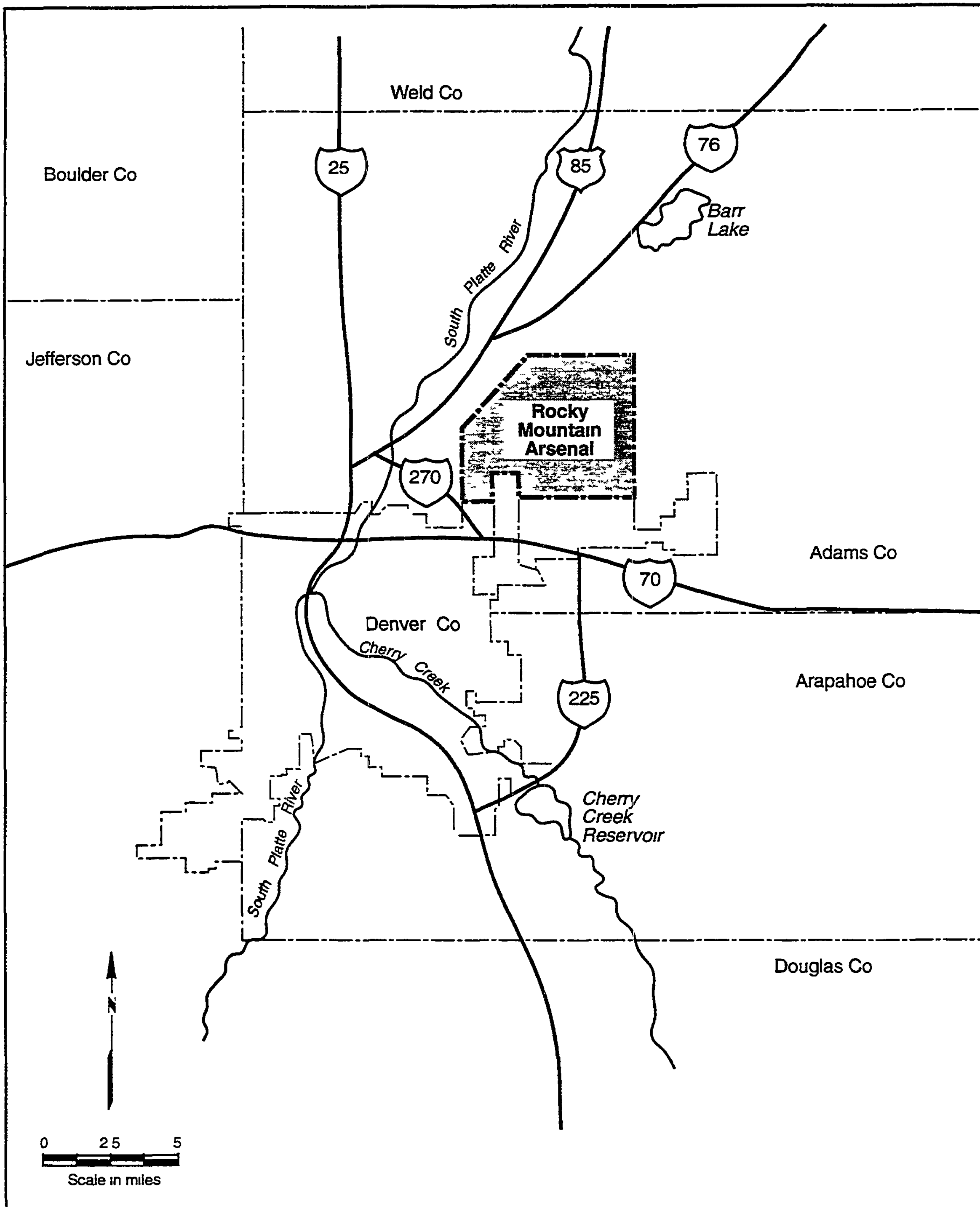
a Time frames are preliminary and subject to change due to uncertainties associated with implementation of the remedy Time frames are in the Federal fiscal year format, i.e , October-December = First Quarter, etc

b Test fill program will be performed as part of the CAMU designation process

c Appendix references refer to the location within the CDD where either guidelines or outlines are presented

d Draft versions of these documents will be produced as part of the 30 percent design Final versions of these documents will be produced during later stages of design or after design

RMA 1251 1 1/8/98 LAM

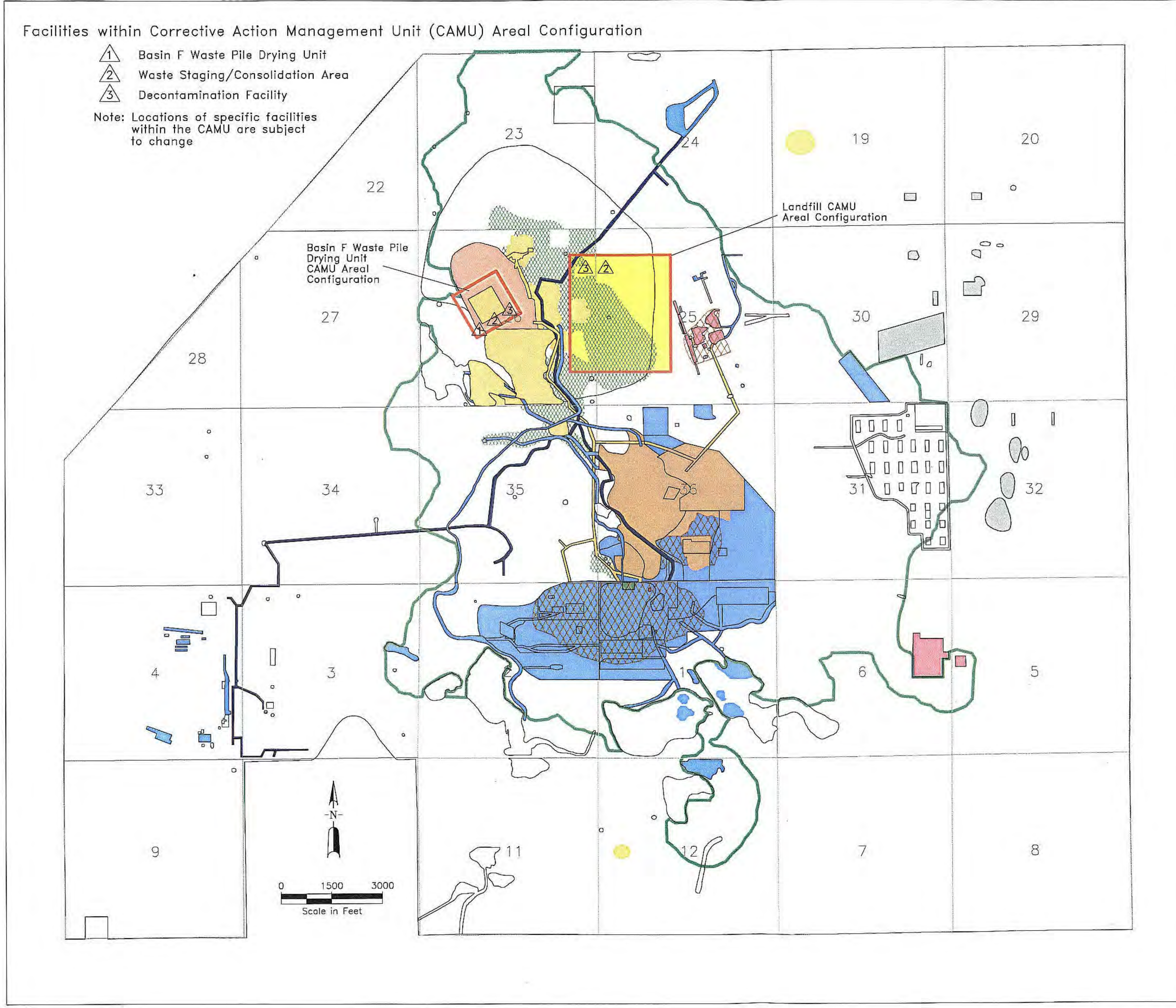


Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure 1

Site Location Map



Explanation

- Arsenal Boundary
- Study Area Report Boundary
- Area of Contamination Boundary
- CAMU Areal Configuration
- Landfill Principal Threat Volume; RCRA-Equivalent Cap
- Caps/Covers
- Direct Solidification/Stabilization
- Hex Pit Excavation
- Landfill Human Health Soil,[1] Consolidation of Biota Soil
- Landfill Human Health Soil[2]
- Landfill Site
- Soil Covers
- Agent Screening Area (Caustic wash/landfill)
- Unexploded Ordnance Screening Area (Detonation/landfill)
- Surficial Soil Consolidation
- Access Restrictions
- 5 Section Number

[1] Refuse from the Sanitary Landfills Medium Group will be consolidated

[2] Wastepile material will be dried prior to landfilling if paint filter test is failed

Prepared for:
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Commerce City, Colorado

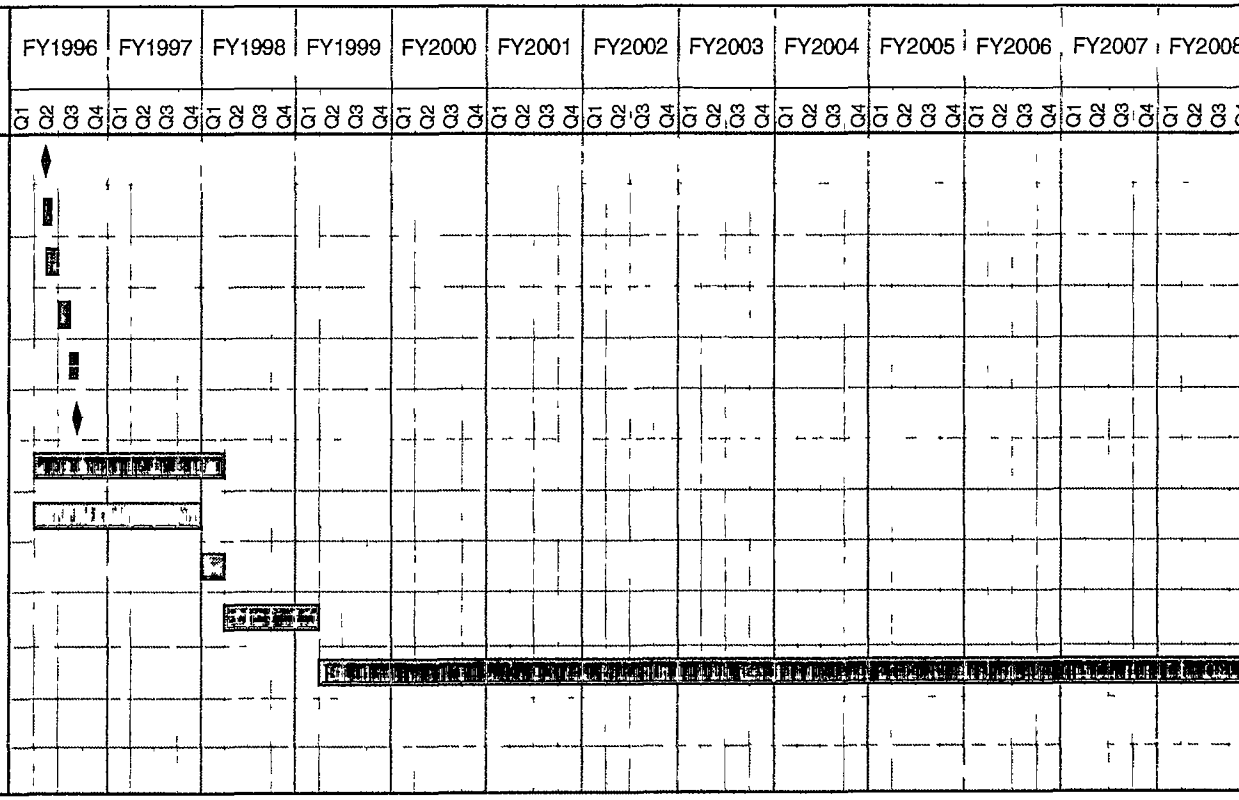
Prepared by: Tetra Tech EC Inc.

Figure 2

Proposed Corrrective Action Management Unit Areal Configuration
Rocky Mountain Arsenal

PROGRAM SCHEDULE

	Start	Finish
Proposed CDD To Parties	January 12 1996	
CDPHE Review	January 12, 1996	March 12 1996
30-Day Public Comment Period	March 16 1996	April 19 1996
30-Day Extension to Public Comment Period	April 20, 1996	May 20 1996
CDPHE Prepares Corrective Action Order	May 21 1996	June 11 1996
CDPHE Issues CDD Designating CAMU	June 11 1996	
Post Designation Submittals[1]	Q2 FY1996	Q1 FY1998
Design[1]	Q2 FY1996	Q4 FY1997
Procurement[1]	Q4 FY1997	Q1 FY1998
Construction[1]	Q1 FY1998	Q1 FY1999
Operation[1]	Q1 FY1999	Q4 FY2008
Closure Activities[2]		
Post-Closure Activities[3]		



RMA 1259 06/07/96 ECS

CAMU Corrective Action Management Unit

CDD CAMU Designation Document

CDPHE Colorado Department Public Health and Environment

FY Fiscal Year

Q Quarter

1 This schedule is preliminary and subject to change due to uncertainties associated with implementation of the remedy

2 Closure of the CAMU includes the construction phase, certification phase, and post-closure care phase Based on Foster Wheeler's current schedule for remediation, final closure of the CAMU is anticipated to occur at the end of fiscal year 2008 The schedule for remediation is preliminary and subject to change due to uncertainties associated with the funding and implementation of the remedy

3 The Army will perform post-closure care of the landfill for 30 years after certification of final closure If appropriate, the Army may request that the post-closure care period be reduced CDPHE may extend the post-closure care period if it is found that the extended period is necessary to protect human health and the environment

Prepared for
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Prepared by
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Figure 3

Schedule of CAMU Activities

Appendix A

PART 2 SITING CRITERIA COMPLIANCE DEMONSTRATION

CONTENTS

TABLES

FIGURES

ATTACHMENTS

1.0 INTRODUCTION

This Part 2 Siting Criteria Compliance Demonstration has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) This designation will be part of a corrective action order issued under the authority of 25-15-308 C R.S The CDD and it appendixes are being submitted to CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This appendix has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work.

1.1 CAMU Description

The Final Detailed Analysis of Alternatives Report Version 4 1 (DAA) (Foster Wheeler, 1995) proposes the construction of one or more onsite landfill cells for the disposal of contaminated materials The DAA is a document prepared in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) The landfill cells will be located within a CAMU designated in accordance with the provisions of Section 264 552 of 6 Code of Colorado Regulations (CCR) 1007-3 The areal configuration of the CAMU is shown in Figure 2 of the CDD The portion of the CAMU that includes the landfill development area is 245 acres in size and is located in Sections 25 and 26 of RMA between Former Basin F and North Plants Double-lined cells within the landfill will receive principal threat and human health exceedance materials, as defined in the DAA, from 17 contaminated areas of RMA. In addition, **a** triple-lined **cell** will be constructed to receive remediation waste from the closure of the Basin F Waste Pile and from **Former Basin F, Sand Creek Lateral soil and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.**

1.2 Document Objectives and Organization

6 CCR 1007-3, Section 264.552(a)(3) states that where remediation wastes placed into a CAMU are hazardous waste, the CAMU shall comply with Subparts B, C, D, and E of Part 265 and when such remediation wastes will remain in place after closure of the CAMU, the CAMU shall comply with the requirements for siting of hazardous waste disposal sites found in 6 CCR 1007-2, Part 2. This appendix to the CDD has been prepared to be responsive to those siting requirements. The appendix also addresses 6 CCR 1007-3, Section 265.18. Section 265.18 specifies general facility standards relative to siting.

The requirements are referenced in this appendix as they are addressed. Section 2.0 addresses those aspects of Part 2 that relate to siting and design, Section 3.0 addresses Part 2 Minimum Design Performance Criteria, and Section 4.0 addresses the 6 CCR 1007-3, Section 265.18(a) Installation Standards. Sections 5.0 and 6.0 are the acronyms used throughout the CDD and the bibliography of references used in this document, respectively.

2.0 SITING AND DESIGN (6 CCR 1007-2, PART 2, SECTION 2.5)

An analysis of compliance with Section 2 5 3 of Part 2 requirements for siting and design is presented first to establish that the design and siting of the landfill will provide a reasonable assurance that the waste will be isolated in the disposal site and away from natural environmental pathways that could expose the public for 1,000 years

2.1 Requirement for 1,000-Year Isolation from Natural Environmental Pathways (Section 2.5.3 of Part 2)

Section 2 5 3 of the Part 2 siting regulations requires that reasonable assurance be provided that hazardous wastes can be isolated within the designated disposal area of the site and away from natural environmental pathways that could expose the public for 1,000 years The regulations require such assurance be based on several considerations

The discussion of these considerations has been organized as follows

- The evaluation of waste isolation from usable aquifers is presented in Section 2 1 1 of this appendix This evaluation addresses Sections 2 5 3 (b), (c), and (f) of Part 2 These regulations require that this evaluation consider
    - A combination of planned engineered barriers and the geologic strata surrounding the site
    - The groundwater flow in the immediate area of the site and
    - The geochemical characteristics of the geologic strata at the site relative to the ability of the geologic strata to inhibit migration of waste constituents
- A discussion of the stability of the geomorphic conditions at the site is presented in Section 2 1 2 of this appendix This discussion addresses Section 2 5 3 (a) of Part 2
- A discussion of waste isolation from surface water is presented in Section 2 1 3 of this appendix This discussion addresses Section 2 5 3 (d) of Part 2
- An evaluation of the drainage and erosion considerations at the site is presented in Section 2 1 4 of this appendix This discussion addressed Section 2 5 3 (e) of Part 2

2.1.1 Evaluation of Waste Isolation from Useable Aquifers (Section 2.5.3 [b], [c], and [f] of Part 2)

This section evaluates the isolation of the waste relative to usable aquifers by first presenting the engineered barriers that will be included in the landfill design followed by a summary of the natural geologic conditions and groundwater flow conditions underlying the landfill site An analysis of the ability of these siting and design characteristics to isolate the waste from usable aquifers for at least 1,000 years is then presented

2.1.1.1 Engineered Barriers

The design of the landfill will include the following engineered barriers· the landfill cover, multiple liner systems, and leachate collection/leak detection systems The design parameters for these engineered barriers, which are pertinent to the analysis of the 1,000-year isolation, have been specified in Appendix B

2.1.1.2 Natural Geologic Conditions

The natural geologic strata underlying the landfill area consists of unconsolidated Quaternary alluvium and the Denver Formation The alluvium encountered in the landfill area generally consists of the following two types of material (1) clay and sandy clay and (2) sand, silty sand and clayey sand with occasional gravel

In general, the depth to weathered bedrock (Denver Formation) follows the surface topography in the landfill area and ranges from approximately 5 feet to 60 feet The areas where depth to bedrock is shallowest correspond with areas of high surface topographic elevation The Denver Formation generally consists of three strata (1) claystone with interbedded siltstone, lignite, and sandstone, (2) sandstone, and (3) lignite/lignitic claystone The alluvium is generally underlain by claystone, however, there are areas in the vicinity of the landfill siting area where Denver Formation channel sand units (sandstone) are in contact with the alluvium A cross section grid was constructed across the landfill area and is illustrated in Figure A1 Geologic cross sections are presented in Figures A2 through A14

Attachment A1 presents the boring logs used to supplement existing information to construct the geologic cross sections

The unsaturated zone beneath the landfill, through both adsorption and absorption, will mitigate further movement of waste constituents that may migrate from the landfill units To take advantage of the containment capabilities of the unsaturated zone, a minimum separation between the bottom of the landfill and the top of the underlying groundwater system has been specified in the landfill design parameters presented within Appendix B

2.1.1.3 Underlying Groundwater System

The upper two groundwater flow systems that underlie the proposed landfill location are the unconfined and the confined flow systems The unconfined flow system is the primary flow system of concern because it is the shallowest groundwater system encountered beneath the site The unconfined flow system occurs at depths ranging from 20 to 70 feet below ground surface (bgs) The groundwater flow direction in the unconfined flow system is generally to the northwest A groundwater surface contour map of the area is presented in Figure A15 The low permeabilities (approximately 0 075 ft/day) and moderate gradients of the unconfined flow system (approximately 0 03 ft/ft) indicate that the unconfined flow system has minimal groundwater flow (on the order of 4 feet per year assuming an effective porosity of 0 20)

2.1.1.4 Analysis of 1,000-Year Isolation

The analysis of the effectiveness of the landfill's engineered barriers and the underlying geologic conditions to isolate waste from useable aquifers for at least 1,000 years is discussed below The analysis includes the following steps

- Identification of a scenario for the potential release of waste constituents to the underlying groundwater system
- A discussion of a conceptual model for evaluating the impact of a potential release For purposes of the 1,000-year demonstration, the model addresses the following
    - Leachate generation

- Presence of the waste constituents of concern
- Transport analysis of waste constituents through the liner system
- Transport analysis of waste constituents through the unsaturated zone

• Summary and conclusions of the results of the analysis

Potential Release Mechanisms

For the 1,000-year isolation analysis, it has been assumed that the primary long-term release mechanism to groundwater is the potential for vertical transport of contaminated leachate through several engineered and natural geologic barriers The engineered barriers include multiple liner systems The natural geologic barriers include the underlying unsaturated (vadose) zone followed by the potential for migration through the saturation zone flow system to a point of public exposure

Conceptual Model for Assessing Potential Impact of a Release

In order to assess the 1,000-year isolation, a conceptual model of potential contaminant migration was developed A description of the conceptual model and its assumptions are summarized below

1 Before contaminant migration can occur, leachate must be generated and accumulate on the uppermost liner

2 The first barrier to contaminant migration is the uppermost composite liner system Migration begins when leachate collects on top of the uppermost liner system resulting in a hydraulic head on the liner During the active life and post-closure period, accumulated leachate (waste drainage) is removed until the waste moisture content is reduced to field capacity, thereby eliminating further drainage from the waste As discussed below, post-closure generation of leachate due to infiltration is minimized by the cover system Therefore, long-term hydraulic head is limited to isolated areas where leachate may be "trapped" in portions of the leachate collection/detection system due to clogging of the system

3 If a hydraulic head of leachate occurs, contaminants in the leachate could potentially migrate through the uppermost composite liner In this case, the migration would occur via molecular diffusion in the water phase and through specific defects (i e , pinholes) via advective movement of water Diffusion is movement at the molecular level Advective flow is the bulk movement of water If such movement occurs, contaminants will be subject to sorption onto clay materials thereby reducing the contaminant concentrations as leachate migrates through the layer In the case of triple-lined cells, the same process must repeat itself for the tertiary liner system

4 Only in the unlikely event that the above two steps have occurred does leachate begin to collect and impose a hydraulic head on top of the lowermost liner system

5 For purposes of this conceptual model, contaminants in the leachate are assumed to migrate through the lowermost composite liner via molecular diffusion in the water phase and via

advective movement of water through specific defects The lowermost composite liner in both the double- and triple-lined cells will consist of a flexible membrane liner (FML) underlain by a minimum 3-foot compacted clay layer (CCL) If such movement occurs, contaminants will also be subject to sorption onto the CCL component of the lowermost liner, thereby further reducing the contaminant concentrations

6 The unsaturated zone beneath the landfill cells acts as an additional barrier to the migration of contaminants to groundwater For purposes of this conceptual model, contaminants are assumed to enter the unsaturated zone and migrate via both molecular diffusion in the air phase and advective movement in the water phase Contaminants are subject to sorption onto soil material within the unsaturated zone Contaminants in the air phase are also subject to absorption or repartitioning back into the water and soil phases Contaminants are also subject to chemical and biological degradation in the soil environment

7 The underlying unconfined flow system (the saturated zone) represents the first potential natural environmental pathway that could expose the public For exposure to the public to occur, a contaminant must first migrate via this pathway to a potential receptor. However, potential exposure to a contaminant beyond a point where access to the unconfined system is controlled cannot occur until the contaminant has migrated beyond that point of control At a minimum, access to the unconfined system will not occur within the limits of the CAMU landfill boundary Conservatively, the time for contaminants to move through this pathway to the first conceivable point of exposure to the public is not included in the 1,000-year isolation analysis If contaminants enter the saturated zone, migration via advective water movement and both mechanical and molecular diffusion within the unconfined zone will occur Contaminants will be subject to dilution and degradation within the saturated zone and are subject to sorption onto saturated zone materials

This conceptual model is illustrated in Figure A16 Each component of this conceptual model has a time frame for contaminant migration associated with it If estimates of these time frames add up to more than 1,000 years, then it can be reasonably concluded that a combination of the landfill's engineered components and the natural geologic conditions will isolate the waste from the public in a manner that is protective of human health for 1,000 years In assessing these time frames, the liner systems are assumed to cumulatively include a minimum of 6 feet of compacted clay The analysis presented herein focuses only on the barriers to migration provided by the 6 feet of clay and the underlying unsaturated zone If it can be demonstrated that the time required for migration of contaminants through these two barriers is more than 1,000 years, then any additional components of the engineered barriers and the natural hydrogeologic conditions (migration through the saturated zone) serve to provide additional conservatism in the demonstrated 1 000-year isolation

Creation of Hydraulic Head

In order for a potential release to occur, leachate production has to be of sufficient quantity to impose a hydraulic head on top of the uppermost liner system During the active life, leachate production occurs due to drainage of precipitation through the waste profile It is assumed that this leachate will be removed through routine pumping of the leachate collection system (LCS)

After closure, continued leachate production can potentially occur as a result of these mechanisms (1) consolidation of the waste profile, (2) drainage of precipitation that entered the waste during the active life, and (3) infiltration through the cover

Waste consolidation could potentially generate leachate during the post closure period The waste processing, placement, and compaction procedures that will be employed in the landfill operation will preclude significant post closure consolidation of the waste and consolidation is expected to be substantially completed by the end of the post closure period Any leachate generated during the post closure period will be removed by routine pumping of the LCS

After closure, portions of the waste profile may be saturated from precipitation that occurred during the active life This leachate will continue to drain from the waste until the moisture content of the waste is reduced to field capacity At field capacity, the "suction" in the pore spaces will prevent further drainage It is assumed that drainage will reduce the waste moisture content to field capacity during the post closure period The leachate created by this drainage will be removed from the LCS during the post closure period Therefore, long-term (after post closure) production of leachate from continued waste drainage is not expected to occur

The cover system will be designed to control long-term infiltration using a variety of components that add redundancy to the system The design parameters that are important to the cover's performance relative to providing 1,000-years of isolation are presented in Appendix B Infiltration of precipitation will be controlled by grading that facilitates runoff and a water balance system that promotes evapotranspiration (Drawing C8 of Appendix B) During normal precipitation events, water will runoff via surface flow and little infiltration will occur The scant infiltration that does occur generally reenters the atmosphere via evapotranspiration from the uppermost vegetation layer In general, it is only during extended precipitation, or extreme precipitation events that significant infiltration below the vegetation layer is expected to occur An extreme event may include multiple components, such as rainfall during or shortly after snowmelt has saturated the surface soil

The layer beneath the vegetation layer will consist of a fine-grained soil designed to provide water storage capacity that is sufficient to contain the infiltration that could occur during extreme or extended precipitation events The water storage layer is underlain by an aggregate layer (biota/drainage layer) that provides a capillary break These two layers together provide physical conditions that are favorable to storage of infiltration near the surface where it can be subsequently removed via evapotranspiration

The capillary break occurs because water in the fine-grained soil will be held by capillary (suction) forces in the small pore spaces of the soil Water held at suction within the fine-grained soil (at a lower hydraulic pressure) cannot flow into the larger pore spaces of the underlying coarse-grained layer (at a higher hydraulic pressure) because there is a net upward vertical hydraulic gradient between the two layers In order for water to overcome the upward vertical gradient and flow downward through the capillary break and onto the underlying composite barrier, infiltration must be sufficient to completely saturate the water storage layer However, when this occurs, the drainage layer immediately above the composite hydraulic barrier will drain away any water before it can accumulate on top of the composite hydraulic barrier, thus adding redundancy to the system The biota layer will be designed to stop burrowing animals from potentially impacting the composite hydraulic barrier (see Appendix B), therefore, the primary potential failure scenario for the cover system is failure of the water storage and drainage layers allowing buildup of hydraulic head on top of the composite hydraulic barrier

EPA's Hydrologic Evaluation of Landfill Performance (HELP) modeling methodology (EPA, 1994) was used to evaluate potential infiltration rates through the composite hydraulic barrier of the cover system, assuming a failure of the drainage layer The HELP model incorporates equations developed by Giroud and Bonaparte (1989) and Giroud and others (1992) that estimate both diffusive and advective flow of water through composite systems Diffusive flow is the movement of the water at the molecular level Advective flow (the bulk movement of the water) is assumed to occur primarily through holes in the FML, which occur both from manufacturing errors (FML pinholes in the HELP model) and from defects in construction

The composite hydraulic barrier will consist of a FML underlain by either a CCL or a geosynthetic clay layer (GCL) The equation used in the HELP methodology assumes that diffusive flow through the intact FML portion of the composite system can be estimated using a form of Darcy's Equation which incorporates an "equivalent hydraulic conductivity" (EPA, 1994) The "equivalent hydraulic conductivity" represents the potential for both liquid and vapor diffusion through the FML The amount of advective flow through holes in the FML is a function of the contact between the FML and the underlying low permeability portion of the composite (either CCL or GCL) system The equations utilized in the HELP methodology allow for the calculation of the advective flow through the composite hydraulic barrier, as discussed in Attachment A2

A spreadsheet model (described in Attachment A2) incorporating the HELP methodology was developed to calculate estimates of diffusive and advective flow through the composite barrier planned for the cover For this analysis, the composite barrier is assumed to employ an FML underlain by a GCL The estimates of flow were calculated assuming a hydraulic head of 1 5 feet As discussed above, hydraulic head buildup on the FML will occur only if both of the overlying water storage and drainage layers fail Failure in the drainage layer would most likely occur due to localized blockage of the drainage material and buildup of water behind the blockage When the water level exceeded the height of the blockage, drainage would resume Therefore, the height of the water buildup and subsequent hydraulic head on the FML would be limited to the thickness of the drainage layer For purposes of this analysis, a maximum thickness of 1 5 feet was used

It was assumed that the FML in the cover was installed correctly (good construction), and thus included one pinhole per acre and three construction defects per acre (EPA, 1994) It was also assumed that excellent contact existed between the FML and clay component Excellent contact is the applicable assumption for a GCL per HELP model guidance (EPA, 1994) Table A1 presents the results of this analysis, which indicates that even at 1 5 feet of head buildup (due to long-term clogging of the biota/ drainage layer), only 0 001 inches/year of flow would be expected through the composite barrier

These results indicate that even if the water balance and drainage components of the cover system fail early in the 1,000-year period, little if any water will infiltrate through the composite hydraulic barrier in the cover Even if the 0 001 inch/year rate was applied for the entire 1,000-year period, a total of only 1 0 inch of water would have infiltrated through the cover The analysis of the cover's ability to prevent significant post-closure infiltration through the underlying waste profile is believed to be conservative because the mechanisms that mitigate post-closure infiltration into the waste profile work sequentially as follows

- As demonstrated in Appendix B of the CDD, the lack of subsidence, waste consolidation, and excessive erosion will allow for a positive grade throughout the 1,000-year analysis period The positive grade will promote surface-water runoff and minimize infiltration

- The water storage layer is natural material that allows for the retention and subsequent evapo-transportation of excessive infiltration The performance of the water storage layer would be most impacted by erosion that reduces the thickness of the layer Results of erosion loss calculations performed using the Revised Universal Soil Loss Equation (RUSLE) indicate that a design may be completed where approximately 30 inches of the upper soil layer will remain in place after 1,000 years

- The drainage layer provides for removal, by gravity, of water that infiltrates through the water storage area during extreme precipitation events This removal of infiltration will mitigate the build-up of hydraulic head on the underlying composite hydraulic barrier

- The composite hydraulic barrier significantly reduces the potential for hydraulic flow or infiltration into the underlying waste profile The life expectancy of the FML component has been estimated to be in excess of 800 years (Koerner, 1990)

The results of this analysis indicate that the cover will be protective for the 1,000-year period and that no significant leachate production will occur as a result of infiltration through the cover. On the basis of the above discussion, it can be reasonably assumed that there will be no long-term generation of leachate, and the only source of hydraulic head on the liner will be "remnants" of leachate that may remain in the leachate collection system. Identification of potential contaminants of concern in the leachate and analysis of the potential transport of these chemicals through the lowermost liner system and the unsaturated zone are discussed below.

Identification of Waste Constituents of Concern. Potential transport of chemical constituents is dependent on the type and amount of contaminants that may be in the landfill leachate. The waste placed in the triple-lined **cell** will consist of principal threat **and human health exceedance** soils from the Basin F Waste Pile and **Former Basin F, human health exceedance soils from Sand Creek Lateral, and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.** The waste placed in the double-liner cells will come from 17 other RMA locations. Basin F Waste Pile leachate data are likely to be reasonable representations of landfill leachate quality in the triple-lined cells. The existing Basin F Waste Pile leachate data is believed to be conservative because concentrations of volatile organic chemicals (VOCs) and semi-volatile organic chemicals (SVOCs) present in the Basin F Waste Pile should be reduced during excavation and drying of the material. Therefore, current Basin F Waste Pile leachate characterizations are used in the model.

Analytical data from analysis of the Basin F Waste Pile leachate (See Attachment A2) were reviewed versus constituents of concern in groundwater identified in the Detailed Analysis of Alternatives (DAA) (Table 2.2-3 for the North Boundary System, which is near the proposed landfill [Foster Wheeler, 1995]). Contaminants present at elevated levels in the leachate, which were identified as constituents of concern in the DAA, include aldrin, atrazine, arsenic, chloroform, chlorophenylmethyl sulfoxide (CPMSO), chlorophenylmethyl sulfone (CPMSOP), dibromochloropropane (DBCP), dieldrin, and diisopropylmethyl phosphonate (DIMP). The chemicals in the leachate that are basically nonvolatile (arsenic, atrazine) or highly sorptive (aldrin, dieldrin) were screened from the analysis because they are generally not mobile in the unsaturated zone. The remaining constituents (CPMSO, CPMSOZ, chloroform, DBCP, and DIMP) were present in leachate at elevated concentrations relative to their preliminary remediation goals (PRGs) established within the DAA and are potentially mobile in the unsaturated zone   Of these constituents, CPMSO2 was deleted from the evaluation because   (1) it was present in lower concentrations than the CPMSO and (2) it is similar to CPMSO with respect to mobility in the unsaturated zone (similar Kds and Henry's constants [Attachment A2])   Therefore, the constituents present in Basin F leachate, which are of potential concern and are included in the transport analysis, are CPMSO, chloroform, DBCP, and DIMP

Contaminated soil from a variety of other RMA locations has been designated for disposal in double-lined landfill cells   A review of soil information provided in the DAA indicates that elevated detections of potentially mobile constituents (VOCs and SVOCs) occurred primarily in soil to be placed in the landfill from in the South Plants Central Processing Area (chloroform, DBCP) and Chemical Sewer System (DBCP) (Foster Wheeler, 1995)

A review of soil data from the Rocky Mountain Arsenal Environmental Database (RMAED) was performed for the South Plants Central Processing Area   These data indicate that for the upper 5 feet of soil (the soil to be excavated), less than 1 percent of samples had detections of chloroform and less than 3 percent of samples had detections of DBCP   These detections are primarily from 1985, with a few detections of DBCP from 1987, with no detections of either compound after 1987   Therefore, it is unlikely that elevated concentrations of chloroform or DBCP will be present in leachate from the South Plants soils

As indicated previously, the Basin F Waste Pile leachate data is believed to be a reasonably conservative estimate of future landfill leachate characteristics   The Basin F Waste Pile leachate data is also believed to be a reasonable characterization (particularly for volatile constituents) of future leachate from the South Plants soils for the following reasons

1   Samples from the upper 5 feet of soil in the South Plants Central Processing Area had only a small percentage of detections of VOCs

2 The South Plant soils will undergo excavation, transport and placement that will reduce the concentration in the soils of volatile constituents, such as chloroform The Basin F Waste Pile soils underwent similar handling

3 The concentrations within the leachate will be reduced with time during the active life and post-closure period of the landfill The leachate generated during this period will be removed The leachate remaining after the post-closure period would be expected to exhibit lower concentrations A similar process has occurred in the Basin F Waste Pile

Analysis of Transport Through the Liner System As discussed above, the potential for long-term generation of leachate and corresponding hydraulic head on the liner system will be mitigated by collection of leachate that drains from the waste during the active life and post-closure period of the landfill In addition, the cover system will be designed to effectively eliminate significant additional leachate production that would occur as a result of infiltration through the cover Therefore, the reasonable assumption for a source of hydraulic head on the liner system would be "remnants" of leachate remaining in the waste and/or the leachate collection system after the post-closure period This leachate has the potential to pool in certain areas, possibly as a result of clogging of the leachate collection system or due to differential settlement As discussed above for the cover system, hydraulic head on the liner would generally be limited to the thickness of the drainage layer because of the blockage of the layer (greater head buildup would flow over the blockage and disperse in the leachate collection system) For purposes of this analysis it is assumed that the hydraulic head will be less than 1 foot Except for the sump areas, 1 foot is consistent with the maximum thickness of the leachate collection system contemplated by the design parameters presented in Appendix B The sumps may have a depth greater than 1 foot, however, they represent only a small percentage of the base area, and can be dewatered to less than 1 foot of leachate

There are two primary mechanisms for potential contaminant migration through the liner systems, diffusive transport and advective transport In the liner system, diffusion is caused by random movement of molecules within either the air or water phase in response to concentration gradients (i e , molecules tend to move from areas of high concentration to areas of low concentration) Dispersion due to advective mixing is not considered because of the low rates of advective water movement

Advective transport of contaminants occurs due to the physical or bulk movement of water through the liner As previously described, potential advective movement of water (and thus advective chemical migration) through the composite liner occurs primarily through pinholes or defects in the FML, while diffusion of water (and thus chemicals) is assumed to occur across the entire FML

Contaminants in the landfill can exist in the air phase, liquid phase (i e , in solution), or contaminants may be sorbed onto solid particles The amount of chemical mass in any of these phases is a function of the physical properties of the chemical (Henry's constant, solubility, etc) and the properties of the waste or the liner material (organic carbon content, moisture content, etc) It is assumed that the liner material will be generally saturated after landfill construction (EPA, 1994), therefore, migration of contaminants through the liner systems occurs generally in the water phase Migration through the liner system will be subject to potential sorption onto clay liner materials

It is assumed that vertical migration through the liner systems is the primary pathway for contaminants to reach groundwater Potential horizontal migration (through the sideslopes) would result in longer pathways and require longer time frames Contaminants migrate through the liner system via molecular diffusion in the liquid phase (in solution) and advective water movement

Analysis of Advective Transport. The maximum rate of advective water movement through the liner was evaluated using the HELP model methodology as described in Attachment A2 To achieve a maximum estimate of the advective flow rate, the analysis was performed for only the lowermost liner system, assuming only 3 feet of CCL It has been assumed that the liner will be installed with good construction practices, resulting in one pinhole and three defects per acre (EPA, 1994) Contact between the compacted clay and the FML has conservatively been assumed to be "poor" in HELP model terminology, which is defined as a geomembrane installed with a certain number of wrinkles on a poorly compacted, low permeability surface that does not appear smooth (EPA, 1994) Actual construction practice is expected to result in "good" contact Good contact is defined as a geomembrane installed with as few wrinkles as possible and low permeability soil with a smooth surface (EPA, 1994) Table A2 presents the results of this analysis, indicating that 1 foot of hydraulic head on the lower most liner system would potentially result in a total of 0 007 inches/year of advective water flow through the lower most composite liner, assuming poor contact

At this low rate, virtually no mass of contaminant would move advectively through the minimum 3-foot compacted clay component of the lower liner within a 1,000-year period (it would take 5,143 years for water to move through 36 inches of clay at 0 007 inches/year) Therefore, diffusion of a contaminant in the liquid phase is assumed to be the dominant transport process within the liner systems Analysis of diffusive transport is discussed below

Analysis of Diffusive Transport. Diffusive migration can be described by solutions to the advective/dispersive equation A solution was developed by Ogata and Banks (1961) and was applied using the approach described in Attachment 2 This Ogata and Banks analysis was used to estimate a ratio of the concentration (in water) of the constituent at the base of the lowermost liner and (C_L) to Co, the initial concentration of that chemical in the leachate above the liner Because the aqueous diffusive properties of the chemicals of concern are similar, a single analysis was performed using a representative diffusion coefficient (5×10^{-6} cm^2/sec) The analysis ignored any contribution that the FML components of the liner system may have on retarding diffusive transport and only considered the compacted clay component of the liner system For purposes of the model, the cumulative thickness of the CCL component of the liner system was assumed to be six feet Results of this analysis are presented in Figure A17 The analysis also assumes that the presence of leachate will provide a continuous source of contamination for the entire 1,000-year period at a constant concentration This assumption is conservative because organic chemicals are subject to biodegradation For example, published half-life for both chloroform and DBCP are in the range of 6 months to 1 year under aerobic conditions (Geraghty and Miller, 1986) Although conditions within the landfill are likely to be anaerobic over the long term, biodegradation of these constituents will still occur (Kobayashi, H , and Rittman, B.E , 1982)

As shown in Figure A17, the concentration at the bottom of the liner system versus the initial concentration in the leachate (Cl/Co) slowly increases over the 1,000-year period This analysis provided input concentrations for simulating potential contaminant migration through the unsaturated zone

Potential Contaminant Migration Through the Unsaturated Zone. The mechanisms controlling migration of contaminants through the unsaturated zone beneath the landfill include advective movement of water and thus contaminant mass, diffusion of contaminant mass primarily in the vapor phase, and adsorption of contaminant mass onto soil particles and reabsorption back into the liquid phase The Ogata-Banks solution was used in the evaluation of molecular diffusion through the liner because chemical migration was assumed to occur in a single phase (water) Because migration in the unsaturated zone is subject to mechanisms that affect more than one phase (vapor phase diffusion, water phase advective movement, solid phase sorption), a multiphase chemical transport model is more appropriate for the unsaturated zone evaluation Accordingly, EPA's VLEACH model (EPA, 1995) was chosen to evaluate potential contaminant migration in the unsaturated zone because it was designed to simulate these mechanisms VLEACH is a one-dimensional finite difference solution designed to simulate the migration of volatile contaminant through the unsaturated zone The model simulates four processes, liquid-phase advection, vapor phase diffusion, solid phase sorption, and three phase equilibrium

The VLEACH model has been thoroughly reviewed by EPA, and has been verified in a wide variety of applications For example, VLEACH was used to evaluate the potential for VOCs in the unsaturated zone to impact groundwater quality at the Phoenix-Goodyear Airport Superfund site in Arizona In the Arizona study, results of VLEACH calculations were compared to other methods including analytical solutions for unsaturated zone transport and a finite-difference simulation of a field study conducted by the United States Geological Survey (USGS) for a site near Lubbock, Texas (Rosenbloom, et at , 1993) Results were also compared to in situ soil gas samples These comparisons indicate that VLEACH simulations of liquid-phase advection and equilibrium adsorption, and diffusive transport of VOCs within the unsaturated zone produced results consistent with both in situ soil gas samples and other modeling methodologies The VLEACH model has also been verified against an analytical solution developed by Shan and Stephens (1995) While these applications are not exactly analogous to this study, they do show that the model is an appropriate tool for estimating vadose zone contaminant transport

The VLEACH model is based on the following assumptions (EPA, 1995)

- Contaminant partitioning between phases follows linear relationships
- The three phases present are in equilibrium in each model cell
- The moisture content profile within the unsaturated zone is constant and in steady state with respect to water
- The contaminant is not subject to in situ production or degradation
- The unsaturated soil is homogeneous and behaves as a uniform porous media

Prior to performing VLEACH modeling, the potential for migration of contaminant mass due to advective movement of water was evaluated Conceptually, after the landfill has been constructed, the unsaturated zone underneath the landfill footprint will be isolated from the surface environment and will not be subject to infiltration events An analysis based on Clapp and Hornberger (1978), was used to estimate the long-term moisture content (see Attachment A2)

The rate of advective water movement through the unsaturated zone after the landfill has been constructed was used to identify a range of leakage rates from the liner that could result in advective water movement through 20 feet of vadose zone material in 1,000 years Assumptions used in this approach include

- Total Porosity (θ_s) = 0 40, from HELP model value cited for a silty clay loam (EPA, 1994)
- Vertical Saturated Hydraulic Conductivity (k_s) estimates range from 0 0022 ft/day to 0 70 ft/day, based on a preliminary assessment of slug testing in the saturated portions of the unconfined Denver groundwater flow system (see Attachment A3) The lower limit (0 0022 ft/day) is the geometric mean value for slug testing in clay materials assuming a 10 1 horizontal to vertical anisotropy, while the upper limit is the geometric mean value from slug tests in sand materials, also assuming a 10 1 horizontal to vertical anisotropy The geometric mean value from all the tests was 0 022 ft/day, assuming a 10 1 anisotropy (The final assessment of the slug tests

actually resulted in a lower geometric mean of 0 03 ft/day The modeling conservatively used the higher preliminary value)

- Clapp and Hornberger (1978) soil constant (b) ranges from 5 to 10 5, with a mean of 7 75 for a silty clay loam

This analysis (See Attachment A2 for calculation methodology) indicates that if potential leakage from the lowermost liner is less than approximately 0 04 inches per year, advective water movement will take longer than 1,000 years to migrate through 20 feet of unsaturated zone materials As previously stated, the predicted long-term potential advective flow rate through the lowermost liner is 0 007 inches per year, conservatively assuming poor liner contact Therefore, the potential for chemical transport due to advective water movement is expected to be minimal and would not be a component of potential migration to the groundwater within 1,000 years

The above results indicate that diffusion in the vapor phase and adsorption onto soil particles will be the dominant transport processes in the unsaturated zone beneath the landfill Chemical parameters required to describe these processes include Henry's Constant, which describes a chemical's volatility, the soil-water distribution coefficient (Kd), which describes the soil's sorptive capacity for the chemical, and the free-air diffusion coefficient, which describes a chemical's ability to diffuse in the air phase Soil parameters that impact these processes include total porosity, moisture content, and organic carbon content

Table A3 presents the chemical parameters and Table A4 presents a summary of physical parameters used in the VLEACH simulations The VLEACH evaluation consisted of simulating potential contaminant transport through 20 feet of unsaturated zone for the four chemicals of concern for 1,000 years The model was discretized into 1,000 segments of 0 02 feet each, with a constant input of water at 0 007 inches per year at the top the unsaturated zone The 0 007 inches per year is the predicted potential rate of leakage from the lowermost liner This leakage from the lower liner and into the unsaturated zone was assumed to have a constant average concentration, as discussed below The initial concentration of the chemical constituents modeled was assumed to be zero throughout the soil profile

Chemical mass in the vapor phase was restricted from exiting the model via the upper boundary (i e , vapor transport was constrained to be vertically downward)

Concentration inputs for the VLEACH simulations were based on the Cl/Co ratios predicted for the constituents at the base of the lowermost liner An average input Cl/Co ratio was calculated for 10-year increments for the constituents (Figure A17) VLEACH simulations were thus performed in 10-year increments, with the final concentration profile from one run providing the initial conditions for the subsequent run This technique included the predicted steady increase in concentration (Cl/Co curves) at the top of the unsaturated zone (the base of the lowermost liner) The 10-year increments were based on a sensitivity analysis of several different time increments The VLEACH simulations predicted a ratio of chemical constituent concentrations, Cv/Co, where Cv is the potential constituent concentration (in water) at the bottom of the unsaturated zone and Co is the chemical concentration in the leachate above the lowermost liner

Results of the model simulations are presented in Table A4 Using the PRG value for the chemical and the Cv/Co ratio, a prediction of a threshold concentration was estimated for each constituent The threshold concentration for each constituent represents a concentration in the leachate that would be necessary to result in the occurrence of predicted concentrations at the top of the saturated zone above the PRG for that constituent in 1,000 years or less

Table A4 also presents the range of concentrations of the chemicals of concern that may be present in the future landfill leachate, as evidenced by concentrations measured in Basin F Waste Pile leachate As discussed above, the Basin F Waste Pile leachate data are believed to be the most representative of leachate from all waste sources Also included in the table is the threshold concentrations (discussed above) for each chemical from the VLEACH modeling As shown on the table, the range of potential leachate concentrations for all chemicals are lower than the predicted threshold concentrations Given the degree of conservatism used in the analysis, the comparison of the expected landfill leachate concentrations with the threshold concentrations predicted by the model are believed to be conservative and provide a reasonable assurance that the concentrations at the top of the saturated zone will not exceed the PRGs for the constituents modeled

Summary of Modeling Results The analytical results of the modeling is summarized below

- Maximum predicted long-term infiltration through the cover — 0 001 in/yr
- Maximum predicted long-term rate of advective water movement through the lowermost liner system with only 3 feet clay — 0 007 in/yr
- Rate of advective water movement through the lowermost liner that would be required to migrate through the unsaturated zone in 1,000 years — 0 04 in/yr
- Threshold concentration of constituents of concern in leachate that must be exceeded to result in potential concentrations, in water, at the top of the saturated zone that would exceed the PRG for that constituent within 1,000 years

- Chloroform	108,000 μg/l
- DIMP	1,797,000 μg/l
- DBCP	1,500 μg/l
- CPSMO	591,000 μg/l

- The reasonable assumptions for future landfill leachate concentrations based on Basin F Waste Pile data are as follows

- Chloroform	21	to	610 μg/l
- DIMP	740	to	1,300 μg/l
- DBCP	2	to	3 μg/l
- CPSMO	10,000	to	19,000 μg/l

Conclusions of the 1,000-Year Isolation Analysis The analyses presented above provides reasonable assurance that the landfill can be designed to isolate the waste from public exposure in a manner that is protective of human health for at least 1,000 years after the post-closure period This conclusion is based on the following

- The landfill cover will be designed to restrict infiltration and remain in place for the 1,000-year period, thus no significant leachate production will occur as a result of post-closure infiltration through the cover

- A composite liner system with an FML and 3-foot clay layer with 1 foot of hydraulic head is estimated to transmit water at a rate of 0 007 inches/year (Table A2) It is estimated that a rate of 0 04 inches/year or higher is required for water to move through 20 feet of underlying unsaturated geologic strata in 1,000 years This analysis of advective water movement is based on a conservative assumption that all the geologic strata underlying the landfill area have permeabilities associated with silty sand Much of the strata are clay and claystone units that have permeabilities in the order of four orders of magnitude lower than that used in the analysis This analysis also conservatively assumes poor contact between the FML and clay The anticipated landfill design will result in good contact

- Concentrations of chemical constituents will be reduced if they migrate through the clay layer component of the liner systems This analysis also makes the conservative assumption that the leachate concentrations for the waste constituents above the liner will remain constant throughout the 1,000 years Natural biodegradation of these chemicals will result in a reduction in the leachate concentrations over time The analysis does not take this reduction in concentrations into account

- The analyses of contaminant transport only addresses a cumulative 6 feet of the compacted clay component of the liner system and does not include time frame estimates for migration through any other component of the liner systems, thus adding additional assurance to the analysis

- The analysis of potential contaminant transport within the unsaturated zone indicates that, after 1,000 years, the expected concentration (within the leachate) for each of the most mobile chemicals of concern is significantly below the concentration that would be necessary to result in a concentration at the water table in excess of the chemical's PRG The PRG has been defined within the DAA as a concentration that is protective of human health The analysis is conservative in that it only addresses potential vertical transport immediately beneath the landfill where there is not even a potential for exposure of the public Further reduction of the chemical concentrations would occur during transport via the groundwater pathway to a point where potential exposure could actually occur

- The above analysis indicates that the time for impact via the "natural exposure pathway" represented by groundwater which would potentially expose the public is greater than 1,000 years This assessment did not consider the time for migration through all of the components of the contemplated landfill design and site characteristics that serve to isolate the waste within the CAMU disposal area. If these additional components were considered, then isolation of the waste would be reasonably assured for a period that is substantially in excess of the 1,000-year requirement

2.1.2 Evaluation of Geomorphic Conditions (Section 2.5.3 (a) of Part 2)

The proposed location for the landfill is in the western half of Section 25 and a small portion of Section 26 Figure A18 presents a topographic elevation contour map of the area The ground surface topography in the vicinity ranges in elevation from 5,225 feet above mean sea level (MSL) to 5,280 feet above MSL The area topography consists of gently rolling hills and treeless plains Overall, the area slopes toward the northwest Geomorphic conditions are not expected to change to the extent that the landfill design would be impacted over the 1,000-year analysis period The onsite soil conditions in regard to geologic and geomorphic conditions are discussed in more detail in Appendix R

2.1.3 Protection of Surface Water (Section 2.5.3(d) of Part 2)

As shown in the 100-year floodplain map of RMA (Figure A19), there are no major drainage channels across the landfill area First Creek is a well-defined channel crossing RMA to the east of the landfill area The landfill will be designed to contain and control runoff that may come in contact with contaminated materials (Appendix B) Therefore, there is reasonable assurance that the waste disposal locations will not impact nor be impacted by surface water Section 2 5 3(d) addresses the protection of surface water relative to the demonstration of 1,000 years of isolation. Protection of surface water during operations is addressed in Appendixes B and C of the CDD

2.1.4 Evaluation of Drainage and Erosion (Section 2.5.3 (e) of Part 2)

The terrain in the landfill area can accommodate drainage ditches and other drainage facilities to allow for conveyance of precipitation away from the disposal area The cover components and configuration (Appendix B) will minimize water and wind erosion by maintaining good vegetative cover, an acceptable slope, and armoring the top of the cover with a soil/gravel admixture Based on the cover design parameters presented in Appendix B, the potential for wind and water erosion was estimated Wind erosion was calculated using the wind erosion equation from the U S Soil Conservation Service (National Agronomy Manual, 1988) The calculated soil loss attributable to wind erosion is 0 003 inches per year, or approximately 3 inches of soil loss to wind erosion over 1,000 years (wind erosion calculation is presented in Attachment A2) Water erosion was calculated using the Revised Universal U S Soil Conservation Society Soil Loss Equation (RUSLE), Version 1 04 (1995) to evaluate the total depth of soil loss over a 1,000-year period of the cover system (water erosion calculations are presented in Attachment A2) The RUSLE analyses indicates that a cover can be designed to restrict the maximum soil loss to approximately 15 5 inches over 1,000 years based on landfill layout design parameters presented in Appendix B thus, reasonably demonstrating that the terrain of the site will accommodate a cover that can be installed with a vegetative/water balance layer that will remain functional for 1,000 years

2.2 Liner Design (Section 2.5.4 of Part 2)

The landfill design (Appendix B) will include multiple liner systems Section 2 5 4 of Part 2 requires that, if necessary, the design of a hazardous waste disposal site shall include a liner, the performance of which will comply with Sections 2 4 1, 2 4 2, 2 4 3, and 2 4 5 of Part 2 These sections of Part 2 specify long-term performance standards for preventing adverse impacts on human health and the environment Part 2 defines long-term as that period of time after completion of postclosure activities

Section 2 1 1 of this appendix demonstrates that a combination of the landfill's engineered liner systems and the underlying natural geologic conditions will provide for long-term protection. Appendix B to the CDD specifies design performance standards that will provide for liner systems that are equivalent or better than the liner system that was the basis of the demonstration presented in Section 2 1 1 Therefore, the liner systems contemplated by the Appendix B design standard will comply with 6 CCR 1007-2 Part 2, Sections 2 4 1, 2 4 2, 2 4 3, and 2 4 5

2.3 Leachate and Runoff Control System (Section 2.5.5 of Part 2)

The landfill design parameters presented in Appendix B will provide for leachate and runoff control systems that will provide compliance with the minimum design performance criteria specified in 6 CCR 1007-2 Part 2, Section 2 4 The runoff control system will be designed considering the climate of the area including precipitation events The volume and characteristics of the leachate and runoff will also be considered in the management of any leachate or runoff that is collected at the facility

Leachate collected from the landfill leachate collection and leak detection systems will be managed in accordance in accordance with applicable regulations at either an onsite treatment facility or transported to an appropriately permitted offsite facility

2.4 Prevention of Adverse Impacts from Unexpected Discharges (Section 2.5.6 of Part 2)

The location of the landfill will be at least 1 mile from the RMA fenced boundary This 1-mile distance from potential public exposure combined with the 24-hour-day RMA security force and fire department provide an acceptable means to prevent adverse effects on the public health should unexpected discharges of hazardous waste occur A Contingency Plan (See outline in Appendix Q) specific to the landfill will be developed and submitted to CDPHE for review and approval After approval, the contingency plan will be appended to the RMA Contingency Plan to provide the specific procedures to be implemented in the event of an unexpected release The submission to CDPHE of the contingency plan will be in accordance with the schedule discussed in Section 5 of the CDD

2.5 Section 2.5.2 of Part 2, Operational Considerations

Subparts B, C, D, and E of Part 265 of 6 CCR 1007-3 and 264 552(e)(2) of 6 CCR 1007-3 address operational requirements for a CAMU Compliance with these regulations is discussed within Appendix C of the CDD The design and design performance issues addressed by Section 2 5 2 of Part 2 are also addressed within Subparts B, C, D, and E, of 265 and 264 552(e)(2) and therefore, the Section 2 5 2 operational considerations are addressed within the following appendixes of the CDD

Appendix C	Guidelines for the Development of an Operations Narrative
Appendix E	Security Plan Outline
Appendix H	Construction Quality Assurance Plan Outline
Appendix Q	Contingency Plan Outline

3.0 MINIMUM DESIGN PERFORMANCE CRITERIA (6 CCR 1007-2, PART 2, SECTION 2.4)

Compliance with the regulatory requirements for minimum design performance criteria for onsite hazardous waste landfills (Section 2 4 of Part 2) is reviewed in this section Section 2 4 1 of Part 2 indicates that the purpose or objective of the Section 2 4 design performance standards is to ensure that landfills will be located and designed in a manner that will assure long-term protection of human health and the environment. Long-term is defined within Part 2 as being that period of time after completion of postclosure activities

3.1 Protection of Groundwater (Section 2.4.2 of Part 2)

The analysis concluding that a landfill design can be implemented whereby waste placed in the proposed landfill will be isolated from groundwater pathways that could potentially expose the public for 1,000 years (Section 2 1 of this Appendix) also demonstrates that the contemplated landfill design and site characteristics will prevent adverse effects on groundwater quality The design parameters presented in Appendix B incorporates the considerations listed in Section 2 4 2 of Part 2 to satisfy the requirement of Section 2 4 2 that the long-term design performance of the liner systems will be such that adverse effects on groundwater quality will be prevented

3.2 Protection of Surface Water (Section 2.4.3 of Part 2)

The analysis concluding that a design can be implemented whereby waste placed in the proposed landfill will be isolated from the public and the environment for 1,000 years (Section 2 1 of this Appendix) also demonstrates that long-term prevention of adverse effects on surface water quality can be achieved The design parameters presented in Appendix B consider the requirements listed in Section 2 4 3 of Part 2 to satisfy the provision that the long-term performance of the landfill facility will prevent adverse effects on surface water quality

3.3 Protection of Air Quality (Section 2.4.4 of Part 2)

This regulation requires that the CAMU landfill units be designed to prevent post-closure adverse effects on air quality Considerations of air quality during operations are addressed within Appendix C of the

CDD It has been demonstrated that a landfill cover can be designed that will remain in place for a minimum of 1,000 years and, therefore, potential air exposure pathways will be significantly limited

In addition, evaluation of existing air quality data, including the Basin F Waste Pile vent system (Ebasco, October, 1994) indicates that the waste pile has not adversely impacted air quality The Basin F waste pile vent system is a passive system that operates in a similar fashion to the passive vent system that is being considered as part of the design of the CAMU landfill Therefore, based on the vent system similarity, waste similarity, and performance of the Basin F pile vent system, it can be concluded that remediation waste left in place after closure of the CAMU will not adversely effect air quality

3.4 Protection of Public Health and the Environment (Section 2.4.5 of Part 2)

Section 2 4 5 of Part 2 requires that the disposal site be designed to prevent long-term adverse effects on public health and the environment due to migration of waste constituents in the surface and subsurface environment Long-term is defined within Part 2 as that period of time after the completion of post-closure As more fully discussed within Section 2 1 of this appendix, the most likely pathway for potential long-term exposure is potential migration through the underlying groundwater The discussions within Section 2 1 fully address this potential pathway and demonstrate that the disposal site can be designed in a manner that isolates the waste from the public and the environment for 1,000 years Therefore, the demonstration of 1,000-year isolation also demonstrates that the performance standard of Section 2 4 5 of Part 2 can also be met

3.5 Protection of the Function and Physical Integrity of Liners (Section 2.4.6 of Part 2)

The landfill design parameters presented in Appendix B address the protection of the function and physical integrity of the landfill liner system

3.6 Leachate and Runoff Control System Capacity (Section 2.4.7 of Part 2)

The design parameters presented in Appendix B provide for landfill leachate and runoff control systems that have sufficient capacity to remove generated leachate to the extent necessary to minimize the buildup of head on the landfill liner systems It has been reasonably demonstrated (See Section 2 1 of this appendix) that a design can be implemented such that leachate generation during the post-closure period will be minimal and any leachate remaining in the system will be isolated from potential environmental pathways that could expose the public for at least 1,000 years

3.7 Protection During Closure and Post-Closure (Section 2.4.8 of Part 2)

The design parameters (Appendix B), demonstration of 1,000-year isolation (Section 2 1 1 Appendix A), and the final Closure Plan (which will be submitted for CDPHE review and approval) will provide reasonable assurance of long-term compliance with the requirements of Section 2 4 8 of Part 2 Guidelines for development of the final closure plan are presented in Appendix L to the CDD The final plan will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 of the CDD

3.8 Surface and Groundwater Monitoring (Section 2.4.9 of Part 2)

The design of the landfill will include a system for monitoring groundwater that will be developed in accordance with the guidelines for the Groundwater Monitoring Program presented in Appendix K of the CDD The landfill will be designed to prevent runoff water from contacting the waste, therefore the design performance of preventing adverse effects to surface water will be accomplished Monitoring for performance of the surface-water control system will be provided for in the CAMU Inspection Plan (outlined in Appendix G) The Groundwater Monitoring Program and CAMU Inspection Plan will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of the CDD

3.9 Construction Quality Assurance/Quality Control (Section 2.4.10 of Part 2)

Quality control of materials in construction of the landfill will be in accordance with the Construction Quality Assurance Plan (CQAP) (outline presented in Appendix H) Construction of the landfill will follow the CQA procedures presented in the CQAP The CQAP will include applicable requirements for supervision during construction and certification by a professional geologist or professional engineer to demonstrate that the facility is constructed in accordance with the design as approved The CQAP will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 of the CDD

4.0 INSTALLATION STANDARDS (6 CCR 1007-3 SECTION 265.18)

This section reviews compliance of the CAMU with the general facility installation standards of 6 CCR 1007-3 Section 265 18 The installation standards address general siting requirements for facilities that treat, store, or dispose of hazardous waste These requirements are applicable to the CAMU in accordance with 6 CCR 1007-3 Section 264 552(a)(3)

4.1 Seismic Considerations (Section 265.18 [a])

Section 265 18 (a) states that hazardous waste facilities may not be located within 1,000 feet of a fault that has had displacement in Holocene time (i e , the last 10,000 years) The geology of the proposed site has been reviewed in the Landfill Feasibility Study (FS) and no evidence of faulting during the Holocene Epoch has been established at RMA (HLA, 1995d)

4.2 Floodplains (Section 265.18 [b])

This regulation states that new landfills must be located outside the 100-year floodplain, which is defined as any area subject to a 1 percent or greater chance of flooding in any given year from any source The U S Army Corps of Engineers (COE) produced a 100-year floodplain map of the RMA area (COE, 1983) which is shown in Figure A22 The proposed CAMU landfill development area is outside this 100-year floodplain.

4.3 Salt Dome Formations (Section 265.18 [c])

The placement of any noncontainerized or bulk liquid hazardous waste in any salt dome formation, salt bed formation, underground mine, or cave is prohibited according to this regulation No known salt formations, underground mines, or caves exist at RMA In addition, liquids will not be placed into the CAMU disposal area

4.4 Surface Water and Groundwater (Section 265.18 [d])

This regulation states that hazardous waste disposal facilities shall not place wastes directly under or into surface water or groundwater that has a potential or existing beneficial use or that is in direct communication with an aquifer The landfill design parameters presented in Appendix B require that the landfill be designed such that the base of the landfill cells will be a minimum of 20 feet above groundwater

5.0 ACRONYMS

ARDL	Applied Research and Development Laboratories
Army	U S Department of the Army
BDL	Below detection limit
bgs	Below ground surface
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CCL	Compacted clay layer
C1/C0	Ratio of the concentration of constituent in water at the base of the lowermost liner (C1) to the initial concentration of chemical in leachate above the liner (C0)
CHWMA	Colorado Hazardous Waste Management Act
cm/s	Centimeters per second
COE	U S Army Corps of Engineers
COR	Contracting Officer's Representative
CPMSO	Chlorophenylmethyl sulfoxide
$CPMSO_2$	Chlorophenylmethyl sulfone
CQA	Construction quality assurance
CRS	Colorado Revised Statute
CVAA	Cold vapor atomic adsorption
DAA	Final Detailed Analysis of Alternatives
DBCP	Dibromochloropropane
DIMP	Diisopropylmethyl phosphonate
DMMP	Dimethyl methyl phosphate

EA	Endangerment assessment
Ebasco	Ebasco Services, Inc
ECD	Electron capture detector
EPA	U S Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc
FID	Flame ionization detector
FFA	Federal Facilities Agreement
FML	Flexible membrane liner
FPD	Flame photometric detector
FS	Feasibility study
g	Gram
GC	Gas chromatography
GCL	Geosynthetic clay liner
GC/MS	Gas chromatography/mass spectrometry
GFAA	Graphite furnace atomic adsorption
GMP	Groundwater Monitoring Program
HELP	Hydraulic Evaluation of Landfill Performance
HLA	Harding Lawson Associates
HDPE	High density polyethylene
HPLC	High pressure liquid chromatography
ICP	Inductively coupled plasma spectrophotometry
in/yr	Inches per year
IRA	Interim response action
K	Hydraulic conductivity
Kd	Soil/water partitioning coefficient for compounds in the environment
LCS	Leachate collection system
ml	Milliliter

mil	One-thousandth of an inch
MKE	Morrison-Knudsen Environmental Services, Inc (formerly Morrison-Knudsen Engineers, Inc)
MSL	Mean sea level
NA	Not applicable
NPD	Nitrogen phosphorous detector
PID	Photoionization detector
PCB	Polychlorinated biphenyl
PMRMA	Program Manager for Rocky Mountain Arsenal
PRG	Preliminary remediation goal
RI	Remedial investigation
RMA	Rocky Mountain Arsenal
ROD	Record of Decision
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
State	State of Colorado
SVE	Soil vapor extraction
SVOC	Semivolatile organic compound
$\mu g/l$	Micrograms per liter
USC	United States Code
USCS	Unified Soil Classification System
USFWS	U S Fish and Wildlife Service
USGS	U S Geological Survey
UXO	Unexploded ordnance
VOC	Volatile organic compound
Walsh	J P Walsh and Associates, Inc

6.0 BIBLIOGRAPHY

Arthur D Little 1979 *Hydrogeologic description of Rocky Mountain Arsenal groundwater module, fourth interim report, installation, restoration, simulation and cost benefit analysis* Prepared for Geraghty and Miller RIC No 81295R16

Bopp, and others 1979 *Hydrogeology and water quality of Basin A neck area, Rocky Mountain Arsenal, Denver, Colorado, draft report* U S Army Engineer Waterways Experiment Station, C E Vicksburg, Miss

Boutwell, G P 1992 *The STEI two-stage borehole field permeability test* Presented at Containment Alignment and Subtitle D, sponsored by Geotechnical Committee Houston Branch, American Society of Civil Engineers, March 12

Broughton, J , W Miller, and G Mitchell 1979 *Geology and groundwater definition, Basin A area, Rocky Mountain Arsenal, Denver, Colorado* U S Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 81266R27

Clapp, R B , and G Hornberger 1978 *Empirical equations for some soil hydraulic properties* Water Resource Research, 14 601-604

Colorado Climate Center 1994 *Public access meteorological data base* Fort Collins, Colo

Devoto, R H 1968 *Quaternary history of the Rocky Mountain Arsenal and environs, Adams County, Colorado* Quarterly of the Colorado School of Mines RIC No 84291R01

Dragun, J 1988 The Soil Chemistry of Hazardous Materials Hazardous Materials Hazardous Control Research Institute, Silver Spring, Md

Earth Technology Corporation 1981 *Hydraulic conductivity and the Unified Soils Classification System at Rocky Mountain Arsenal, Denver, Colorado* Project Number 82-169 Prepared for the U S Army Toxic and Hazardous Materials Agency and Computer Sciences Corporation Long Beach, Calif RIC No 81352R135.

Ebasco Services, Inc 1988a *Final report, task number 27, hazardous waste land disposal facility assessment report*

——— 1988b *Hazardous waste land disposal facility assessment* Rocky Mountain Arsenal, September

——— 1989a. *Final remedial investigation, north central study area* Prepared for the Program Manager for Rocky Mountain Arsenal, July

——— 1989b *Final water remedial investigation report, vol III version 3 3* Prepared for the Program Manager for Rocky Mountain Arsenal, RIC No 89186R01, July

——— 1994 *Final comprehensive air quality and meteorological monitoring program air quality data assessment report for FY 1993, version 2 0* Prepared for the Program Manage for Rocky Mountain Arsenal, Commerce City, RIC No 94347ROI, October

Ebasco Services, Inc , and others 1991 *Draft final remedial investigation summary report, version 2 3* Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colo RIC No 91137R01, May

Ebasco Services, Inc , R.L Stollar & Associates, Inc , Munter/ESE, Inc , and Harding Lawson Associates 1989a *Proposed final water remedial investigation report (version 3 2), vols I, II, III,* June

Emmons, S F , and others 1896 *Geology of the Denver Basin in Colorado* U.S Geological Survey Monographs Volume 27

Environmental Science and Engineering, Inc , Harding Lawson Associates, and Applied Environmental, Inc 1988 *Offpost operable unit remedial investigation and chemical specific applicable or relevant and appropriate requirements, final report, Version 3 1* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 89173R01, December

Evans, D M 1965 *Denver area earthquakes and the Rocky Mountain Arsenal disposal well* Mountain Geologist, Vol 3, no 1 23-36 RIC No 81356R32

Foster Wheeler Environmental Corporation 1995 Final detail analysis of alternatives, Version 4 1 Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colo October

Freeze, R A and J A Cherry 1979 *Groundwater* Prentice-Hall, Englewood Cliffs, NJ

Geraghty and Miller 1986 *Rocky mountain arsenal chemical index* Volume I

Giroud, J P , A Khatami, and K Badu-Tweneboah 1989 "Evaluation of the rate of leakage through composite liners," *Geotextiles and Geomembranes*, 8(4), 337-340

Giroud, J P and R Bonaparte 1989 "Leakage through liners constructed with geomembrane liners--parts I and II and technical note," *Geotextiles and Geomembranes* 8(1), 27-67, 8(2), 71-111, 8(4), 337-340

Giroud, J P , K Badu-Tweneboah, and R Bonaparte (1992) "Rate of leakage through a composite liner due to geomembrane defects," *Geotextiles and Gemembranes* 11(1), 1-28

Hansen, W R , and E J Crosby 1982 *Environmental geology of the front range urban corridor and vicinity, Colorado* USGS Professional Paper No 1230

Harding Lawson Associates 1989 *Regional ground-water flow modeling at the Rocky Mountain Arsenal, Denver, Colorado* Draft final report, Version 2 1

——— 1992a *Groundwater monitoring program final annual groundwater monitoring report for 1991* Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colo RIC No 92272R01, September

——— 1992b *Results of treatability studies for groundwater containment and/or control and subsurface drains final report* Volume I of IV, September 18

——— 1994a *Final geophysical assessment report, Rocky Mountain Arsenal, Commerce City, Colorado*, February

——— 1994b *Final fourth year reevaluation report for complex disposal trenches interim response action, Rocky Mountain Arsenal, Commerce City, Colorado*, September

——— 1994c *Final work plan for material and area feasibility studies, soils support program, Rocky Mountain Arsenal, Commerce City, Colorado*, November

——— 1995a *Final feasibility study soils support program report, Rocky Mountain Arsenal, Commerce City, Colorado*, January

——— 1995b *Groundwater monitoring program final annual groundwater monitoring report for 1993, Rocky Mountain Arsenal, Commerce City, Colorado*, March.

——— 1995c *Final technical plan task 94-02 conceptual design of the groundwater pump and treatment system for section 36 and south plants with supporting field work, Rocky Mountain Arsenal, Commerce City, Colorado*, March

——— 1995d *Final landfill site feasibility report, Rocky Mountain Arsenal, Commerce City, Colorado*, July

Harding Lawson Associates and Environmental Science and Engineering, Inc , 1992 *Offpost operable unit remedial investigation final addendum* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 92156R01, March.

Howard Needles Tammen & Bergendoff 1981 *Chemical waste treatment/solidification disposal facility plan* Prepared for Highway 36 Land Development Co , Adams County, Colo April

Hynes, J L , and C J Sutton. 1980 *Hazardous wastes in Colorado A preliminary evaluation of generation and geologic criteria for disposal* Prepared by the Colorado Department of Health and Colorado Geological Survey Department of Natural Resources

Jury, W A , W F Spensor, and W J Farmer 1983 Behavior Assessment Model for Trace Organics in Soil I Model Description. Journ Environmental Qual Vol 12, No 4. 558-564

Kirkham, R J , and W P Rogers 1981 *Earthquake potential in Colorado* Colorado Geological Survey, Bulletin 43

Kobayashi, M and B E Rittmann. 1982 *Microbial removal of hazardous organic compounds* Environmental Science & Technology, Vol 16, No 3 170-183

Koerner, R Halse, Y , and A Lord 1990 *Long-term durability and aging of geomembranes, in waste containment systems* GSP, No 26 R Bonaparte, Ed , ASCE, New York. 106-134

Lyman, W J , W F Reehl, and D H Rosenblatt 1982 Handbook of chemical property estimation methods, American Chemical Society, Washington, D C

Lindvall, R M 1980 *Geological map of the Commerce City quadrangle, Adams and Denver Counties, Colorado* U S Geological Survey Map CQ-1541

——— 1983 *Geological map of the Sable quadrangle, Adams and Denver Counties, Colorado* U S Geological Survey Map MF-1180

May, J H 1982 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado report 1, hydrogeological definition* U.S Army Corps of Engineers Waterways Experiment Station. Vicksburg, Miss RIC No 82295R01, July

May, J H , J D Crabtree, R W Hunt, and M L Murphy 1983 *Hydrogeology of basin A/south plants area, Rocky Mountain Arsenal, Denver, Colorado, phase I* U S Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 83299R01

——— 1983 *Hydrogeology of Basin A/South Plants area, Rocky Mountain Arsenal, Denver, Colorado, phase I* Final Report Geotechnical Laboratory, U S Army Engineer Waterways Experiment Station, September

Miller, C H , and others 1979 *Preliminary magnetic, seismic, and petrographic investigation of a possible igneous dike at the Rocky Mountain Arsenal* Denver, Colo U S Geological Survey, Open File Report 79-1685

Millington, R J 1959 Gas Diffusion in Porous Media Science, Vol 130, July 10

Morrison-Knudsen Engineers, Inc 1987 *Preliminary recharge estimates for RMA regional flow model, final version*

——— 1988 *Geology of the Rocky Mountain Arsenal, Adams County, Colorado* Prepared for Holme, Roberts, and Owens Denver, Colo

Morrison-Knudsen Environmental Services, Inc 1994 White paper evaluation of the Denver Formation at Rocky Mountain Arsenal, April

Ogata, A , and R B Banks 1961 A Solution of the Differential Equation of Longitudinal Dispersion in Porous Media U S Geol Survey Professional Paper 411-A A1-A7 Reston, Va

Pacific Western Technologies 1993 *Groundwater monitoring program final annual groundwater monitoring report for 1992* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 94230R02, August

Rauch, R 1994 U S Fish and Wildlife Service, Rocky Mountain Arsenal, Commerce City, Colorado Letter to Charles Sharmann, Program Manager for Rocky Mountain Arsenal, September 22

Richardson, G N 1995 Review of Repository Alternatives Letter to Harding Lawson Associates, February 9

Robson, S G 1987 *Bedrock aquifers in the Denver Basin, Colorado - A quantitative water-resources appraisal* U S Geological Survey Professional Paper 1257 73

Robson, S G , and J C Romero 1981 *Geologic structure, hydrology, and water quality of the Denver Aquifer in the Denver Basin, Colorado* Prepared for the U S Geological Survey and the Colorado Division of Water Resources RIC No 82350M02

Rosenbloom, J, P Mock, P Lawson, J Brown, and H J Turin. 1993 *Application of VLEACH to Vadose Zone Transport of VOCs at an Arizona Superfund Site,* 159-169 Groundwater Monitoring Review, Summer

Rust Environment and Infrastructure 1994 Landfill Quantity, Borrow Materials, and Landfill Generation Rate Summary Letter to Harding Lawson Associates, December 22

Sampson, J , T Babor, and C Prentiss 1974 *Soil survey of Adams County, Colorado* CSU, USDA RIC No 81266R54

Schawzenbach, R P , et al 1993 *Environmental organic chemistry* John Wiley & Sons Inc

Shepherd, W D 1982 Letter to Commander of RMA from J H Knaus, Shell Oil Col, including data from aquifer tests dated May 5, 1982

Shan, C , and D B Stephens 1995 An analytical solution for vertical transport of volatile chemicals in the vadose zone 259-277 Journal of Contaminant Hydrology, No 18

Spaine, P A , D W Thompson, and J H Dildane 1984 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado Report 2 contamination distribution* U.S Army Corps of Engineers Waterways Experiment Station, Environmental Laboratory Vicksburg, Miss

Stollar, R L , and F Van der Leeden 1981 *Evaluation of the hydrogeological system and contaminant migration patterns, Rocky Mountain Arsenal final report.* Geraghty and Miller, Inc Prepared for the U S Army Toxic and Hazardous Materials Agency Denver, Colo RIC No 81293R05

Trimble and Machette 1979 *Geologic map of the greater Denver area, front range urban corridor, Colorado* U S Geological Survey Map I-856-H

U S Army Corps of Engineers 1983 *Evaluation of the existing and future flood potential on the Rocky Mountain Arsenal, Denver, Colorado* Omaha, Nebr RIC No 84066R01.

U S Army Toxic and Hazardous Materials Agency 1984 *Decontamination assessment for land and facilities at Rocky Mountain Arsenal* Draft Final Report. RIC No 84034R01

——— 1983 *Selection of a contamination control strategy for Rocky Mountain Arsenal* Final Report. RIC No 83326R01

U S Environmental Protection Agency 1988 *Guidance for conducting remedial investigations and feasibility studies under CERCLA,* Interim Final October

——— 1988 *Interactive simulation of the fate of hazardous chemicals during land treatment of oily wastes RITZ user's guide* January EPA/600/8-88/001

——— 1994 *The hydrologic evaluation of landfill performance (HELP) model, engineering documentation for version 3* September EPA/600/R-94/168b

——— 1995 Vleach. Vadose Zone Leaching Model, Version 2 2, Center for Subsurface Modeling Support, Ada, OK October

U S Soil Conservation Service 1988 *National Agronomy Manual*

U S Soil Conservation Society 1995 *Revised universal soil loss equation,* version 1 04 May

Vispi, M A. 1978 *Report of findings, RMA pumping tests, USAEWES report* U S Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 81266R70

Waterways Experiment Station (Crabtree, J D , and Thompson, D. W) 1983 *Proposed hazardous waste landfill siting and suitability, Rocky Mountain Arsenal, Denver, Colorado* Prepared for the U S Army Toxic and Hazardous Materials Agency November

Weimer, R 1973 *A guide to Uppermost Cretaceous stratigraphy, central front range, Colorado* Department of Geology, Colorado School of Mines, Golden, Colo RIC No 81266R59

Table A1: Estimates of Potential Advective Water Movement through a Composite System - Landfill Cover Analysis

Geosynthetic Clay Liner	
Thickness of FML (inches) =	0 06
Thickness of Soil Barrier (inches) =	0 25
Saturated K of FML (cm/s) =	2 30E-13
Saturated K of FML (in/day) =	7 82E-09
Saturated K of Soil Barrier Layer (cm/s) =	3 00E-09
Saturated K of Soil Barrier Layer (in/day) =	1 02E-04
Number of Pinholes per acre =	1
Number of Defects per acre =	3

Head on top of liner (inches)	Q, areal through FML (in/yr)	R, pinholes (m)	R, defects (m)	Gradient, pinholes	Gradient, defects	Q, pinholes (in/yr)	Q, defects (in/yr)	Q, total, (in/yr)
12	0 0006	0 5850	0 7456	4 3971	5 9137	0 00004	0 0003	0 0009
18	0 0009	0 7165	0 9131	5 9535	8 0769	0 00008	0 0005	0 0014

cm/s Centimeters per second
FML Flexible membrane liners
in Inches
K Hydraulic conductivity
m Meter
Q Flow
R Radius
yr Year

21907 705011 1
0212031396 RAF

Table A2: Estimates of Potential Advective Water Movement through a Composite System - Lowermost Landfill Liner Analysis

Compacted Clay Liner	
Thickness of FML (inches) =	0 06
Thickness of Soil Barrier (inches) =	36
Saturated K of FML (cm/s) =	2 30e-13
Saturated K of FML (in/day) =	7 82e 09
Saturated K of Soil Barrier Layer (cm/s) =	1 00e-07
Saturated K of Soil Barrier Layer (in/day) =	3 40e-03
Number of Pinholes per acre =	1
Number of Defects per acre =	3

Head on top of liner (inches)	Q, areal through FML (in/yr)	R, pinholes (m)	R, defects (m)	Gradient, pinholes	Gradient, defects	Q, pinholes (in/yr)	Q, defects (in/yr)	Q, total (in/yr)
12	0 0006	1 1145	1 4219	1 0216	1 0301	0 0011	0 0053	0 007

cm/s Centimeters per second
FML Flexible membrane liners
in Inches
m Meters
Q Flow
R Radius
yr Year

21907 705011 1
0212031396 RAF

Table A3: Summary of Chemical Parameters for Compounds Modeled using VLEACH

Compound	Solubility (mg/l)	Source	Henry's Constant	Source
CPMSO	1,100	Offpost EA	5 00E-04	Offpost EA MLE
Dibromochloropropane (DBCP)	1,100	Offpost EA	0 0147	Offpost EA, RME
DIMP	22,000	Offpost EA	8.20E-05	Offpost EA, MLE
Chloroform	7,700	Offpost EA	0 17	Offpost EA, RME

Compound	K_d	Source
CPMSO	0 15	K_d Study, HLA, 1987
Dibromochloropropane (DBCP)	0 49	K_d Study, HLA, 1987
DIMP	0 3	K_d Study, HLA, 1987
Chloroform	0.29	K_d Study, HLA, 1987

cm	Centimeters
CPMSO	4-Chlorophenylmethyl sulfone
DIMP	Diisopropylmethyl phosphonate
EA	Endangerment Assessment
g	Gram
HLA	Harding Lawson Associates
K_d	Soil-water partition coefficient
m	Meter
mg/l	Milligrams per liter
r	Radius
MLE	Most likely exposure
RME	Reasonable maximum exposure

Table A4: Summary of Physical Parameters Used in VLEACH Simulations

	Value	Source
Porosity =	0 4	HELP model, sandy clay loam
Bulk Density (g/cm³) =	1 6	Assumed
Moisture Content =	0 25	Clapp and Hornberber analysis
Advective Velocity (inches/year) =	0 0068	HELP model result
Fraction Organic Carbon =	0 005	Reasonable low value, RMA SVE study

cm Centimeters
g Grams
HELP Hydrologic evaluation of landfill performance
RMA Rocky Mountain Arsenal
SVE Soil vapor extraction

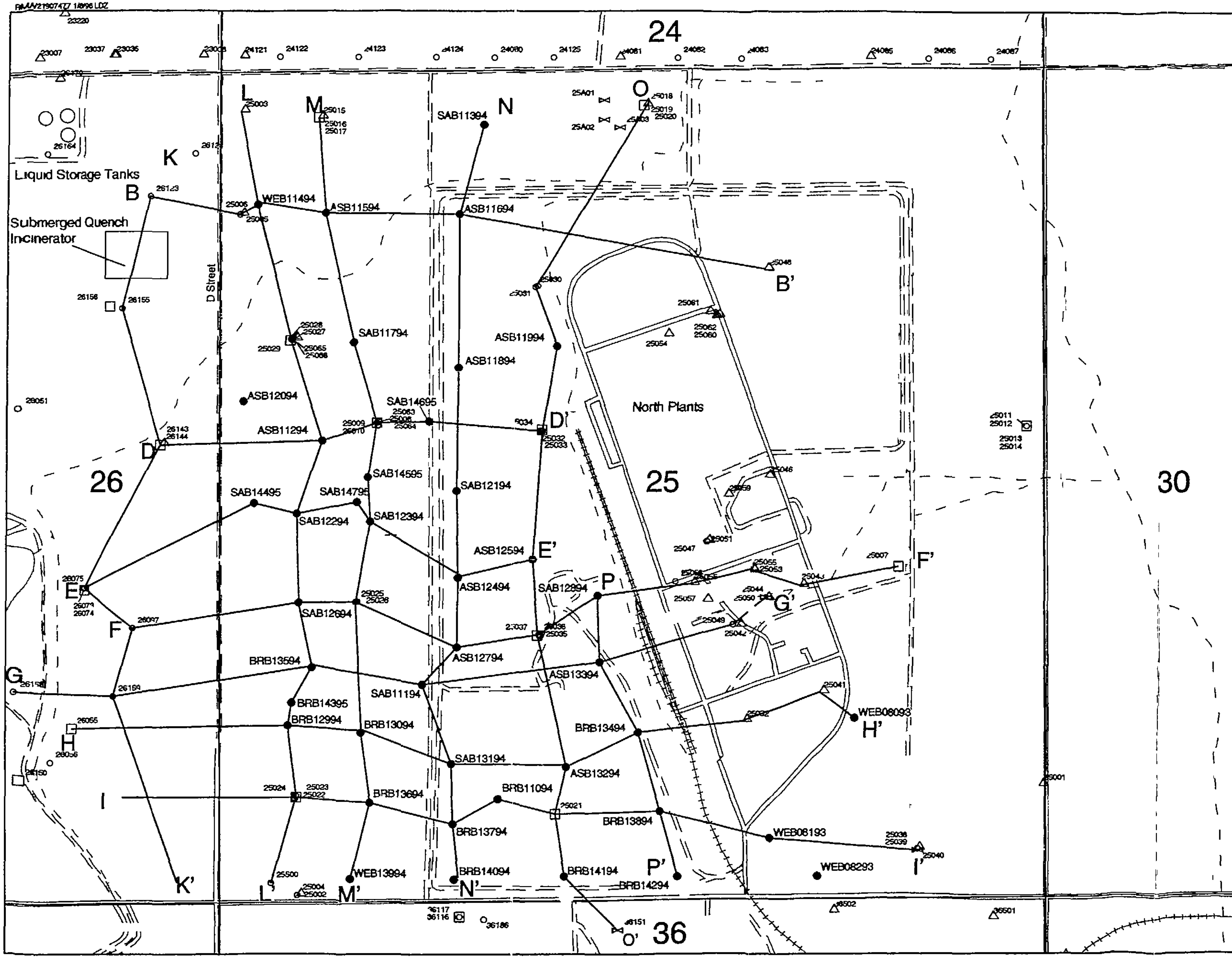
Table A5: Summary of Potential Leachate Concentrations versus Predicted Threshold Concentrations

Constituent	Predicted Cv/Co	PRG from DAA (μg/l)	Predicted Threshold Concentrations* (μg/l)	Characterization of Potential Future Landfill Leachate# (μg/l)
CPMSO	6.1×10^{-5}	36	591,000	10,000 to 19,000
Dibromochloropropane (DBCP)	1.3×10^{-4}	0.2	1,500	2
DIMP	4.5×10^{-6}	8	1,797,000	740 to 1,300
Chloroform	5.6×10^{-5}	6	108,000	21 to 610

CPMSO 4-Chlorophenylmethyl sulfone
Co Concentration of compound in the leachate above the lowermost liner
Cv Predicted concentration of compound at the bottom of the unsaturated zone
DAA Detailed Analysis of Alternatives
DIMP Diisopropylmethyl phosphonate
PRG Preliminary remediation goals
μg/l Micrograms per liter

* The concentration in leachate necessary to result in the occurrence of predicted concentrations at the top of the saturated zone above the PRG for that constituent in 1,000 years or less, assuming a single 3-foot composite clay liner and 20 feet to groundwater

\# Based on Range of Concentrations in Basin F Waste Pile leachate since 1989 (Attachment A2)



Explanation

24065 Alluvial well with well number

25058 Unconfined Denver Formation well with well number

26156 Confined Denver Formation well with well number

25050 Unknown well classification

WEB11494 Soil Borings

Unpaved roadway

Surface drainage

Section number

D ——— D' Cross sections developed for evaluation of geologic data

N

0 600

Scale in feet

Prepared for:

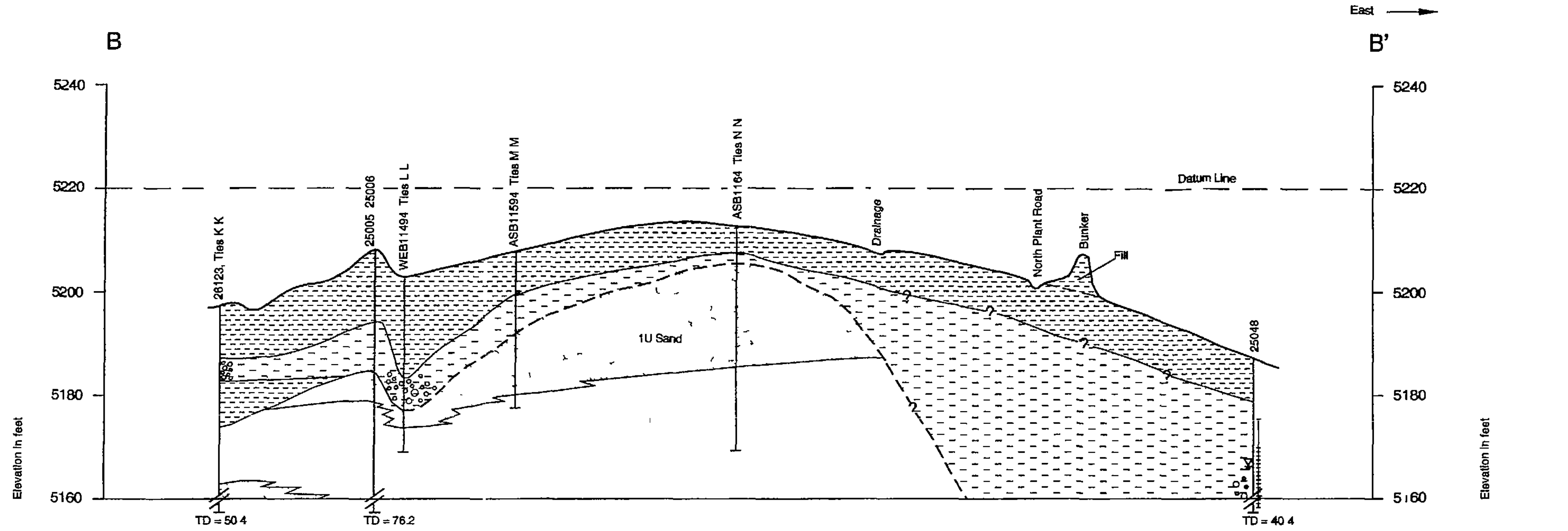
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by

Harding Lawson Associates

Figure A1

Site Map Showing
Cross Section Locations



Explanation

Alluvium	Bedrock (Denver Formation)
Clay sandy clay (CL CH)	Lignite/Lignitic claystone
Sand silty sand clayey sand (SP SM SC SW)	Sandstone
Gravel	Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note.
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite, and claystone is unknown.

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20

0

0 400

Scale in feet
Vertical exaggeration = 20x

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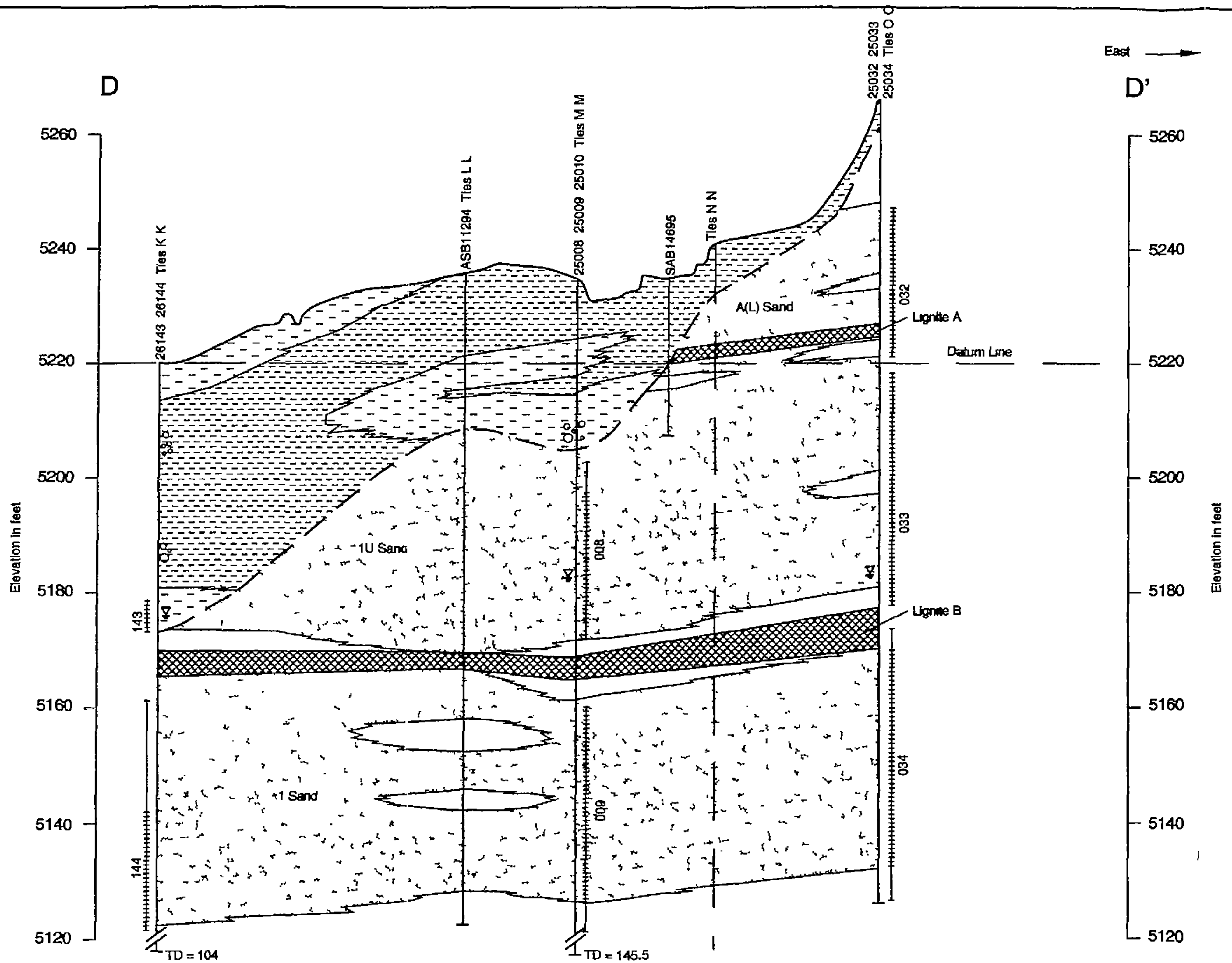
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado
Prepared by
Harding Lawson Associates

Figure A2

Geologic Cross Section B-B



Explanation

Alluvium

- Clay, sandy clay (CL,CH)
- Sand, silty sand, clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20
0
0 400
Scale in feet
Vertical exaggeration = 20x

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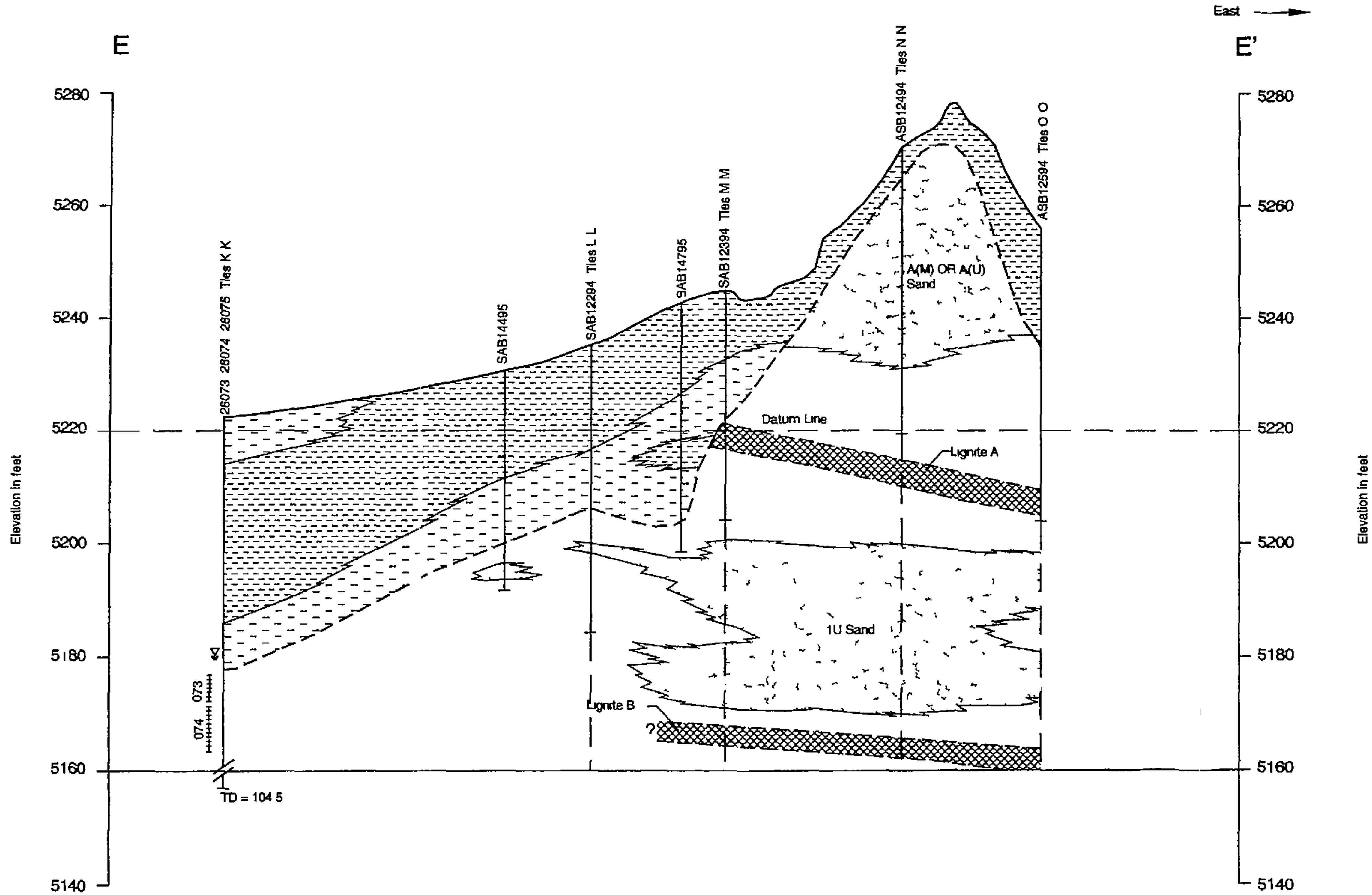
Rocky Mountain Arsenal
Commerce City Colorado
Prepared by
Harding Lawson Associates

Figure A3

Geologic Cross Section D-D'



Explanation

Alluvium

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note.
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20
0
0 400
Scale in feet
Vertical exaggeration = 20x

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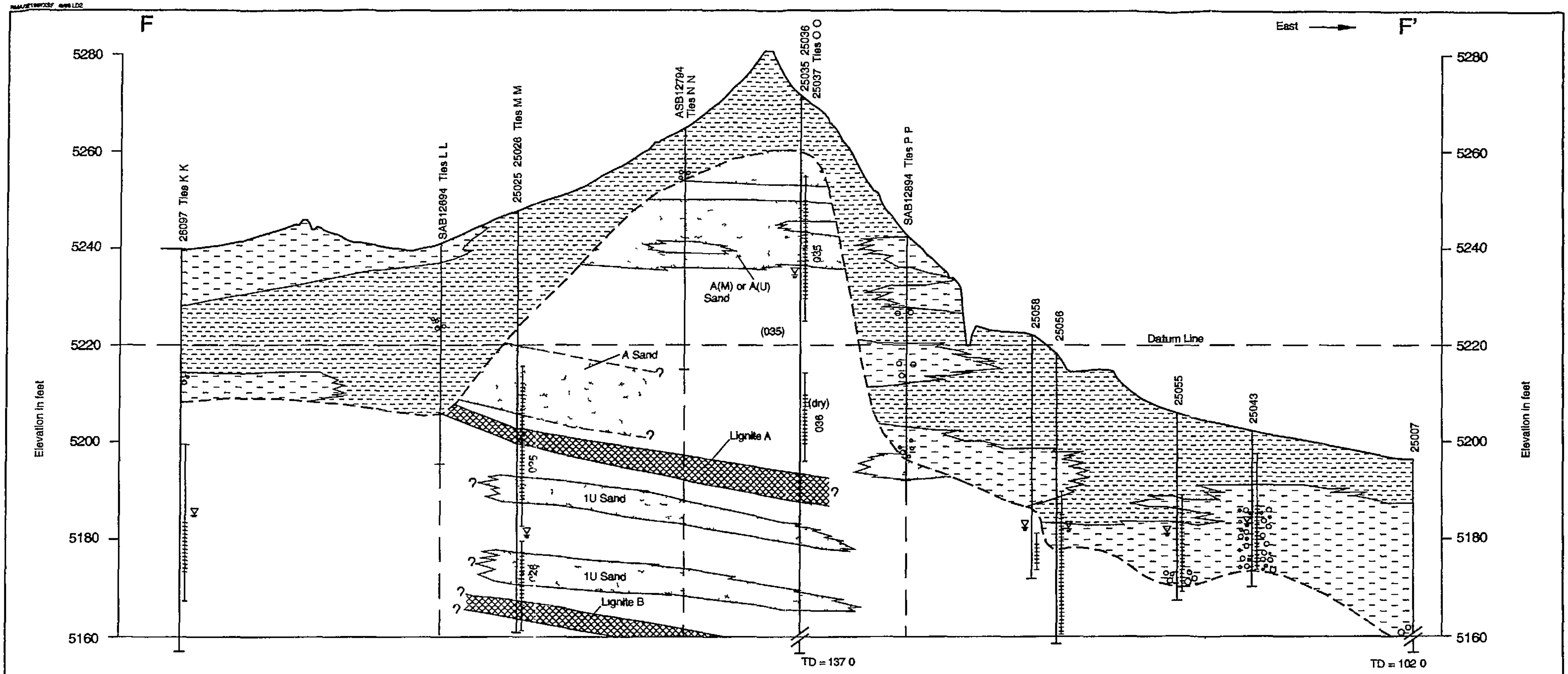
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
Harding Lawson Associates

Figure A4

Geologic Cross Section E E



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite, and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note:
In areas of no lithologic control, lateral extent of Denver Formation sandstone, lignite and claystone is unknown

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20 — 0 — 400

Scale in feet
Vertical exaggeration = 20x

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Commerce City Colorado
Prepared by
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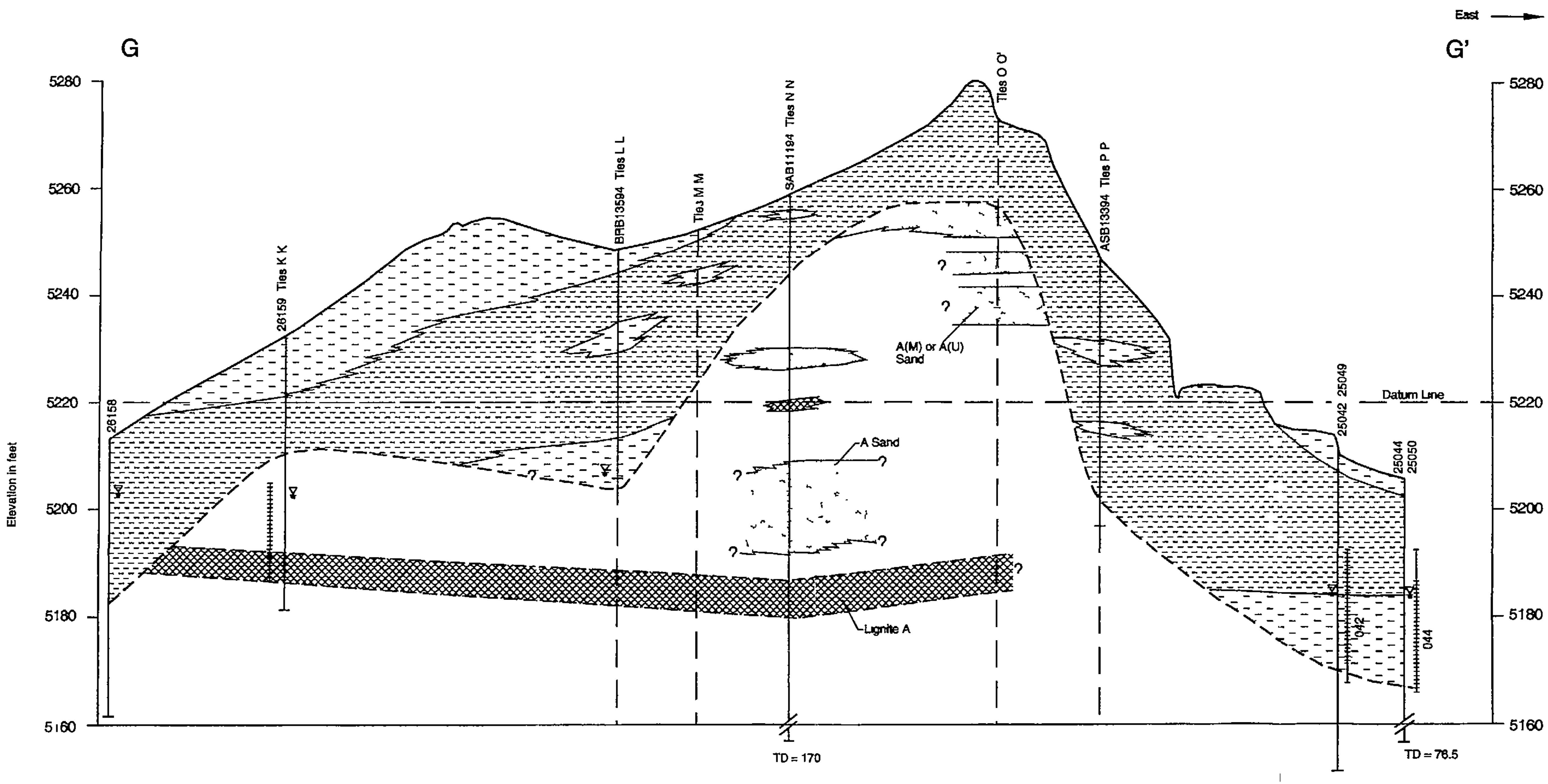
Figure A5

Geologic Cross Section F-F'



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite, and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note:
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20

0

0 400

Scale in feet
Vertical exaggeration = 20x

Prepared for
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Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
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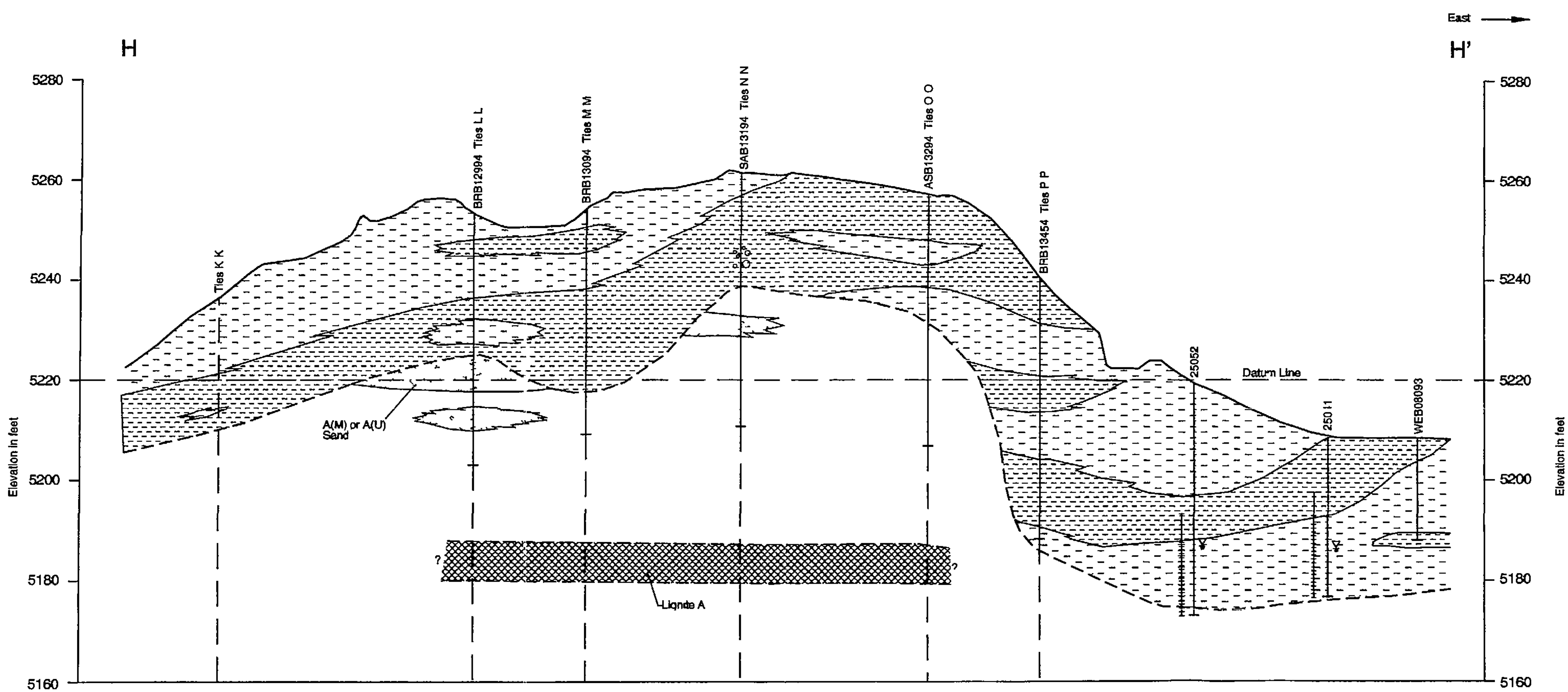
Figure A6

Geologic Cross Section G-G'



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite, and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite, and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20 / 0 / 400

Scale in feet
Vertical exaggeration = 20x

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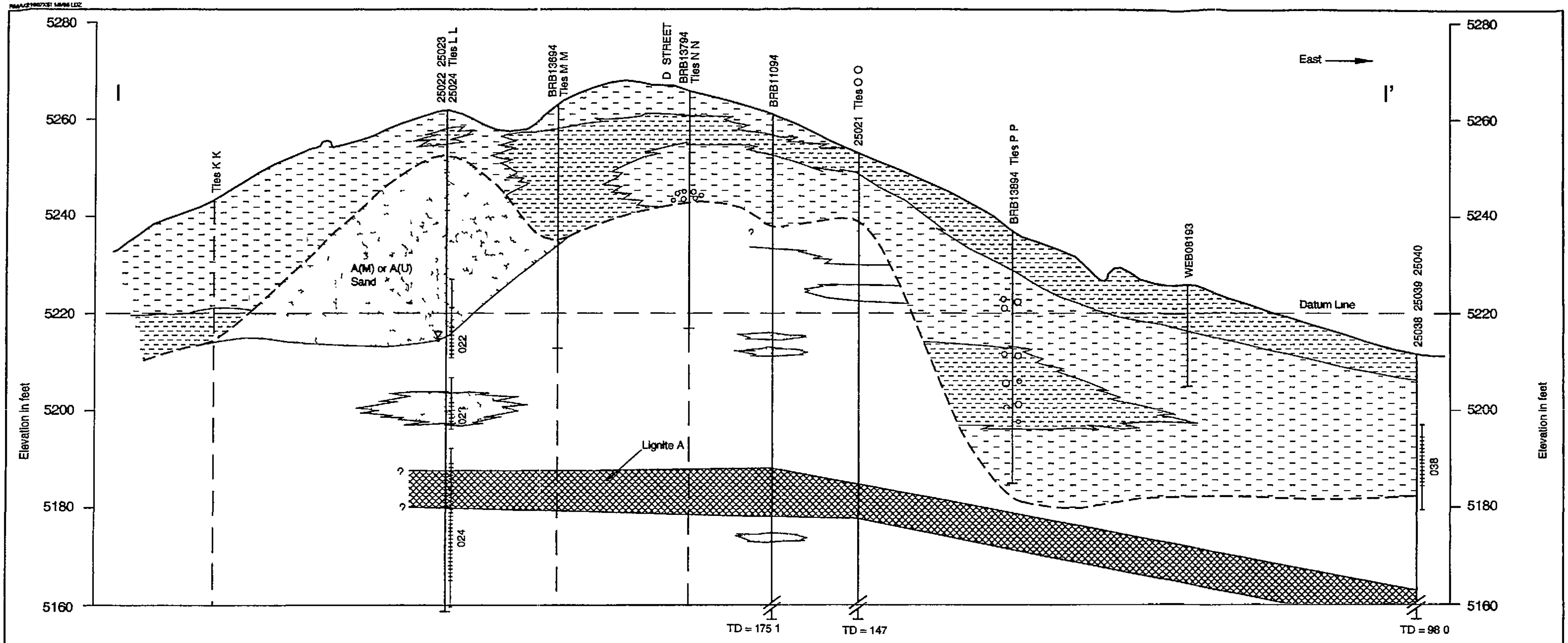
Commerce City Colorado
Prepared by
Harding Lawson Associates

Figure A7

Geologic Cross Section H-H'



Explanation

Alluvium:

- Clay sandy clay (CL CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note.
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

Screened interval with well number

101

TD = Total depth in feet

Scale in feet
Vertical exaggeration = 20x

0 — 400 (horizontal); 0 — 20 (vertical)

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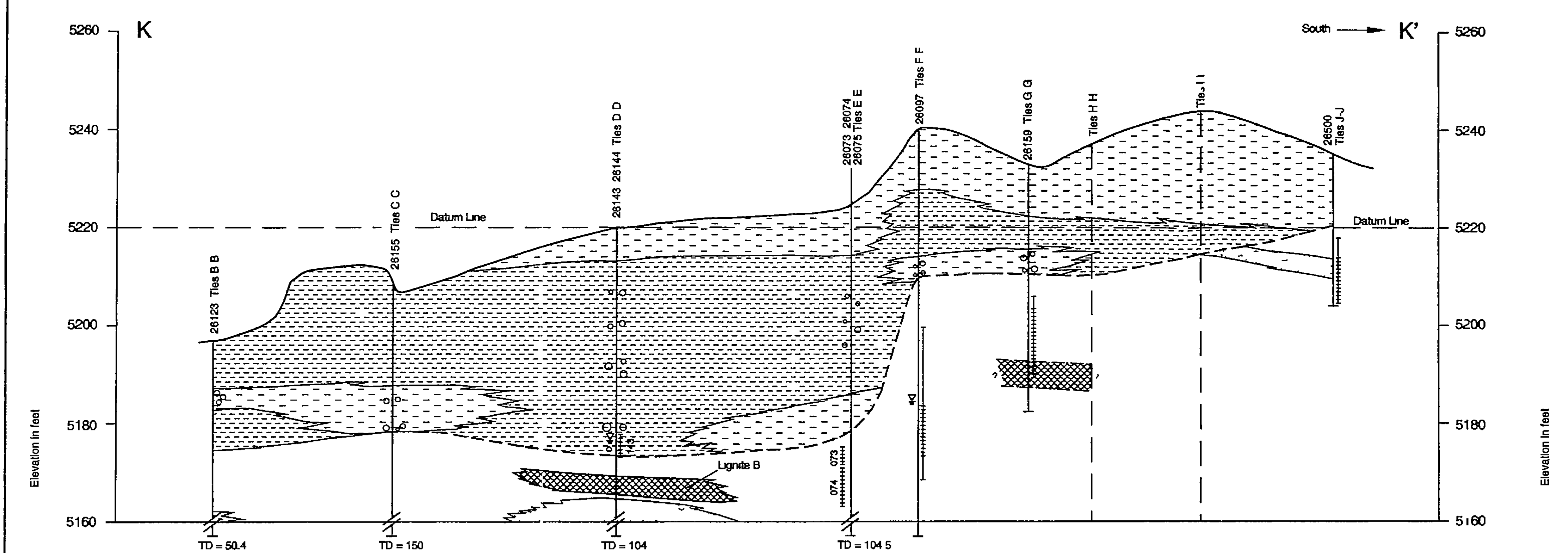
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure A8

Geologic Cross Section I-I



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown.

SAB11194 — Boring Identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

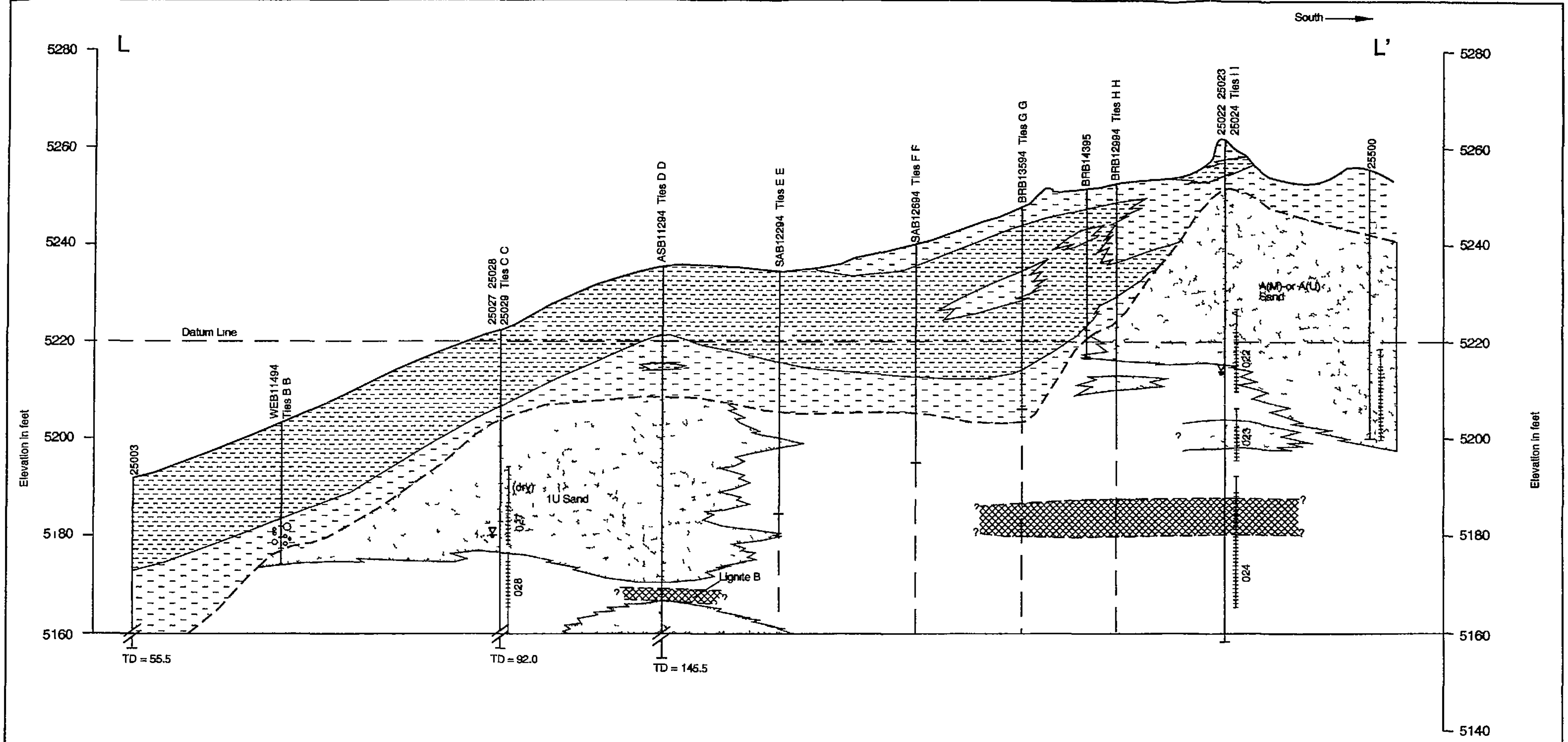
20
0
0 400
Scale in feet
Vertical exaggeration = 20x

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by:
Harding Lawson Associates

Figure A9

Geologic Cross Section K K



Explanation

Alluvium

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

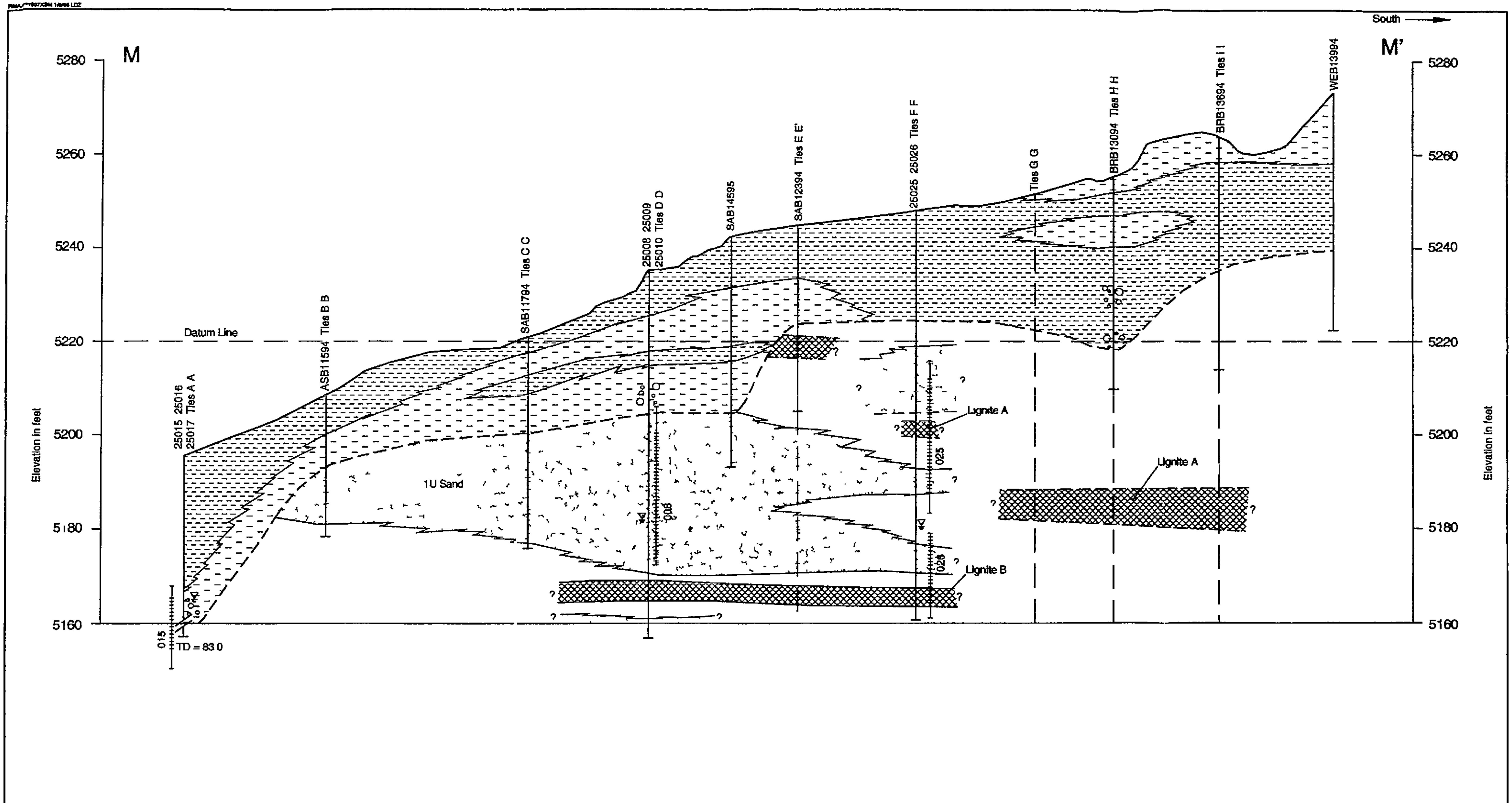
TD = Total depth in feet

20
0
0 400
Scale in feet
Vertical exaggeration = 20x

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado
Prepared by
Harding Lawson Associates

Figure A10

Geologic Cross Section L-L



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note.
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown.

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20

0

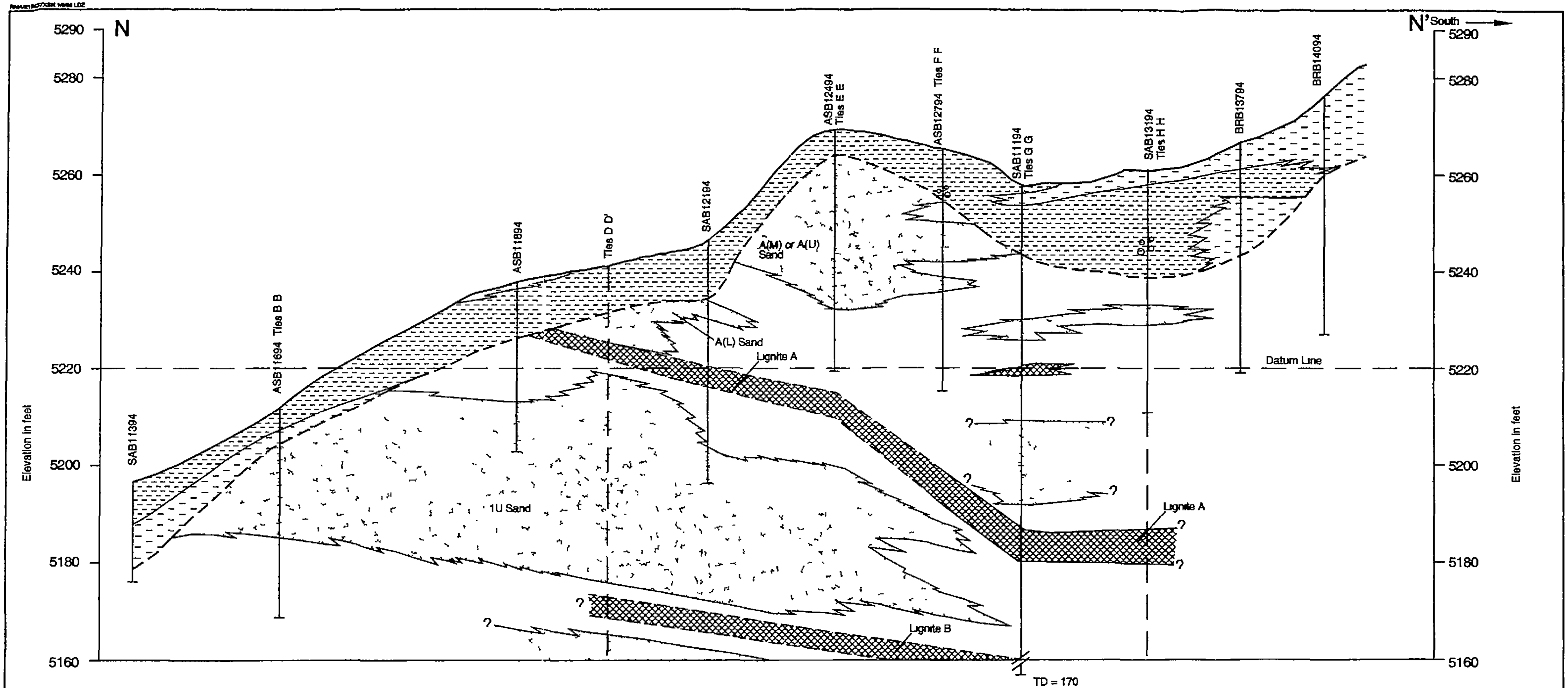
0 400

Scale in feet
Vertical exaggeration = 20x

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
Harding Lawson Associates

Figure A11

Geologic Cross Section M M



Explanation

Alluvium

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite and sandstone (see note)

Top of weathered bedrock

Note
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20
0
0
400
Scale in feet
Vertical exaggeration = 20x

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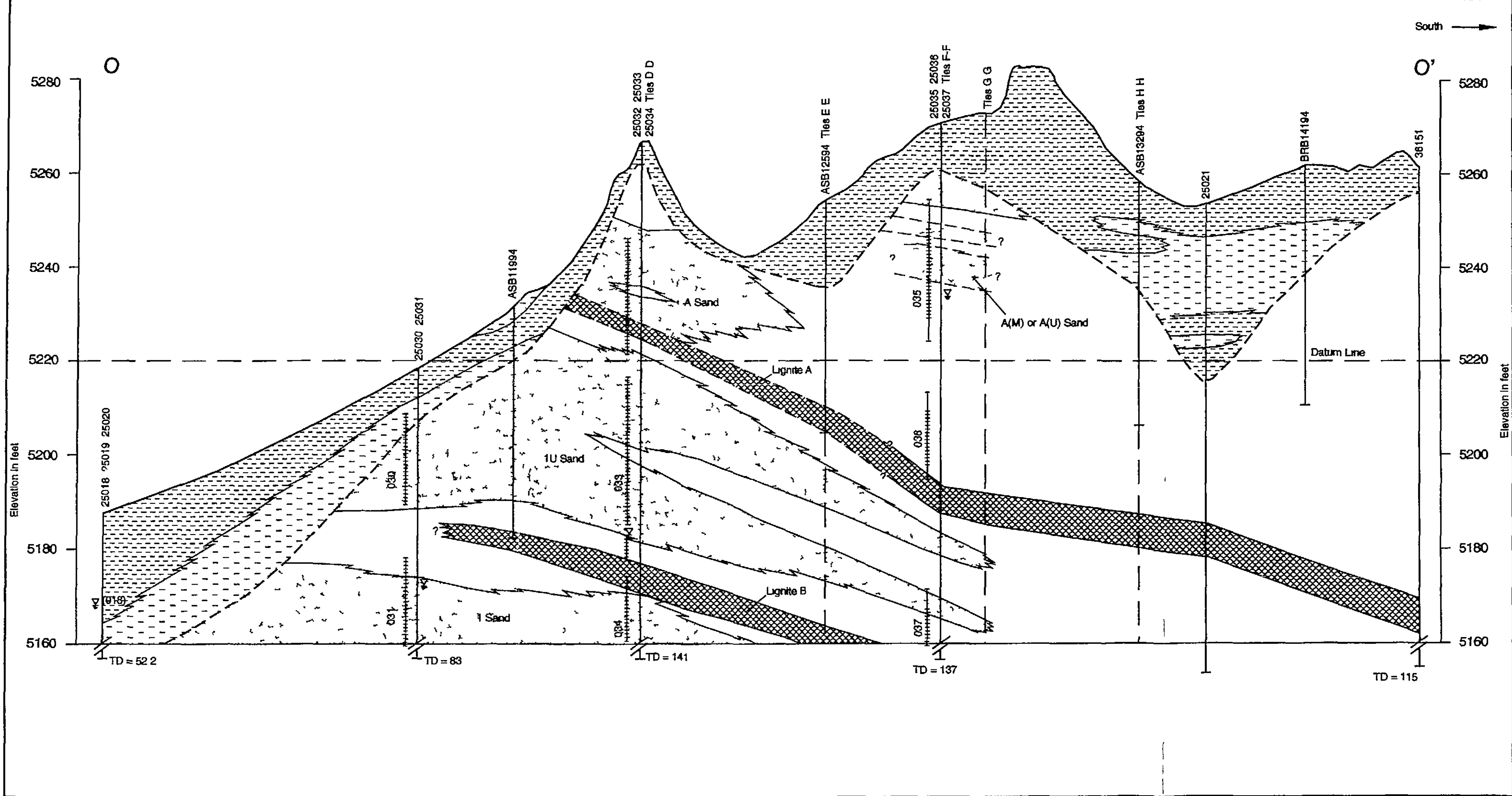
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure A12

Geologic Cross Section N-N



Explanation

Alluvium

- Clay sandy clay (CL,CH)
- Sand, silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic Claystone
- Sandstone
- Claystone with interbedded siltstone lignite, and sandstone (see note)

Top of weathered bedrock

Maximum recorded groundwater elevation

Note:
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB1 '94 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20

0

0 400

Scale in feet
Vertical exaggeration = 20x

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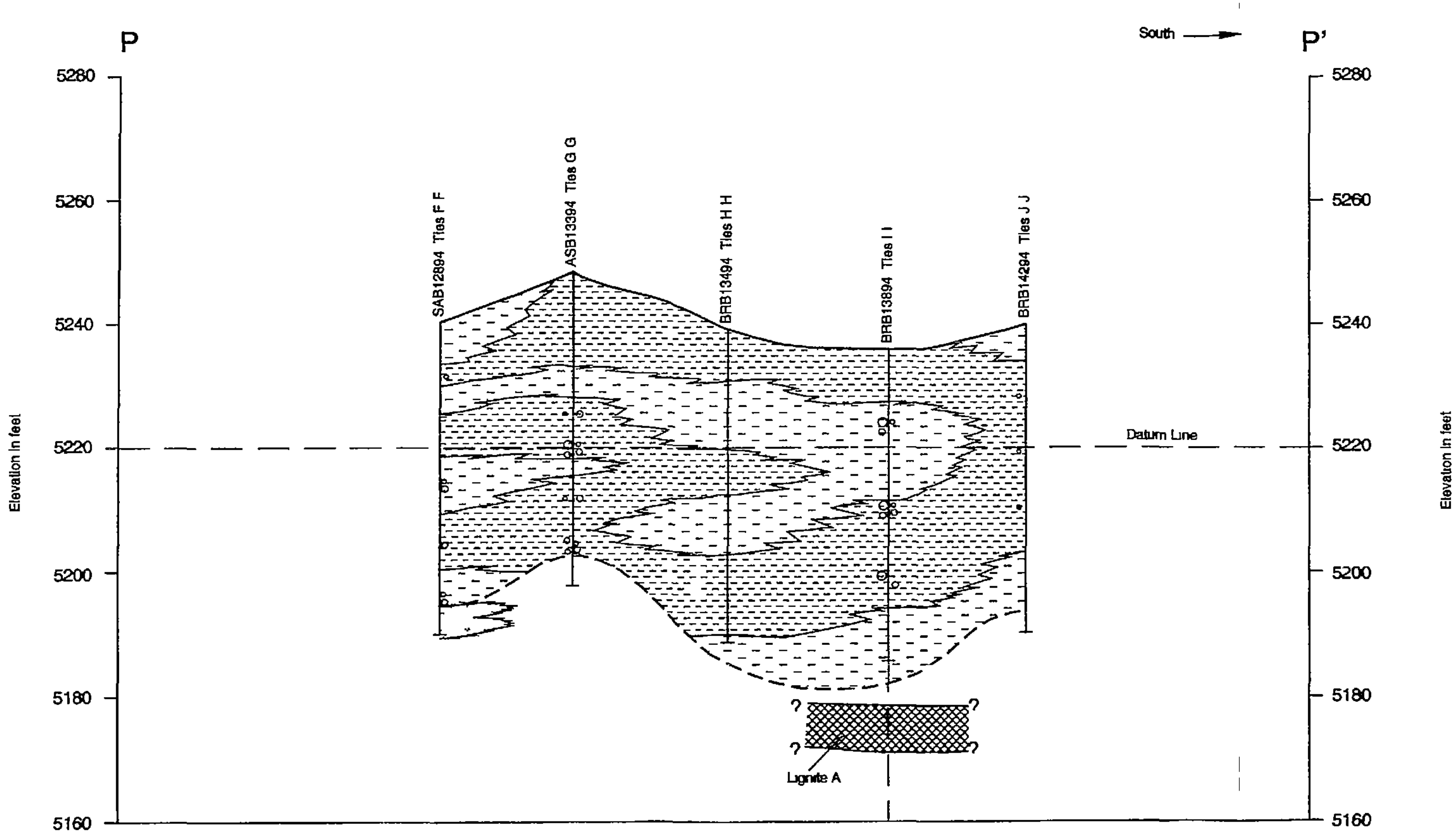
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
Harding Lawson Associates

Figure A13

Geologic Cross Section O-O'



Explanation

Alluvium:

- Clay sandy clay (CL,CH)
- Sand, silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite and sandstone (see note)

Top of weathered bedrock

Note:
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20
0
0 400
Scale in feet
Vertical exaggeration = 20x

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Prepared by
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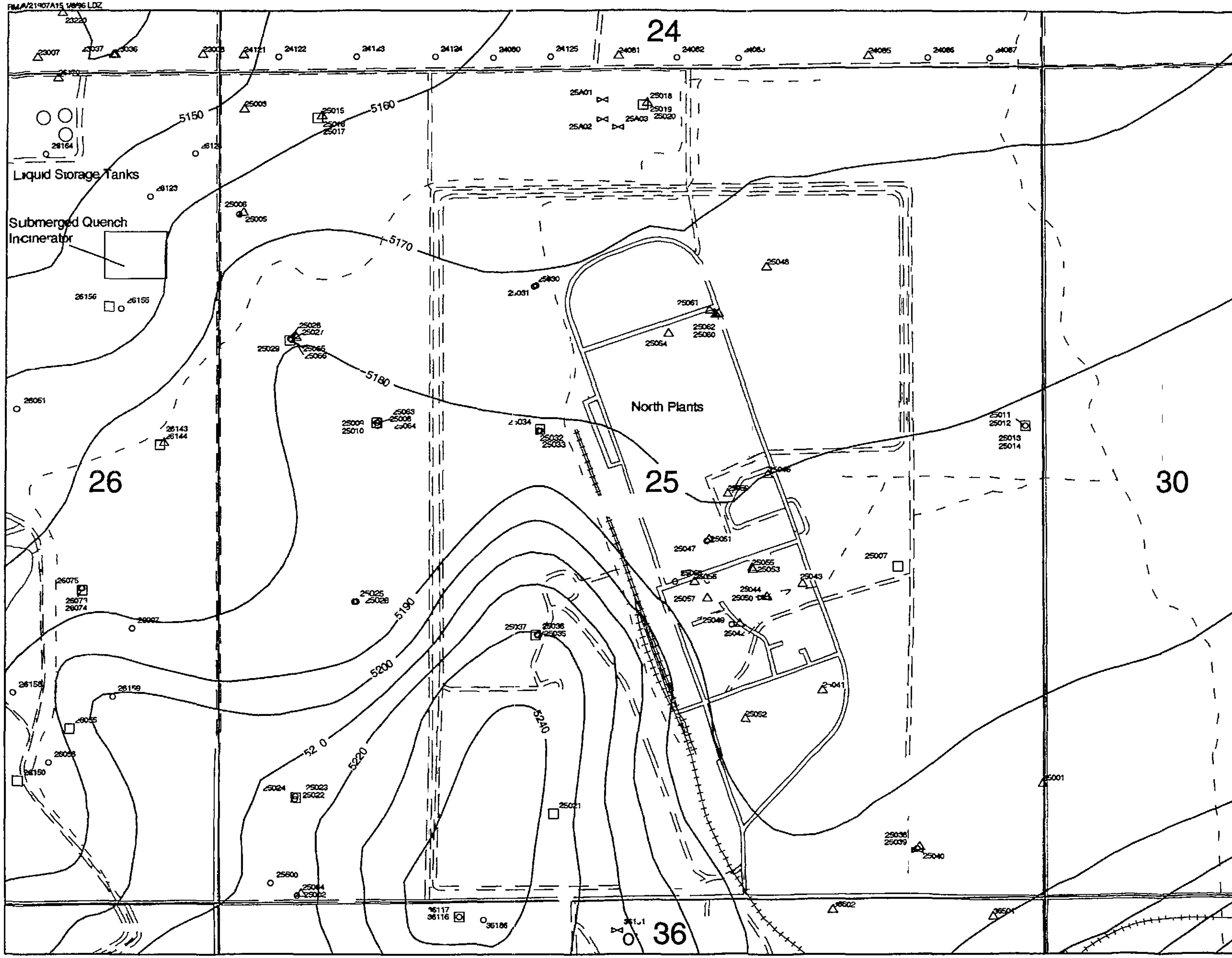
Figure A14

Geologic Cross Section P-P

RMA/21907A15 1/8/96 LDZ



Explanation

- Alluvial well with well number (24085)
- Unconfined Denver Formation well with well number (25058)
- Confined Denver Formation well with well number (26156)
- Unknown well classification (25050)
- Unpaved roadway
- Surface drainage
- 30 Section number
- Water table elevation (10 foot contour interval)

Source: Groundwater Monitoring Program Groundwater Monitoring Report for 1993 (HLA, 1995)

N

0 600
Scale in feet

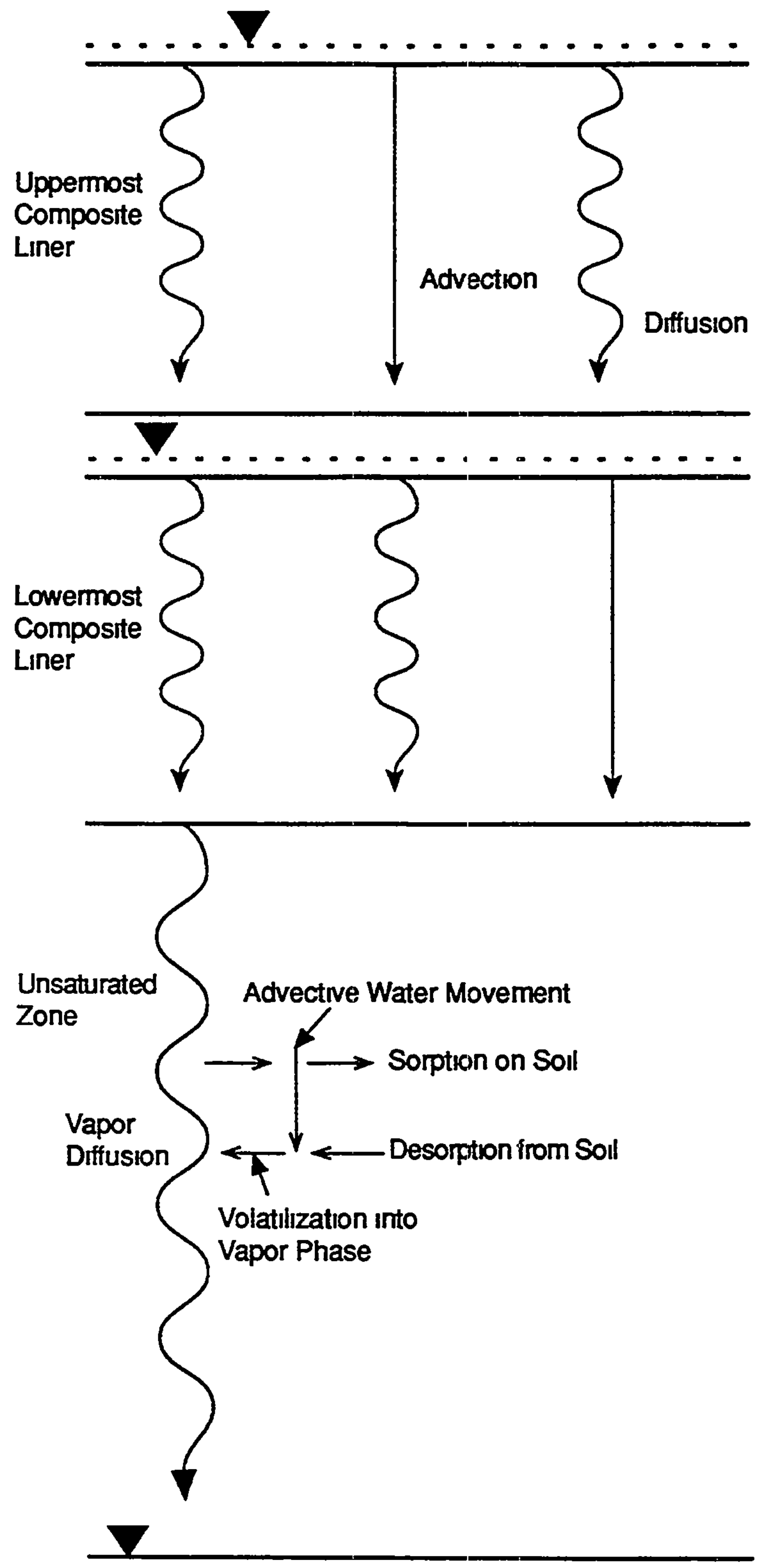
Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure A15

Water-Table Map of the Unconfined Flow System Section 25

RMA 1287 4d 010896 ECS



1 Leachate collects on top of uppermost liner

2 Potential migration via molecular diffusion in water and advective water movement

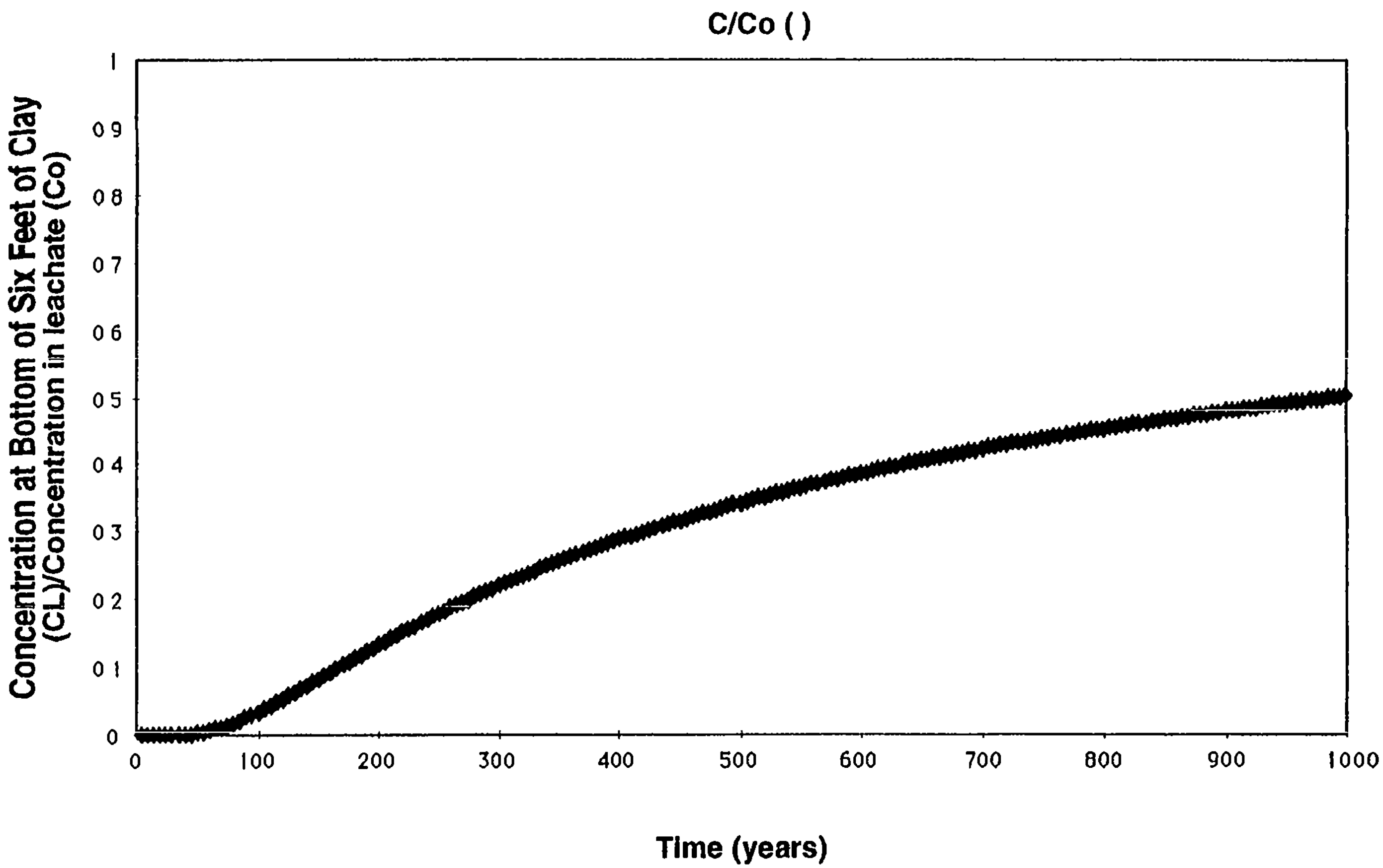
3 Leachate collects on top of most lower liner

4 Potential migration via molecular diffusion in water and advective water movement

5 Contaminants potentially enter the unsaturated zone in water phase, migration occurs primarily by vapor phase diffusion, also subject to advective water movement and sorption onto soil particles

6 Contaminants potentially enter groundwater and migrate via unconfined flow system

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure A16 Conceptual Model of Potential Contaminant Migration Through Lower Most Liner and Unsaturated Zone



Time (yrs)	Average CL/Co
100	0 01
200	0 08
300	0 18
400	0 26
500	0 32
600	0 36
700	0 40
800	0 44
900	0 47
1000	0 49

RMA 1257 4e 02/14/96 LAM

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Commerce City, Colorado

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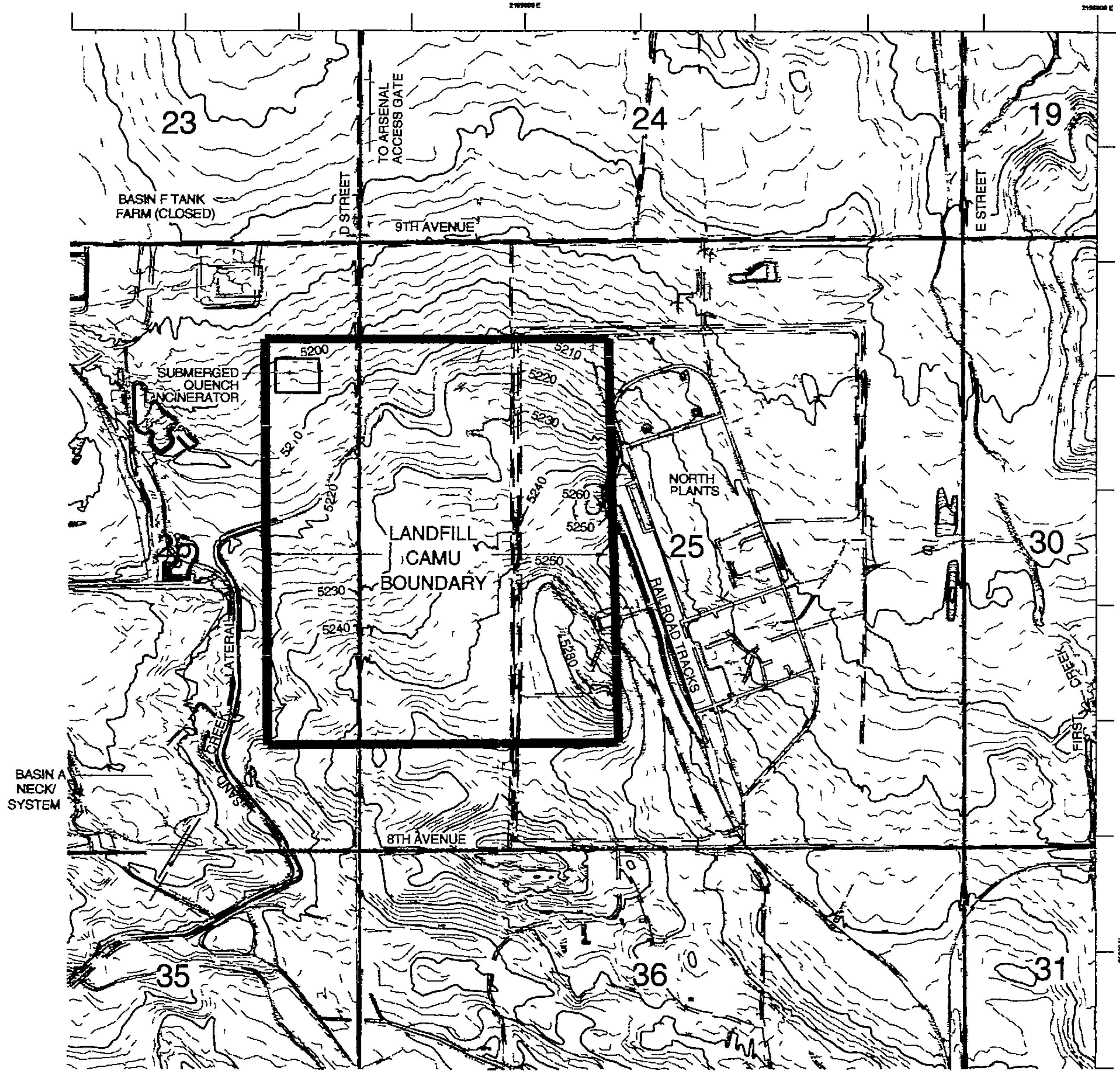
Figure A17

Diffusion of Constituents Through Six Feet of Clay



Explanation

Surface topography (2-foot contour interval)

Paved and unpaved roads

25 Section numbers

N

0 500 1000

Scale in feet

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Commerce City, Colorado

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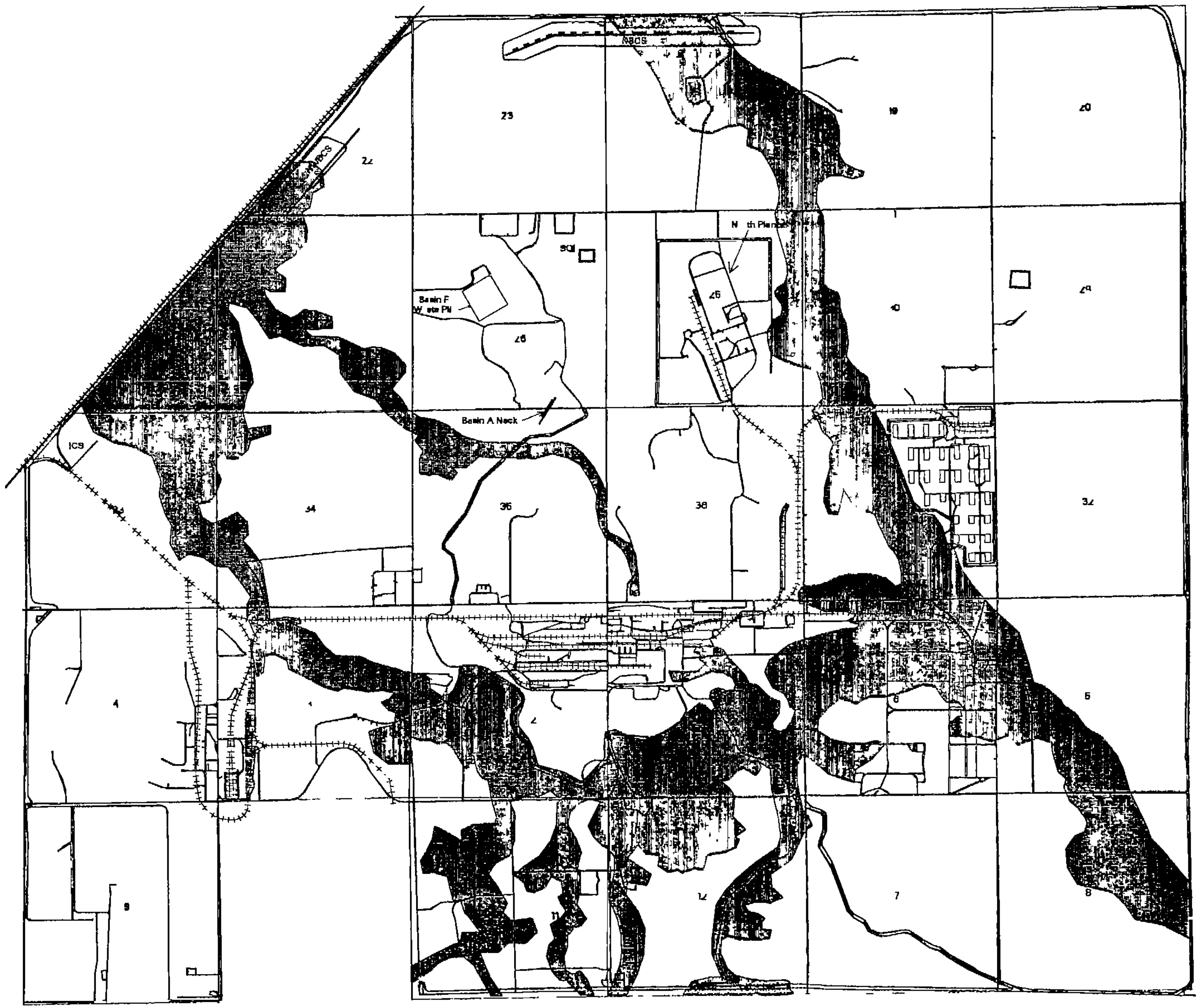
Figure A18

Surface Topography of the Landfill CAMU Boundary and Surrounding Area



Explanation

- 100-Year Floodplain
- Road
- Railroad
- Section line
- 12 Section number
- NBCS North Boundary Containment System
- NWBCS Northwest Boundary Containment System
- ICS Irondale Containment System
- SQI Submerged Quench Incinerator

1000 0 2000 4000 FEET

Scale 1 36 000
One inch represents 3 000 feet

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure A19

100-Year Floodplain Map
RIC No 84066R01

(U S Army Corps of Engineers 1983)

Attachment A1

SUPPLEMENTAL GEOLOGIC BORING LOGS WITH SURVEY COORDINATES AND UNIFIED SOIL CLASSIFICATION CHART

Table A1.1: Rocky Mountain Arsenal Task 93-03, Geotechnical Boring Coordinates, Elevations, and Total Depths

Boring Number	Northing	Easting	Elevation (feet)	Total Depth (feet)
BRB14395	187135	2184026	5252 16	34 0
SAB14495	188401	2183785	5230 18	39 0
SAB14595	188565	2184509	5242 40	49 5
SAB14695	188921	2184902	5234 71	24 0
SAB14795	188407	2184437	5242 86	43 0

The boreholes were surveyed by a State of Colorado licensed surveyor using the horizontal North American Datum of 1927 (NAD27) and the National Geodetic Vertical Datum of 1929 (NGVD29)

Unified Soil Classification Chart

MAJOR DIVISIONS			SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS OVER 50%>No 200 SIEVE SIZE	GRAVELS MORE THAN 1/2 OF COARSE FRACTION> No 4 SIEVE SIZE	CLEAN GRAVELS WITH LESS THAN 5% FINES	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH OVER 15% FINES	GM	Silty gravels, gravel-sand mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS MORE THAN 1/2 OF COARSE FRACTION< No 4 SIEVE SIZE	CLEAN SANDS WITH LESS THAN 5% FINES	SW	Well-graded sands or gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH OVER 15% FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS OVER 50%<No 200 SIEVE SIZE	SILTS & CLAYS LIQUID LIMIT 50% OR LESS		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS & CLAYS LIQUID LIMIT GREATER THAN 50%		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
DEBRIS ZONE*				Metal, concrete, plastic, brick, wood, etc
CONSTRUCTION DEBRIS*				Concrete, wood, rebar, asphalt

SYMBOLS KEY

	Bulk or classification sample
	No sample recovery
	"Undisturbed" sample
	First-encountered groundwater level
	Static groundwater level
(10YR 4/4)	Munsell soil color chart 1990 edition

GRAIN SIZE CHART

CLASSIFICATION	RANGE OF GRAIN SIZES	
	U S Standard Sieve Size	Grain Size in Millimeters
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76 2
GRAVEL	3" to No 4	76.2 to 4 75
coarse	3" to 3/4"	76.2 to 19 1
fine	3/4" to No 4	19 1 to 4 75
SAND	No 4 to No 200	4.75 to 0.075
coarse	No 4 to No 10	4 75 to 2.00
medium	No 10 to No 40	2 00 to 0 425
fine	No 40 to No 200	0 425 to 0 075
SILT & CLAY	Below No 200	Below 0 075

Source ASTM D 2488-90, based on Unified Soil Classification System
* Not part of ASTM Classification System

SOILCLS2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

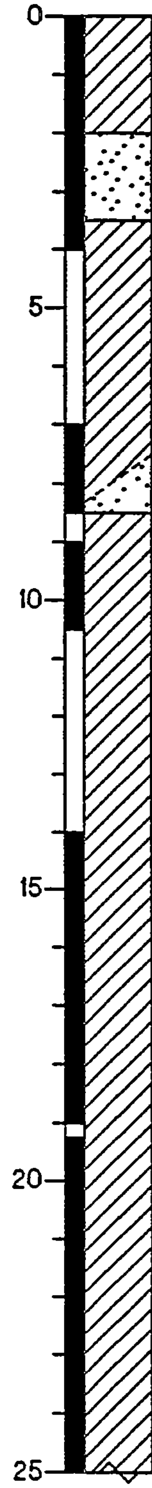
Prepared by.
Harding Lawson Associates

Unified Soil Classification Chart

Blows/6" | HNU/OVA (ppm) | Depth (ft.) | Sample

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5252 16   Date 11/13/95



(CL) SANDY CLAY, fine-grained sand, 10 YR 5/4 - yellowish brown, moist to dry, alluvium (25%)

(SW) SAND, some clay fine sand, 10 YR 6/4 - light yellowish brown nonplastic, moist alluvium

(CL) CLAY, little fine-grained sand 10 YR 6/4 - light yellowish brown, nonplastic, dry, alluvium

Becomes stiff calcareous

Driller notes hard material at 6 5 ft

(SW) SAND, fine sand, some clay and silt, 10 YR 6/6 - brownish yellow nonplastic , dry, alluvium

(CL) SANDY CLAY, little fine sand, 10 YR 6/4 - light yellowish brown, nonplastic, dry, calcareous, alluvium

Locally very heavy white caliche

Some fine sand little very coarse-grained sand and very fine-grained pea gravel

Color change to 7 5 YR 5/6 - strong brown, becomes hard moist with abundant white caliche veining scattered fine- to medium-grained sand (25%) coarse sand (5%) and very fine gravel

Increase in fine- to medium-grained sand (30%) and color change to 10 YR 6/6 - brownish yellow, slightly moist with some little little crystalline caliche or gypsum veining

Decrease in fine-grained sand (25%) with scattered trace coarse-grained sand to (rounded) pebbles (<5%), color change to 10 YR 6/4 - light yellowish brown, sand content decreases with depth

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

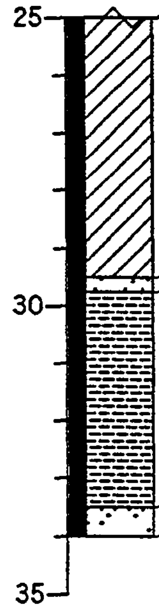
Figure A1.2

Log of Boring BRB14395

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5252 16 Date 11/13/95

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample



(SW) SAND, some clay, fine-grained sand 2 5 Y 6/6 – olive yellow, dense moist alluvium

CLAYSTONE, 2 5 Y 5/2– grayish brown thinly laminated, fractured to crushed, white caliche coated fractures to 30 feet, locally iron-oxide stain mottling at 31 5 ft , slightly lignitic common trace yellow brown iron-oxide staining on fractures and bedding, minor manganese oxide weathered bedrock, noncalcareous

SANDSTONE, 2 5 Y 6/6 – olive yellow, fine sand, very uniform grain size thinly laminated, weak little strength noncalcareous weathered bedrock

Total depth = 34 0 ft

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

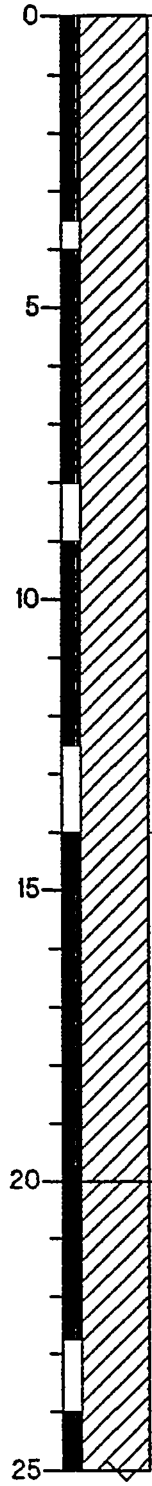
Figure A1.2

Log of Boring BRB14395

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5230 18 Date 11/13/95

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample



(CL) SANDY CLAY to CLAY, fine-grained sand, 10 YR 6/4 - light yellowish brown, stiff, nonplastic, dry, calcareous alluvium

Locally sand content increases to 40%

Color changes to 10 YR 5/8 - yellowish brown with minor white caliche veining

Color changes to 10 YR 6/6 - brownish yellow with some fine- to coarse-grained sand (40%)

Decrease in sand content to 25%

Scattered fine-grained granite gravel, sand content decreases

(SC) CLAYEY SAND, fine- to medium-grained sand (25%), clay matrix 10 YR 6/4 - light yellowish brown, dense, nonplastic, moist, calcareous alluvium

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

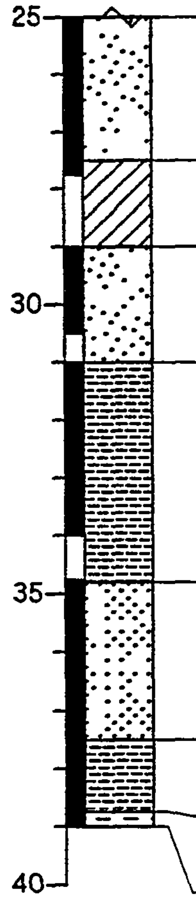
Figure A1.1

Log of Boring SAB14495

Blows/6" | HNU/OVA (ppm) | Depth (ft) | Sample

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5230 18 Date 11/13/95



(SW) SAND, fine- to coarse-grained sand, fine gravel, (pink granite gravel) and quartzite pebble, 10 YR 6/4 - light yellowish brown, nonplastic, moist, minor calcium carbonate , alluvium

(SC) CLAYEY SAND, fine- to coarse-grained sand, some clay (<25%), 10 YR 6/4 - light yellowish brown, moist, calcareous, alluvium

(SW) SAND, fine- to coarse-grained sand, pea gravel, some pebbles, 10 YR 6/4 - light yellowish brown moist, locally calcareous, alluvium

CLAYSTONE, 5 Y 6/4 - pale olive, fractured, low hardness, iron-oxide stain mottling, weathered bedrock

SANDSTONE, fine-grained sand 5 Y 6/6 - olive yellow, moist, weathered bedrock

CLAYSTONE, 5 Y 4/2 - olive gray fractured, minor iron-oxide on fractures weathered bedrock

CLAYEY SILTSTONE, very fine-grained sand, 5 Y 6/6 - olive yellow, friable weak moist, weathered bedrock

Total depth = 39 0 ft

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure A1.1

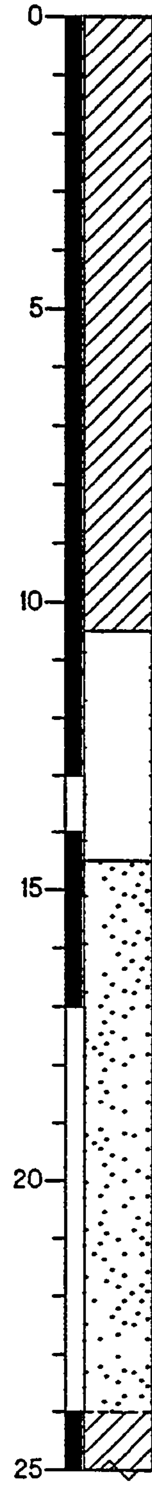
Log of Boring SAB14495

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	

Equipment: Mobile CME-75, Continuous Core Barrel Sampling

Elevation: 5242 40

Date: 11/14/95



(CL) SANDY SILTY CLAY, fine- medium-grained sand (10%) and silt 10 YR 4/6 - dark yellowish brown stiff to hard, plastic, moist, alluvium

Becomes calcareous, nonplastic, dry and color changes to 10 YR 7/2 - light gray

Sand and silt (<25%), fine- to medium-grained sand, color changes to 10 YR 5/6 - yellowish brown with heavy white caliche

(SP) SAND, fine- to medium-grained sand trace scattered fine gravel, 12 0 to 12 5 ft and clay, 10 YR 6/4 - light yellow brown, dry alluvium

(SW) SAND and GRAVEL, fine- to coarse-grained sand, subangular, fine to coarse gravel some rounded pebbles, trace cobble, 10 YR 6/4 - light yellowish brown, dry, alluvium

(CL) SILTY CLAY, 10 YR 6/2 - light brownish gray, stiff to hard slightly plastic, moist minor local iron-oxide staining alluvium

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

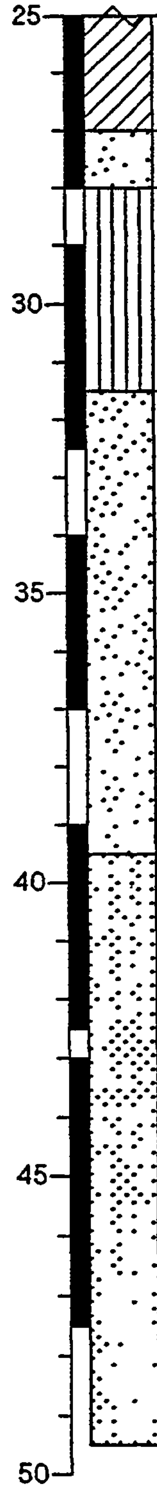
Figure A1.3

Log of Boring SAB14595

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5242 40 Date 11/14/95



(SW) SAND, fine- to coarse-grained sand, some pea gravel (pink granite) dry alluvium

(SM) SILTY SAND, fine-grained sand and silt, 10 YR 7/2 - light gray,dry, thin layers alluvium

Increase in clay content (<30%)

(SW) SAND, fine- to medium-grained sand, some coarse-grained sand, trace silt, 10 YR 6/4 - yellowish brown dry to slightly moist, alluvium

Fine gravel (pink granite)

Rounded pebbles to small cobbles of white granite and pink granite

Driller notes hard drilling

Driller notes hard drilling

SANDSTONE, fine- to medium-grained sand 2 5 Y 6/6 - olive yellow, to 2 5 Y 6/4 - light yellowish brown friable, weak slightly moist to dry weathered bedrock

Black sand (2%)

Total depth = 49 5 ft

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure A1.3

Log of Boring SAB14595

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5234 71 Date 11/14/95

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
		0		(CL) SILTY CLAY, 10 YR 4/4 – dark yellowish brown, stiff to hard, plastic, moist, rooted alluvium
				Color change to 10 YR 5/4 – yellowish brown
				Some fine- to medium-grained sand (15%), some local white caliche
		5		Increase in fine- to coarse-grained sand (<20%) color change to 10 YR 5/6 – yellowish brown slightly plastic to nonplastic, dry to slightly moist
				Scattered very coarse sand (pink granite), generally <25% sand
		10		Trace scattered gravel (pink granite)
				Thin layer (1) of coarse-grained sand
		15		(SP) SAND, fine- to medium-grained sand, 2 5 Y 6/4 – light yellowish brown dry to slightly moist, alluvium
				(SW) SAND, fine- to very coarse-grained sand 10 YR 6/4 – light yellowish brown, dry, alluvium
				Gravel pebbles, and cobbles
				CLAYSTONE, 5 YR 4/3 – olive, fractured, weathered bedrock
				SILTSTONE, 2 5 Y 6/3 – light yellowish brown, thin laminated friable, light iron-oxide staining along laminations weathered bedrock
		20		Color change to 2 5 Y 6/6 – olive yellow, fine- to medium-grained sand
				Total depth = 24 0 ft
		25		

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

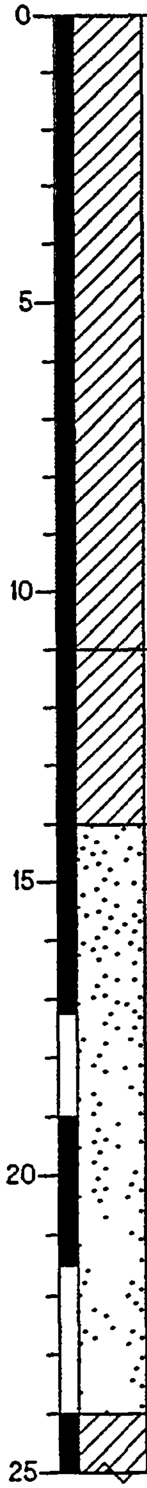
Figure A1.4

Log of Boring SAB14695

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5242 88 Date 11/14/95

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample



(CL) SANDY CLAY, fine- to medium-grained sand (<15%) some silt 10 YR 6/3 - pale brown hard nonplastic, alluvium

Color change to 10 YR 4/6 - dark yellowish brown, local white caliche fracture filling

Abundant white caliche fracture filling

Little to no white caliche sand content increases to 30%

CLAYEY SAND (SC), 10 YR 5/6 - yellowish brown nonplastic, dry, alluvium

(SW) SAND, fine- to coarse-grained sand, 10 YR 6/4 - light yellowish brown, nonplastic dry, coarsens downward some round gravel (pink granite), alluvium

2-inch fragment of highly oxidized fine sand, 10 YR 4/6 - dark yellowish brown, cemented

(CL) CLAY, trace silt and fine sand, scattered trace fine gravel (pink granite), 10 YR 6/2 - light brownish gray stiff to hard, plastic moist minor light iron-oxide staining on fractures alluvium

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

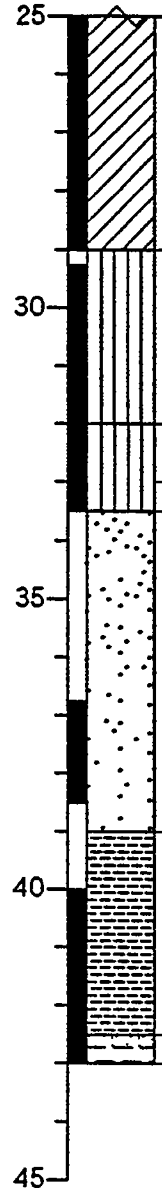
RMA2

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure A1.5** **Log of Boring SAB14795**

Equipment Mobile CME-75, Continuous Core Barrel Sampling

Elevation 5242.88 Date 11/14/95

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



(SM) SILTY SAND, fine-grained sand some clay, 2.5 Y 6/3 - light yellowish brown plastic, moist, alluvium

2-inch-thick gray clay layer

(ML) SANDY SILT, fine- to medium-grained sand, some clay matrix and clay rich layers, alluvium

Some iron-oxide staining along bedding layers

(SW) SAND, fine-grained sand, uncemented, weak friable also 2-inch fragment of hard cemented sandstone fine- to medium-grained sand, trace rounded gravel (pink granite), contains trace black sand (<%5), alluvium
Increase in rounded pebbles gravel, heterolithic pebbles 10 YR 4/6 - dark brown, nonplastic moist local iron -oxide matrix

CLAYSTONE, 10 YR 5/1 - gray little fractured, plastic iron-oxide stained along fractures weathered bedrock

Silt content increases with depth

SANDY CLAYSTONE, very fine sand 2.5 Y 6/6 - olive yellow, weak, friable, local heavy iron-oxide fracture filling weathered bedrock

Total depth = 43.0 ft.

RMA2

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure A1.5

Log of Boring SAB14795

Attachment A2

1,000-YEAR ISOLATION SUPPORTING DOCUMENTATION

NARRATIVE DESCRIPTION OF CALCULATION METHODOLOGIES

EPA's HELP Model for Calculating Advective Water Movement Through Composite Liners

A review of the methodology presented in the HELP model documentation (pp 74 through 98, Equations 138 through 168) versus the equations included in the HELP model code was performed to verify consistency between HELP model and results derived using the equations developed by Giroud and Bonaparte (1989) Results of the review indicated a few important differences between the code and the model documentation for Version 3 01 of the HELP model One difference was for the set of equations that estimate the wetted radius of pinhole and defect leaks in the flexible membrane liner (FML), which varies based on contact. Equations 156 and 157 (EPA, 1994) are described as being equivalent in the calculation of the wetted radius R, where R in Equation 156 is in meters and R in Equation 157 is in inches Review of how these equations were coded, along with recalculation of the equivalency factors, indicates that R in Equation 157 is also in meters This also affects subsequent equations presented for the various levels of liner contact

Another difference between the coded equations and those presented in the documentation occurs for Equation 151 (EPA, 1994), which includes a temperature correction factor as reported in the original work of Giroud and Bonaparte, 1989, and Giroud and others, 1992 This temperature correction factor is not included in the coded equation used in the HELP model

After these differences were assessed, the equations developed to estimate diffusive and advective flow of water through FML composites (Equations 138 through 168, applied as appropriate) were incorporated into a spreadsheet model This model was then applied to various levels of head build up on top of compacted clay layer (CCL) and geosynthetic clay liners (GCL) composite liners The calculation of flow through the liner consists of three separate components, diffusive flow (Equation 141), flow through manufacturing defects (or pinholes, Equations 151, 152, and appropriate equations based on liner contact), and flow through installation defects (Equations 151, 152, and appropriate equations based on liner contact) These numbers are calculated on a per acre basis as diffusive flow over an acre, flow through a single pinhole times the total number of pinholes per acre, and flow through a single defect times the number of defects per acre These values are then added together to estimate the total advective rate of water flow through the liner in inches/year/acre The use of this advective flow rate in a one-dimensional sense in the VLEACH modeling (discussed in Section 2.1 1 4) is thus conservative, as the value is additive over an acre Actual flow values associated with a specific liner location would be less than the value calculated using this methodology Actual flow will likely be more isolated than a unit area of one acre Hydraulic head is assumed to result from isolated "remnants" of leachate which would not necessarily cover an entire acre Given the source of head, only one defect may actually be applicable The acre approach assumes 3 defects and 1 pinhole The use of an acre unit also adds a diffusion component for the entire acre when the area of the head causing the diffusion may actually be less

Solutions to the Advective/Dispersive Equation for Contaminant Transport

The rate a which a chemical "spreads out" in one dimension is described by the advective/dispersive equation (Freeze and Cherry, 1979)

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial X^2} - V\frac{\partial c}{\partial X}$$

where

C = chemical Concentration

D = diffusion Coefficient

X = distance along flowpath

V = advective Velocity

t = time

The solution for a constant source at X = 0 into a media initially at C = 0 was originally present by Ogata and Banks, 1961, and is as follows

$$\frac{C}{C_o} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{X-Vt}{2\sqrt{Dt}}\right) + \exp\left(\frac{VX}{D}\right)\operatorname{erfc}\left(\frac{X+Vt}{2\sqrt{Dt}}\right)\right]$$

where

erfc = complimentary error function

This equation was developed into a spreadsheet model which was used to predict Cl/Co over time at the bottom of a cumulative six-feet of the compacted clay component of the liner system for the constituents of potential concern.

For estimating diffusive migration in the lower liner, it is necessary to have an estimate of the appropriate diffusion coefficient (D) for a chemical of concern. The diffusion coefficient of a chemical in free water has been related to the chemicals molecular weight (Lyman and others, 1982) However, a variety of factors affect diffusion in saturated soil including adsorption of chemical onto soil, tortuosity of flowpaths, and the physical nature of the soil aggregates that can impact flowpaths (i e , development of soil "crusts" that can act as capillary breaks, presence of entrapped air, etc) (Dragun, 1988) Jury and others (1983), present an effective diffusion coefficient in water that is reduced by a tortuosity factor that is a function of porosity

$$De = \left[\frac{\Theta_w^{10/3}}{\Phi^2}\right] D_w$$

where

De = effective diffusion coefficient

Θ_w = volumetric water content

Φ = total Porosity

D_w = free water diffusion coefficient

Assuming a porosity of 40 percent for the clay and saturated conditions, the effective diffusion coefficient is approximately 30 percent of the free water diffusion coefficient of the chemical It is important to note that this relationship is based only on a tortuosity factor and conservatively does not include other potential effects

The chemicals of concern identified in Appendix A (chloroform, CPMSO, DIMP, and DBCP) have, in general, similar diffusive properties in water Therefore, a single analysis was performed to estimate the relative concentration input (Cl/Co) at the base of the liner systems for input into the VLEACH modeling A free-water diffusion coefficient of 5 x 10^{-6} square centimeters per second (4 x 10^{-5} square meters per day) was used to represent the constituents For the liner system analyzed, it was assumed that there would be a cumulative minimum of 6 feet of compacted clay The FMLs associated with the CCLs were conservatively assumed to have no effect in the diffusion estimated Results of this analysis are presented in Figure A17 of Appendix A.

Rate of Advective Water Movement through the Unsaturated Zone

An analysis based on Clapp and Hornberger, 1978, was used to estimate both the long-term moisture content and rate of advective water movement through the vadose zone after the landfill has been constructed The equations for estimating the long-term soil moisture content and advective water movement in the unsaturated zone are (EPA's RITZ model, EPA, 1988)

$$V_a = V_d/\theta$$

$$\theta = \theta_s[V_d/k_s]^{1/(2b+3)}$$

where

V_a = advective water velocity

V_d = infiltration or recharge rate

θ = long-term soil water content at recharge rate V_d on a volume basis

θ_s = saturated water content of the soil on a volume basis

k_s = saturated hydraulic conductivity of the soil

b = Clapp and Hornberger, 1978, soil constant

These equations were used to identify a range of leakage rates from the liner which could result in advective water movement through 20 feet of vadose zone material in 1,000 years The leakage rates were then compared to predictions of leakage through a single CCL made using the HELP model methodology

Basin F Waste Pile Leachate Analytical Results

Analysis of leachate from the primary and secondary sumps at the Basin F Waste Pile have been performed intermittently since 1989 A historical summary of the results of these analyses are presented in Table A2 1 These data were generated by several laboratories and no review of quality control data has been performed to evaluate the accuracy of the results

Composite samples of Basin F Waste Pile leachate from the primary and secondary sumps were collected on March 30, 1994 for purposes of updating the leachate characterization. The composite leachate samples were obtained from the collection tank at the base of the waste pile and sent to five laboratories for analysis of the following parameters

1 Volatile organic compounds (VOCs) by gas chromatography (GC) with electrolytic conductivity detector (ECD) flame ionization detector (FID), photoionization detector (PID), and gas chromatography/mass spectrometry (GC/MS)

2 Semivolatile organic compounds (SVOCs) by GC/MS

3 Organochlorine pesticides and polychlorinated biphenyls (PCBs) by GC with electron capture detector (ECD), and GC/MS

4 Organosulfur compounds by GC with flame photometric detector (FPD) and GC/MS

5 Organophosphorus compounds by GC with nitrogen phosphorus detector (NPD) and GC/MS

6 Agent degradation products by high pressure liquid chromatography (HPLC) and ion chromatography

7 Total and dissolved metals by inductively coupled plasma (ICP) atomic emission spectroscopy, graphite furnace atomic absorption spectroscopy (GFAA), and cold vapor atomic absorption spectroscopy (CVAA)

8 Anions by ion chromatography

9 General water chemistry parameters by various methods

The specific analytes covered by each method are listed in the leachate data summary tables (Tables A2.2 and A2 3)

The following laboratories performed the analytical work

1 DataChem Laboratories, Salt Lake City, Utah

2 Environmental Science and Engineering, Inc , (ESE) Gainsville, Florida, and Denver, Colorado

3 CKY Incorporated, Torrance, California

4 Inchcape/NDRC Laboratories, Richardson, Texas

5 Applied Research and Development Laboratories, Inc , (ARDL), Mt. Vernon, Illinois

DataChem and ESE were the only PMRMA-certified laboratories in the group at the time of the study The designation 'PMRMA-certified' means that DataChem and ESE have demonstrated proficiency with PMRMA methods, including methods for certain Army-specific parameters, such as DIMP and CPMSO The other laboratories were included in the study because they were recent additions to the PMRMA laboratory program and were working on achieving certification

Each laboratory was requested to analyze duplicate samples of the leachate for each analytical method to provide a measure of analytical variability However, because of analytical difficulties caused by the leachate matrix, full data sets were not provided by all laboratories for all methods, and significant inter- and intralaboratory analytical variability was observed in the data that were reported

Only the data from ESE and DataChem are included in this report because they were the only PMRMA-certified laboratories in the group and their data were deemed to be the most reliable However, it must be noted that even though DataChem and ESE were PMRMA-certified and the data have undergone extensive review, there is still significant analytical uncertainty in the data that is caused by the highly complex nature of the leachate matrix For example, dilutions factors as high as 10,000 were required to bring some analytes within detection range, thus precluding the detection of lower concentration analytes Also, the high concentrations of some analytes created positive and negative interferences with the detection of other analytes and generally caused the deterioration of overall methods performance Thus, the data shown below are considered to be, at best, an estimate of actual analyte concentrations

The combined results of the GC/MS data are summarized in Table A2 2 and the combined results of the non-GC/MS methods data are summarized in Table A2 3 The data are grouped by analyte type, which corresponds to the various analytical methods If an analyte was not detected the detection limit is reported in the column "Not Detected " If an analyte was detected the range of detections are reported in the column "Detected Results" along with the average and standard deviation of the detected concentration All results are shown in units of micrograms per liter (μg/l)

CALCULATE DEPTH OF TOPSOIL/ADMIX CAP LOST TO WIND EROSION

Use the Wind Erosion Equation (Ton/Acres/Year)

E = IKCLV

E = wind erosion, ton/acre/year

I = soil erodeability tons/acre/year

K = surface roughness factor, dimensionless

C = climatic factor, dimensionless

L = unsheltered field-width factor, dimensionless

V = vegetative cover factor, dimensionless

Reference document National Agronomy Manual March 1988 Soil Conservation Service

I (From Wind Erosion Groups)

Assume Sandy Loam Soil - 86 tons/acre/year Subpart G Exhibit 502 61(a)

K Conservatively assume that the surface roughness factor is 1 0.

C 60 - taken from annual "C" values of the wind erosion equation (interpolated from nearest 10 isoline for Colorado) See attached sheet. Exhibit 502 53(a)

L = 1,000 ft (longest assumed dimension of any surface) dimension of the cover

V Will establish vegetation on cover V for alfalfa is 3,000 lb/acre We will conservatively use 2,000 lb/acre

E 0 5 tons/acre-year (see lookup table)

EROSION IS 0.6 TONS/ACRE/YEAR

This calculation conservatively assumes that this is the erosion rate for 1,000 years Assumption is conservative because if erosion of the cap occurs, the cap will, by design, become armored (topsoil-gravel admix) It is likely that vegetation will decrease at some point in the thousand-year period The decrease in vegetation will be associated with a reduction of wind erosion emissions as the cover armors As topsoil erodes, a gravel surface will be established that forms a "desert pavement."

Average soil density for the ascalon series on the Rocky Mountain Arsenal site is 105 pounds per cubic foot Soil density was taken from "soil vegetation and inventory of the Rocky Mountain Arsenal, Adams County, Colorado, on October 19, 1988, James P Walsh & Associates, Inc

Compute potential soil loss over 1,000 years

$$1 \text{ ton top soil} * \frac{1 \text{ ft}^3}{105 \text{ lb}} * \frac{2{,}000 \text{ lb}}{1 \text{ ton}} * \frac{(12 \text{ in})^3}{(1 \text{ ft})^3}$$

32,914 in^3 per 1 ton of topsoil

$$\frac{0\ 5 \text{ tons}}{\text{Acre-year}} * \frac{1 \text{ acre}}{43{,}560 \text{ ft}^2} * \frac{(1 \text{ ft})^2}{(12 \text{ in})^2} * \frac{32{,}914 \text{ in}^3}{\text{Ton}}$$

$0\ 003 \ \frac{in}{yr}$ of topsoil loss attributable to wind erosion,

or approximately a 3-inch soil loss attributable to wind erosion over the period of 1,000 years

Table A2.1: Summary of Historical Basin F Waste Pile Leachate Analytical Data

Location	Cell 1 Primary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/26/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
DMMP (mg/l)	1 8	9 5	9 6	13 0	7 3	7 4	7 6	7 7	4 9	1 3	0 59	0 13
CPMSO2 (mg/l)	3 9	13 0	15 3	15 0	9 0	12 0	14 0	16	15	12	14	1 62
Aldrin (mg/l)	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	25 0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1 1-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethane	NA	NA	12 0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3 Dimethylbenzene	NA	NA	43 7	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	31 6	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	10	BDL	NA
Carbon tetrachloride	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	124	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Chloroform	NA	NA	58 5	33 0	100	82	80	150	130	170	140	NA
Chlorobenzene	NA	NA	18 5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	15 0	BDL	BDL	BDL	BDL	35	BDL	31	33	NA
Tetrachloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	35 3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	130	27 0	BDL	BDL	BDL	6 1	BDL	BDL	BDL	BDL	NA
Copper (total)	NA	546	210	237	409	331	650	520	467	848	408	NA
Sodium (total)	NA	10,300	74,000	37,000	48,200	54,300	47,600	87,300	70,000	108,000	53,300	NA
Zinc (total)	NA	2 3	1 9	BDL	4 4	3 3	2 2	BDL	3 0	BDL	3 9	NA

Table A2.1 (continued)

Location	Cell 2 Primary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/26/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
DMMP (mg/l)	11 2	21 1	34 4	9 9	8 5	22	16	20	NA	NA	0 91	0 8
CPMSO2 (mg/l)	12 9	15 5	16 4	14 0	5 1	13	11	16	NA	NA	9 9	1 0
Aldrin (mg/l)	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA	NA	BDL	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	44 8	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3-Dimethylbenzene	NA	NA	BDL	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	72 6	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	5	BDL	NA
Carbon tetrachloride	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	27 6	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Chloroform	NA	NA	54 5	38	BDL	190	130	410	270	610	120	NA
Chlorobenzene	NA	NA	62 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	11 9	BDL	BDL	BDL	BDL	20	BDL	31	BDL	NA
Tetrachloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	170	35 0	BDL	BDL	BDL	14 1	BDL	NA	NA	NA	NA
Copper (total)	NA	784	320	228	226	300	600	349	NA	NA	NA	NA
Sodium (total)	NA	11,500	84,000	30,800	26,800	44,400	48,000	90,800	NA	NA	NA	NA
Zinc (total)	NA	4 2	4 00	BDL	4 11	3 0	3 0	BDL	NA	NA	NA	NA

Table A2.1 (continued)

Location	Cell 3 Primary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/20/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
DMMP (mg/l)	9 2	15 2	17 3	23 0	13 0	33	24	18	16	3 3	1 1	1 3
CPMSO2 (mg/l)	9 9	8 5	12 4	16 0	8 8	20	16	13	17	14	11	1 1
Aldrin (mg/l)	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	58 5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1 Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3-Dimethylbenzene	NA	NA	BDL	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	6	BDL	NA
Carbon tetrachloride	NA	NA	74 8	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	194	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Chloroform	NA	NA	231	290	BDL	250	200	380	300	340	240	NA
Chlorobenzene	NA	NA	56 1	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	46 1	BDL	39 0	BDL	BDL	BDL	BDL	BDL	68	NA
Tetrachloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	210	39 0	BDL	BDL	BDL	11	BDL	BDL	BDL	BDL	NA
Copper (total)	NA	723	50 0	169	203	120	450	307	167	150	176	NA
Sodium (total)	NA	12,800	50,000	45,800	44,100	32,800	49,000	105,000	75,800	122,000	56,900	NA
Zinc (total)	NA	3 7	3 5	BDL	3 5	2 1	2 2	BDL	2 7	BDL	4 9	NA

Table A2.1 (continued)

Location	Cell 1 Secondary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/26/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
DMMP (mg/l)	2 2	7 5	6 4	9 4	4 6	6 3	BDL	1 3	0 57	BDL	0 34	BDL
CPMSO2 (mg/l)	2 2	7 7	6 4	1 1	4 7	10	12	3 9	6 0	1 2	0 900	0 31
Aldrin (mg/l)	NA	0 06	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0 06	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	70	BDL	BDL	4	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	27 0	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3-Dimethylbenzene	NA	NA	BDL	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	2	NA
Carbon tetrachloride	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	209 0	1100	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Chloroform	NA	NA	28 2	BDL	BDL	50	BDL	BDL	39	94	53	NA
Chlorobenzene	NA	NA	35 5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	51	12	NA
Tetrachloroethene	NA	NA	52 9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	26 0	BDL	BDL	BDL	BDL	BDL	BDL	10	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	70	5 10	BDL	BDL	BDL	7 2	BDL	BDL	BDL	BDL	NA
Copper (total)	NA	239	99 0	119	120	348	500	64 8	58 5	4 8	8 5	NA
Sodium (total)	NA	9300	45,900	35,000	38,200	60,000	60,200	36,700	28,200	2,670	2,320	NA
Zinc (total)	NA	3 0	1 8	4 5	5 8	3 3	2 4	BDL	BDL	2 0	2 0	NA

Table A2.1 (continued)

Location	Cell 2 Secondary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/26/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
DMMP (mg/l)	8 1	36 4	18 4	29 0	13 0	30	24	14	18	3 4	1 2	0 4
CPMSO2 (mg/l)	8 2	17 3	12 6	14 0	6 0	15	17	8 9	18	14	11	0 9
Aldrin (mg/l)	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	110	BDL	BDL	7	5	BDL	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	54 3	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1 Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2 Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3-Dimethylbenzene	NA	NA	BDL	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	116	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Carbon tetrachloride	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	95 9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA°
Chloroform	NA	NA	38 8	BDL	BDL	BDL	80	96	210	260	51	NA
Chlorobenzene	NA	NA	95 9	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	7	BDL	NA
Tetrachloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	36 2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	220	28 0	BDL	BDL	BDL	14 5	BDL	BDL	BDL	BDL	NA
Copper (total)	NA	854	320	268	404	318	400	591	380	243	302	NA
Sodium (total)	NA	12,100	119,000	34,500	39,900	43,900	48,000	112,000	74,000	152,000	43,500	NA
Zinc (total)	NA	4 0	4 7	3 1	5 7	3 9	2 8	BDL	4 5	BDL	4 0	NA

Table A2.1 (continued)

Location	Cell 3 Secondary Sump											
Laboratory	RMA	RMA	RMA	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RFW	RMA
Date sampled	07/05/89	07/27/89	08/25/89	10/05/89	02/21/90	04/18/90	07/26/90	10/09/90	04/15/91	09/10/91	04/16/92	07/20/93
Unit	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l	μg/l
DMMP (mg/l)	7 2	9 5	23 3	23 0	14 0	18 0	24 0	4 3	1 6	0 11	0 3	0 03
CPMSO2 (mg/l)	6 8	13 0	14 3	14 0	8 9	12 0	16 0	10	6 6	3 0	3 5	0 8
Aldrin (mg/l)	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
1,1,1-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	84	22	BDL	13	NA
1,1,2-Trichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethene	NA	NA	33 4	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,1-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloroethane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,2-Dichloropropane	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
1,3-Dimethylbenzene	NA	NA	BDL	BDL	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloroethylvinyl ether	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Benzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Carbon tetrachloride	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Methylene chloride	NA	NA	101	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Bromoform	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Chloroform	NA	NA	BDL	93 0	BDL	100	110	71	120	260	52	NA
Chlorobenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	24	BDL	NA
Dicyclopentadiene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Ethylbenzene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Toluene	NA	NA	BDL	BDL	BDL	BDL	BDL	30	BDL	BDL	BDL	NA
Tetrachloroethene	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Trichloroethene	NA	NA	BDL	BDL	BDL	50	BDL	BDL	BDL	BDL	BDL	NA
Xylenes	NA	NA	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	NA
Metal Results (mg/l)												
Calcium (total)	NA	270	32 0	BDL	BDL	BDL	13 1	BDL	BDL	BDL	BDL	NA
Copper (total)	NA	714	150	150	270	170	200	61 4	76 2	28 6	69 6	NA
Sodium (total)	NA	12,100	128,000	38,400	54,500	56,400	40,200	28,700	31,900	13,800	33,200	NA
Zinc (total)	NA	2 8	4 3	2 5	7 1	2 6	1 8	BDL	BDL	BDL	BDL	NA

NA Not analyzed
BDL Below detection limit

Table A2.2: GC/MS Results by Analyte Group*
for Basin F Waste Pile Leachate
from March 1994 Sampling

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Organophosphorus Compounds				
Diisopropylmethyl phosphonate		910 to 1,300	1,100	270
Dimethylmethyl phosphate		570 to 880	720	220
Organosulfur Compounds				
1,4-Oxathiane	27			
4-Chlorophenylmethyl sulfide		230 to 310	270	57
4-Chlorophenylmethyl sulfone		15,000 to 19,000	17,000	2,800
4-Chlorophenylmethyl sulfoxide		2,800 to 4,000	3,400	800
Dimethyl disulfide		8		
Dithiane	3			
Organochlorine Pesticides and PCBs				
DDT	18			
DDD	18			
DDE	14			
Aldrin	13			
alpha-Benzenehexachloride	5			
alpha-Endosulfan	23			
Atrazine	6			
beta-Benzenehexachloride	17			
Chlordane	37			
delta-Benzenehexachloride	3			
Dieldrin	26			
Endosulfan sulfate	50			
Endrin	18			
Endrin aldehyde	5			
Endrin ketone	6			
Heptachlor	38			
Heptachlor epoxide	28			
Hexachlorocyclopentadiene	38			
Isodrin	8			
Lindane	7			
Malathion	21			
Methoxychlor	11			
Parathion	37			
PCB 1016	9			
PCB 1221	9			
PCB 1232	9			
PCB 1242	9			

Table A2.2 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
PCB 1248	9			
PCB 1254	9			
PCB 1260	13			
Supona	19			
Toxaphene	17			
Vapona	9			
Semivolatiles Organic Compounds				
1,2,3-Trichlorobenzene	6			
1,2,4-Trichlorobenzene	2			
1,2-Diphenylhydrazine	13			
1,3-Dinitrobenzene	10			
2,3,6-Trichlorophenol	2			
2,4,5-Trichlorophenol	3			
2,4,6-Trichlorophenol	4			
2,4-Dichlorophenol	8			
2,4-Dimethylphenol	4			
2,4-Dinitrophenol	170			
2,4-Dinitrotoluene	6			
2,6-Dinitroaniline	9			
2,6-Dinitrotoluene	7			
2-Chloronaphthalene	3			
2-Chlorophenol	3			
2-Methyl-4,6-dinitrophenol	50			
2-Methylnaphthalene	1			
2-Methylphenol	4			
2-Nitroaniline	31			
2-Nitrophenol	8			
3,3'-Dichlorobenzidine	5			
3,5-Dinitroaniline	21			
3-Nitroaniline	15			
3-Nitrotoluene	3			
4-Bromophenylphenyl ether	7			
3-Methyl-4-chlorophenol	9			
4-Chloroaniline	1			
4-Chlorophenylphenyl ether	20			
4-Methylphenol	3			
4-Nitroaniline	31			
4-Nitrophenol	96			
Acenaphthene	6			
Acenaphthylene	5			
Anthracene	5			
Benzo[a]anthracene	10			

Table A2.2 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Benzo[a]pyrene	6			
Benzo[b]fluoranthene	7			
Benzo[def]phenanthrene	5			
Benzo[g,h,i]perylene	6			
Benzo[k]fluoranthene	10			
Benzoic acid	3			
Benzyl alcohol	4			
beta-Endosulfan	42			
bis(2-Chloroethoxy)methane	7			
bis(2-Chloroethyl)ether	1			
bis(2-Chloroisopropyl)ether	5			
bis(2-Ethylhexyl)phthalate		30 to 38	34	6
Bromacil	3			
Butylbenzyl phthalate	6			
Chlordecone	20			
Chrysene	7			
Di-N-butyl phthalate		120		
Di-N-octyl phthalate	2			
Dibenz[ah]anthracene	10			
Dibenzofuran	5			
Diethyl phthalate	6			
Dimethyl phthalate	2			
Famphur / Famophos	20			
Fluoranthene	5			
Fluorene	7			
Hexachloro-1,3-butadiene	5			
Hexachlorobenzene	5			
Hexachloroethane	6			
Indeno[1,2,3-c,d]pyrene	21			
Isophorone	2			
Mirex	24			
N-Nitrosodi-N-propylamine		810 to 990	900	130
N-Nitrosodimethylamine	10			
N-Nitrosodiphenylamine	4			
Naphthalene	0			
Nitrobenzene	4			
Pentachlorophenol	9			
Phenanthrene	5			
Phenol	2			
Volatile Organic Compounds				
1,1,1-Trichloroethane	1			
1,1,2,2-Tetrachloroethane	2			

Table A2.2 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
1,1,2-Trichloroethane	1			
1,1-Dichloroethane	1			
1,1-Dichloroethene	1			
1,2-Dichlorobenzene	1			
1,2-Dichloroethane	1			
1,2-Dichloroethylenes (cis and trans isomers)	3			
1,2-Dichloropropane	1			
1,3-Dichlorobenzene	1			
1,3-Dichloropropane	5			
1,3-Dimethylbenzene/ m-Xylene	1			
1,4-Dichlorobenzene	2			
2-Butanone		340 to 450	400	80
2-Chloroethyl vinyl ether	4			
2-Hexanone	1			
Acetone		1,500 to 15,000	8,000	7,000
Acrylonitrile	8			
Benzene	1			
Bicyclo[2,2,1]hepta-2,5-diene	2			
Bromodichloromethane	1			
Bromoform	11			
Bromomethane	5			
Carbon disulfide	5			
Carbon tetrachloride	1			
Chlorobenzene	1			
Chloroethane	8			
Chloroform		21 to 36	30	7
Chloromethane	1			
cis-1,3-Dichloropropene	5			
Dibromochloromethane	1			
Dibromochloropropane	6			
Dichloromethane	1			
Dicyclopentadiene	4			
Ethylbenzene	1			
Methyl isobutyl ketone		5 to 13	9	5
Styrene	5			
Tetrachloroethene	1			
Toluene		6		
trans-1,3-Dichloropropene	5			
Trichloroethene	1			
Trichlorofluoromethane	1			
Vinyl acetate	1			
Vinyl chloride	12			

Table A2.2 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Xylenes	2			

* Results in $\mu g/l$

Table A2.3: Non-GC/MS Results by Analyte Group*
for Basin F Waste Pile Leachate
from March, 1994 Sampling

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Agent Degradation Products				
Chloroacetic acid	25,000			
Fluoroacetic acid	25,000			
Isopropylmethyl phosphonic acid		5 6E+06 to 7 3E+06	6 5E+06	
Methylphosphonic acid		1 8E+06 to 2 0E+06	1 9E+06	140,000
Thiodiglycol		27,000 to 29,000	28,000	1,000
Thiodiglycolic acid		540,000 to 580,000	560,000	28,000
Anions				
Chloride		1 5E+08 to 1 9E+08	1 7E+08	1 7E+07
Cyanide		420 to 870	575	210
Fluoride		32,000 to 36,000	34,200	2,000
Nitrate as nitrogen		870,000 to 930,000	900,000	42,000
Nitrite as nitrogen	61,000			
Nitrite plus nitrate		7 6E+0600 to 1 8E+07	1 3E+07	7 4E+06
Sulfate		2 3E+07 to 3 2E+07	2 8E+07	4 7E+06
General Chemistry Parameters				
Alkalinity		1 7E+07 to 3 0E+07	2 6E+07	4 6E+06
Ammonia nitrogen		2 1E+07 to 2 3E+07	2 2E+07	850,000
Chemical oxygen demand		4 9E+07 to 8 2E+08	1 9E+08	2 7E+08
pH		8 05 to 8 45	8 30	
Phosphorus		2 0E+07 to 2 1E+07	2 0E+07	300,000
Specific conductivity		217,000 to 530,000	370,000	170,000
Sulfide		26,000 to 32,000	29,000	5,000
Total hardness		56,000 to 217,000	110,000	83,000
Total organic carbon		1 8E+07 to 4 9E+07	3 3E+07	1 7E+07
Total organic halogens		80,000 to 220,000	144,000	67,000
Total suspended solids		404,000 to 649,000	536,000	125,000
Metals				
Aluminum		380 to 470	430	50
Arsenic		1,100 to 1,400		
Barium		33 to 40	35	3
Cadmium		120 to 140	90	50
Calcium		21,000 to 22,000		
Chromium		280 to 310	300	10
Cobalt		700 to 730	720	20
Copper		240,000 to 250,000		

Table A2.3 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Metals (continued)				
Iron		5,840 to 6,100	6,000	130
Lead		60 to 120	90	40
Magnesium		7,000 to 8,200	7,600	500
Manganese		560 to 590	580	20
Mercury		12 to 16		
Nickel		7,200 to 7,600	7,500	180
Potassium		57,000 to 890,000	460,000	420,000
Sodium		9 0E+07 to 1 0E+08		
Zinc		1,800 to 2,600	2,300	320
Organophosphorus Compounds				
Diisopropylmethyl phosphonate		740 to 1,000	860	120
Dimethylmethyl phosphate		4,600 to 5,600	5,200	
Organosulfur Compounds				
1,4-Oxathiane		7 to 85	45	40
4-Chlorophenylmethyl sulfide	6			
4-Chlorophenylmethyl sulfone		10,000 to 16,000	13,000	3,000
4-Chlorophenylmethyl sulfoxide		2,900 to 3,800	3,400	400
Benzothiazole		42 to 44	43	1
Dimethyl disulfide		8 to 11	9	1
Dithiane		16		
Organochlorine Pesticides				
DDT	0 05			
DDD	0 05			
DDE	0 05			
Aldrin		0 7 to 6	3	3
Atrazine		130 to 170	150	30
Chlordane	0 1			
Dieldrin		0 2		
Endrin	0 05			
Hexachlorocyclopentadiene	0 4			
Isodrin	0 05			
Malathion	4			
Parathion		6 to 13	9	5
Supona	8			
Vapona	4			
Volatile Organic Compounds				
1,1,1-Trichloroethane	8			
1,1,2-Trichloroethane	8			

Table A2.3 (continued)

Group/Analyte	Not Detected Reporting Limit	Detected Results Range	Average	Standard Deviation
Volatile Organic Compounds (continued)				
1,1-Dichloroethane	7			
1,1-Dichloroethene	17			
1,2-Dichloroethane	11			
1,2-Dichloroethylenes (cis and trans isomers)	8			
1,3-Dimethylbenzene/ m-Xylene	13			
Benzene	11			
Bicyclo[2,2,1]hepta-2,5-diene	14			
Carbon tetrachloride	10			
Chlorobenzene	8			
Chloroform		18 to 26	22	6
Dibromochloropropane		2		
Dichloromethane	74			
Dicyclopentadiene		42 to 50	46	6
Ethylbenzene	14			
Methyl isobutyl ketone		15		
Tetrachloroethene	7			
Toluene		7 to 11	9	2
Trichloroethene	6			
Vinyl chloride	10			
Xylenes	14			

* Results in $\mu g/l$

Table A2.4: South Plants Area Groundwater Analytical Data Geometric Mean by Well

Analyte	Well 01078 (µg/l)	Well 01513 (µg/l)	Well 01524 (µg/l)	Well 36054 (µg/l)	Well 36168 (µg/l)	Well 36210 (µg/l)	Well 36211 (µg/l)	Well 36212 (µg/l)
Chloroform	44,667	43,081	19 06	280,000	3,046,498	100,000	56,234	354,813
CPMSO	16 73	8 56	16 82	40 26	10 12	75 9	7 8	151 4
DIMP	1 01	—	1 8	3 08	3 84	2 2	0	0
DBCP	2,400	—	2 24	58	26 8	30 2	0	9 6

— Not detected
CPMSO 4-Chlorophenylmethyl sulfone
DIMP Dnsopropylmethyl phosphate
DBCP Dibromochloropropane
µg/l Micrograms per liter

VLEACH MODEL RESULTS

RMA 93-03 Chloroform Transport, First 100 years

```
  1
      0.1       100.        50.       100.
     58.0       .17        7700.      0.85
Polygon I
       1.       0.25     .00057       1.6        0.40         .25         .005
     .165       -1.         0.
   80y     100.0
    1    1        0.0
    2    2        0.0
    3    3        0.0
    4    4        0.0
    5    5        0.0
    6    6        0.0
    7    7        0.0
    8    8        0.0
    9    9        0.0
   10   10        0.0
   11   11        0.0
   12   12        0.0
   13   13        0.0
   14   14        0.0
   15   15        0.0
   16   16        0.0
   17   17        0.0
   18   18        0.0
   19   19        0.0
   20   20        0.0
   21   21        0.0
   22   22        0.0
   23   23        0.0
   24   24        0.0
   25   25        0.0
   26   26        0.0
   27   27        0.0
   28   28        0.0
   29   29        0.0
   30   30        0.0
   31   31        0.0
   32   32        0.0
   33   33        0.0
   34   34        0.0
   35   35        0.0
   36   36        0.0
   37   37        0.0
   38   38        0.0
   39   39        0.0
   40   40        0.0
   41   41        0.0
   42   42        0.0
   43   43        0.0
   44   44        0.0
   45   45        0.0
   46   46        0.0
   47   47        0.0
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48	48	0.0
49	49	0.0
50	50	0.0
51	51	0.0
52	52	0.0
53	53	0.0
54	54	0.0
55	55	0.0
56	56	0.0
57	57	0.0
58	58	0.0
59	59	0.0
60	60	0.0
61	61	0.0
62	62	0.0
63	63	0.0
64	64	0.0
65	65	0.0
66	66	0.0
67	67	0.0
68	68	0.0
69	69	0.0
70	70	0.0
71	71	0.0
72	72	0.0
73	73	0.0
74	74	0.0
75	75	0.0
76	76	0.0
77	77	0.0
78	78	0.0
79	79	0.0
80	80	0.0

```
|-------------------------------------------------------------|
                 VLEACH (Version 2.2, 1995)

                           By:
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                  (USEPA Contractors)
        Center for Subsurface Modeling Support
        Robert S. Kerr Environmental Research Laboratory
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        P.O. Box 1198
        Ada, OK 74820

        Based on the original VLEACH (version 1.0)
        developed by CH2M Hill, Redding, California
        for USEPA Region IX
|-------------------------------------------------------------|

RMA 93-03 Chloroform Transport, First 100 years
  1 polygons.
Timestep =   0.10 years.  Simulation length =  100.00 years.
Printout every  50.00 years.  Vertical profile stored every 100.00 years.
Koc =      58.000     ml/g,      0.20482E-02cu.ft./g
Kh =     0.17000      (dimensionless).
Aqueous solubility =      7700.0     mg/l,       218.04     g/cu.ft
Free air diffusion coefficient = .85000     sq. m/day,  3339.7      sq.ft./yr


Polygon   1
Polygon I
Polygon area =       1.0000    sq. ft.
 80 cells, each cell  0.250 ft. thick.
Soil Properties:
 Bulk density =      1.6000    g/ml,        45307.    g/cu.ft.
 Porosity = 0.4000 Volumetric water content = 0.2500
 Organic carbon content = 0.00500000
Recharge Rate = 0.00057000 ft/yr
Conc. in recharge water =     0.16500    mg/l,      0.46723E-02g/cu.ft
Atmospheric concentration =     -1.0000    mg/l,     -0.28317E-01g/cu.ft
Water table has a fixed concentration of     0.00000    mg/l,      0.00000
   with respect to gas diffusion.
```

Time: 100.000 - Chloroform - 100 years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.84310E-05	0.49594E-04	0.50790E-09
2	0.14556E-05	0.85626E-05	0.87691E-10
3	0.13731E-05	0.80772E-05	0.82720E-10
4	0.13548E-05	0.79692E-05	0.81615E-10
5	0.13370E-05	0.78649E-05	0.80546E-10
6	0.13193E-05	0.77606E-05	0.79478E-10
7	0.13016E-05	0.76563E-05	0.78410E-10
8	0.12838E-05	0.75520E-05	0.77342E-10
9	0.12661E-05	0.74478E-05	0.76275E-10
10	0.12484E-05	0.73436E-05	0.75208E-10
11	0.12307E-05	0.72395E-05	0.74141E-10
12	0.12130E-05	0.71353E-05	0.73074E-10
13	0.11953E-05	0.70312E-05	0.72008E-10
14	0.11776E-05	0.69272E-05	0.70942E-10
15	0.11599E-05	0.68231E-05	0.69877E-10
16	0.11422E-05	0.67191E-05	0.68811E-10
17	0.11246E-05	0.66151E-05	0.67746E-10
18	0.11069E-05	0.65111E-05	0.66682E-10
19	0.10892E-05	0.64072E-05	0.65617E-10
20	0.10716E-05	0.63033E-05	0.64553E-10
21	0.10539E-05	0.61994E-05	0.63489E-10
22	0.10362E-05	0.60955E-05	0.62425E-10
23	0.10186E-05	0.59917E-05	0.61362E-10
24	0.10009E-05	0.58879E-05	0.60299E-10
25	0.98329E-06	0.57841E-05	0.59236E-10
26	0.96566E-06	0.56803E-05	0.58173E-10
27	0.94802E-06	0.55766E-05	0.57111E-10
28	0.93039E-06	0.54729E-05	0.56049E-10
29	0.91277E-06	0.53692E-05	0.54987E-10
30	0.89514E-06	0.52655E-05	0.53926E-10
31	0.87753E-06	0.51619E-05	0.52864E-10
32	0.85991E-06	0.50583E-05	0.51803E-10
33	0.84230E-06	0.49547E-05	0.50742E-10
34	0.82470E-06	0.48511E-05	0.49682E-10
35	0.80709E-06	0.47476E-05	0.48621E-10
36	0.78949E-06	0.46441E-05	0.47561E-10
37	0.77190E-06	0.45406E-05	0.46501E-10
38	0.75431E-06	0.44371E-05	0.45441E-10
39	0.73672E-06	0.43337E-05	0.44382E-10
40	0.71914E-06	0.42302E-05	0.43322E-10
41	0.70156E-06	0.41268E-05	0.42263E-10
42	0.68398E-06	0.40234E-05	0.41204E-10
43	0 66640E-06	0.39200E-05	0.40146E-10
44	0 64883E-06	0.38167E-05	0.39087E-10
45	0.63127E-06	0.37133E-05	0.38029E-10
46	0 61370E-06	0.36100E-05	0.36971E-10
47	0.59614E-06	0.35067E-05	0.35913E-10
48	0.57858E-06	0.34034E-05	0.34855E-10
49	0.56102E-06	0.33001E-05	0.33797E-10
50	0.54347E-06	0.31969E-05	0.32740E-10
51	0.52592E-06	0.30936E-05	0.31683E-10
52	0.50837E-06	0.29904E-05	0.30625E-10
53	0.49082E-06	0.28872E-05	0.29568E-10

54	0.47328E-06	0.27840E-05	0.28512E-10
55	0.45574E-06	0.26808E-05	0.27455E-10
56	0.43820E-06	0.25777E-05	0.26398E-10
57	0.42066E-06	0.24745E-05	0.25342E-10
58	0.40313E-06	0.23713E-05	0 24285E-10
59	0.38560E-06	0.22682E-05	0.23229E-10
60	0.36806E-06	0.21651E-05	0 22173E-10
61	0.35054E-06	0.20620E-05	0 21117E-10
62	0.33301E-06	0.19589E-05	0 20061E-10
63	0.31548E-06	0.18558E-05	0.19005E-10
64	0.29796E-06	0.17527E-05	0 17950E-10
65	0.28043E-06	0.16496E-05	0.16894E-10
66	0.26291E-06	0.15465E-05	0 15838E-10
67	0.24539E-06	0.14435E-05	0.14783E-10
68	0.22787E-06	0.13404E-05	0 13727E-10
69	0.21035E-06	0.12374E-05	0 12672E-10
70	0.19283E-06	0.11343E-05	0.11617E-10
71	0.17531E-06	0.10313E-05	0.10561E-10
72	0.15780E-06	0.92822E-06	0.95061E-11
73	0.14028E-06	0.82518E-06	0 84508E-11
74	0.12276E-06	0.72214E-06	0.73956E-11
75	0.10525E-06	0.61911E-06	0 63404E-11
76	0.87734E-07	0.51608E-06	0 52853E-11
77	0.70218E-07	0.41305E-06	0.42301E-11
78	0.52703E-07	0.31002E-06	0 31749E-11
79	0.35188E-07	0.20699E-06	0.21198E-11
80	0.17672E-07	0.10395E-06	0 10646E-11

```
RMA 93-03 Chloroform Transport, 200 years
  1
       0.1       100.        50.       100.
      58.0       .17       7700.       0.85
Polygon I
        1.       0.25     .00057        1.6        0.40        .25        .005
      .424        -1.   9.13E-06
   80y      100.0
    1     1  8.10E-01
    2     2  1.40E-01
    3     3  1.32E-01
    4     4  1.30E-01
    5     5  1.28E-01
    6     6  1.27E-01
    7     7  1.25E-01
    8     8  1.23E-01
    9     9  1.22E-01
   10    10  1.20E-01
   11    11  1.18E-01
   12    12  1.17E-01
   13    13  1.15E-01
   14    14  1.13E-01
   15    15  1.11E-01
   16    16  1.10E-01
   17    17  1.08E-01
   18    18  1.06E-01
   19    19  1.05E-01
   20    20  1.03E-01
   21    21  1.01E-01
   22    22  9.96E-02
   23    23  9.79E-02
   24    24  9.62E-02
   25    25  9.45E-02
   26    26  9.28E-02
   27    27  9.11E-02
   28    28  8.94E-02
   29    29  8.77E-02
   30    30  8.60E-02
   31    31  8.43E-02
   32    32  8.26E-02
   33    33  8.09E-02
   34    34  7.92E-02
   35    35  7.75E-02
   36    36  7.59E-02
   37    37  7.42E-02
   38    38  7.25E-02
   39    39  7.08E-02
   40    40  6.91E-02
   41    41  6.74E-02
   42    42  6.57E-02
   43    43  6.40E-02
   44    44  6.23E-02
   45    45  6.07E-02
   46    46  5.90E-02
   47    47  5.73E-02
```

48	48	5.56E-02
49	49	5.39E-02
50	50	5.22E-02
51	51	5.05E-02
52	52	4.88E-02
53	53	4.72E-02
54	54	4.55E-02
55	55	4.38E-02
56	56	4.21E-02
57	57	4.04E-02
58	58	3.87E-02
59	59	3.70E-02
60	60	3.54E-02
61	61	3.37E-02
62	62	3.20E-02
63	63	3.03E-02
64	64	2.86E-02
65	65	2.69E-02
66	66	2.53E-02
67	67	2.36E-02
68	68	2.19E-02
69	69	2.02E-02
70	70	1.85E-02
71	71	1.68E-02
72	72	1.52E-02
73	73	1.35E-02
74	74	1.18E-02
75	75	1.01E-02
76	76	8.43E-03
77	77	6.75E-03
78	78	5.06E-03
79	79	3.38E-03
80	80	1.70E-03

Time: 100.000 - Chloroform - 200 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.21722E-04	0.12777E-03	0.13086E-08
2	0.37976E-05	0.22339E-04	0.22878E-09
3	0.35855E-05	0.21091E-04	0.21600E-09
4	0.35384E-05	0.20814E-04	0.21316E-09
5	0.34928E-05	0.20546E-04	0.21041E-09
6	0.34472E-05	0.20278E-04	0.20767E-09
7	0.34016E-05	0.20009E-04	0.20492E-09
8	0.33560E-05	0.19741E-04	0.20218E-09
9	0.33105E-05	0.19473E-04	0.19943E-09
10	0.32649E-05	0.19205E-04	0.19669E-09
11	0.32194E-05	0.18937E-04	0.19394E-09
12	0.31738E-05	0.18669E-04	0.19120E-09
13	0.31283E-05	0.18402E-04	0.18845E-09
14	0.30827E-05	0.18134E-04	0.18571E-09
15	0.30372E-05	0.17866E-04	0.18297E-09
16	0.29917E-05	0.17598E-04	0.18023E-09
17	0.29462E-05	0.17331E-04	0.17749E-09
18	0.29007E-05	0.17063E-04	0.17474E-09
19	0.28552E-05	0.16795E-04	0.17200E-09
20	0.28097E-05	0.16528E-04	0.16926E-09
21	0.27642E-05	0.16260E-04	0.16652E-09
22	0.27188E-05	0.15993E-04	0.16378E-09
23	0.26733E-05	0.15725E-04	0.16105E-09
24	0.26278E-05	0.15458E-04	0.15831E-09
25	0.25824E-05	0.15191E-04	0.15557E-09
26	0.25369E-05	0.14923E-04	0.15283E-09
27	0.24915E-05	0.14656E-04	0.15009E-09
28	0.24461E-05	0.14389E-04	0.14736E-09
29	0.24006E-05	0.14121E-04	0.14462E-09
30	0.23552E-05	0.13854E-04	0.14188E-09
31	0.23098E-05	0.13587E-04	0.13915E-09
32	0.22644E-05	0.13320E-04	0.13641E-09
33	0.22190E-05	0.13053E-04	0.13368E-09
34	0.21736E-05	0.12786E-04	0.13094E-09
35	0.21282E-05	0.12519E-04	0.12821E-09
36	0.20828E-05	0.12252E-04	0.12547E-09
37	0.20375E-05	0.11985E-04	0.12274E-09
38	0.19921E-05	0.11718E-04	0.12001E-09
39	0.19467E-05	0.11451E-04	0.11727E-09
40	0.19014E-05	0.11184E-04	0.11454E-09
41	0.18560E-05	0.10918E-04	0.11181E-09
42	0.18106E-05	0.10651E-04	0.10908E-09
43	0.17653E-05	0.10384E-04	0.10635E-09
44	0.17200E-05	0.10117E-04	0.10361E-09
45	0.16746E-05	0.98507E-05	0.10088E-09
46	0.16293E-05	0.95840E-05	0.98152E-10
47	0.15840E-05	0.93174E-05	0.95421E-10
48	0.15386E-05	0.90507E-05	0.92690E-10
49	0.14933E-05	0.87841E-05	0.89960E-10
50	0.14480E-05	0.85176E-05	0.87230E-10
51	0.14027E-05	0.82510E-05	0.84500E-10
52	0.13574E-05	0.79845E-05	0.81771E-10
53	0.13121E-05	0.77180E-05	0.79042E-10

54	0.12668E-05	0.74515E-05	0.76313E-10
55	0.12215E-05	0.71851E-05	0.73584E-10
56	0.11762E-05	0.69186E-05	0.70855E-10
57	0.11309E-05	0.66522E-05	0.68126E-10
58	0.10856E-05	0.63858E-05	0.65398E-10
59	0.10403E-05	0.61194E-05	0.62670E-10
60	0.99501E-06	0.58530E-05	0.59942E-10
61	0.94973E-06	0.55866E-05	0.57214E-10
62	0.90445E-06	0.53203E-05	0.54486E-10
63	0.85917E-06	0.50540E-05	0.51759E-10
64	0.81390E-06	0.47876E-05	0.49031E-10
65	0.76862E-06	0.45213E-05	0.46304E-10
66	0.72335E-06	0.42550E-05	0.43576E-10
67	0.67808E-06	0.39887E-05	0.40849E-10
68	0.63281E-06	0.37224E-05	0.38122E-10
69	0.58754E-06	0.34561E-05	0.35395E-10
70	0.54228E-06	0.31899E-05	0.32668E-10
71	0.49701E-06	0.29236E-05	0.29941E-10
72	0.45174E-06	0.26573E-05	0.27214E-10
73	0.40648E-06	0.23911E-05	0.24487E-10
74	0.36121E-06	0.21248E-05	0.21760E-10
75	0.31595E-06	0.18585E-05	0.19034E-10
76	0.27068E-06	0.15923E-05	0.16307E-10
77	0.22542E-06	0.13260E-05	0.13580E-10
78	0.18015E-06	0.10597E-05	0.10853E-10
79	0.13489E-06	0.79346E-06	0.81260E-11
80	0.89622E-07	0.52719E-06	0.53991E-11

```
RMA 93-03 Chloroform Transport, 300 years
  1
       0.1      100.        50.      100.
      58.0      .17       7700.      0.85
Polygon I
        1.      0.25     .00057       1.6       0.40        .25       .005
      .538       -1.   3.27E-05
   80y      100.0
     1     1  2.09E+00
     2     2  3.65E-01
     3     3  3.44E-01
     4     4  3.40E-01
     5     5  3.36E-01
     6     6  3.31E-01
     7     7  3.27E-01
     8     8  3.22E-01
     9     9  3.18E-01
    10    10  3.14E-01
    11    11  3.09E-01
    12    12  3.05E-01
    13    13  3.01E-01
    14    14  2.96E-01
    15    15  2.92E-01
    16    16  2.87E-01
    17    17  2.83E-01
    18    18  2.79E-01
    19    19  2.74E-01
    20    20  2.70E-01
    21    21  2.66E-01
    22    22  2.61E-01
    23    23  2.57E-01
    24    24  2.52E-01
    25    25  2.48E-01
    26    26  2.44E-01
    27    27  2.39E-01
    28    28  2.35E-01
    29    29  2.31E-01
    30    30  2.26E-01
    31    31  2.22E-01
    32    32  2.18E-01
    33    33  2.13E-01
    34    34  2.09E-01
    35    35  2.04E-01
    36    36  2.00E-01
    37    37  1.96E-01
    38    38  1.91E-01
    39    39  1.87E-01
    40    40  1.83E-01
    41    41  1.78E-01
    42    42  1.74E-01
    43    43  1.70E-01
    44    44  1.65E-01
    45    45  1.61E-01
    46    46  1.57E-01
    47    47  1.52E-01
```

48	48	1.48E-01
49	49	1.43E-01
50	50	1.39E-01
51	51	1.35E-01
52	52	1.30E-01
53	53	1.26E-01
54	54	1.22E-01
55	55	1.17E-01
56	56	1.13E-01
57	57	1.09E-01
58	58	1.04E-01
59	59	1.00E-01
60	60	9.56E-02
61	61	9.12E-02
62	62	8.69E-02
63	63	8.25E-02
64	64	7.82E-02
65	65	7.38E-02
66	66	6.95E-02
67	67	6.51E-02
68	68	6.08E-02
69	69	5.65E-02
70	70	5.21E-02
71	71	4.78E-02
72	72	4.34E-02
73	73	3.91E-02
74	74	3.47E-02
75	75	3.04E-02
76	76	2.60E-02
77	77	2.17E-02
78	78	1.73E-02
79	79	1.30E-02
80	80	8.61E-03

Time: 100.000 - Chloroform - 300 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.27680E-04	0.16282E-03	0.16675E-08
2	0.49374E-05	0.29044E-04	0.29744E-09
3	0.46683E-05	0.27461E-04	0.28123E-09
4	0.46085E-05	0.27109E-04	0.27763E-09
5	0.45506E-05	0.26768E-04	0.27414E-09
6	0.44927E-05	0.26428E-04	0.27065E-09
7	0.44348E-05	0.26087E-04	0.26717E-09
8	0.43770E-05	0.25747E-04	0.26368E-09
9	0.43191E-05	0.25406E-04	0.26019E-09
10	0.42612E-05	0.25066E-04	0.25671E-09
11	0.42034E-05	0.24726E-04	0.25322E-09
12	0.41455E-05	0.24385E-04	0.24974E-09
13	0.40877E-05	0.24045E-04	0.24625E-09
14	0.40298E-05	0.23705E-04	0.24276E-09
15	0.39720E-05	0.23364E-04	0.23928E-09
16	0.39141E-05	0.23024E-04	0.23580E-09
17	0.38563E-05	0.22684E-04	0.23231E-09
18	0.37984E-05	0.22344E-04	0.22883E-09
19	0.37406E-05	0.22003E-04	0.22534E-09
20	0.36827E-05	0.21663E-04	0.22186E-09
21	0.36249E-05	0.21323E-04	0.21837E-09
22	0.35671E-05	0.20983E-04	0.21489E-09
23	0.35093E-05	0.20643E-04	0.21141E-09
24	0.34514E-05	0.20303E-04	0.20792E-09
25	0.33936E-05	0.19962E-04	0.20444E-09
26	0.33358E-05	0.19622E-04	0.20096E-09
27	0.32780E-05	0.19282E-04	0.19747E-09
28	0.32201E-05	0.18942E-04	0.19399E-09
29	0.31623E-05	0.18602E-04	0.19051E-09
30	0.31045E-05	0.18262E-04	0.18702E-09
31	0.30467E-05	0.17922E-04	0.18354E-09
32	0.29889E-05	0.17582E-04	0.18006E-09
33	0.29311E-05	0.17242E-04	0.17658E-09
34	0.28733E-05	0.16902E-04	0.17309E-09
35	0.28155E-05	0.16562E-04	0.16961E-09
36	0.27577E-05	0.16222E-04	0.16613E-09
37	0.26999E-05	0.15882E-04	0.16265E-09
38	0.26421E-05	0.15542E-04	0.15917E-09
39	0.25843E-05	0.15202E-04	0.15569E-09
40	0.25265E-05	0.14862E-04	0.15220E-09
41	0.24688E-05	0.14522E-04	0.14872E-09
42	0.24110E-05	0.14182E-04	0.14524E-09
43	0.23532E-05	0.13842E-04	0.14176E-09
44	0.22954E-05	0.13502E-04	0.13828E-09
45	0.22376E-05	0.13162E-04	0.13480E-09
46	0.21798E-05	0.12823E-04	0.13132E-09
47	0.21221E-05	0.12483E-04	0.12784E-09
48	0.20643E-05	0.12143E-04	0.12436E-09
49	0.20065E-05	0.11803E-04	0.12088E-09
50	0.19487E-05	0.11463E-04	0.11740E-09
51	0.18910E-05	0.11123E-04	0.11392E-09
52	0.18332E-05	0.10783E-04	0.11044E-09
53	0.17754E-05	0.10444E-04	0.10696E-09

54	0.17176E-05	0.10104E-04	0.10348E-09
55	0.16599E-05	0.97640E-05	0.99995E-10
56	0.16021E-05	0.94242E-05	0.96515E-10
57	0.15443E-05	0.90844E-05	0.93035E-10
58	0.14866E-05	0.87446E-05	0.89555E-10
59	0.14288E-05	0.84048E-05	0.86075E-10
60	0.13710E-05	0.80650E-05	0.82595E-10
61	0.13133E-05	0.77252E-05	0.79115E-10
62	0.12555E-05	0.73854E-05	0.75635E-10
63	0.11977E-05	0.70456E-05	0.72155E-10
64	0.11400E-05	0.67058E-05	0.68675E-10
65	0.10822E-05	0.63660E-05	0.65195E-10
66	0.10245E-05	0.60262E-05	0.61715E-10
67	0.96669E-06	0.56864E-05	0.58235E-10
68	0.90892E-06	0.53466E-05	0.54756E-10
69	0.85116E-06	0.50068E-05	0.51276E-10
70	0.79339E-06	0.46670E-05	0.47796E-10
71	0.73563E-06	0.43272E-05	0.44316E-10
72	0.67786E-06	0.39874E-05	0.40836E-10
73	0.62009E-06	0.36476E-05	0.37356E-10
74	0.56233E-06	0.33078E-05	0.33876E-10
75	0.50456E-06	0.29680E-05	0.30396E-10
76	0.44679E-06	0.26282E-05	0.26916E-10
77	0.38902E-06	0.22884E-05	0.23435E-10
78	0.33125E-06	0.19485E-05	0.19955E-10
79	0.27348E-06	0.16087E-05	0.16475E-10
80	0.21570E-06	0.12689E-05	0.12995E-10

```
RMA 93-03 Chloroform Transport, 400 years
  1
       0.1       100.         50.       100.
      58.0       .17        7700.       0.85
Polygon I
        1.       0.25      .00057        1.6       0.40        .25       .005
      .604        -1.    6.28E-05
   80y      100.0
    1     1  2.66E+00
    2     2  4.74E-01
    3     3  4.49E-01
    4     4  4.43E-01
    5     5  4.37E-01
    6     6  4.32E-01
    7     7  4.26E-01
    8     8  4.21E-01
    9     9  4.15E-01
   10    10  4.09E-01
   11    11  4.04E-01
   12    12  3.98E-01
   13    13  3.93E-01
   14    14  3.87E-01
   15    15  3.82E-01
   16    16  3.76E-01
   17    17  3.71E-01
   18    18  3.65E-01
   19    19  3.59E-01
   20    20  3.54E-01
   21    21  3.48E-01
   22    22  3.43E-01
   23    23  3.37E-01
   24    24  3.32E-01
   25    25  3.26E-01
   26    26  3.20E-01
   27    27  3.15E-01
   28    28  3.09E-01
   29    29  3.04E-01
   30    30  2.98E-01
   31    31  2.93E-01
   32    32  2.87E-01
   33    33  2.82E-01
   34    34  2.76E-01
   35    35  2.71E-01
   36    36  2.65E-01
   37    37  2.59E-01
   38    38  2.54E-01
   39    39  2.48E-01
   40    40  2.43E-01
   41    41  2.37E-01
   42    42  2.32E-01
   43    43  2.26E-01
   44    44  2.21E-01
   45    45  2.15E-01
   46    46  2.09E-01
   47    47  2.04E-01
```

48	48	1.98E-01
49	49	1.93E-01
50	50	1.87E-01
51	51	1.82E-01
52	52	1.76E-01
53	53	1.71E-01
54	54	1.65E-01
55	55	1.59E-01
56	56	1.54E-01
57	57	1.48E-01
58	58	1.43E-01
59	59	1.37E-01
60	60	1.32E-01
61	61	1.26E-01
62	62	1.21E-01
63	63	1.15E-01
64	64	1.10E-01
65	65	1.04E-01
66	66	9.84E-02
67	67	9.29E-02
68	68	8.73E-02
69	69	8.18E-02
70	70	7.62E-02
71	71	7.07E-02
72	72	6.51E-02
73	73	5.96E-02
74	74	5.40E-02
75	75	4.85E-02
76	76	4.29E-02
77	77	3.74E-02
78	78	3.18E-02
79	79	2.63E-02
80	80	2.07E-02

Time: 100.000 - Chloroform - 400 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.31205E-04	0.18356E-03	0.18798E-08
2	0.56736E-05	0.33374E-04	0.34179E-09
3	0.53715E-05	0.31597E-04	0.32359E-09
4	0.53044E-05	0.31202E-04	0.31955E-09
5	0.52393E-05	0.30820E-04	0.31563E-09
6	0.51744E-05	0.30437E-04	0.31172E-09
7	0.51094E-05	0.30055E-04	0.30780E-09
8	0.50444E-05	0.29673E-04	0.30389E-09
9	0.49794E-05	0.29291E-04	0.29997E-09
10	0.49144E-05	0.28908E-04	0.29606E-09
11	0.48495E-05	0.28526E-04	0.29214E-09
12	0.47845E-05	0.28144E-04	0.28823E-09
13	0.47195E-05	0.27762E-04	0.28431E-09
14	0.46545E-05	0.27380E-04	0.28040E-09
15	0.45896E-05	0.26997E-04	0.27649E-09
16	0.45246E-05	0.26615E-04	0.27257E-09
17	0.44596E-05	0.26233E-04	0.26866E-09
18	0.43947E-05	0.25851E-04	0.26474E-09
19	0.43297E-05	0.25469E-04	0.26083E-09
20	0.42647E-05	0.25087E-04	0.25692E-09
21	0.41998E-05	0.24705E-04	0.25300E-09
22	0.41348E-05	0.24322E-04	0.24909E-09
23	0.40698E-05	0.23940E-04	0.24518E-09
24	0.40049E-05	0.23558E-04	0.24126E-09
25	0.39399E-05	0.23176E-04	0.23735E-09
26	0.38750E-05	0.22794E-04	0.23344E-09
27	0.38100E-05	0.22412E-04	0.22952E-09
28	0.37451E-05	0.22030E-04	0.22561E-09
29	0.36801E-05	0.21648E-04	0.22170E-09
30	0.36151E-05	0.21266E-04	0.21778E-09
31	0.35502E-05	0.20883E-04	0.21387E-09
32	0.34852E-05	0.20501E-04	0.20996E-09
33	0.34203E-05	0.20119E-04	0.20605E-09
34	0.33553E-05	0.19737E-04	0.20213E-09
35	0.32904E-05	0.19355E-04	0.19822E-09
36	0.32254E-05	0.18973E-04	0.19431E-09
37	0.31605E-05	0.18591E-04	0.19040E-09
38	0.30955E-05	0.18209E-04	0.18648E-09
39	0.30306E-05	0.17827E-04	0.18257E-09
40	0.29657E-05	0.17445E-04	0.17866E-09
41	0.29007E-05	0.17063E-04	0.17475E-09
42	0.28358E-05	0.16681E-04	0.17083E-09
43	0.27708E-05	0.16299E-04	0.16692E-09
44	0.27059E-05	0.15917E-04	0.16301E-09
45	0.26409E-05	0.15535E-04	0.15910E-09
46	0.25760E-05	0.15153E-04	0.15518E-09
47	0.25111E-05	0.14771E-04	0.15127E-09
48	0.24461E-05	0.14389E-04	0.14736E-09
49	0.23812E-05	0.14007E-04	0.14345E-09
50	0.23162E-05	0.13625E-04	0.13954E-09
51	0.22513E-05	0.13243E-04	0.13562E-09
52	0.21863E-05	0.12861E-04	0.13171E-09
53	0.21214E-05	0.12479E-04	0.12780E-09

54	0.20565E-05	0.12097E-04	0.12389E-09
55	0.19915E-05	0.11715E-04	0.11997E-09
56	0.19266E-05	0.11333E-04	0.11606E-09
57	0.18616E-05	0.10951E-04	0.11215E-09
58	0.17967E-05	0.10569E-04	0.10824E-09
59	0.17318E-05	0.10187E-04	0.10433E-09
60	0.16668E-05	0.98048E-05	0.10041E-09
61	0.16019E-05	0.94228E-05	0.96501E-10
62	0.15369E-05	0.90408E-05	0.92589E-10
63	0.14720E-05	0.86588E-05	0.88676E-10
64	0.14070E-05	0.82768E-05	0.84764E-10
65	0.13421E-05	0.78947E-05	0.80852E-10
66	0.12772E-05	0.75127E-05	0.76939E-10
67	0.12122E-05	0.71307E-05	0.73027E-10
68	0.11473E-05	0.67487E-05	0.69114E-10
69	0.10823E-05	0.63666E-05	0.65202E-10
70	0.10174E-05	0.59846E-05	0.61289E-10
71	0.95243E-06	0.56025E-05	0.57377E-10
72	0.88748E-06	0.52205E-05	0.53464E-10
73	0.82253E-06	0.48384E-05	0.49551E-10
74	0.75758E-06	0.44564E-05	0.45638E-10
75	0.69263E-06	0.40743E-05	0.41726E-10
76	0.62768E-06	0.36922E-05	0.37813E-10
77	0.56272E-06	0.33101E-05	0.33900E-10
78	0.49777E-06	0.29280E-05	0.29987E-10
79	0.43281E-06	0.25459E-05	0.26074E-10
80	0.36785E-06	0.21638E-05	0.22160E-10

```
RMA 93-03 Chloroform Transport, 500 years
  1
       0.1      100.       50.      100.
      58.0      .17       7700.     0.85
Polygon I
        1.      0.25    .00057      1.6       0.40       .25       .005
      .648       -1.  9.66E-05
   80y      100.0
    1     1  3.00E+00
    2     2  5.45E-01
    3     3  5.16E-01
    4     4  5.10E-01
    5     5  5.03E-01
    6     6  4.97E-01
    7     7  4.91E-01
    8     8  4.85E-01
    9     9  4.78E-01
   10    10  4.72E-01
   11    11  4.66E-01
   12    12  4.60E-01
   13    13  4.53E-01
   14    14  4.47E-01
   15    15  4.41E-01
   16    16  4.35E-01
   17    17  4.28E-01
   18    18  4.22E-01
   19    19  4.16E-01
   20    20  4.10E-01
   21    21  4.04E-01
   22    22  3.97E-01
   23    23  3.91E-01
   24    24  3.85E-01
   25    25  3.79E-01
   26    26  3.72E-01
   27    27  3.66E-01
   28    28  3.60E-01
   29    29  3.54E-01
   30    30  3.47E-01
   31    31  3.41E-01
   32    32  3.35E-01
   33    33  3.29E-01
   34    34  3.22E-01
   35    35  3.16E-01
   36    36  3.10E-01
   37    37  3.04E-01
   38    38  2.97E-01
   39    39  2.91E-01
   40    40  2.85E-01
   41    41  2.79E-01
   42    42  2.72E-01
   43    43  2.66E-01
   44    44  2.60E-01
   45    45  2.54E-01
   46    46  2.48E-01
   47    47  2.41E-01
```

48	48	2.35E-01
49	49	2.29E-01
50	50	2.23E-01
51	51	2.16E-01
52	52	2.10E-01
53	53	2.04E-01
54	54	1.98E-01
55	55	1.91E-01
56	56	1.85E-01
57	57	1.79E-01
58	58	1.73E-01
59	59	1.66E-01
60	60	1.60E-01
61	61	1.54E-01
62	62	1.48E-01
63	63	1.41E-01
64	64	1.35E-01
65	65	1.29E-01
66	66	1.23E-01
67	67	1.16E-01
68	68	1.10E-01
69	69	1.04E-01
70	70	9.77E-02
71	71	9.15E-02
72	72	8.53E-02
73	73	7.90E-02
74	74	7.28E-02
75	75	6.65E-02
76	76	6.03E-02
77	77	5.41E-02
78	78	4.78E-02
79	79	4.16E-02
80	80	3.53E-02

Time: 100.000 - Chloroform - 500 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.33619E-04	0.19776E-03	0.20253E-08
2	0.62296E-05	0.36644E-04	0.37528E-09
3	0.59055E-05	0.34738E-04	0.35576E-09
4	0.58334E-05	0.34314E-04	0.35142E-09
5	0.57637E-05	0.33904E-04	0.34722E-09
6	0.56940E-05	0.33494E-04	0.34302E-09
7	0.56242E-05	0.33084E-04	0.33882E-09
8	0.55545E-05	0.32674E-04	0.33462E-09
9	0.54848E-05	0.32264E-04	0.33042E-09
10	0.54151E-05	0.31853E-04	0.32622E-09
11	0.53454E-05	0.31443E-04	0.32202E-09
12	0.52757E-05	0.31033E-04	0.31782E-09
13	0.52059E-05	0.30623E-04	0.31362E-09
14	0.51362E-05	0.30213E-04	0.30942E-09
15	0.50665E-05	0.29803E-04	0.30522E-09
16	0.49968E-05	0.29393E-04	0.30102E-09
17	0.49271E-05	0.28983E-04	0.29682E-09
18	0.48574E-05	0.28573E-04	0.29262E-09
19	0.47877E-05	0.28163E-04	0.28842E-09
20	0.47180E-05	0.27753E-04	0.28422E-09
21	0.46483E-05	0.27343E-04	0.28002E-09
22	0.45785E-05	0.26933E-04	0.27582E-09
23	0.45088E-05	0.26523E-04	0.27162E-09
24	0.44391E-05	0.26112E-04	0.26742E-09
25	0.43694E-05	0.25702E-04	0.26322E-09
26	0.42997E-05	0.25292E-04	0.25902E-09
27	0.42300E-05	0.24882E-04	0.25483E-09
28	0.41603E-05	0.24472E-04	0.25063E-09
29	0.40906E-05	0.24062E-04	0.24643E-09
30	0.40209E-05	0.23652E-04	0.24223E-09
31	0.39512E-05	0.23242E-04	0.23803E-09
32	0.38815E-05	0.22832E-04	0.23383E-09
33	0.38118E-05	0.22422E-04	0.22963E-09
34	0.37421E-05	0.22012E-04	0.22543E-09
35	0.36724E-05	0.21602E-04	0.22123E-09
36	0.36027E-05	0.21192E-04	0.21703E-09
37	0.35330E-05	0.20782E-04	0.21283E-09
38	0.34633E-05	0.20372E-04	0.20863E-09
39	0.33936E-05	0.19962E-04	0.20444E-09
40	0.33238E-05	0.19552E-04	0.20024E-09
41	0.32541E-05	0.19142E-04	0.19604E-09
42	0.31844E-05	0.18732E-04	0.19184E-09
43	0.31147E-05	0.18322E-04	0.18764E-09
44	0.30450E-05	0.17912E-04	0.18344E-09
45	0.29753E-05	0.17502E-04	0.17924E-09
46	0.29056E-05	0.17092E-04	0.17504E-09
47	0.28359E-05	0.16682E-04	0.17084E-09
48	0.27662E-05	0.16272E-04	0.16664E-09
49	0.26965E-05	0.15862E-04	0.16244E-09
50	0.26268E-05	0.15452E-04	0.15825E-09
51	0.25571E-05	0.15042E-04	0.15405E-09
52	0.24874E-05	0.14632E-04	0.14985E-09
53	0.24177E-05	0.14222E-04	0.14565E-09

54	0.23480E-05	0.13812E-04	0.14145E-09
55	0.22783E-05	0.13402E-04	0.13725E-09
56	0.22086E-05	0.12992E-04	0.13305E-09
57	0.21389E-05	0.12582E-04	0.12885E-09
58	0.20692E-05	0.12172E-04	0.12465E-09
59	0.19995E-05	0.11762E-04	0.12045E-09
60	0.19297E-05	0.11351E-04	0.11625E-09
61	0.18600E-05	0.10941E-04	0.11205E-09
62	0.17903E-05	0.10531E-04	0.10785E-09
63	0.17206E-05	0.10121E-04	0.10365E-09
64	0.16509E-05	0.97112E-05	0.99454E-10
65	0.15812E-05	0.93011E-05	0.95255E-10
66	0.15115E-05	0.88911E-05	0.91055E-10
67	0.14418E-05	0.84810E-05	0.86855E-10
68	0.13721E-05	0.80709E-05	0.82656E-10
69	0.13023E-05	0.76608E-05	0.78456E-10
70	0.12326E-05	0.72507E-05	0 74256E-10
71	0.11629E-05	0.68406E-05	0.70056E-10
72	0.10932E-05	0.64305E-05	0 65856E-10
73	0.10235E-05	0.60203E-05	0.61656E-10
74	0.95374E-06	0.56102E-05	0 57455E-10
75	0.88401E-06	0.52001E-05	0 53255E-10
76	0.81429E-06	0.47899E-05	0 49055E-10
77	0.74456E-06	0.43798E-05	0.44854E-10
78	0.67484E-06	0.39696E-05	0.40654E-10
79	0.60511E-06	0.35595E-05	0 36453E-10
80	0.53538E-06	0.31493E-05	0 32252E-10

```
RMA 93-03 Chloroform Transport, 600 years
  1
       0.1      100.        50.       100.
      58.0      .17       7700.       0.85
Polygon I
        1.      0.25    .00057        1.6       0.40        .25       .005
      .681       -1.  1.33E-04
   80y      100.0
    1     1  3.23E+00
    2     2  5.99E-01
    3     3  5.67E-01
    4     4  5.60E-01
    5     5  5.54E-01
    6     6  5.47E-01
    7     7  5.40E-01
    8     8  5.34E-01
    9     9  5.27E-01
   10    10  5.20E-01
   11    11  5.14E-01
   12    12  5.07E-01
   13    13  5.00E-01
   14    14  4.93E-01
   15    15  4.87E-01
   16    16  4.80E-01
   17    17  4.73E-01
   18    18  4.67E-01
   19    19  4.60E-01
   20    20  4.53E-01
   21    21  4.47E-01
   22    22  4.40E-01
   23    23  4.33E-01
   24    24  4.27E-01
   25    25  4.20E-01
   26    26  4.13E-01
   27    27  4.06E-01
   28    28  4.00E-01
   29    29  3.93E-01
   30    30  3.86E-01
   31    31  3.80E-01
   32    32  3.73E-01
   33    33  3.66E-01
   34    34  3.60E-01
   35    35  3.53E-01
   36    36  3.46E-01
   37    37  3.39E-01
   38    38  3.33E-01
   39    39  3.26E-01
   40    40  3.19E-01
   41    41  3.13E-01
   42    42  3.06E-01
   43    43  2.99E-01
   44    44  2.93E-01
   45    45  2.86E-01
   46    46  2.79E-01
   47    47  2.72E-01
```

48	48	2.66E-01
49	49	2.59E-01
50	50	2.52E-01
51	51	2.46E-01
52	52	2.39E-01
53	53	2.32E-01
54	54	2.26E-01
55	55	2.19E-01
56	56	2.12E-01
57	57	2.06E-01
58	58	1.99E-01
59	59	1.92E-01
60	60	1.85E-01
61	61	1.79E-01
62	62	1.72E-01
63	63	1.65E-01
64	64	1.59E-01
65	65	1.52E-01
66	66	1.45E-01
67	67	1.39E-01
68	68	1.32E-01
69	69	1.25E-01
70	70	1.18E-01
71	71	1.12E-01
72	72	1.05E-01
73	73	9.83E-02
74	74	9.16E-02
75	75	8.49E-02
76	76	7.82E-02
77	77	7.15E-02
78	78	6.48E-02
79	79	5.81E-02
80	80	5.14E-02

Time: 100.000 - Chloroform - 600 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.35482E-04	0.20872E-03	0.21375E-08
2	0.66991E-05	0.39407E-04	0.40357E-09
3	0.63586E-05	0.37403E-04	0.38306E-09
4	0.62828E-05	0.36958E-04	0.37849E-09
5	0.62095E-05	0.36527E-04	0.37408E-09
6	0.61363E-05	0.36096E-04	0.36966E-09
7	0.60630E-05	0.35665E-04	0.36525E-09
8	0.59897E-05	0.35234E-04	0.36084E-09
9	0.59165E-05	0.34803E-04	0.35642E-09
10	0.58432E-05	0.34372E-04	0.35201E-09
11	0.57699E-05	0.33941E-04	0.34759E-09
12	0.56967E-05	0.33510E-04	0.34318E-09
13	0.56234E-05	0.33079E-04	0.33877E-09
14	0.55501E-05	0.32648E-04	0.33435E-09
15	0.54769E-05	0.32217E-04	0.32994E-09
16	0.54036E-05	0.31786E-04	0.32553E-09
17	0.53304E-05	0.31355E-04	0.32111E-09
18	0.52571E-05	0.30924E-04	0.31670E-09
19	0.51838E-05	0.30493E-04	0.31229E-09
20	0.51106E-05	0.30062E-04	0.30787E-09
21	0.50373E-05	0.29631E-04	0.30346E-09
22	0.49640E-05	0.29200E-04	0.29904E-09
23	0.48908E-05	0.28769E-04	0.29463E-09
24	0.48175E-05	0.28338E-04	0.29022E-09
25	0.47442E-05	0.27907E-04	0.28580E-09
26	0.46710E-05	0.27476E-04	0.28139E-09
27	0.45977E-05	0.27045E-04	0.27698E-09
28	0.45244E-05	0.26614E-04	0.27256E-09
29	0.44512E-05	0.26183E-04	0.26815E-09
30	0.43779E-05	0.25752E-04	0.26374E-09
31	0.43047E-05	0.25322E-04	0.25932E-09
32	0.42314E-05	0.24891E-04	0.25491E-09
33	0.41581E-05	0.24460E-04	0.25050E-09
34	0.40849E-05	0.24029E-04	0.24608E-09
35	0.40116E-05	0.23598E-04	0.24167E-09
36	0.39383E-05	0.23167E-04	0.23726E-09
37	0.38651E-05	0.22736E-04	0.23284E-09
38	0.37918E-05	0.22305E-04	0.22843E-09
39	0.37186E-05	0.21874E-04	0.22401E-09
40	0.36453E-05	0.21443E-04	0.21960E-09
41	0.35720E-05	0.21012E-04	0.21519E-09
42	0.34988E-05	0.20581E-04	0.21077E-09
43	0.34255E-05	0.20150E-04	0.20636E-09
44	0.33522E-05	0.19719E-04	0.20195E-09
45	0.32790E-05	0.19288E-04	0.19753E-09
46	0.32057E-05	0.18857E-04	0.19312E-09
47	0.31324E-05	0.18426E-04	0.18871E-09
48	0.30592E-05	0.17995E-04	0.18429E-09
49	0.29859E-05	0.17564E-04	0.17988E-09
50	0.29126E-05	0.17133E-04	0.17546E-09
51	0.28394E-05	0.16702E-04	0.17105E-09
52	0.27661E-05	0.16271E-04	0.16664E-09
53	0.26928E-05	0.15840E-04	0.16222E-09

54	0.26196E-05	0.15409E-04	0.15781E-09
55	0.25463E-05	0.14978E-04	0.15339E-09
56	0.24730E-05	0.14547E-04	0.14898E-09
57	0.23997E-05	0.14116E-04	0.14457E-09
58	0.23265E-05	0.13685E-04	0.14015E-09
59	0.22532E-05	0.13254E-04	0.13574E-09
60	0.21799E-05	0.12823E-04	0.13132E-09
61	0.21066E-05	0.12392E-04	0.12691E-09
62	0.20334E-05	0.11961E-04	0.12250E-09
63	0.19601E-05	0.11530E-04	0.11808E-09
64	0.18868E-05	0.11099E-04	0.11367E-09
65	0.18135E-05	0.10668E-04	0.10925E-09
66	0.17403E-05	0.10237E-04	0.10484E-09
67	0.16670E-05	0.98057E-05	0.10042E-09
68	0.15937E-05	0.93747E-05	0.96008E-10
69	0.15204E-05	0.89436E-05	0.91593E-10
70	0.14471E-05	0.85125E-05	0.87178E-10
71	0.13738E-05	0.80814E-05	0.82763E-10
72	0.13006E-05	0.76503E-05	0.78348E-10
73	0.12273E-05	0.72192E-05	0.73933E-10
74	0.11540E-05	0.67881E-05	0.69518E-10
75	0.10807E-05	0.63569E-05	0.65103E-10
76	0.10074E-05	0.59258E-05	0.60687E-10
77	0.93409E-06	0.54947E-05	0.56272E-10
78	0.86080E-06	0.50635E-05	0.51857E-10
79	0.78750E-06	0.46324E-05	0.47441E-10
80	0.71420E-06	0.42012E-05	0.43025E-10

```
RMA 93-03 Chloroform Transport, 700 years
  1
       0.1      100.         50.       100.
      58.0      .17        7700.       0.85
Polygon I
        1.      0.25      .00057        1.6        0.40         .25        .005
      .706       -1.   1.71E-04
   80y      100.0
    1     1  3.41E+00
    2     2  6.44E-01
    3     3  6.11E-01
    4     4  6.04E-01
    5     5  5.97E-01
    6     6  5.90E-01
    7     7  5.83E-01
    8     8  5.75E-01
    9     9  5.68E-01
   10    10  5.61E-01
   11    11  5.54E-01
   12    12  5.47E-01
   13    13  5.40E-01
   14    14  5.33E-01
   15    15  5.26E-01
   16    16  5.19E-01
   17    17  5.12E-01
   18    18  5.05E-01
   19    19  4.98E-01
   20    20  4.91E-01
   21    21  4.84E-01
   22    22  4.77E-01
   23    23  4.70E-01
   24    24  4.63E-01
   25    25  4.56E-01
   26    26  4.49E-01
   27    27  4.42E-01
   28    28  4.35E-01
   29    29  4.28E-01
   30    30  4.21E-01
   31    31  4.14E-01
   32    32  4.07E-01
   33    33  4.00E-01
   34    34  3.92E-01
   35    35  3.85E-01
   36    36  3.78E-01
   37    37  3.71E-01
   38    38  3.64E-01
   39    39  3.57E-01
   40    40  3.50E-01
   41    41  3.43E-01
   42    42  3.36E-01
   43    43  3.29E-01
   44    44  3.22E-01
   45    45  3.15E-01
   46    46  3.08E-01
   47    47  3.01E-01
```

48	48	2.94E-01
49	49	2.87E-01
50	50	2.80E-01
51	51	2.73E-01
52	52	2.66E-01
53	53	2.59E-01
54	54	2.52E-01
55	55	2.45E-01
56	56	2.38E-01
57	57	2.31E-01
58	58	2.24E-01
59	59	2.16E-01
60	60	2.09E-01
61	61	2.02E-01
62	62	1.95E-01
63	63	1.88E-01
64	64	1.81E-01
65	65	1.74E-01
66	66	1.67E-01
67	67	1.60E-01
68	68	1.53E-01
69	69	1.46E-01
70	70	1.39E-01
71	71	1.32E-01
72	72	1.25E-01
73	73	1.18E-01
74	74	1.11E-01
75	75	1.04E-01
76	76	9.68E-02
77	77	8.97E-02
78	78	8.27E-02
79	79	7.57E-02
80	80	6.86E-02

Time: 100.000 - Chloroform - 700 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.36943E-04	0.21731E-03	0.22256E-08
2	0.71050E-05	0.41794E-04	0.42802E-09
3	0.67519E-05	0.39717E-04	0.40675E-09
4	0.66734E-05	0.39255E-04	0.40202E-09
5	0.65974E-05	0.38808E-04	0.39744E-09
6	0.65215E-05	0.38362E-04	0.39287E-09
7	0.64455E-05	0.37915E-04	0.38829E-09
8	0.63696E-05	0.37468E-04	0.38372E-09
9	0.62936E-05	0.37021E-04	0.37914E-09
10	0.62177E-05	0.36574E-04	0.37457E-09
11	0.61417E-05	0.36128E-04	0.36999E-09
12	0.60657E-05	0.35681E-04	0.36541E-09
13	0.59898E-05	0.35234E-04	0.36084E-09
14	0.59138E-05	0.34787E-04	0.35626E-09
15	0.58379E-05	0.34340E-04	0.35169E-09
16	0.57619E-05	0.33894E-04	0.34711E-09
17	0.56860E-05	0.33447E-04	0.34254E-09
18	0.56100E-05	0.33000E-04	0.33796E-09
19	0.55341E-05	0.32553E-04	0.33338E-09
20	0.54581E-05	0.32106E-04	0.32881E-09
21	0.53821E-05	0.31660E-04	0.32423E-09
22	0.53062E-05	0.31213E-04	0.31966E-09
23	0.52302E-05	0.30766E-04	0.31508E-09
24	0.51543E-05	0.30319E-04	0.31051E-09
25	0.50783E-05	0.29872E-04	0.30593E-09
26	0.50024E-05	0.29426E-04	0.30135E-09
27	0.49264E-05	0.28979E-04	0.29678E-09
28	0.48504E-05	0.28532E-04	0.29220E-09
29	0.47745E-05	0.28085E-04	0.28763E-09
30	0.46985E-05	0.27638E-04	0.28305E-09
31	0.46226E-05	0.27192E-04	0.27847E-09
32	0.45466E-05	0.26745E-04	0.27390E-09
33	0.44707E-05	0.26298E-04	0.26932E-09
34	0.43947E-05	0.25851E-04	0.26475E-09
35	0.43187E-05	0.25404E-04	0.26017E-09
36	0.42428E-05	0.24958E-04	0.25560E-09
37	0.41668E-05	0.24511E-04	0.25102E-09
38	0.40909E-05	0.24064E-04	0.24644E-09
39	0.40149E-05	0.23617E-04	0.24187E-09
40	0.39389E-05	0.23170E-04	0.23729E-09
41	0.38630E-05	0.22723E-04	0.23272E-09
42	0.37870E-05	0.22277E-04	0.22814E-09
43	0.37111E-05	0.21830E-04	0.22356E-09
44	0.36351E-05	0.21383E-04	0.21899E-09
45	0.35591E-05	0.20936E-04	0.21441E-09
46	0.34832E-05	0.20489E-04	0.20983E-09
47	0.34072E-05	0.20042E-04	0.20526E-09
48	0.33312E-05	0.19596E-04	0.20068E-09
49	0.32553E-05	0.19149E-04	0.19611E-09
50	0.31793E-05	0.18702E-04	0.19153E-09
51	0.31033E-05	0.18255E-04	0.18695E-09
52	0.30274E-05	0.17808E-04	0.18238E-09
53	0.29514E-05	0.17361E-04	0.17780E-09

54	0.28754E-05	0.16914E-04	0.17322E-09
55	0.27995E-05	0.16467E-04	0 16865E-09
56	0.27235E-05	0.16021E-04	0 16407E-09
57	0.26475E-05	0.15574E-04	0.15949E-09
58	0.25716E-05	0.15127E-04	0.15492E-09
59	0.24956E-05	0.14680E-04	0.15034E-09
60	0.24196E-05	0.14233E-04	0 14576E-09
61	0.23436E-05	0.13786E-04	0.14119E-09
62	0.22677E-05	0.13339E-04	0.13661E-09
63	0.21917E-05	0.12892E-04	0 13203E-09
64	0.21157E-05	0.12445E-04	0 12745E-09
65	0.20397E-05	0.11998E-04	0.12288E-09
66	0.19637E-05	0.11551E-04	0.11830E-09
67	0.18878E-05	0.11104E-04	0 11372E-09
68	0.18118E-05	0.10657E-04	0.10915E-09
69	0.17358E-05	0.10211E-04	0 10457E-09
70	0.16598E-05	0.97635E-05	0 99990E-10
71	0.15838E-05	0.93165E-05	0 95412E-10
72	0.15078E-05	0.88695E-05	0 90835E-10
73	0.14318E-05	0.84225E-05	0.86257E-10
74	0.13558E-05	0.79755E-05	0 81679E-10
75	0.12798E-05	0.75285E-05	0 77101E-10
76	0.12039E-05	0.70815E-05	0.72523E-10
77	0.11279E-05	0.66345E-05	0.67945E-10
78	0.10519E-05	0.61874E-05	0.63366E-10
79	0.97586E-06	0.57403E-05	0.58788E-10
80	0.89986E-06	0.52933E-05	0.54210E-10

```
RMA 93-03 Chloroform Transport, 800 years
  1
       0.1      100.        50.       100.
      58.0      .17       7700.       0.85
Polygon I
        1.      0.25    .00057         1.6        0.40         .25        .005
      .726       -1.  2.11E-04
   80y      100.0
    1     1  3.55E+00
    2     2  6.83E-01
    3     3  6.49E-01
    4     4  6.41E-01
    5     5  6.34E-01
    6     6  6.27E-01
    7     7  6.19E-01
    8     8  6.12E-01
    9     9  6.05E-01
   10    10  5.97E-01
   11    11  5.90E-01
   12    12  5.83E-01
   13    13  5.75E-01
   14    14  5.68E-01
   15    15  5.61E-01
   16    16  5.54E-01
   17    17  5.46E-01
   18    18  5.39E-01
   19    19  5.32E-01
   20    20  5.24E-01
   21    21  5.17E-01
   22    22  5.10E-01
   23    23  5.03E-01
   24    24  4.95E-01
   25    25  4.88E-01
   26    26  4.81E-01
   27    27  4.73E-01
   28    28  4.66E-01
   29    29  4.59E-01
   30    30  4.51E-01
   31    31  4.44E-01
   32    32  4.37E-01
   33    33  4.30E-01
   34    34  4.22E-01
   35    35  4.15E-01
   36    36  4.08E-01
   37    37  4.00E-01
   38    38  3.93E-01
   39    39  3.86E-01
   40    40  3.78E-01
   41    41  3.71E-01
   42    42  3.64E-01
   43    43  3.57E-01
   44    44  3.49E-01
   45    45  3.42E-01
   46    46  3.35E-01
   47    47  3.27E-01
```

48	48	3.20E-01
49	49	3.13E-01
50	50	3.05E-01
51	51	2.98E-01
52	52	2.91E-01
53	53	2.84E-01
54	54	2.76E-01
55	55	2.69E-01
56	56	2.62E-01
57	57	2.54E-01
58	58	2.47E-01
59	59	2.40E-01
60	60	2.32E-01
61	61	2.25E-01
62	62	2.18E-01
63	63	2.11E-01
64	64	2.03E-01
65	65	1.96E-01
66	66	1.89E-01
67	67	1.81E-01
68	68	1.74E-01
69	69	1.67E-01
70	70	1.59E-01
71	71	1.52E-01
72	72	1.45E-01
73	73	1.38E-01
74	74	1.30E-01
75	75	1.23E-01
76	76	1.16E-01
77	77	1.08E-01
78	78	1.01E-01
79	79	9.38E-02
80	80	8.65E-02

Time: 100.000 - Chloroform - 800 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.38158E-04	0.22446E-03	0.22987E-08
2	0.74756E-05	0.43974E-04	0.45035E-09
3	0.71126E-05	0.41839E-04	0.42848E-09
4	0.70319E-05	0.41364E-04	0.42362E-09
5	0.69537E-05	0.40904E-04	0.41891E-09
6	0.68756E-05	0.40445E-04	0.41420E-09
7	0.67975E-05	0.39985E-04	0.40950E-09
8	0.67194E-05	0.39526E-04	0.40479E-09
9	0.66413E-05	0.39067E-04	0.40009E-09
10	0.65632E-05	0.38607E-04	0.39538E-09
11	0.64851E-05	0.38148E-04	0.39068E-09
12	0.64070E-05	0.37688E-04	0.38597E-09
13	0.63289E-05	0.37229E-04	0.38127E-09
14	0.62508E-05	0.36769E-04	0.37656E-09
15	0.61727E-05	0.36310E-04	0.37186E-09
16	0.60946E-05	0.35850E-04	0.36715E-09
17	0.60165E-05	0.35391E-04	0.36245E-09
18	0.59384E-05	0.34932E-04	0.35774E-09
19	0.58603E-05	0.34472E-04	0.35304E-09
20	0.57821E-05	0.34013E-04	0.34833E-09
21	0.57040E-05	0.33553E-04	0.34362E-09
22	0.56259E-05	0.33094E-04	0.33892E-09
23	0.55478E-05	0.32634E-04	0.33421E-09
24	0.54697E-05	0.32175E-04	0.32951E-09
25	0.53916E-05	0.31715E-04	0.32480E-09
26	0.53135E-05	0.31256E-04	0.32010E-09
27	0.52354E-05	0.30796E-04	0.31539E-09
28	0.51573E-05	0.30337E-04	0.31069E-09
29	0.50792E-05	0.29877E-04	0.30598E-09
30	0.50011E-05	0.29418E-04	0.30128E-09
31	0.49229E-05	0.28959E-04	0.29657E-09
32	0.48448E-05	0.28499E-04	0.29186E-09
33	0.47667E-05	0.28040E-04	0.28716E-09
34	0.46886E-05	0.27580E-04	0.28245E-09
35	0.46105E-05	0.27121E-04	0.27775E-09
36	0.45324E-05	0.26661E-04	0.27304E-09
37	0.44543E-05	0.26202E-04	0.26834E-09
38	0.43762E-05	0.25742E-04	0.26363E-09
39	0.42980E-05	0.25283E-04	0.25892E-09
40	0.42199E-05	0.24823E-04	0.25422E-09
41	0.41418E-05	0.24364E-04	0.24951E-09
42	0.40637E-05	0.23904E-04	0.24481E-09
43	0.39856E-05	0.23445E-04	0.24010E-09
44	0.39075E-05	0.22985E-04	0.23540E-09
45	0.38294E-05	0.22526E-04	0.23069E-09
46	0.37512E-05	0.22066E-04	0.22598E-09
47	0.36731E-05	0.21607E-04	0.22128E-09
48	0.35950E-05	0.21147E-04	0.21657E-09
49	0.35169E-05	0.20687E-04	0.21186E-09
50	0.34388E-05	0.20228E-04	0.20716E-09
51	0.33606E-05	0.19768E-04	0.20245E-09
52	0.32825E-05	0.19309E-04	0.19775E-09
53	0.32044E-05	0.18849E-04	0.19304E-09

54	0.31263E-05	0.18390E-04	0.18833E-09
55	0.30481E-05	0.17930E-04	0.18363E-09
56	0.29700E-05	0.17471E-04	0.17892E-09
57	0.28919E-05	0.17011E-04	0.17421E-09
58	0.28137E-05	0.16551E-04	0.16951E-09
59	0.27356E-05	0.16092E-04	0.16480E-09
60	0.26575E-05	0.15632E-04	0.16009E-09
61	0.25794E-05	0.15173E-04	0.15539E-09
62	0.25012E-05	0.14713E-04	0.15068E-09
63	0.24231E-05	0.14253E-04	0.14597E-09
64	0.23449E-05	0.13794E-04	0.14127E-09
65	0.22668E-05	0.13334E-04	0.13656E-09
66	0.21887E-05	0.12875E-04	0.13185E-09
67	0.21105E-05	0.12415E-04	0.12714E-09
68	0.20324E-05	0.11955E-04	0.12244E-09
69	0.19543E-05	0.11496E-04	0.11773E-09
70	0.18761E-05	0.11036E-04	0.11302E-09
71	0.17980E-05	0.10576E-04	0.10831E-09
72	0.17198E-05	0.10117E-04	0.10361E-09
73	0.16417E-05	0.96569E-05	0.98898E-10
74	0.15635E-05	0.91972E-05	0.94190E-10
75	0.14854E-05	0.87375E-05	0 89482E-10
76	0.14072E-05	0.82777E-05	0.84774E-10
77	0.13291E-05	0.78180E-05	0.80066E-10
78	0.12509E-05	0.73583E-05	0.75358E-10
79	0.11727E-05	0.68985E-05	0.70649E-10
80	0.10946E-05	0.64388E-05	0.65941E-10

```
RMA 93-03 Chloroform Transport, 900 years
  1
      0.1      100.       50.      100.
     58.0      .17      7700.      0.85
Polygon I
       1.      0.25    .00057       1.6       0.40       .25       .005
     .742       -1.  2.52E-04
   80y     100.0
    1    1  3.67E+00
    2    2  7.18E-01
    3    3  6.83E-01
    4    4  6.76E-01
    5    5  6.68E-01
    6    6  6.61E-01
    7    7  6.53E-01
    8    8  6.46E-01
    9    9  6.38E-01
   10   10  6.31E-01
   11   11  6.23E-01
   12   12  6.16E-01
   13   13  6.08E-01
   14   14  6.01E-01
   15   15  5.93E-01
   16   16  5.86E-01
   17   17  5.78E-01
   18   18  5.71E-01
   19   19  5.63E-01
   20   20  5.56E-01
   21   21  5.48E-01
   22   22  5.41E-01
   23   23  5.33E-01
   24   24  5.26E-01
   25   25  5.18E-01
   26   26  5.11E-01
   27   27  5.03E-01
   28   28  4.96E-01
   29   29  4.88E-01
   30   30  4.80E-01
   31   31  4.73E-01
   32   32  4.65E-01
   33   33  4.58E-01
   34   34  4.50E-01
   35   35  4.43E-01
   36   36  4.35E-01
   37   37  4.28E-01
   38   38  4.20E-01
   39   39  4.13E-01
   40   40  4.05E-01
   41   41  3.98E-01
   42   42  3.90E-01
   43   43  3.83E-01
   44   44  3.75E-01
   45   45  3.68E-01
   46   46  3.60E-01
   47   47  3.53E-01
```

48	48	3.45E-01
49	49	3.38E-01
50	50	3.30E-01
51	51	3.23E-01
52	52	3.15E-01
53	53	3.08E-01
54	54	3.00E-01
55	55	2.93E-01
56	56	2.85E-01
57	57	2.78E-01
58	58	2.70E-01
59	59	2.63E-01
60	60	2.55E-01
61	61	2.48E-01
62	62	2.40E-01
63	63	2.33E-01
64	64	2.25E-01
65	65	2.18E-01
66	66	2.10E-01
67	67	2.03E-01
68	68	1.95E-01
69	69	1.88E-01
70	70	1.80E-01
71	71	1.73E-01
72	72	1.65E-01
73	73	1.58E-01
74	74	1.50E-01
75	75	1.43E-01
76	76	1.35E-01
77	77	1.28E-01
78	78	1.20E-01
79	79	1.13E-01
80	80	1.05E-01

Time: 100.000 - Chloroform - 900 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.39172E-04	0.23043E-03	0.23598E-08
2	0.78154E-05	0.45973E-04	0.47082E-09
3	0.74444E-05	0.43791E-04	0.44847E-09
4	0.73619E-05	0.43305E-04	0.44350E-09
5	0.72820E-05	0.42835E-04	0.43869E-09
6	0.72022E-05	0.42366E-04	0.43388E-09
7	0.71224E-05	0.41896E-04	0.42907E-09
8	0.70426E-05	0.41427E-04	0.42426E-09
9	0.69627E-05	0.40957E-04	0.41945E-09
10	0.68829E-05	0.40488E-04	0.41464E-09
11	0.68031E-05	0.40018E-04	0.40983E-09
12	0.67233E-05	0.39549E-04	0.40503E-09
13	0.66434E-05	0.39079E-04	0.40022E-09
14	0.65636E-05	0.38610E-04	0.39541E-09
15	0.64838E-05	0.38140E-04	0.39060E-09
16	0.64040E-05	0.37670E-04	0.38579E-09
17	0.63241E-05	0.37201E-04	0.38098E-09
18	0.62443E-05	0.36731E-04	0.37617E-09
19	0.61645E-05	0.36262E-04	0.37136E-09
20	0.60847E-05	0.35792E-04	0.36655E-09
21	0.60048E-05	0.35323E-04	0.36175E-09
22	0.59250E-05	0.34853E-04	0.35694E-09
23	0.58452E-05	0.34383E-04	0.35213E-09
24	0.57654E-05	0.33914E-04	0.34732E-09
25	0.56855E-05	0.33444E-04	0.34251E-09
26	0.56057E-05	0.32975E-04	0.33770E-09
27	0.55259E-05	0.32505E-04	0.33289E-09
28	0.54460E-05	0.32035E-04	0.32808E-09
29	0.53662E-05	0.31566E-04	0.32327E-09
30	0.52864E-05	0.31096E-04	0.31846E-09
31	0.52065E-05	0.30627E-04	0.31365E-09
32	0.51267E-05	0.30157E-04	0.30884E-09
33	0.50469E-05	0.29688E-04	0.30404E-09
34	0.49670E-05	0.29218E-04	0.29923E-09
35	0.48872E-05	0.28748E-04	0.29442E-09
36	0.48074E-05	0.28279E-04	0.28961E-09
37	0 47275E-05	0.27809E-04	0.28480E-09
38	0.46477E-05	0.27339E-04	0.27999E-09
39	0.45679E-05	0.26870E-04	0.27518E-09
40	0.44880E-05	0.26400E-04	0.27037E-09
41	0.44082E-05	0.25931E-04	0.26556E-09
42	0.43284E-05	0.25461E-04	0.26075E-09
43	0.42485E-05	0.24991E-04	0.25594E-09
44	0.41687E-05	0.24522E-04	0.25113E-09
45	0.40888E-05	0.24052E-04	0.24632E-09
46	0.40090E-05	0.23582E-04	0.24151E-09
47	0.39292E-05	0.23113E-04	0.23670E-09
48	0.38493E-05	0.22643E-04	0.23189E-09
49	0 37695E-05	0.22173E-04	0.22708E-09
50	0.36896E-05	0.21704E-04	0.22227E-09
51	0.36098E-05	0.21234E-04	0.21746E-09
52	0.35299E-05	0.20764E-04	0.21265E-09
53	0.34501E-05	0.20295E-04	0.20784E-09

54	0.33702E-05	0.19825E-04	0.20303E-09
55	0.32904E-05	0.19355E-04	0.19822E-09
56	0.32105E-05	0.18885E-04	0.19341E-09
57	0.31307E-05	0.18416E-04	0.18860E-09
58	0.30508E-05	0.17946E-04	0.18379E-09
59	0.29710E-05	0.17476E-04	0.17898E-09
60	0.28911E-05	0.17007E-04	0.17417E-09
61	0.28113E-05	0.16537E-04	0.16936E-09
62	0.27314E-05	0.16067E-04	0.16455E-09
63	0.26515E-05	0.15597E-04	0.15973E-09
64	0.25717E-05	0.15127E-04	0.15492E-09
65	0.24918E-05	0.14658E-04	0.15011E-09
66	0.24119E-05	0.14188E-04	0.14530E-09
67	0.23321E-05	0.13718E-04	0.14049E-09
68	0.22522E-05	0.13248E-04	0.13568E-09
69	0.21723E-05	0.12779E-04	0.13087E-09
70	0.20925E-05	0.12309E-04	0.12606E-09
71	0.20126E-05	0.11839E-04	0.12124E-09
72	0.19327E-05	0.11369E-04	0.11643E-09
73	0.18529E-05	0.10899E-04	0.11162E-09
74	0.17730E-05	0.10429E-04	0.10681E-09
75	0.16931E-05	0.99595E-05	0.10200E-09
76	0.16132E-05	0.94896E-05	0.97185E-10
77	0.15334E-05	0.90197E-05	0.92373E-10
78	0.14535E-05	0.85498E-05	0.87561E-10
79	0.13736E-05	0.80799E-05	0.82748E-10
80	0.12937E-05	0.76100E-05	0.77936E-10

```
RMA 93-03 Chloroform Transport, 1000 years
  1
       0.1      100.       50.      100.
      58.0      .17      7700.      0.85
Polygon I
        1.      0.25    .00057       1.6       0.40       .25       .005
      .756       -1.  2.94E-04
   80y      100.0
    1    1  3.76E+00
    2    2  7.51E-01
    3    3  7.15E-01
    4    4  7.07E-01
    5    5  7.00E-01
    6    6  6.92E-01
    7    7  6.84E-01
    8    8  6.77E-01
    9    9  6.69E-01
   10   10  6.61E-01
   11   11  6.54E-01
   12   12  6.46E-01
   13   13  6.38E-01
   14   14  6.31E-01
   15   15  6.23E-01
   16   16  6.15E-01
   17   17  6.08E-01
   18   18  6.00E-01
   19   19  5.92E-01
   20   20  5.85E-01
   21   21  5.77E-01
   22   22  5.69E-01
   23   23  5.62E-01
   24   24  5.54E-01
   25   25  5.46E-01
   26   26  5.39E-01
   27   27  5.31E-01
   28   28  5.23E-01
   29   29  5.16E-01
   30   30  5.08E-01
   31   31  5.00E-01
   32   32  4.93E-01
   33   33  4.85E-01
   34   34  4.77E-01
   35   35  4.70E-01
   36   36  4.62E-01
   37   37  4.54E-01
   38   38  4.47E-01
   39   39  4.39E-01
   40   40  4.31E-01
   41   41  4.24E-01
   42   42  4.16E-01
   43   43  4.08E-01
   44   44  4.01E-01
   45   45  3.93E-01
   46   46  3.85E-01
   47   47  3.78E-01
```

48	48	3.70E-01
49	49	3.62E-01
50	50	3.55E-01
51	51	3.47E-01
52	52	3.39E-01
53	53	3.31E-01
54	54	3.24E-01
55	55	3.16E-01
56	56	3.08E-01
57	57	3.01E-01
58	58	2.93E-01
59	59	2.85E-01
60	60	2.78E-01
61	61	2.70E-01
62	62	2.62E-01
63	63	2.55E-01
64	64	2.47E-01
65	65	2.39E-01
66	66	2.32E-01
67	67	2.24E-01
68	68	2.16E-01
69	69	2.09E-01
70	70	2.01E-01
71	71	1.93E-01
72	72	1.86E-01
73	73	1.78E-01
74	74	1.70E-01
75	75	1.63E-01
76	76	1.55E-01
77	77	1.47E-01
78	78	1.40E-01
79	79	1.32E-01
80	80	1.24E-01

Time: 100.000 Chloroform - 1000 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.40089E-04	0.23582E-03	0.24151E-08
2	0.81420E-05	0.47894E-04	0.49049E-09
3	0.77640E-05	0.45671E-04	0.46772E-09
4	0.76799E-05	0.45176E-04	0.46266E-09
5	0.75986E-05	0.44698E-04	0.45776E-09
6	0.75173E-05	0.44219E-04	0.45286E-09
7	0.74359E-05	0.43741E-04	0.44796E-09
8	0.73546E-05	0.43262E-04	0.44306E-09
9	0.72733E-05	0.42784E-04	0.43816E-09
10	0.71920E-05	0.42306E-04	0.43326E-09
11	0.71106E-05	0.41827E-04	0.42836E-09
12	0.70293E-05	0.41349E-04	0.42346E-09
13	0.69480E-05	0.40870E-04	0.41856E-09
14	0.68666E-05	0.40392E-04	0.41366E-09
15	0.67853E-05	0.39914E-04	0.40876E-09
16	0.67040E-05	0.39435E-04	0.40386E-09
17	0.66227E-05	0.38957E-04	0.39896E-09
18	0.65413E-05	0.38478E-04	0.39407E-09
19	0.64600E-05	0.38000E-04	0.38917E-09
20	0.63787E-05	0.37522E-04	0.38427E-09
21	0.62973E-05	0.37043E-04	0.37937E-09
22	0.62160E-05	0.36565E-04	0.37447E-09
23	0.61347E-05	0.36086E-04	0.36957E-09
24	0.60533E-05	0.35608E-04	0.36467E-09
25	0.59720E-05	0.35129E-04	0.35977E-09
26	0.58907E-05	0.34651E-04	0.35487E-09
27	0.58093E-05	0.34173E-04	0.34997E-09
28	0.57280E-05	0.33694E-04	0.34507E-09
29	0.56467E-05	0.33216E-04	0.34017E-09
30	0.55653E-05	0.32737E-04	0.33527E-09
31	0.54840E-05	0.32259E-04	0.33037E-09
32	0 54027E-05	0.31780E-04	0.32547E-09
33	0.53213E-05	0.31302E-04	0.32057E-09
34	0.52400E-05	0.30823E-04	0.31567E-09
35	0.51587E-05	0.30345E-04	0.31077E-09
36	0.50773E-05	0.29867E-04	0.30587E-09
37	0.49960E-05	0.29388E-04	0.30097E-09
38	0.49146E-05	0.28910E-04	0.29607E-09
39	0.48333E-05	0.28431E-04	0.29117E-09
40	0.47520E-05	0.27953E-04	0.28627E-09
41	0.46706E-05	0.27474E-04	0.28137E-09
42	0 45893E-05	0.26996E-04	0.27647E-09
43	0.45079E-05	0.26517E-04	0.27157E-09
44	0.44266E-05	0.26039E-04	0.26667E-09
45	0 43452E-05	0.25560E-04	0.26177E-09
46	0.42639E-05	0.25082E-04	0.25687E-09
47	0 41825E-05	0.24603E-04	0.25197E-09
48	0.41012E-05	0.24125E-04	0.24707E-09
49	0 40198E-05	0.23646E-04	0.24216E-09
50	0.39385E-05	0.23168E-04	0.23726E-09
51	0.38571E-05	0.22689E-04	0.23236E-09
52	0.37758E-05	0.22211E-04	0.22746E-09
53	0.36944E-05	0.21732E-04	0.22256E-09

54	0.36131E-05	0.21253E-04	0.21766E-09
55	0.35317E-05	0.20775E-04	0.21276E-09
56	0.34504E-05	0.20296E-04	0.20786E-09
57	0.33690E-05	0.19818E-04	0.20296E-09
58	0.32877E-05	0.19339E-04	0.19806E-09
59	0.32063E-05	0.18861E-04	0.19315E-09
60	0.31249E-05	0.18382E-04	0.18825E-09
61	0.30436E-05	0.17903E-04	0.18335E-09
62	0.29622E-05	0.17425E-04	0.17845E-09
63	0.28808E-05	0.16946E-04	0.17355E-09
64	0.27995E-05	0.16467E-04	0.16865E-09
65	0.27181E-05	0.15989E-04	0.16374E-09
66	0.26367E-05	0.15510E-04	0.15884E-09
67	0.25554E-05	0.15032E-04	0.15394E-09
68	0.24740E-05	0.14553E-04	0.14904E-09
69	0.23926E-05	0.14074E-04	0.14414E-09
70	0.23112E-05	0.13596E-04	0.13923E-09
71	0.22299E-05	0.13117E-04	0.13433E-09
72	0.21485E-05	0.12638E-04	0.12943E-09
73	0.20671E-05	0.12159E-04	0.12453E-09
74	0.19857E-05	0.11681E-04	0.11962E-09
75	0.19043E-05	0.11202E-04	0.11472E-09
76	0.18230E-05	0.10723E-04	0 10982E-09
77	0.17416E-05	0.10245E-04	0 10492E-09
78	0.16602E-05	0.97658E-05	0.10001E-09
79	0.15788E-05	0.92870E-05	0 95110E-10
80	0.14974E-05	0.88083E-05	0.90207E-10

```
RMA 93-03 CPMSO Transport, First 100 years
  1
       0.1      100.       50.      100.
      30.0     .0005     1100.      0.58
Polygon I
        1.      0.25    .00057       1.6      0.40       .25      .005
      .160       -1.        0.
   80y     100.0
    1    1       0.0
    2    2       0.0
    3    3       0.0
    4    4       0.0
    5    5       0.0
    6    6       0.0
    7    7       0.0
    8    8       0.0
    9    9       0.0
   10   10       0.0
   11   11       0.0
   12   12       0.0
   13   13       0.0
   14   14       0.0
   15   15       0.0
   16   16       0.0
   17   17       0.0
   18   18       0.0
   19   19       0.0
   20   20       0.0
   21   21       0.0
   22   22       0.0
   23   23       0.0
   24   24       0.0
   25   25       0.0
   26   26       0.0
   27   27       0.0
   28   28       0.0
   29   29       0.0
   30   30       0.0
   31   31       0.0
   32   32       0.0
   33   33       0.0
   34   34       0.0
   35   35       0.0
   36   36       0.0
   37   37       0.0
   38   38       0.0
   39   39       0.0
   40   40       0.0
   41   41       0.0
   42   42       0.0
   43   43       0.0
   44   44       0.0
   45   45       0.0
   46   46       0.0
   47   47       0.0
```

48	48	0.0
49	49	0.0
50	50	0.0
51	51	0.0
52	52	0.0
53	53	0.0
54	54	0.0
55	55	0.0
56	56	0.0
57	57	0.0
58	58	0.0
59	59	0.0
60	60	0.0
61	61	0.0
62	62	0.0
63	63	0.0
64	64	0.0
65	65	0.0
66	66	0.0
67	67	0.0
68	68	0.0
69	69	0.0
70	70	0.0
71	71	0.0
72	72	0.0
73	73	0.0
74	74	0.0
75	75	0.0
76	76	0.0
77	77	0.0
78	78	0.0
79	79	0.0
80	80	0.0

```
|-----------------------------------------------------------|
|                VLEACH (Version 2.2, 1995)                 |
|                                                           |
|                           By:                             |
|        Varadhan Ravi and Jeffrey A. Johnson               |
|                 (USEPA Contractors)                       |
|        Center for Subsurface Modeling Support             |
|        Robert S. Kerr Environmental Research Laboratory   |
|        U.S. Environmental Protection Agency               |
|        P.O. Box 1198                                      |
|        Ada, OK 74820                                      |
|                                                           |
|        Based on the original VLEACH (version 1.0)         |
|        developed by CH2M Hill, Redding, California        |
|        for USEPA Region IX                                |
|-----------------------------------------------------------|

RMA 93-03 CPMSO Transport, First 100 years
  1 polygons.
Timestep =   0.10 years.  Simulation length =  100.00 years.
Printout every  50.00 years.  Vertical profile stored every 100.00 years.
Koc =       30.000   ml/g,       0.10594E-02cu.ft./g
Kh =      0.50000E-03 (dimensionless).
Aqueous solubility =      1100.0     mg/l,       31.149     g/cu.ft
Free air diffusion coefficient = .58000     sq. m/day,  2278.8     sq.ft./yr


Polygon    1
Polygon I
Polygon area =       1.0000    sq. ft.
 80 cells, each cell  0.250 ft. thick.
Soil Properties:
 Bulk density =      1.6000    g/ml,         45307.    g/cu.ft.
 Porosity = 0 4000 Volumetric water content = 0.2500
 Organic carbon content = 0.00500000
Recharge Rate = 0.00057000 ft/yr
Conc. in recharge water =      0.16000    mg/l,       0.45307E-02g/cu.ft
Atmospheric concentration =      -1.0000    mg/l,      -0.28317E-01g/cu.ft
Water table has a fixed concentration of      0.00000    mg/l,       0.00000     g/
   with respect to gas diffusion.
```

Time: 100.000 - CPMSO - 100 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.78971E-06	0.15794E-02	0.83664E-08
2	0.16834E-06	0.33668E-03	0.17834E-08
3	0.28081E-07	0.56163E-04	0.29750E-09
4	0.64397E-08	0.12879E-04	0.68224E-10
5	0.37517E-08	0.75033E-05	0.39747E-10
6	0.33210E-08	0.66421E-05	0.35184E-10
7	0.31138E-08	0.62277E-05	0.32989E-10
8	0.29341E-08	0.58683E-05	0.31085E-10
9	0.27658E-08	0.55315E-05	0.29301E-10
10	0.26071E-08	0.52142E-05	0.27621E-10
11	0.24576E-08	0.49151E-05	0.26036E-10
12	0.23166E-08	0.46331E-05	0.24542E-10
13	0.21837E-08	0.43673E-05	0.23134E-10
14	0.20584E-08	0.41167E-05	0.21807E-10
15	0.19402E-08	0.38805E-05	0.20556E-10
16	0.18289E-08	0.36578E-05	0.19376E-10
17	0.17239E-08	0.34479E-05	0.18264E-10
18	0.16250E-08	0.32499E-05	0.17215E-10
19	0.15317E-08	0.30633E-05	0.16227E-10
20	0.14437E-08	0.28875E-05	0.15295E-10
21	0.13608E-08	0.27216E-05	0.14417E-10
22	0.12826E-08	0.25653E-05	0.13589E-10
23	0.12090E-08	0.24179E-05	0.12808E-10
24	0.11395E-08	0.22789E-05	0.12072E-10
25	0.10740E-08	0.21479E-05	0.11378E-10
26	0.10122E-08	0.20244E-05	0.10724E-10
27	0.95399E-09	0.19080E-05	0.10107E-10
28	0.89909E-09	0.17982E-05	0.95253E-11
29	0.84733E-09	0.16947E-05	0.89769E-11
30	0.79853E-09	0.15971E-05	0.84599E-11
31	0.75251E-09	0.15050E-05	0.79723E-11
32	0.70911E-09	0.14182E-05	0.75126E-11
33	0.66819E-09	0.13364E-05	0.70791E-11
34	0.62960E-09	0.12592E-05	0.66702E-11
35	0.59321E-09	0.11864E-05	0.62847E-11
36	0.55889E-09	0.11178E-05	0.59210E-11
37	0.52651E-09	0.10530E-05	0.55781E-11
38	0.49598E-09	0.99195E-06	0.52545E-11
39	0.46717E-09	0.93434E-06	0.49494E-11
40	0.43999E-09	0.87999E-06	0.46614E-11
41	0.41435E-09	0.82871E-06	0.43898E-11
42	0.39016E-09	0.78032E-06	0.41335E-11
43	0.36732E-09	0.73465E-06	0.38916E-11
44	0.34577E-09	0.69154E-06	0.36632E-11
45	0.32543E-09	0.65085E-06	0.34477E-11
46	0.30622E-09	0.61243E-06	0.32442E-11
47	0.28807E-09	0.57615E-06	0.30520E-11
48	0.27094E-09	0.54188E-06	0.28704E-11
49	0.25475E-09	0.50949E-06	0.26989E-11
50	0.23945E-09	0.47889E-06	0.25368E-11
51	0.22498E-09	0.44996E-06	0.23835E-11
52	0.21130E-09	0.42259E-06	0.22386E-11
53	0.19835E-09	0.39671E-06	0.21014E-11

54	0.18610E-09	0.37220E-06	0.19716E-11
55	0.17450E-09	0.34900E-06	0.18487E-11
56	0.16351E-09	0.32701E-06	0.17322E-11
57	0.15308E-09	0.30617E-06	0.16218E-11
58	0.14320E-09	0.28639E-06	0.15171E-11
59	0.13381E-09	0.26762E-06	0.14176E-11
60	0.12489E-09	0.24977E-06	0.13231E-11
61	0.11640E-09	0.23280E-06	0.12332E-11
62	0.10832E-09	0.21664E-06	0.11476E-11
63	0.10062E-09	0.20124E-06	0.10660E-11
64	0.93270E-10	0.18654E-06	0.98813E-12
65	0.86245E-10	0.17249E-06	0.91371E-12
66	0.79522E-10	0.15904E-06	0.84248E-12
67	0.73076E-10	0.14615E-06	0.77419E-12
68	0.66885E-10	0.13377E-06	0.70860E-12
69	0.60927E-10	0.12185E-06	0.64548E-12
70	0.55182E-10	0.11036E-06	0.58462E-12
71	0.49630E-10	0.99260E-07	0.52580E-12
72	0.44251E-10	0.88502E-07	0.46881E-12
73	0.39026E-10	0.78053E-07	0.41346E-12
74	0.33938E-10	0.67876E-07	0.35955E-12
75	0.28968E-10	0.57936E-07	0.30689E-12
76	0.24099E-10	0.48197E-07	0.25531E-12
77	0.19314E-10	0.38628E-07	0.20462E-12
78	0.14596E-10	0.29193E-07	0.15464E-12
79	0.99296E-11	0.19859E-07	0.10520E-12
80	0.52976E-11	0.10595E-07	0.56124E-13

```
RMA 93-03 CPMSO Transport, 200 years
  1
       0.1       100.        50.        100.
      30.0      .0005      1100.        0.58
Polygon I
        1.       0.25     .00057         1.6        0.40         .25         .005
      .417        -1.   8.68E-07
   80y     100.0
    1    1  1.71E+01
    2    2  3.64E+00
    3    3  6.07E-01
    4    4  1.39E-01
    5    5  8.12E-02
    6    6  7.18E-02
    7    7  6.74E-02
    8    8  6.35E-02
    9    9  5.98E-02
   10   10  5.64E-02
   11   11  5.32E-02
   12   12  5.01E-02
   13   13  4.72E-02
   14   14  4.45E-02
   15   15  4.20E-02
   16   16  3.96E-02
   17   17  3.73E-02
   18   18  3.51E-02
   19   19  3.31E-02
   20   20  3.12E-02
   21   21  2.94E-02
   22   22  2.77E-02
   23   23  2.62E-02
   24   24  2.46E-02
   25   25  2.32E-02
   26   26  2.19E-02
   27   27  2.06E-02
   28   28  1.94E-02
   29   29  1.83E-02
   30   30  1.73E-02
   31   31  1.63E-02
   32   32  1.53E-02
   33   33  1.45E-02
   34   34  1.36E-02
   35   35  1.28E-02
   36   36  1.21E-02
   37   37  1.14E-02
   38   38  1.07E-02
   39   39  1.01E-02
   40   40  9.52E-03
   41   41  8.96E-03
   42   42  8.44E-03
   43   43  7.95E-03
   44   44  7.48E-03
   45   45  7.04E-03
   46   46  6.62E-03
   47   47  6.23E-03
```

48	48	5.86E-03
49	49	5.51E-03
50	50	5.18E-03
51	51	4.87E-03
52	52	4.57E-03
53	53	4.29E-03
54	54	4.03E-03
55	55	3.77E-03
56	56	3.54E-03
57	57	3.31E-03
58	58	3.10E-03
59	59	2.89E-03
60	60	2.70E-03
61	61	2.52E-03
62	62	2.34E-03
63	63	2.18E-03
64	64	2.02E-03
65	65	1.87E-03
66	66	1.72E-03
67	67	1.58E-03
68	68	1.45E-03
69	69	1.32E-03
70	70	1.19E-03
71	71	1.07E-03
72	72	9.57E-04
73	73	8.44E-04
74	74	7.34E-04
75	75	6.27E-04
76	76	5.21E-04
77	77	4.18E-04
78	78	3.16E-04
79	79	2.15E-04
80	80	1.15E-04

Time: 100.000 - CPMSO - 200 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.24905E-05	0.49810E-02	0.26385E-07
2	0.73503E-06	0.14701E-02	0.77872E-08
3	0.18396E-06	0.36792E-03	0.19489E-08
4	0.51260E-07	0.10252E-03	0.54307E-09
5	0.24034E-07	0.48068E-04	0.25462E-09
6	0.18535E-07	0.37071E-04	0.19637E-09
7	0.16880E-07	0.33760E-04	0.17883E-09
8	0.15850E-07	0.31699E-04	0.16792E-09
9	0.14946E-07	0.29892E-04	0.15834E-09
10	0.14103E-07	0.28205E-04	0.14941E-09
11	0.13309E-07	0.26617E-04	0.14100E-09
12	0.12558E-07	0.25115E-04	0.13304E-09
13	0.11848E-07	0.23697E-04	0.12553E-09
14	0.11180E-07	0.22360E-04	0.11845E-09
15	0.10551E-07	0.21102E-04	0.11178E-09
16	0.99568E-08	0.19914E-04	0.10549E-09
17	0.93948E-08	0.18790E-04	0.99531E-10
18	0.88630E-08	0.17726E-04	0.93898E-10
19	0.83626E-08	0.16725E-04	0.88596E-10
20	0.78906E-08	0.15781E-04	0.83596E-10
21	0.74450E-08	0.14890E-04	0.78875E-10
22	0.70243E-08	0.14049E-04	0.74418E-10
23	0.66297E-08	0.13259E-04	0.70238E-10
24	0.62539E-08	0.12508E-04	0.66256E-10
25	0.59000E-08	0.11800E-04	0.62507E-10
26	0.55673E-08	0.11135E-04	0.58982E-10
27	0.52519E-08	0.10504E-04	0.55640E-10
28	0.49540E-08	0.99080E-05	0.52484E-10
29	0.46738E-08	0.93475E-05	0.49515E-10
30	0.44106E-08	0.88212E-05	0.46727E-10
31	0.41612E-08	0.83225E-05	0.44086E-10
32	0.39239E-08	0.78478E-05	0.41571E-10
33	0.37026E-08	0.74052E-05	0.39227E-10
34	0.34916E-08	0.69831E-05	0.36991E-10
35	0.32922E-08	0.65844E-05	0.34879E-10
36	0.31056E-08	0.62111E-05	0.32901E-10
37	0.29291E-08	0.58581E-05	0.31031E-10
38	0.27611E-08	0.55222E-05	0.29252E-10
39	0.26034E-08	0.52069E-05	0.27582E-10
40	0.24548E-08	0.49095E-05	0.26007E-10
41	0.23140E-08	0.46280E-05	0.24515E-10
42	0.21811E-08	0.43622E-05	0.23107E-10
43	0.20556E-08	0.41111E-05	0.21777E-10
44	0.19368E-08	0.38737E-05	0.20519E-10
45	0.18246E-08	0.36492E-05	0.19331E-10
46	0.17185E-08	0.34369E-05	0.18206E-10
47	0.16182E-08	0.32364E-05	0.17144E-10
48	0.15234E-08	0.30469E-05	0.16140E-10
49	0.14338E-08	0.28676E-05	0.15190E-10
50	0.13490E-08	0.26979E-05	0.14291E-10
51	0.12688E-08	0.25375E-05	0.13442E-10
52	0.11927E-08	0.23853E-05	0.12635E-10
53	0.11206E-08	0.22412E-05	0.11872E-10

54	0.10525E-08	0.21050E-05	0.11150E-10
55	0.98763E-09	0.19753E-05	0.10463E-10
56	0.92637E-09	0.18527E-05	0.98143E-11
57	0.86808E-09	0.17362E-05	0.91967E-11
58	0.81282E-09	0.16256E-05	0.86113E-11
59	0.76010E-09	0.15202E-05	0.80528E-11
60	0.71009E-09	0.14202E-05	0.75229E-11
61	0.66256E-09	0.13251E-05	0.70194E-11
62	0.61708E-09	0.12342E-05	0.65376E-11
63	0.57388E-09	0.11478E-05	0.60799E-11
64	0.53254E-09	0.10651E-05	0.56419E-11
65	0.49300E-09	0.98600E-06	0.52230E-11
66	0.45498E-09	0.90995E-06	0.48202E-11
67	0.41852E-09	0.83703E-06	0.44339E-11
68	0.38361E-09	0.76722E-06	0.40641E-11
69	0.34993E-09	0.69985E-06	0.37072E-11
70	0.31726E-09	0.63453E-06	0.33612E-11
71	0.28575E-09	0.57150E-06	0.30273E-11
72	0.25533E-09	0.51067E-06	0.27051E-11
73	0.22574E-09	0.45149E-06	0.23916E-11
74	0.19689E-09	0.39378E-06	0.20859E-11
75	0.16870E-09	0.33740E-06	0.17873E-11
76	0.14106E-09	0.28211E-06	0.14944E-11
77	0.11390E-09	0.22780E-06	0.12067E-11
78	0.87130E-10	0.17426E-06	0.92309E-12
79	0.60646E-10	0.12129E-06	0.64250E-12
80	0.34369E-10	0.68737E-07	0.36411E-12

```
RMA 93-03 CPMSO Transport, 300 years
  1
       0.1       100.        50.       100.
      30.0      .0005      1100.       0.58
Polygon I
        1.       0.25     .00057       1.6       0.40       .25       .005
      .533        -1.   5.23E-06
   80y       100.0
    1    1  5.39E+01
    2    2  1.59E+01
    3    3  3.98E+00
    4    4  1.11E+00
    5    5  5.20E-01
    6    6  4.01E-01
    7    7  3.65E-01
    8    8  3.43E-01
    9    9  3.23E-01
   10   10  3.05E-01
   11   11  2.88E-01
   12   12  2.72E-01
   13   13  2.56E-01
   14   14  2.42E-01
   15   15  2.28E-01
   16   16  2.15E-01
   17   17  2.03E-01
   18   18  1.92E-01
   19   19  1.81E-01
   20   20  1.71E-01
   21   21  1.61E-01
   22   22  1.52E-01
   23   23  1.43E-01
   24   24  1.35E-01
   25   25  1.28E-01
   26   26  1.20E-01
   27   27  1.14E-01
   28   28  1.07E-01
   29   29  1.01E-01
   30   30  9.54E-02
   31   31  9.00E-02
   32   32  8.49E-02
   33   33  8.01E-02
   34   34  7.55E-02
   35   35  7.12E-02
   36   36  6.72E-02
   37   37  6.34E-02
   38   38  5.97E-02
   39   39  5.63E-02
   40   40  5.31E-02
   41   41  5.01E-02
   42   42  4.72E-02
   43   43  4.45E-02
   44   44  4.19E-02
   45   45  3.95E-02
   46   46  3.72E-02
   47   47  3.50E-02
```

48	48	3.30E-02
49	49	3.10E-02
50	50	2.92E-02
51	51	2.74E-02
52	52	2.58E-02
53	53	2.42E-02
54	54	2.28E-02
55	55	2.14E-02
56	56	2.00E-02
57	57	1.88E-02
58	58	1.76E-02
59	59	1.64E-02
60	60	1.54E-02
61	61	1.43E-02
62	62	1.33E-02
63	63	1.24E-02
64	64	1.15E-02
65	65	1.07E-02
66	66	9.84E-03
67	67	9.05E-03
68	68	8.30E-03
69	69	7.57E-03
70	70	6.86E-03
71	71	6.18E-03
72	72	5.52E-03
73	73	4.88E-03
74	74	4.26E-03
75	75	3.65E-03
76	76	3.05E-03
77	77	2.46E-03
78	78	1.88E-03
79	79	1.31E-03
80	80	7.43E-04

Time: 100.000 - CPMSO - 300 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.39958E-05	0.79916E-02	0.42333E-07
2	0.16078E-05	0.32156E-02	0.17034E-07
3	0.54832E-06	0.10966E-02	0.58091E-08
4	0.18551E-06	0.37101E-03	0.19653E-08
5	0.81875E-07	0.16375E-03	0.86741E-09
6	0.55045E-07	0.11009E-03	0.58317E-09
7	0.47360E-07	0.94720E-04	0.50175E-09
8	0.43894E-07	0.87789E-04	0.46503E-09
9	0.41319E-07	0.82639E-04	0.43775E-09
10	0.39016E-07	0.78032E-04	0.41335E-09
11	0.36863E-07	0.73727E-04	0.39054E-09
12	0.34834E-07	0.69668E-04	0.36905E-09
13	0.32895E-07	0.65791E-04	0.34850E-09
14	0.31081E-07	0.62161E-04	0.32928E-09
15	0.29357E-07	0.58713E-04	0.31101E-09
16	0.27726E-07	0.55453E-04	0.29374E-09
17	0.26194E-07	0.52387E-04	0.27750E-09
18	0.24757E-07	0.49513E-04	0.26228E-09
19	0.23388E-07	0.46776E-04	0.24778E-09
20	0.22098E-07	0.44197E-04	0.23412E-09
21	0.20869E-07	0.41737E-04	0.22109E-09
22	0.19712E-07	0.39423E-04	0.20883E-09
23	0.18610E-07	0.37219E-04	0.19716E-09
24	0.17576E-07	0.35152E-04	0.18620E-09
25	0.16617E-07	0.33234E-04	0.17605E-09
26	0.15684E-07	0.31368E-04	0.16616E-09
27	0.14826E-07	0.29652E-04	0.15707E-09
28	0.13997E-07	0.27994E-04	0.14829E-09
29	0.13216E-07	0.26433E-04	0.14002E-09
30	0.12484E-07	0.24969E-04	0.13226E-09
31	0.11792E-07	0.23583E-04	0.12493E-09
32	0.11136E-07	0.22272E-04	0.11798E-09
33	0.10516E-07	0.21033E-04	0.11141E-09
34	0.99291E-08	0.19858E-04	0.10519E-09
35	0.93743E-08	0.18749E-04	0.99315E-10
36	0.88517E-08	0.17703E-04	0.93778E-10
37	0.83578E-08	0.16716E-04	0.88546E-10
38	0.78881E-08	0.15776E-04	0.83569E-10
39	0.74449E-08	0.14890E-04	0.78874E-10
40	0.70269E-08	0.14054E-04	0.74446E-10
41	0.66325E-08	0.13265E-04	0.70267E-10
42	0.62582E-08	0.12516E-04	0.66302E-10
43	0.59044E-08	0.11809E-04	0.62553E-10
44	0.55688E-08	0.11138E-04	0.58998E-10
45	0.52522E-08	0.10504E-04	0.55643E-10
46	0.49523E-08	0.99046E-05	0.52466E-10
47	0.46676E-08	0.93351E-05	0.49450E-10
48	0.43996E-08	0.87993E-05	0.46611E-10
49	0.41440E-08	0.82881E-05	0.43903E-10
50	0.39032E-08	0.78063E-05	0.41351E-10
51	0.36733E-08	0.73466E-05	0.38916E-10
52	0.34571E-08	0.69143E-05	0.36626E-10
53	0.32510E-08	0.65020E-05	0.34442E-10

54	0.30576E-08	0.61152E-05	0.32393E-10
55	0.28733E-08	0.57467E-05	0.30441E-10
56	0.26960E-08	0.53920E-05	0.28562E-10
57	0.25297E-08	0.50594E-05	0.26800E-10
58	0.23713E-08	0.47426E-05	0.25123E-10
59	0.22188E-08	0.44375E-05	0.23506E-10
60	0.20762E-08	0.41523E-05	0.21996E-10
61	0.19380E-08	0.38760E-05	0.20532E-10
62	0.18060E-08	0.36121E-05	0.19134E-10
63	0.16815E-08	0.33631E-05	0.17815E-10
64	0.15622E-08	0.31243E-05	0.16550E-10
65	0.14491E-08	0.28981E-05	0.15352E-10
66	0.13389E-08	0.26778E-05	0.14185E-10
67	0.12330E-08	0.24660E-05	0.13063E-10
68	0.11315E-08	0.22631E-05	0.11988E-10
69	0.10337E-08	0.20674E-05	0.10952E-10
70	0.93905E-09	0.18781E-05	0.99486E-11
71	0.84751E-09	0.16950E-05	0.89788E-11
72	0.75876E-09	0.15175E-05	0.80386E-11
73	0.67251E-09	0.13450E-05	0.71248E-11
74	0.58854E-09	0.11771E-05	0.62352E-11
75	0.50642E-09	0.10128E-05	0.53651E-11
76	0.42583E-09	0.85166E-06	0.45114E-11
77	0.34658E-09	0.69315E-06	0.36717E-11
78	0.26847E-09	0.53695E-06	0.28443E-11
79	0.19135E-09	0.38270E-06	0.20272E-11
80	0.11485E-09	0.22970E-06	0.12168E-11

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RMA 93-03 CPMSO Transport, 400 years
  1
       0.1       100.        50.       100.
      30.0      .0005      1100.       0.58
Polygon I
        1.       0.25     .00057        1.6        0.40         .25        .005
      .600        -1.   1.63E-05
   80y      100.0
    1    1  8.64E+01
    2    2  3.48E+01
    3    3  1.19E+01
    4    4  4.01E+00
    5    5  1.77E+00
    6    6  1.19E+00
    7    7  1.02E+00
    8    8  9.49E-01
    9    9  8.94E-01
   10   10  8.44E-01
   11   11  7.97E-01
   12   12  7.53E-01
   13   13  7.12E-01
   14   14  6.72E-01
   15   15  6.35E-01
   16   16  6.00E-01
   17   17  5.67E-01
   18   18  5.36E-01
   19   19  5.06E-01
   20   20  4.78E-01
   21   21  4.51E-01
   22   22  4.26E-01
   23   23  4.03E-01
   24   24  3.80E-01
   25   25  3.59E-01
   26   26  3.39E-01
   27   27  3.21E-01
   28   28  3.03E-01
   29   29  2.86E-01
   30   30  2.70E-01
   31   31  2.55E-01
   32   32  2.41E-01
   33   33  2.27E-01
   34   34  2.15E-01
   35   35  2.03E-01
   36   36  1.91E-01
   37   37  1.81E-01
   38   38  1.71E-01
   39   39  1.61E-01
   40   40  1.52E-01
   41   41  1.43E-01
   42   42  1.35E-01
   43   43  1.28E-01
   44   44  1.20E-01
   45   45  1.14E-01
   46   46  1.07E-01
   47   47  1.01E-01
```

48	48	9.52E-02
49	49	8.96E-02
50	50	8.44E-02
51	51	7.95E-02
52	52	7.48E-02
53	53	7.03E-02
54	54	6.61E-02
55	55	6.22E-02
56	56	5.83E-02
57	57	5.47E-02
58	58	5.13E-02
59	59	4.80E-02
60	60	4.49E-02
61	61	4.19E-02
62	62	3.91E-02
63	63	3.64E-02
64	64	3.38E-02
65	65	3.13E-02
66	66	2.90E-02
67	67	2.67E-02
68	68	2.45E-02
69	69	2.24E-02
70	70	2.03E-02
71	71	1.83E-02
72	72	1.64E-02
73	73	1.45E-02
74	74	1.27E-02
75	75	1.10E-02
76	76	9.21E-03
77	77	7.50E-03
78	78	5.81E-03
79	79	4.14E-03
80	80	2.48E-03

Time: 100.000 - CPMSO - 400 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.51553E-05	0.10311E-01	0.54617E-07
2	0.25486E-05	0.50972E-02	0.27001E-07
3	0.10867E-05	0.21735E-02	0.11513E-07
4	0.43862E-06	0.87725E-03	0.46469E-08
5	0.19985E-06	0.39969E-03	0.21172E-08
6	0.12255E-06	0.24511E-03	0.12984E-08
7	0.97974E-07	0.19595E-03	0.10380E-08
8	0.88483E-07	0.17697E-03	0.93742E-09
9	0.82840E-07	0.16568E-03	0.87763E-09
10	0.78195E-07	0.15639E-03	0.82842E-09
11	0.73927E-07	0.14785E-03	0.78321E-09
12	0.69920E-07	0.13984E-03	0.74076E-09
13	0.66151E-07	0.13230E-03	0.70082E-09
14	0.62561E-07	0.12512E-03	0.66279E-09
15	0.59172E-07	0.11834E-03	0.62689E-09
16	0.55971E-07	0.11194E-03	0.59298E-09
17	0.52946E-07	0.10589E-03	0.56093E-09
18	0.50089E-07	0.10018E-03	0.53066E-09
19	0.47371E-07	0.94741E-04	0.50186E-09
20	0.44800E-07	0.89600E-04	0.47463E-09
21	0.42357E-07	0.84713E-04	0.44874E-09
22	0.40052E-07	0.80104E-04	0.42433E-09
23	0.37892E-07	0.75784E-04	0.40144E-09
24	0.35825E-07	0.71650E-04	0.37954E-09
25	0.33875E-07	0.67750E-04	0.35888E-09
26	0.32031E-07	0.64062E-04	0.33935E-09
27	0.30309E-07	0.60618E-04	0.32110E-09
28	0.28665E-07	0.57330E-04	0.30369E-09
29	0.27100E-07	0.54201E-04	0.28711E-09
30	0.25620E-07	0.51239E-04	0.27142E-09
31	0.24222E-07	0.48444E-04	0.25662E-09
32	0.22905E-07	0.45810E-04	0.24266E-09
33	0.21642E-07	0.43285E-04	0.22929E-09
34	0.20470E-07	0.40939E-04	0.21686E-09
35	0.19356E-07	0.38711E-04	0.20506E-09
36	0.18280E-07	0.36560E-04	0.19367E-09
37	0.17287E-07	0.34574E-04	0.18314E-09
38	0.16347E-07	0.32694E-04	0.17318E-09
39	0.15440E-07	0.30880E-04	0.16358E-09
40	0.14586E-07	0.29172E-04	0.15453E-09
41	0.13768E-07	0.27537E-04	0.14587E-09
42	0.13002E-07	0.26005E-04	0.13775E-09
43	0.12296E-07	0.24591E-04	0.13027E-09
44	0.11600E-07	0.23200E-04	0.12289E-09
45	0.10965E-07	0.21931E-04	0.11617E-09
46	0.10346E-07	0.20692E-04	0.10961E-09
47	0.97631E-08	0.19526E-04	0.10343E-09
48	0.92117E-08	0.18423E-04	0.97592E-10
49	0.86860E-08	0.17372E-04	0.92022E-10
50	0.81886E-08	0.16377E-04	0.86753E-10
51	0.77183E-08	0.15437E-04	0.81770E-10
52	0.72711E-08	0.14542E-04	0.77032E-10
53	0.68448E-08	0.13690E-04	0.72516E-10

54	0.64410E-08	0.12882E-04	0.68239E-10
55	0.60601E-08	0.12120E-04	0.64203E-10
56	0.56941E-08	0.11388E-04	0.60326E-10
57	0.53466E-08	0.10693E-04	0.56643E-10
58	0.50170E-08	0.10034E-04	0.53151E-10
59	0.47018E-08	0.94036E-05	0.49813E-10
60	0.44017E-08	0.88034E-05	0.46633E-10
61	0.41145E-08	0.82290E-05	0.43590E-10
62	0.38412E-08	0.76825E-05	0.40695E-10
63	0.35799E-08	0.71598E-05	0.37927E-10
64	0.33291E-08	0.66582E-05	0.35270E-10
65	0.30882E-08	0.61763E-05	0.32717E-10
66	0.28591E-08	0.57182E-05	0.30290E-10
67	0.26377E-08	0.52754E-05	0.27945E-10
68	0.24240E-08	0.48481E-05	0.25681E-10
69	0.22183E-08	0.44367E-05	0.23502E-10
70	0.20180E-08	0.40360E-05	0.21379E-10
71	0.18240E-08	0.36479E-05	0.19324E-10
72	0.16368E-08	0.32737E-05	0.17341E-10
73	0.14540E-08	0.29080E-05	0.15404E-10
74	0.12765E-08	0.25530E-05	0.13524E-10
75	0.11050E-08	0.22099E-05	0.11706E-10
76	0.93449E-09	0.18690E-05	0.99003E-11
77	0.76690E-09	0.15338E-05	0.81248E-11
78	0.60185E-09	0.12037E-05	0.63762E-11
79	0.43872E-09	0.87744E-06	0.46480E-11
80	0.27688E-09	0.55376E-06	0.29333E-11

```
RMA 93-03 CPMSO Transport, 500 years
  1
      0.1       100.         50.       100.
     30.0      .0005       1100.       0.58
Polygon I
       1.       0.25      .00057        1.6       0 40        .25        .005
     .645        -1.    3.68E-05
   80y      100.0
    1    1   1.12E+02
    2    2   5.51E+01
    3    3   2.35E+01
    4    4   9.49E+00
    5    5   4.32E+00
    6    6   2.65E+00
    7    7   2.12E+00
    8    8   1.91E+00
    9    9   1.79E+00
   10   10   1.69E+00
   11   11   1.60E+00
   12   12   1.51E+00
   13   13   1.43E+00
   14   14   1.35E+00
   15   15   1.28E+00
   16   16   1.21E+00
   17   17   1.15E+00
   18   18   1.08E+00
   19   19   1.02E+00
   20   20   9.69E-01
   21   21   9.16E-01
   22   22   8.66E-01
   23   23   8.20E-01
   24   24   7.75E-01
   25   25   7.33E-01
   26   26   6.93E-01
   27   27   6.56E-01
   28   28   6.20E-01
   29   29   5.86E-01
   30   30   5.54E-01
   31   31   5.24E-01
   32   32   4.95E-01
   33   33   4.68E-01
   34   34   4.43E-01
   35   35   4.19E-01
   36   36   3.95E-01
   37   37   3.74E-01
   38   38   3.54E-01
   39   39   3.34E-01
   40   40   3.16E-01
   41   41   2.98E-01
   42   42   2.81E-01
   43   43   2.66E-01
   44   44   2.51E-01
   45   45   2.37E-01
   46   46   2.24E-01
   47   47   2.11E-01
```

48	48	1.99E-01
49	49	1.88E-01
50	50	1.77E-01
51	51	1.67E-01
52	52	1.57E-01
53	53	1.48E-01
54	54	1.39E-01
55	55	1.31E-01
56	56	1.23E-01
57	57	1.16E-01
58	58	1.09E-01
59	59	1.02E-01
60	60	9.52E-02
61	61	8.90E-02
62	62	8.31E-02
63	63	7.74E-02
64	64	7.20E-02
65	65	6.68E-02
66	66	6.18E-02
67	67	5.71E-02
68	68	5.24E-02
69	69	4.80E-02
70	70	4.37E-02
71	71	3.95E-02
72	72	3.54E-02
73	73	3.15E-02
74	74	2.76E-02
75	75	2.39E-02
76	76	2.02E-02
77	77	1.66E-02
78	78	1.30E-02
79	79	9.49E-03
80	80	5.99E-03

Time: 100.000 - CPMSO - 500 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.60355E-05	0.12071E-01	0.63942E-07
2	0.34226E-05	0.68452E-02	0.36260E-07
3	0.17122E-05	0.34245E-02	0.18140E-07
4	0.80038E-06	0.16008E-02	0.84795E-08
5	0.39152E-06	0.78304E-03	0.41479E-08
6	0.23169E-06	0.46337E-03	0.24546E-08
7	0.17354E-06	0.34708E-03	0.18385E-08
8	0.15089E-06	0.30178E-03	0.15986E-08
9	0.13944E-06	0.27888E-03	0.14773E-08
10	0.13127E-06	0.26254E-03	0.13907E-08
11	0.12421E-06	0.24842E-03	0.13159E-08
12	0.11754E-06	0.23509E-03	0.12453E-08
13	0.11132E-06	0.22265E-03	0.11794E-08
14	0.10537E-06	0.21075E-03	0.11164E-08
15	0.99843E-07	0.19969E-03	0.10578E-08
16	0.94564E-07	0.18913E-03	0.10018E-08
17	0.89689E-07	0.17938E-03	0.95020E-09
18	0.84805E-07	0.16961E-03	0.89846E-09
19	0.80196E-07	0.16039E-03	0.84962E-09
20	0.76012E-07	0.15202E-03	0.80530E-09
21	0.72009E-07	0.14402E-03	0.76289E-09
22	0.68183E-07	0.13637E-03	0.72235E-09
23	0.64582E-07	0.12916E-03	0 68421E-09
24	0.61148E-07	0.12230E-03	0 64782E-09
25	0.57896E-07	0.11579E-03	0 61337E-09
26	0.54811E-07	0.10962E-03	0 58068E-09
27	0.51908E-07	0.10382E-03	0.54993E-09
28	0.49142E-07	0.98283E-04	0 52062E-09
29	0.46514E-07	0.93027E-04	0 49278E-09
30	0.44026E-07	0.88052E-04	0 46643E-09
31	0.41678E-07	0.83357E-04	0.44156E-09
32	0.39442E-07	0.78884E-04	0 41786E-09
33	0.37328E-07	0.74657E-04	0 39547E-09
34	0.35343E-07	0.70685E-04	0 37443E-09
35	0.33460E-07	0.66920E-04	0 35448E-09
36	0.31641E-07	0.63282E-04	0.33522E-09
37	0 29945E-07	0.59890E-04	0 31725E-09
38	0.28350E-07	0.56701E-04	0 30035E-09
39	0.26815E-07	0.53630E-04	0 28409E-09
40	0.25371E-07	0.50742E-04	0 26879E-09
41	0.23986E-07	0.47972E-04	0.25411E-09
42	0.22665E-07	0.45330E-04	0.24012E-09
43	0.21438E-07	0.42875E-04	0.22712E-09
44	0.20267E-07	0.40534E-04	0 21471E-09
45	0.19155E-07	0.38310E-04	0 20293E-09
46	0.18108E-07	0 36215E-04	0 19184E-09
47	0.17100E-07	0.34200E-04	0 18116E-09
48	0.16145E-07	0.32289E-04	0 17104E-09
49	0.15249E-07	0.30498E-04	0 16155E-09
50	0.14389E-07	0.28779E-04	0 15245E-09
51	0.13578E-07	0.27156E-04	0 14385E-09
52	0.12798E-07	0.25597E-04	0.13559E-09
53	0.12064E-07	0.24128E-04	0 12781E-09

54	0.11359E-07	0.22719E-04	0.12034E-09
55	0.10698E-07	0.21397E-04	0.11334E-09
56	0.10065E-07	0.20129E-04	0.10663E-09
57	0.94728E-08	0.18946E-04	0.10036E-09
58	0.89066E-08	0.17813E-04	0.94359E-10
59	0.83558E-08	0.16712E-04	0.88524E-10
60	0.78223E-08	0.15645E-04	0.82872E-10
61	0.73174E-08	0.14635E-04	0.77523E-10
62	0.68379E-08	0.13676E-04	0.72443E-10
63	0.63783E-08	0.12757E-04	0.67574E-10
64	0.59388E-08	0.11878E-04	0.62917E-10
65	0.55169E-08	0.11034E-04	0.58448E-10
66	0.51111E-08	0.10222E-04	0.54149E-10
67	0.47232E-08	0.94464E-05	0.50039E-10
68	0.43461E-08	0.86922E-05	0.46044E-10
69	0.39836E-08	0.79673E-05	0.42204E-10
70	0.36330E-08	0.72660E-05	0.38489E-10
71	0.32920E-08	0.65840E-05	0.34876E-10
72	0.29597E-08	0.59194E-05	0.31356E-10
73	0.26381E-08	0.52763E-05	0.27949E-10
74	0.23229E-08	0.46459E-05	0.24610E-10
75	0.20166E-08	0.40332E-05	0.21365E-10
76	0.17155E-08	0.34310E-05	0.18175E-10
77	0.14199E-08	0.28397E-05	0.15043E-10
78	0.11274E-08	0.22548E-05	0.11944E-10
79	0.83901E-09	0.16780E-05	0.88888E-11
80	0.55305E-09	0.11061E-05	0.58592E-11

```
RMA 93-03 CPMSO Transport, 600 years
  1
      0.1       100.        50.       100.
     30.0      .0005      1100.       0.58
Polygon I
       1.       0.25     .00057        1.6       0.40        .25       .005
     .678        -1.   6.95E-05
   80y      100.0
    1    1  1.31E+02
    2    2  7.40E+01
    3    3  3.70E+01
    4    4  1.73E+01
    5    5  8.47E+00
    6    6  5.01E+00
    7    7  3.75E+00
    8    8  3.26E+00
    9    9  3.02E+00
   10   10  2.84E+00
   11   11  2.69E+00
   12   12  2.54E+00
   13   13  2.41E+00
   14   14  2.28E+00
   15   15  2.16E+00
   16   16  2.05E+00
   17   17  1.94E+00
   18   18  1.83E+00
   19   19  1.73E+00
   20   20  1.64E+00
   21   21  1.56E+00
   22   22  1.47E+00
   23   23  1.40E+00
   24   24  1.32E+00
   25   25  1.25E+00
   26   26  1.19E+00
   27   27  1.12E+00
   28   28  1.06E+00
   29   29  1.01E+00
   30   30  9.52E-01
   31   31  9.02E-01
   32   32  8.53E-01
   33   33  8.07E-01
   34   34  7.64E-01
   35   35  7.24E-01
   36   36  6.84E-01
   37   37  6.48E-01
   38   38  6.13E-01
   39   39  5.80E-01
   40   40  5.49E-01
   41   41  5.19E-01
   42   42  4.90E-01
   43   43  4.64E-01
   44   44  4.38E-01
   45   45  4.14E-01
   46   46  3.92E-01
   47   47  3.70E-01
```

48	48	3.49E-01
49	49	3.30E-01
50	50	3.11E-01
51	51	2.94E-01
52	52	2.77E-01
53	53	2.61E-01
54	54	2.46E-01
55	55	2.31E-01
56	56	2.18E-01
57	57	2.05E-01
58	58	1.93E-01
59	59	1.81E-01
60	60	1.69E-01
61	61	1.58E-01
62	62	1.48E-01
63	63	1.38E-01
64	64	1.28E-01
65	65	1.19E-01
66	66	1.11E-01
67	67	1.02E-01
68	68	9.40E-02
69	69	8.62E-02
70	70	7.86E-02
71	71	7.12E-02
72	72	6.40E-02
73	73	5.71E-02
74	74	5.02E-02
75	75	4.36E-02
76	76	3.71E-02
77	77	3.07E-02
78	78	2.44E-02
79	79	1.81E-02
80	80	1.20E-02

Time: 100.000 - CPMSO - 600 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.66921E-05	0.13384E-01	0.70899E-07
2	0.41729E-05	0.83457E-02	0.44209E-07
3	0.23493E-05	0.46985E-02	0 24889E-07
4	0.12357E-05	0.24713E-02	0.13091E-07
5	0.65458E-06	0.13092E-02	0.69349E-08
6	0.38918E-06	0.77836E-03	0.41231E-08
7	0.27860E-06	0.55719E-03	0 29516E-08
8	0.23288E-06	0.46576E-03	0.24672E-08
9	0.21133E-06	0.42267E-03	0.22390E-08
10	0.19772E-06	0.39544E-03	0 20947E-08
11	0.18689E-06	0.37378E-03	0.19800E-08
12	0.17693E-06	0.35386E-03	0.18745E-08
13	0.16778E-06	0.33556E-03	0.17775E-08
14	0.15906E-06	0.31812E-03	0.16852E-08
15	0.15082E-06	0.30164E-03	0 15979E-08
16	0.14312E-06	0.28624E-03	0.15163E-08
17	0.13572E-06	0.27144E-03	0.14378E-08
18	0.12850E-06	0.25699E-03	0 13613E-08
19	0.12167E-06	0.24334E-03	0 12890E-08
20	0.11535E-06	0.23069E-03	0.12220E-08
21	0.10954E-06	0.21908E-03	0.11605E-08
22	0.10376E-06	0.20751E-03	0.10992E-08
23	0.98499E-07	0.19700E-03	0.10435E-08
24	0.93313E-07	0.18663E-03	0.98859E-09
25	0.88416E-07	0.17683E-03	0.93670E-09
26	0.83963E-07	0.16793E-03	0.88953E-09
27	0.79495E-07	0.15899E-03	0.84219E-09
28	0.75280E-07	0.15056E-03	0.79754E-09
29	0.71493E-07	0.14299E-03	0.75743E-09
30	0.67727E-07	0.13545E-03	0.71753E-09
31	0.64175E-07	0.12835E-03	0.67990E-09
32	0.60797E-07	0.12159E-03	0.64410E-09
33	0.57593E-07	0.11519E-03	0.61016E-09
34	0.54570E-07	0.10914E-03	0.57813E-09
35	0.51728E-07	0.10346E-03	0.54802E-09
36	0.48989E-07	0.97978E-04	0.51901E-09
37	0.46416E-07	0.92831E-04	0.49174E-09
38	0.43969E-07	0.87937E-04	0.46582E-09
39	0.41645E-07	0.83289E-04	0.44120E-09
40	0.39446E-07	0.78892E-04	0.41791E-09
41	0.37348E-07	0.74695E-04	0.39567E-09
42	0.35335E-07	0.70670E-04	0.37435E-09
43	0.33454E-07	0.66907E-04	0.35442E-09
44	0.31649E-07	0.63298E-04	0.33530E-09
45	0.29940E-07	0.59880E-04	0.31720E-09
46	0.28341E-07	0.56681E-04	0.30025E-09
47	0.26803E-07	0.53606E-04	0.28396E-09
48	0.25328E-07	0.50656E-04	0.26833E-09
49	0.23945E-07	0.47890E-04	0.25368E-09
50	0.22616E-07	0.45233E-04	0.23960E-09
51	0.21370E-07	0.42740E-04	0.22640E-09
52	0.20173E-07	0.40346E-04	0.21372E-09
53	0.19030E-07	0.38061E-04	0.20161E-09

54	0.17948E-07	0.35895E-04	0.19014E-09
55	0.16901E-07	0.33801E-04	0.17905E-09
56	0.15927E-07	0.31853E-04	0.16873E-09
57	0.14995E-07	0.29991E-04	0.15887E-09
58	0.14112E-07	0.28224E-04	0.14951E-09
59	0.13258E-07	0.26517E-04	0.14046E-09
60	0.12423E-07	0.24846E-04	0.13162E-09
61	0.11628E-07	0.23256E-04	0.12319E-09
62	0.10884E-07	0.21767E-04	0.11530E-09
63	0.10166E-07	0.20333E-04	0.10771E-09
64	0.94644E-08	0.18929E-04	0.10027E-09
65	0.87993E-08	0.17599E-04	0.93222E-10
66	0.81812E-08	0.16362E-04	0.86675E-10
67	0.75624E-08	0.15125E-04	0.80118E-10
68	0.69690E-08	0.13938E-04	0.73832E-10
69	0.63984E-08	0.12797E-04	0.67787E-10
70	0.58451E-08	0.11690E-04	0.61925E-10
71	0.53069E-08	0.10614E-04	0.56223E-10
72	0.47831E-08	0.95661E-05	0.50673E-10
73	0.42753E-08	0.85507E-05	0.45294E-10
74	0.37768E-08	0.75535E-05	0.40012E-10
75	0.32911E-08	0.65821E-05	0.34867E-10
76	0.28153E-08	0.56306E-05	0.29826E-10
77	0.23473E-08	0.46946E-05	0.24868E-10
78	0.18860E-08	0.37721E-05	0.19981E-10
79	0.14284E-08	0.28568E-05	0.15133E-10
80	0.97759E-09	0.19552E-05	0.10357E-10

```
RMA 93-03 CPMSO Transport, 700 years
  1
       0.1       100.        50.       100.
      30.0      .0005      1100.       0.58
Polygon I
        1.       0.25     .00057        1.6        0.40        .25        .005
      .703        -1.   1.17E 04
   80y      100.0
    1    1   1.45E+02
    2    2   9.03E+01
    3    3   5.08E+01
    4    4   2.67E+01
    5    5   1.42E+01
    6    6   8.42E+00
    7    7   6.03E+00
    8    8   5.04E+00
    9    9   4.57E+00
   10   10   4.28E+00
   11   11   4.04E+00
   12   12   3.83E+00
   13   13   3.63E+00
   14   14   3.44E+00
   15   15   3.26E+00
   16   16   3.10E+00
   17   17   2.94E+00
   18   18   2.78E+00
   19   19   2.63E+00
   20   20   2.50E+00
   21   21   2.37E+00
   22   22   2.24E+00
   23   23   2.13E+00
   24   24   2.02E+00
   25   25   1.91E+00
   26   26   1.82E+00
   27   27   1.72E+00
   28   28   1.63E+00
   29   29   1.55E+00
   30   30   1.46E+00
   31   31   1.39E+00
   32   32   1.32E+00
   33   33   1.25E+00
   34   34   1.18E+00
   35   35   1.12E+00
   36   36   1.06E+00
   37   37   1.00E+00
   38   38   9.51E-01
   39   39   9.01E-01
   40   40   8.53E-01
   41   41   8.08E-01
   42   42   7.64E-01
   43   43   7.24E-01
   44   44   6.85E-01
   45   45   6.48E-01
   46   46   6.13E-01
   47   47   5.80E-01
```

48	48	5.48E-01
49	49	5.18E-01
50	50	4.89E-01
51	51	4.62E-01
52	52	4.36E-01
53	53	4.12E-01
54	54	3.88E-01
55	55	3.66E-01
56	56	3.45E-01
57	57	3.24E-01
58	58	3.05E-01
59	59	2.87E-01
60	60	2.69E-01
61	61	2.52E-01
62	62	2.35E-01
63	63	2.20E-01
64	64	2.05E-01
65	65	1.90E-01
66	66	1.77E-01
67	67	1.64E-01
68	68	1.51E-01
69	69	1.38E-01
70	70	1.26E-01
71	71	1.15E-01
72	72	1.03E-01
73	73	9.25E-02
74	74	8.17E-02
75	75	7.12E-02
76	76	6.09E-02
77	77	5.08E-02
78	78	4 08E-02
79	79	3.09E-02
80	80	2.11E-02

Time: 100.000 - CPMSO - 700 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.71844E-05	0.14369E-01	0.76114E-07
2	0.47917E-05	0.95833E-02	0.50764E-07
3	0.29485E-05	0.58971E-02	0.31238E-07
4	0.17045E-05	0.34090E-02	0.18058E-07
5	0.97477E-06	0.19495E-02	0 10327E-07
6	0.59540E-06	0.11908E-02	0 63079E-08
7	0.41703E-06	0.83406E-03	0.44182E-08
8	0.33684E-06	0.67368E-03	0.35686E-08
9	0.29868E-06	0.59736E-03	0.31643E-08
10	0.27686E-06	0.55371E-03	0.29331E-08
11	0.26080E-06	0.52160E-03	0.27630E-08
12	0.24709E-06	0.49419E-03	0.26178E-08
13	0.23445E-06	0.46890E-03	0.24838E-08
14	0.22250E-06	0.44499E-03	0.23572E-08
15	0.21115E-06	0.42230E-03	0.22370E-08
16	0.20065E-06	0.40130E-03	0.21257E-08
17	0.19059E-06	0.38118E-03	0.20192E-08
18	0.18077E-06	0.36154E-03	0.19151E-08
19	0.17137E-06	0.34274E-03	0.18156E-08
20	0.16275E-06	0.32549E-03	0.17242E-08
21	0.15453E-06	0.30906E-03	0.16371E-08
22	0.14652E-06	0.29303E-03	0.15522E-08
23	0.13915E-06	0.27829E-03	0.14742E-08
24	0.13214E-06	0.26428E-03	0.13999E-08
25	0.12531E-06	0.25063E-03	0.13276E-08
26	0.11911E-06	0.23822E-03	0.12619E-08
27	0.11300E-06	0.22600E-03	0.11972E-08
28	0.10719E-06	0.21438E-03	0.11356E-08
29	0.10182E-06	0.20365E-03	0.10788E-08
30	0.96446E-07	0.19289E-03	0.10218E-08
31	0.91574E-07	0.18315E-03	0.97017E-09
32	0.86999E-07	0.17400E-03	0.92169E-09
33	0.82557E-07	0.16511E-03	0.87464E-09
34	0.78203E-07	0.15641E-03	0.82851E-09
35	0.74175E-07	0.14835E-03	0.78583E-09
36	0.70334E-07	0.14067E-03	0.74514E-09
37	0.66588E-07	0.13318E-03	0.70546E-09
38	0.63186E-07	0.12637E-03	0.66942E-09
39	0.59949E-07	0.11990E-03	0.63512E-09
40	0.56838E-07	0.11368E-03	0.60216E-09
41	0.53883E-07	0.10777E-03	0.57086E-09
42	0.51046E-07	0.10209E-03	0.54080E-09
43	0.48380E-07	0.96760E-04	0.51255E-09
44	0.45837E-07	0.91674E-04	0.48561E-09
45	0.43412E-07	0.86824E-04	0.45992E-09
46	0.41108E-07	0.82216E-04	0.43551E-09
47	0.38924E-07	0.77847E-04	0.41237E-09
48	0.36833E-07	0.73665E-04	0.39022E-09
49	0.34846E-07	0.69692E-04	0.36917E-09
50	0.32946E-07	0.65892E-04	0.34904E-09
51	0.31147E-07	0.62294E-04	0.32998E-09
52	0.29431E-07	0.58861E-04	0.31180E-09
53	0.27811E-07	0.55623E-04	0.29464E-09

54	0.26247E-07	0.52494E-04	0.27807E-09
55	0.24765E-07	0.49530E-04	0.26237E-09
56	0.23357E-07	0.46714E-04	0.24745E-09
57	0.21990E-07	0.43980E-04	0.23297E-09
58	0.20699E-07	0.41397E-04	0.21929E-09
59	0.19477E-07	0.38954E-04	0.20634E-09
60	0.18292E-07	0.36584E-04	0.19379E-09
61	0.17154E-07	0.34309E-04	0.18174E-09
62	0.16046E-07	0.32092E-04	0.17000E-09
63	0.15007E-07	0.30014E-04	0.15899E-09
64	0.14007E-07	0.28014E-04	0.14840E-09
65	0.13027E-07	0.26053E-04	0.13801E-09
66	0.12110E-07	0.24221E-04	0.12830E-09
67	0.11230E-07	0.22460E-04	0.11897E-09
68	0.10366E-07	0.20732E-04	0.10982E-09
69	0.95139E-08	0.19028E-04	0.10079E-09
70	0.86963E-08	0.17393E-04	0.92132E-10
71	0.79242E-08	0.15848E-04	0.83952E-10
72	0.71495E-08	0.14299E-04	0.75745E-10
73	0.64110E-08	0.12822E-04	0.67921E-10
74	0.56867E-08	0.11373E-04	0.60247E-10
75	0.49758E-08	0.99515E-05	0.52715E-10
76	0.42780E-08	0.85561E-05	0.45323E-10
77	0.35926E-08	0.71851E-05	0.38061E-10
78	0.29161E-08	0.58321E-05	0.30894E-10
79	0.22466E-08	0.44933E-05	0.23802E-10
80	0.15833E-08	0.31665E-05	0.16774E-10

```
RMA 93-03 CPMSO Transport, 800 years
  1
      0.1       100.       50.       100.
     30.0      .0005     1100.      0.58
Polygon I
       1.       0.25    .00057       1.6       0.40       .25       .005
     .723        -1.  1.83E-04
   80y      100.0
    1    1  1.55E+02
    2    2  1.04E+02
    3    3  6.38E+01
    4    4  3.69E+01
    5    5  2.11E+01
    6    6  1.29E+01
    7    7  9.02E+00
    8    8  7.29E+00
    9    9  6.46E+00
   10   10  5.99E+00
   11   11  5.64E+00
   12   12  5.34E+00
   13   13  5.07E+00
   14   14  4.81E+00
   15   15  4.57E+00
   16   16  4.34E+00
   17   17  4.12E+00
   18   18  3.91E+00
   19   19  3.71E+00
   20   20  3.52E+00
   21   21  3.34E+00
   22   22  3.17E+00
   23   23  3.01E+00
   24   24  2.86E+00
   25   25  2.71E+00
   26   26  2.58E+00
   27   27  2.44E+00
   28   28  2.32E+00
   29   29  2.20E+00
   30   30  2.09E+00
   31   31  1.98E+00
   32   32  1.88E+00
   33   33  1.79E+00
   34   34  1.69E+00
   35   35  1.60E+00
   36   36  1.52E+00
   37   37  1.44E+00
   38   38  1.37E+00
   39   39  1.30E+00
   40   40  1.23E+00
   41   41  1.17E+00
   42   42  1.10E+00
   43   43  1.05E+00
   44   44  9.91E-01
   45   45  9.39E-01
   46   46  8.89E-01
   47   47  8.42E-01
```

48	48	7.97E-01
49	49	7.54E-01
50	50	7.13E-01
51	51	6.74E-01
52	52	6.37E-01
53	53	6.02E-01
54	54	5.68E-01
55	55	5.36E-01
56	56	5.05E-01
57	57	4.76E-01
58	58	4.48E-01
59	59	4.21E-01
60	60	3.96E-01
61	61	3.71E-01
62	62	3.47E-01
63	63	3.25E-01
64	64	3.03E-01
65	65	2.82E-01
66	66	2.62E-01
67	67	2.43E-01
68	68	2.24E-01
69	69	2.06E-01
70	70	1.88E-01
71	71	1.71E-01
72	72	1.55E-01
73	73	1.39E-01
74	74	1.23E-01
75	75	1.08E-01
76	76	9.25E-02
77	77	7.77E-02
78	78	6.31E-02
79	79	4.86E-02
80	80	3.42E-02

Time: 100.000 - CPMSO - 800 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.75517E-05	0.15103E-01	0.80005E-07
2	0.52934E-05	0.10587E-01	0.56080E-07
3	0.34855E-05	0.69709E-02	0.36926E-07
4	0.21747E-05	0.43493E-02	0.23039E-07
5	0.13295E-05	0.26590E-02	0.14085E-07
6	0.84319E-06	0.16864E-02	0.89330E-08
7	0.58877E-06	0.11775E-02	0.62376E-08
8	0.46402E-06	0.92803E-03	0.49160E-08
9	0.40230E-06	0.80459E-03	0.42621E-08
10	0.36828E-06	0.73656E-03	0.39017E-08
11	0.34527E-06	0.69054E-03	0.36579E-08
12	0.32663E-06	0.65327E-03	0.34605E-08
13	0.31010E-06	0.62020E-03	0.32853E-08
14	0.29461E-06	0.58922E-03	0.31212E-08
15	0.28007E-06	0.56013E-03	0.29671E-08
16	0.26627E-06	0.53253E-03	0.28209E-08
17	0.25310E-06	0.50620E-03	0.26814E-08
18	0.24053E-06	0.48105E-03	0.25482E-08
19	0.22854E-06	0.45708E-03	0.24212E-08
20	0.21713E-06	0.43426E-03	0.23004E-08
21	0.20629E-06	0.41258E-03	0.21855E-08
22	0.19601E-06	0.39202E-03	0.20766E-08
23	0.18628E-06	0.37256E-03	0.19735E-08
24	0.17710E-06	0.35419E-03	0.18762E-08
25	0.16820E-06	0.33641E-03	0.17820E-08
26	0.15997E-06	0.31995E-03	0.16948E-08
27	0.15186E-06	0.30372E-03	0.16089E-08
28	0.14431E-06	0.28862E-03	0.15289E-08
29	0.13709E-06	0.27418E-03	0.14524E-08
30	0.13028E-06	0.26055E-03	0.13802E-08
31	0.12370E-06	0.24739E-03	0.13105E-08
32	0.11750E-06	0.23499E-03	0.12448E-08
33	0.11176E-06	0.22352E-03	0.11840E-08
34	0.10601E-06	0.21202E-03	0.11231E-08
35	0.10051E-06	0.20103E-03	0.10649E-08
36	0.95444E-07	0.19089E-03	0.10112E-08
37	0 90593E-07	0.18119E-03	0.95977E-09
38	0.86097E-07	0.17219E-03	0.91214E-09
39	0.81795E-07	0.16359E-03	0.86656E-09
40	0.77588E-07	0.15518E-03	0.82200E-09
41	0.73701E-07	0.14740E-03	0.78081E-09
42	0.69743E-07	0.13949E-03	0.73888E-09
43	0.66254E-07	0.13251E-03	0.70192E-09
44	0.62806E-07	0.12561E-03	0.66539E-09
45	0.59532E-07	0.11906E-03	0.63070E-09
46	0.56424E-07	0.11285E-03	0.59778E-09
47	0.53478E-07	0.10696E-03	0.56657E-09
48	0.50671E-07	0.10134E-03	0.53683E-09
49	0.47991E-07	0.95981E-04	0.50843E-09
50	0.45431E-07	0.90862E-04	0.48131E-09
51	0.42990E-07	0.85981E-04	0.45545E-09
52	0.40666E-07	0.81333E-04	0.43083E-09
53	0.38457E-07	0.76915E-04	0.40743E-09

54	0.36336E-07	0.72673E-04	0.38496E-09
55	0.34315E-07	0.68630E-04	0.36354E-09
56	0.32376E-07	0.64751E-04	0.34300E-09
57	0.30532E-07	0.61064E-04	0.32346E-09
58	0.28767E-07	0.57533E-04	0.30476E-09
59	0.27069E-07	0.54139E-04	0.28678E-09
60	0.25461E-07	0.50922E-04	0.26974E-09
61	0.23902E-07	0.47803E-04	0.25322E-09
62	0.22394E-07	0.44789E-04	0.23725E-09
63	0.20969E-07	0.41938E-04	0.22215E-09
64	0.19588E-07	0.39177E-04	0.20753E-09
65	0.18256E-07	0.36512E-04	0.19341E-09
66	0.16977E-07	0.33954E-04	0.17986E-09
67	0.15753E-07	0.31505E-04	0.16689E-09
68	0.14557E-07	0.29114E-04	0.15422E-09
69	0.13402E-07	0.26804E-04	0.14199E-09
70	0.12271E-07	0.24543E-04	0.13001E-09
71	0.11179E-07	0.22358E-04	0.11844E-09
72	0.10134E-07	0.20267E-04	0.10736E-09
73	0.91116E-08	0.18223E-04	0.96531E-10
74	0.81005E-08	0.16201E-04	0.85819E-10
75	0.71219E-08	0.14244E-04	0.75452E-10
76	0.61486E-08	0.12297E-04	0.65140E-10
77	0.51949E-08	0.10390E-04	0.55036E-10
78	0.42577E-08	0.85154E-05	0.45107E-10
79	0.33305E-08	0.66611E-05	0.35285E-10
80	0.24105E-08	0.48209E-05	0.25537E-10

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RMA 93-03 CPMSO Transport, 900 years
  1
       0.1      100.       50.      100.
      30.0     .0005     1100.      0.58
Polygon I
        1.      0.25    .00057       1.6      0.40       .25      .005
      .740       -1.  2.68E-04
   80y      100.0
    1     1  1.63E+02
    2     2  1.15E+02
    3     3  7.54E+01
    4     4  4.70E+01
    5     5  2.88E+01
    6     6  1.82E+01
    7     7  1.27E+01
    8     8  1.00E+01
    9     9  8.70E+00
   10    10  7.97E+00
   11    11  7.47E+00
   12    12  7.07E+00
   13    13  6.71E+00
   14    14  6.37E+00
   15    15  6.06E+00
   16    16  5.76E+00
   17    17  5.47E+00
   18    18  5.20E+00
   19    19  4.94E+00
   20    20  4.70E+00
   21    21  4.46E+00
   22    22  4.24E+00
   23    23  4.03E+00
   24    24  3.83E+00
   25    25  3.64E+00
   26    26  3.46E+00
   27    27  3.28E+00
   28    28  3.12E+00
   29    29  2.97E+00
   30    30  2.82E+00
   31    31  2.68E+00
   32    32  2.54E+00
   33    33  2.42E+00
   34    34  2.29E+00
   35    35  2.17E+00
   36    36  2.06E+00
   37    37  1.96E+00
   38    38  1.86E+00
   39    39  1.77E+00
   40    40  1.68E+00
   41    41  1.59E+00
   42    42  1.51E+00
   43    43  1.43E+00
   44    44  1.36E+00
   45    45  1.29E+00
   46    46  1.22E+00
   47    47  1.16E+00
```

48	48	1.10E+00
49	49	1.04E+00
50	50	9.83E-01
51	51	9.30E-01
52	52	8.80E-01
53	53	8.32E-01
54	54	7.86E-01
55	55	7.42E-01
56	56	7.00E-01
57	57	6.60E-01
58	58	6.22E-01
59	59	5.86E-01
60	60	5.51E-01
61	61	5.17E-01
62	62	4.84E-01
63	63	4.54E-01
64	64	4.24E-01
65	65	3.95E-01
66	66	3.67E-01
67	67	3.41E-01
68	68	3.15E-01
69	69	2.90E-01
70	70	2.65E-01
71	71	2.42E-01
72	72	2.19E-01
73	73	1.97E-01
74	74	1.75E-01
75	75	1.54E-01
76	76	1.33E-01
77	77	1.12E-01
78	78	9.21E-02
79	79	7.20E-02
80	80	5.21E-02

Time: 100.000 - CPMSO - 900 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.78537E-05	0.15707E-01	0.83205E-07
2	0.57007E-05	0.11401E-01	0.60396E-07
3	0.39496E-05	0.78993E-02	0.41844E-07
4	0.26173E-05	0.52346E-02	0.27728E-07
5	0.16974E-05	0.33949E-02	0.17983E-07
6	0.11193E-05	0.22386E-02	0.11858E-07
7	0.78893E-06	0.15779E-02	0.83582E-08
8	0.61297E-06	0.12259E-02	0.64940E-08
9	0.52207E-06	0.10441E-02	0.55310E-08
10	0.47199E-06	0.94397E-03	0.50004E-08
11	0.43976E-06	0.87951E-03	0.46589E-08
12	0.41525E-06	0.83050E-03	0.43993E-08
13	0.39411E-06	0.78822E-03	0.41753E-08
14	0.37459E-06	0.74918E-03	0.39686E-08
15	0.35646E-06	0.71293E-03	0.37765E-08
16	0.33925E-06	0.67849E-03	0.35941E-08
17	0.32271E-06	0.64543E-03	0.34189E-08
18	0.30705E-06	0.61410E-03	0.32530E-08
19	0.29211E-06	0.58422E-03	0.30947E-08
20	0.27804E-06	0.55607E-03	0.29456E-08
21	0.26442E-06	0.52885E-03	0.28014E-08
22	0.25155E-06	0.50309E-03	0.26650E-08
23	0.23933E-06	0.47867E-03	0.25356E-08
24	0.22770E-06	0.45541E-03	0.24124E-08
25	0.21663E-06	0.43327E-03	0.22951E-08
26	0.20611E-06	0.41222E-03	0.21836E-08
27	0.19588E-06	0.39176E-03	0.20752E-08
28	0.18632E-06	0.37263E-03	0.19739E-08
29	0.17737E-06	0.35474E-03	0.18791E-08
30	0.16872E-06	0.33744E-03	0.17875E-08
31	0.16047E-06	0.32095E-03	0.17001E-08
32	0.15246E-06	0.30492E-03	0.16152E-08
33	0.14509E-06	0.29017E-03	0.15371E-08
34	0.13780E-06	0.27560E-03	0.14599E-08
35	0.13080E-06	0.26160E-03	0.13858E-08
36	0.12424E-06	0.24849E-03	0.13163E-08
37	0.11817E-06	0.23633E-03	0.12519E-08
38	0.11232E-06	0.22464E-03	0.11900E-08
39	0.10684E-06	0.21368E-03	0.11319E-08
40	0.10156E-06	0.20312E-03	0.10760E-08
41	0.96379E-07	0.19276E-03	0.10211E-08
42	0.91524E-07	0.18305E-03	0.96964E-09
43	0.86853E-07	0.17371E-03	0.92015E-09
44	0.82523E-07	0.16505E-03	0.87428E-09
45	0.78375E-07	0.15675E-03	0.83034E-09
46	0.74314E-07	0.14863E-03	0.78730E-09
47	0.70561E-07	0.14112E-03	0.74755E-09
48	0.66978E-07	0.13396E-03	0.70959E-09
49	0.63473E-07	0.12695E-03	0.67245E-09
50	0.60094E-07	0.12019E-03	0.63666E-09
51	0.56896E-07	0.11379E-03	0.60278E-09
52	0.53871E-07	0.10774E-03	0.57073E-09
53	0.50984E-07	0.10197E-03	0.54014E-09

54	0.48219E-07	0.96437E-04	0.51085E-09
55	0.45570E-07	0.91141E-04	0.48279E-09
56	0.43037E-07	0.86073E-04	0.45595E-09
57	0.40616E-07	0.81231E-04	0.43030E-09
58	0.38305E-07	0.76611E-04	0.40582E-09
59	0.36104E-07	0.72208E-04	0.38250E-09
60	0.33985E-07	0.67971E-04	0.36005E-09
61	0.31936E-07	0.63872E-04	0.33834E-09
62	0.29952E-07	0.59903E-04	0.31732E-09
63	0.28080E-07	0.56160E-04	0.29749E-09
64	0.26268E-07	0.52537E-04	0.27830E-09
65	0.24511E-07	0.49022E-04	0.25968E-09
66	0.22810E-07	0.45620E-04	0.24166E-09
67	0.21192E-07	0.42383E-04	0.22451E-09
68	0.19616E-07	0.39232E-04	0.20782E-09
69	0.18086E-07	0.36173E-04	0.19161E-09
70	0.16583E-07	0.33167E-04	0.17569E-09
71	0.15146E-07	0.30292E-04	0.16046E-09
72	0.13744E-07	0.27488E-04	0.14561E-09
73	0.12383E-07	0.24766E-04	0.13119E-09
74	0.11044E-07	0.22088E-04	0.11700E-09
75	0.97409E-08	0.19482E-04	0.10320E-09
76	0.84574E-08	0.16915E-04	0.89600E-10
77	0.71829E-08	0.14366E-04	0.76098E-10
78	0.59415E-08	0.11883E-04	0.62947E-10
79	0.47122E-08	0.94244E-05	0.49923E-10
80	0.34918E-08	0.69836E-05	0.36993E-10

```
RMA 93-03 CPMSO Transport, 1000 years
  1
       0.1       100.       50.       100.
      30.0      .0005     1100.       0.58
Polygon I
        1.       0.25    .00057        1.6        0.40        .25        .005
      .754        -1.   3.77E-04
   80y      100.0
    1    1  1.70E+02
    2    2  1.23E+02
    3    3  8.54E+01
    4    4  5.66E+01
    5    5  3.67E+01
    6    6  2.42E+01
    7    7  1.71E+01
    8    8  1.33E+01
    9    9  1.13E+01
   10   10  1.02E+01
   11   11  9.51E+00
   12   12  8.98E+00
   13   13  8.52E+00
   14   14  8.10E+00
   15   15  7.71E+00
   16   16  7.34E+00
   17   17  6.98E+00
   18   18  6.64E+00
   19   19  6.32E+00
   20   20  6.01E+00
   21   21  5.72E+00
   22   22  5.44E+00
   23   23  5.18E+00
   24   24  4.93E+00
   25   25  4.69E+00
   26   26  4.46E+00
   27   27  4.24E+00
   28   28  4.03E+00
   29   29  3.84E+00
   30   30  3.65E+00
   31   31  3.47E+00
   32   32  3.30E+00
   33   33  3.14E+00
   34   34  2.98E+00
   35   35  2.83E+00
   36   36  2.69E+00
   37   37  2.56E+00
   38   38  2.43E+00
   39   39  2.31E+00
   40   40  2.20E+00
   41   41  2.08E+00
   42   42  1.98E+00
   43   43  1.88E+00
   44   44  1.79E+00
   45   45  1.70E+00
   46   46  1.61E+00
   47   47  1.53E+00
```

48	48	1.45E+00
49	49	1.37E+00
50	50	1.30E+00
51	51	1.23E+00
52	52	1.17E+00
53	53	1.10E+00
54	54	1.04E+00
55	55	9.86E-01
56	56	9.31E-01
57	57	8.79E-01
58	58	8.29E-01
59	59	7.81E-01
60	60	7.35E-01
61	61	6.91E-01
62	62	6.48E-01
63	63	6.07E-01
64	64	5.68E-01
65	65	5.30E-01
66	66	4.93E-01
67	67	4.58E-01
68	68	4.24E-01
69	69	3.91E-01
70	70	3.59E-01
71	71	3.28E-01
72	72	2.97E-01
73	73	2.68E-01
74	74	2.39E-01
75	75	2.11E-01
76	76	1.83E-01
77	77	1.55E-01
78	78	1.29E-01
79	79	1.02E-01
80	80	7.55E-02

Time: 100.000 - CPMSO - 1000 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.81154E-05	0.16231E-01	0.85977E-07
2	0.60178E-05	0.12036E-01	0.63754E-07
3	0.43351E-05	0.86703E-02	0.45928E-07
4	0.30195E-05	0.60391E-02	0.31990E-07
5	0.20582E-05	0.41165E-02	0.21806E-07
6	0.14124E-05	0.28247E-02	0.14963E-07
7	0.10149E-05	0.20298E-02	0.10752E-07
8	0.78652E-06	0.15730E-02	0.83327E-08
9	0.65959E-06	0.13192E-02	0.69879E-08
10	0.58779E-06	0.11756E-02	0.62272E-08
11	0.54346E-06	0.10869E-02	0.57576E-08
12	0.51153E-06	0.10231E-02	0.54193E-08
13	0.48507E-06	0.97013E-03	0.51389E-08
14	0.46135E-06	0.92269E-03	0.48876E-08
15	0.43938E-06	0.87876E-03	0.46550E-08
16	0.41866E-06	0.83733E-03	0.44355E-08
17	0.39877E-06	0.79754E-03	0.42247E-08
18	0.37980E-06	0.75959E-03	0.40237E-08
19	0.36181E-06	0.72362E-03	0.38331E-08
20	0.34458E-06	0.68915E-03	0.36506E-08
21	0.32822E-06	0.65645E-03	0.34773E-08
22	0.31259E-06	0.62517E-03	0.33116E-08
23	0.29781E-06	0.59562E-03	0.31551E-08
24	0.28373E-06	0.56745E-03	0.30059E-08
25	0.27024E-06	0.54048E-03	0.28630E-08
26	0.25732E-06	0.51464E-03	0.27261E-08
27	0.24495E-06	0.48991E-03	0.25951E-08
28	0.23313E-06	0.46627E-03	0.24699E-08
29	0.22211E-06	0.44421E-03	0.23531E-08
30	0.21148E-06	0.42295E-03	0.22405E-08
31	0.20129E-06	0.40258E-03	0.21325E-08
32	0.19160E-06	0.38320E-03	0.20299E-08
33	0.18242E-06	0.36485E-03	0.19327E-08
34	0.17351E-06	0.34702E-03	0.18382E-08
35	0.16499E-06	0.32998E-03	0.17479E-08
36	0.15694E-06	0.31388E-03	0.16627E-08
37	0.14939E-06	0.29877E-03	0.15827E-08
38	0.14208E-06	0.28415E-03	0.15052E-08
39	0.13514E-06	0.27027E-03	0.14317E-08
40	0.12866E-06	0.25731E-03	0.13630E-08
41	0.12215E-06	0.24431E-03	0.12941E-08
42	0.11614E-06	0.23229E-03	0.12305E-08
43	0.11042E-06	0.22084E-03	0.11698E-08
44	0.10507E-06	0.21013E-03	0.11131E-08
45	0.99908E-07	0.19982E-03	0.10585E-08
46	0.94843E-07	0.18969E-03	0.10048E-08
47	0.90095E-07	0.18019E-03	0.95450E-09
48	0.85523E-07	0.17105E-03	0.90606E-09
49	0.81035E-07	0.16207E-03	0.85851E-09
50	0.76854E-07	0.15371E-03	0.81422E-09
51	0.72842E-07	0.14568E-03	0.77172E-09
52	0.69156E-07	0.13831E-03	0.73266E-09
53	0.65387E-07	0.13077E-03	0.69273E-09

54	0.61823E-07	0.12365E-03	0.65498E-09
55	0.58545E-07	0.11709E-03	0.62024E-09
56	0.55374E-07	0.11075E-03	0.58665E-09
57	0.52324E-07	0.10465E-03	0.55434E-09
58	0.49396E-07	0.98791E-04	0.52331E-09
59	0.46582E-07	0.93164E-04	0.49350E-09
60	0.43880E-07	0.87760E-04	0.46488E-09
61	0.41288E-07	0.82575E-04	0.43742E-09
62	0.38779E-07	0.77557E-04	0.41083E-09
63	0.36364E-07	0.72728E-04	0.38525E-09
64	0.34051E-07	0.68103E-04	0.36075E-09
65	0.31816E-07	0.63633E-04	0.33707E-09
66	0.29646E-07	0.59292E-04	0.31408E-09
67	0.27562E-07	0.55124E-04	0.29200E-09
68	0.25548E-07	0.51096E-04	0.27066E-09
69	0.23594E-07	0.47188E-04	0.24996E-09
70	0.21697E-07	0.43394E-04	0.22986E-09
71	0.19854E-07	0.39708E-04	0.21034E-09
72	0.18040E-07	0.36080E-04	0.19112E-09
73	0.16291E-07	0.32583E-04	0.17260E-09
74	0.14577E-07	0.29155E-04	0.15444E-09
75	0.12904E-07	0.25807E-04	0.13671E-09
76	0.11251E-07	0.22502E-04	0.11920E-09
77	0.96088E-08	0.19218E-04	0.10180E-09
78	0.80229E-08	0.16046E-04	0.84997E-10
79	0.64404E-08	0.12881E-04	0.68232E-10
80	0.48682E-08	0.97363E-05	0.51575E-10

```
RMA 93-03 DBCP Transport, First 100 years
  1
      0.1       100.        50.       100.
     98.0       .0147     1100.       0.68
Polygon I
       1.       0.25     .00057       1.6        0.40        .25        .005
     .079       -1.         0.
   80y      100.0
    1    1        0.0
    2    2        0.0
    3    3        0.0
    4    4        0.0
    5    5        0.0
    6    6        0.0
    7    7        0.0
    8    8        0.0
    9    9        0.0
   10   10        0.0
   11   11        0.0
   12   12        0.0
   13   13        0.0
   14   14        0.0
   15   15        0.0
   16   16        0.0
   17   17        0.0
   18   18        0.0
   19   19        0.0
   20   20        0.0
   21   21        0.0
   22   22        0.0
   23   23        0.0
   24   24        0.0
   25   25        0.0
   26   26        0.0
   27   27        0.0
   28   28        0.0
   29   29        0.0
   30   30        0.0
   31   31        0.0
   32   32        0.0
   33   33        0.0
   34   34        0.0
   35   35        0.0
   36   36        0.0
   37   37        0.0
   38   38        0.0
   39   39        0.0
   40   40        0.0
   41   41        0.0
   42   42        0.0
   43   43        0.0
   44   44        0.0
   45   45        0.0
   46   46        0.0
   47   47        0.0
```

48	48	0.0
49	49	0.0
50	50	0.0
51	51	0.0
52	52	0.0
53	53	0.0
54	54	0.0
55	55	0.0
56	56	0.0
57	57	0.0
58	58	0.0
59	59	0.0
60	60	0.0
61	61	0.0
62	62	0.0
63	63	0.0
64	64	0.0
65	65	0.0
66	66	0.0
67	67	0.0
68	68	0.0
69	69	0.0
70	70	0.0
71	71	0.0
72	72	0.0
73	73	0.0
74	74	0.0
75	75	0.0
76	76	0.0
77	77	0.0
78	78	0.0
79	79	0.0
80	80	0.0

```
-------------------------------------------------------------
                VLEACH (Version 2.2, 1995)

                          By:
        Varadhan Ravi and Jeffrey A. Johnson
                  (USEPA Contractors)
        Center for Subsurface Modeling Support
        Robert S. Kerr Environmental Research Laboratory
        U.S. Environmental Protection Agency
        P.O. Box 1198
        Ada, OK 74820

        Based on the original VLEACH (version 1.0)
        developed by CH2M Hill, Redding, California
        for USEPA Region IX
-------------------------------------------------------------

RMA 93-03 DBCP Transport, First 100 years
  1 polygons.
Timestep =   0.10 years.  Simulation length =  100.00 years.
Printout every  50.00 years.  Vertical profile stored every 100.00 years.
Koc =       98.000    ml/g,       0.34608E-02cu.ft./g
Kh =     0.14700E-01 (dimensionless).
Aqueous solubility =      1100.0     mg/l,       31.149     g/cu.ft
Free air diffusion coefficient = .68000     sq. m/day,  2671.7     sq.ft./yr


Polygon   1
Polygon I
Polygon area =      1.0000    sq. ft.
 80 cells, each cell  0.250 ft. thick.
Soil Properties:
 Bulk density =     1.6000    g/ml,        45307.    g/cu.ft.
 Porosity = 0.4000 Volumetric water content = 0.2500
 Organic carbon content = 0.00500000
Recharge Rate = 0.00057000 ft/yr
Conc. in recharge water =     0.79000E-01mg/l,      0.22370E-02g/cu.ft
Atmospheric concentration =     -1.0000     mg/l,     -0.28317E-01g/cu.ft
Water table has a fixed concentration of     0.00000    mg/l,       0.00000
   with respect to gas diffusion.
```

Time: 100.000 - DBCP - 100 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.29446E-05	0.20032E-03	0.34663E-08
2	0.35793E-06	0.24349E-04	0.42134E-09
3	0.16607E-06	0.11298E-04	0.19549E-09
4	0.14923E-06	0.10152E-04	0.17567E-09
5	0.14295E-06	0.97247E-05	0.16828E-09
6	0.13739E-06	0.93464E-05	0.16173E-09
7	0.13206E-06	0.89836E-05	0.15545E-09
8	0.12692E-06	0.86343E-05	0.14941E-09
9	0.12198E-06	0.82980E-05	0.14359E-09
10	0.11722E-06	0.79742E-05	0.13799E-09
11	0.11264E-06	0.76626E-05	0.13259E-09
12	0.10823E-06	0.73626E-05	0.12740E-09
13	0.10399E-06	0.70739E-05	0.12241E-09
14	0.99901E-07	0.67960E-05	0.11760E-09
15	0.95969E-07	0.65285E-05	0.11297E-09
16	0.92184E-07	0.62710E-05	0.10851E-09
17	0.88542E-07	0.60233E-05	0.10423E-09
18	0.85037E-07	0.57849E-05	0.10010E-09
19	0.81664E-07	0.55554E-05	0.96131E-10
20	0.78419E-07	0.53346E-05	0.92310E-10
21	0.75295E-07	0.51221E-05	0.88634E-10
22	0.72289E-07	0.49177E-05	0.85095E-10
23	0.69397E-07	0.47209E-05	0.81691E-10
24	0.66614E-07	0.45316E-05	0.78415E-10
25	0.63936E-07	0.43494E-05	0.75262E-10
26	0.61359E-07	0.41741E-05	0.72228E-10
27	0.58879E-07	0.40054E-05	0.69309E-10
28	0.56492E-07	0.38430E-05	0.66500E-10
29	0.54196E-07	0.36868E-05	0.63797E-10
30	0.51986E-07	0.35365E-05	0.61195E-10
31	0.49859E-07	0.33918E-05	0.58692E-10
32	0.47812E-07	0.32525E-05	0.56282E-10
33	0.45842E-07	0.31185E-05	0.53963E-10
34	0.43945E-07	0.29895E-05	0.51730E-10
35	0.42120E-07	0.28653E-05	0.49581E-10
36	0.40362E-07	0.27457E-05	0.47513E-10
37	0.38670E-07	0.26306E-05	0.45521E-10
38	0.37041E-07	0.25198E-05	0.43603E-10
39	0.35472E-07	0.24131E-05	0.41756E-10
40	0.33961E-07	0.23102E-05	0.39977E-10
41	0.32505E-07	0.22112E-05	0.38263E-10
42	0.31102E-07	0.21158E-05	0.36612E-10
43	0.29750E-07	0.20238E-05	0.35021E-10
44	0.28448E-07	0.19352E-05	0.33487E-10
45	0.27191E-07	0.18498E-05	0.32008E-10
46	0.25980E-07	0.17674E-05	0.30583E-10
47	0.24812E-07	0.16879E-05	0.29207E-10
48	0.23684E-07	0.16112E-05	0.27880E-10
49	0.22596E-07	0.15372E-05	0.26599E-10
50	0.21546E-07	0.14657E-05	0.25362E-10
51	0.20531E-07	0.13966E-05	0.24168E-10
52	0.19550E-07	0.13299E-05	0.23013E-10
53	0.18602E-07	0.12654E-05	0.21897E-10

```
RMA 93-03 DBCP Transport, 200 years
  1
      0.1      100.       50.      100.
     98.0     .0147     1100.      0.68
Polygon I
       1.      0.25    .00057       1.6       0.40       .25       .005
     .287       -1.  3.29E-06
   80y      100.0
    1     1  4.59E+00
    2     2  5.58E-01
    3     3  2.59E-01
    4     4  2.33E-01
    5     5  2.23E-01
    6     6  2.14E-01
    7     7  2.06E-01
    8     8  1.98E-01
    9     9  1.90E-01
   10    10  1.83E-01
   11    11  1.76E-01
   12    12  1.69E-01
   13    13  1.62E-01
   14    14  1.56E-01
   15    15  1.50E-01
   16    16  1.44E-01
   17    17  1.38E-01
   18    18  1.33E-01
   19    19  1.27E-01
   20    20  1.22E-01
   21    21  1.17E-01
   22    22  1.13E-01
   23    23  1.08E-01
   24    24  1.04E-01
   25    25  9.96E-02
   26    26  9.56E-02
   27    27  9.17E-02
   28    28  8.80E-02
   29    29  8.44E-02
   30    30  8.10E-02
   31    31  7.77E-02
   32    32  7.45E-02
   33    33  7.14E-02
   34    34  6.85E-02
   35    35  6.56E-02
   36    36  6.29E-02
   37    37  6.03E-02
   38    38  5.77E-02
   39    39  5.53E-02
   40    40  5.29E-02
   41    41  5.06E-02
   42    42  4.85E-02
   43    43  4.64E-02
   44    44  4.43E-02
   45    45  4.24E-02
   46    46  4.05E-02
   47    47  3.87E-02
```

54	0.17684E-07	0.12030E-05	0.20817E-10
55	0.16797E-07	0.11426E-05	0.19772E-10
56	0.15937E-07	0.10842E-05	0.18760E-10
57	0.15104E-07	0.10275E-05	0.17780E-10
58	0.14297E-07	0.97256E-06	0.16829E-10
59	0.13513E-07	0.91926E-06	0.15907E-10
60	0.12752E-07	0.86750E-06	0.15011E-10
61	0.12013E-07	0.81720E-06	0.14141E-10
62	0.11294E-07	0.76828E-06	0.13294E-10
63	0.10594E-07	0.72065E-06	0.12470E-10
64	0.99112E-08	0.67423E-06	0.11667E-10
65	0.92457E-08	0.62896E-06	0.10884E-10
66	0.85958E-08	0.58475E-06	0.10119E-10
67	0.79604E-08	0.54152E-06	0.93706E-11
68	0.73385E-08	0.49922E-06	0.86385E-11
69	0.67290E-08	0.45776E-06	0.79211E-11
70	0.61309E-08	0.41707E-06	0.72170E-11
71	0.55432E-08	0.37709E-06	0.65252E-11
72	0.49649E-08	0.33775E-06	0.58445E-11
73	0.43951E-08	0.29898E-06	0.51736E-11
74	0.38326E-08	0.26072E-06	0.45116E-11
75	0.32767E-08	0.22291E-06	0.38572E-11
76	0.27263E-08	0.18547E-06	0.32093E-11
77	0.21806E-08	0.14834E-06	0.25669E-11
78	0.16385E-08	0.11146E-06	0.19288E-11
79	0.10992E-08	0.74777E-07	0.12940E-11
80	0.56178E-09	0.38216E-07	0.66130E-12

Time: 100.000 - DBCP - 200 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.11117E-04	0.75628E-03	0.13087E-07
2	0.15441E-05	0.10504E-03	0.18177E-08
3	0.77962E-06	0.53035E-04	0.91773E-09
4	0.70490E-06	0.47952E-04	0.82977E-09
5	0.67780E-06	0.46109E-04	0.79787E-09
6	0.65433E-06	0.44512E-04	0.77024E-09
7	0.63181E-06	0.42980E-04	0.74373E-09
8	0.61002E-06	0.41498E-04	0.71809E-09
9	0.58892E-06	0.40063E-04	0.69325E-09
10	0.56855E-06	0.38677E-04	0.66927E-09
11	0.54884E-06	0.37336E-04	0.64606E-09
12	0.52975E-06	0.36037E-04	0.62359E-09
13	0.51126E-06	0.34780E-04	0.60183E-09
14	0.49342E-06	0.33566E-04	0.58083E-09
15	0.47616E-06	0.32392E-04	0.56051E-09
16	0.45945E-06	0.31255E-04	0.54084E-09
17	0.44327E-06	0.30154E-04	0.52180E-09
18	0.42766E-06	0.29093E-04	0.50342E-09
19	0.41251E-06	0.28062E-04	0.48558E-09
20	0.39788E-06	0.27067E-04	0.46836E-09
21	0.38373E-06	0.26104E-04	0.45171E-09
22	0.37009E-06	0.25176E-04	0.43566E-09
23	0.35684E-06	0.24275E-04	0.42006E-09
24	0.34406E-06	0.23406E-04	0.40501E-09
25	0.33168E-06	0.22563E-04	0.39043E-09
26	0.31970E-06	0.21749E-04	0.37634E-09
27	0.30812E-06	0.20961E-04	0.36271E-09
28	0.29692E-06	0.20199E-04	0.34952E-09
29	0.28609E-06	0.19462E-04	0.33677E-09
30	0.27561E-06	0.18749E-04	0.32443E-09
31	0.26547E-06	0.18059E-04	0.31249E-09
32	0.25565E-06	0.17391E-04	0.30094E-09
33	0.24616E-06	0.16745E-04	0.28976E-09
34	0.23697E-06	0.16120E-04	0.27895E-09
35	0.22807E-06	0.15515E-04	0.26848E-09
36	0.21947E-06	0.14930E-04	0.25835E-09
37	0.21114E-06	0.14363E-04	0.24854E-09
38	0.20307E-06	0.13814E-04	0.23904E-09
39	0.19526E-06	0.13283E-04	0.22985E-09
40	0.18769E-06	0.12768E-04	0.22094E-09
41	0.18036E-06	0.12269E-04	0.21231E-09
42	0.17326E-06	0.11786E-04	0.20395E-09
43	0.16638E-06	0.11318E-04	0.19586E-09
44	0.15971E-06	0.10864E-04	0.18800E-09
45	0.15324E-06	0.10425E-04	0.18039E-09
46	0.14697E-06	0.99981E-05	0.17301E-09
47	0.14089E-06	0.95843E-05	0.16585E-09
48	0.13498E-06	0.91826E-05	0.15890E-09
49	0.12925E-06	0.87927E-05	0.15215E-09
50	0.12369E-06	0.84143E-05	0.14560E-09
51	0.11828E-06	0.80465E-05	0.13924E-09
52	0.11303E-06	0.76892E-05	0.13305E-09
53	0.10792E-06	0.73416E-05	0.12704E-09

48	48	3.69E-02
49	49	3.52E-02
50	50	3.36E-02
51	51	3.20E-02
52	52	3.05E-02
53	53	2.90E-02
54	54	2.76E-02
55	55	2.62E-02
56	56	2.48E-02
57	57	2.35E-02
58	58	2.23E-02
59	59	2.11E-02
60	60	1.99E-02
61	61	1.87E-02
62	62	1.76E-02
63	63	1.65E-02
64	64	1.54E-02
65	65	1.44E-02
66	66	1.34E-02
67	67	1.24E-02
68	68	1.14E-02
69	69	1.05E-02
70	70	9.55E-03
71	71	8.64E-03
72	72	7.74E-03
73	73	6.85E-03
74	74	5.97E-03
75	75	5.11E-03
76	76	4.25E-03
77	77	3.40E-03
78	78	2.55E-03
79	79	1.71E-03
80	80	8.75E-04

```
RMA 93-03 DBCP Transport, 300 years
  1
      0.1       100.        50.       100.
     98.0      .0147      1100.       0.68
Polygon I
       1.       0.25     .00057        1.6        0.40        .25        .005
     .412        -1.   2.27E-05
   80y      100.0
    1     1  1.73E+01
    2     2  2.41E+00
    3     3  1.21E+00
    4     4  1.10E+00
    5     5  1.06E+00
    6     6  1.02E+00
    7     7  9.84E-01
    8     8  9.51E-01
    9     9  9.18E-01
   10    10  8.86E-01
   11    11  8.55E-01
   12    12  8.25E-01
   13    13  7.97E-01
   14    14  7.69E-01
   15    15  7.42E-01
   16    16  7.16E-01
   17    17  6.91E-01
   18    18  6.66E-01
   19    19  6.43E-01
   20    20  6.20E-01
   21    21  5.98E-01
   22    22  5.77E-01
   23    23  5.56E-01
   24    24  5.36E-01
   25    25  5.17E-01
   26    26  4.98E-01
   27    27  4.80E-01
   28    28  4.63E-01
   29    29  4.46E-01
   30    30  4.29E-01
   31    31  4.14E-01
   32    32  3.98E-01
   33    33  3.84E-01
   34    34  3.69E-01
   35    35  3.55E-01
   36    36  3.42E-01
   37    37  3.29E-01
   38    38  3.16E-01
   39    39  3.04E-01
   40    40  2.92E-01
   41    41  2.81E-01
   42    42  2.70E-01
   43    43  2.59E-01
   44    44  2.49E-01
   45    45  2.39E-01
   46    46  2.29E-01
   47    47  2.20E-01
```

54	0.10295E-06	0.70037E-05	0.12119E-09
55	0.98118E-07	0.66747E-05	0.11550E-09
56	0.93405E-07	0.63541E-05	0.10995E-09
57	0.88816E-07	0.60419E-05	0.10455E-09
58	0.84346E-07	0.57379E-05	0.99288E-10
59	0.79985E-07	0.54411E-05	0.94154E-10
60	0.75725E-07	0.51513E-05	0.89139E-10
61	0.71560E-07	0.48680E-05	0.84237E-10
62	0.67492E-07	0.45913E-05	0.79448E-10
63	0.63511E-07	0.43205E-05	0.74762E-10
64	0.59611E-07	0.40552E-05	0.70171E-10
65	0.55793E-07	0.37954E-05	0.65676E-10
66	0.52047E-07	0.35406E-05	0.61267E-10
67	0.48367E-07	0.32902E-05	0.56935E-10
68	0.44748E-07	0.30441E-05	0.52675E-10
69	0.41192E-07	0.28022E-05	0.48490E-10
70	0.37687E-07	0.25638E-05	0.44364E-10
71	0.34232E-07	0.23287E-05	0.40296E-10
72	0.30821E-07	0.20967E-05	0.36281E-10
73	0.27450E-07	0.18674E-05	0.32313E-10
74	0.24114E-07	0.16404E-05	0.28386E-10
75	0.20811E-07	0.14157E-05	0.24497E-10
76	0.17533E-07	0.11927E-05	0.20639E-10
77	0.14278E-07	0.97132E-06	0.16808E-10
78	0.11041E-07	0.75111E-06	0.12997E-10
79	0.78184E-08	0.53187E-06	0.92035E-11
80	0.46053E-08	0.31329E-06	0.54212E-11

Time: 100.00 - DBCP - 300 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.17009E-04	0.11570E-02	0.20022E-07
2	0.28797E-05	0.19590E-03	0.33899E-08
3	0.16246E-05	0.11052E-03	0.19124E-08
4	0.14844E-05	0.10098E-03	0.17474E-08
5	0.14350E-05	0.97621E-04	0.16892E-08
6	0.13931E-05	0.94768E-04	0.16399E-08
7	0.13528E-05	0.92024E-04	0.15924E-08
8	0.13136E-05	0.89362E-04	0.15463E-08
9	0.12755E-05	0.86766E-04	0.15014E-08
10	0.12383E-05	0.84235E-04	0.14576E-08
11	0.12020E-05	0.81769E-04	0.14149E-08
12	0.11667E-05	0.79366E-04	0.13734E-08
13	0.11323E-05	0.77029E-04	0.13329E-08
14	0.10988E-05	0.74750E-04	0.12935E-08
15	0.10662E-05	0.72530E-04	0.12551E-08
16	0.10344E-05	0.70367E-04	0.12176E-08
17	0.10034E-05	0.68261E-04	0.11812E-08
18	0.97324E-06	0.66207E-04	0.11457E-08
19	0.94389E-06	0.64210E-04	0.11111E-08
20	0.91527E-06	0.62263E-04	0.10774E-08
21	0.88740E-06	0.60368E-04	0.10446E-08
22	0.86028E-06	0.58522E-04	0.10127E-08
23	0.83382E-06	0.56723E-04	0.98153E-09
24	0.80807E-06	0.54971E-04	0.95122E-09
25	0.78300E-06	0.53266E-04	0.92171E-09
26	0.75856E-06	0.51603E-04	0.89294E-09
27	0.73477E-06	0.49984E-04	0.86493E-09
28	0.71162E-06	0.48409E-04	0.83768E-09
29	0.68904E-06	0.46874E-04	0.81111E-09
30	0.66701E-06	0.45375E-04	0.78517E-09
31	0.64563E-06	0.43920E-04	0.76000E-09
32	0.62472E-06	0.42498E-04	0.73539E-09
33	0.60443E-06	0.41117E-04	0.71150E-09
34	0.58458E-06	0.39767E-04	0.68814E-09
35	0.56525E-06	0.38452E-04	0.66539E-09
36	0.54645E-06	0.37174E-04	0.64326E-09
37	0.52811E-06	0.35926E-04	0.62167E-09
38	0.51020E-06	0.34708E-04	0.60059E-09
39	0.49277E-06	0.33522E-04	0.58007E-09
40	0.47576E-06	0.32365E-04	0.56004E-09
41	0.45920E-06	0.31238E-04	0.54055E-09
42	0.44303E-06	0.30138E-04	0.52152E-09
43	0.42724E-06	0.29064E-04	0.50292E-09
44	0.41186E-06	0.28017E-04	0.48482E-09
45	0.39683E-06	0.26995E-04	0.46713E-09
46	0.38214E-06	0.25996E-04	0.44984E-09
47	0.36784E-06	0.25023E-04	0.43300E-09
48	0.35379E-06	0.24067E-04	0.41646E-09
49	0.34009E-06	0.23136E-04	0.40034E-09
50	0.32676E-06	0.22228E-04	0.38464E-09
51	0.31365E-06	0.21337E-04	0.36922E-09
52	0.30087E-06	0.20467E-04	0.35416E-09
53	0.28835E-06	0.19616E-04	0.33943E-09

48	48	2.10E-01
49	49	2.01E-01
50	50	1.93E-01
51	51	1.84E-01
52	52	1.76E-01
53	53	1.68E-01
54	54	1.60E-01
55	55	1.53E-01
56	56	1.46E-01
57	57	1.38E-01
58	58	1.31E-01
59	59	1.25E-01
60	60	1.18E-01
61	61	1.12E-01
62	62	1.05E-01
63	63	9.90E-02
64	64	9.29E-02
65	65	8.69E-02
66	66	8.11E-02
67	67	7.54E-02
68	68	6.97E-02
69	69	6.42E-02
70	70	5.87E-02
71	71	5.33E-02
72	72	4.80E-02
73	73	4.28E-02
74	74	3.76E-02
75	75	3.24E-02
76	76	2.73E-02
77	77	2.22E-02
78	78	1.72E-02
79	79	1.22E-02
80	80	7.18E-03

```
RMA 93-03 DBCP Transport, 400 years
  1
      0.1      100.       50.       100.
     98.0      .0147     1100.      0.68
Polygon I
       1.       0.25     .00057      1.6       0.40       .25       .005
     .489       -1.    7.46E-05
   80y      100.0
    1     1  2.65E+01
    2     2  4.49E+00
    3     3  2.53E+00
    4     4  2.31E+00
    5     5  2.24E+00
    6     6  2.17E+00
    7     7  2.11E+00
    8     8  2.05E+00
    9     9  1.99E+00
   10    10  1.93E+00
   11    11  1.87E+00
   12    12  1.82E+00
   13    13  1.76E+00
   14    14  1.71E+00
   15    15  1.66E+00
   16    16  1.61E+00
   17    17  1.56E+00
   18    18  1.52E+00
   19    19  1.47E+00
   20    20  1.43E+00
   21    21  1.38E+00
   22    22  1.34E+00
   23    23  1.30E+00
   24    24  1.26E+00
   25    25  1.22E+00
   26    26  1.18E+00
   27    27  1.14E+00
   28    28  1.11E+00
   29    29  1.07E+00
   30    30  1.04E+00
   31    31  1.01E+00
   32    32  9.73E-01
   33    33  9.42E-01
   34    34  9.11E-01
   35    35  8.81E-01
   36    36  8.52E-01
   37    37  8.23E-01
   38    38  7.95E-01
   39    39  7.68E-01
   40    40  7.41E-01
   41    41  7.16E-01
   42    42  6.90E-01
   43    43  6.66E-01
   44    44  6.42E-01
   45    45  6.18E-01
   46    46  5.95E-01
   47    47  5.73E-01
```

54	0.27608E-06	0.18781E-04	0.32499E-09
55	0.26411E-06	0.17967E-04	0.31089E-09
56	0.25238E-06	0.17169E-04	0.29709E-09
57	0.24081E-06	0.16381E-04	0.28346E-09
58	0.22949E-06	0.15612E-04	0.27014E-09
59	0.21845E-06	0.14860E-04	0.25714E-09
60	0.20755E-06	0.14119E-04	0.24431E-09
61	0.19687E-06	0.13393E-04	0.23175E-09
62	0.18633E-06	0.12675E-04	0.21933E-09
63	0.17599E-06	0.11972E-04	0.20716E-09
64	0.16581E-06	0.11280E-04	0.19518E-09
65	0.15578E-06	0.10598E-04	0.18338E-09
66	0.14591E-06	0.99257E-05	0.17175E-09
67	0.13617E-06	0.92631E-05	0.16029E-09
68	0.12655E-06	0.86087E-05	0.14897E-09
69	0.11705E-06	0.79627E-05	0.13779E-09
70	0.10766E-06	0.73239E-05	0.12673E-09
71	0.98371E-07	0.66919E-05	0.11580E-09
72	0.89175E-07	0.60663E-05	0.10497E-09
73	0.80064E-07	0.54465E-05	0.94247E-10
74	0.71024E-07	0.48316E-05	0.83606E-10
75	0.62046E-07	0.42208E-05	0.73038E-10
76	0.53128E-07	0.36141E-05	0.62539E-10
77	0.44257E-07	0.30107E-05	0.52097E-10
78	0.35430E-07	0.24102E-05	0.41706E-10
79	0.26633E-07	0.18118E-05	0.31351E-10
80	0.17858E-07	0.12148E-05	0.21021E-10

Time: 100.000 - DBCP - 400 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.20963E-04	0.14261E-02	0.24677E-07
2	0.40383E-05	0.27471E-03	0.47537E-08
3	0.24651E-05	0.16769E-03	0.29017E-08
4	0.22769E-05	0.15489E-03	0.26803E-08
5	0.22109E-05	0.15040E-03	0.26026E-08
6	0.21555E-05	0.14663E-03	0.25373E-08
7	0.21023E-05	0.14301E-03	0.24747E-08
8	0.20502E-05	0.13947E-03	0.24134E-08
9	0.19991E-05	0.13599E-03	0.23532E-08
10	0.19488E-05	0.13257E-03	0.22941E-08
11	0.18995E-05	0.12922E-03	0.22360E-08
12	0.18517E-05	0.12597E-03	0.21797E-08
13	0.18043E-05	0.12274E-03	0.21239E-08
14	0.17582E-05	0.11960E-03	0.20696E-08
15	0.17131E-05	0.11653E-03	0.20165E-08
16	0.16688E-05	0.11352E-03	0.19644E-08
17	0.16253E-05	0.11056E-03	0.19132E-08
18	0.15832E-05	0.10770E-03	0.18637E-08
19	0.15415E-05	0.10486E-03	0.18145E-08
20	0.15009E-05	0.10211E-03	0.17668E-08
21	0.14607E-05	0.99367E-04	0.17195E-08
22	0.14217E-05	0.96712E-04	0.16735E-08
23	0.13835E-05	0.94114E-04	0.16286E-08
24	0.13460E-05	0.91565E-04	0.15844E-08
25	0.13092E-05	0.89063E-04	0.15412E-08
26	0.12731E-05	0.86607E-04	0.14987E-08
27	0.12377E-05	0.84196E-04	0.14569E-08
28	0.12035E-05	0.81871E-04	0.14167E-08
29	0.11695E-05	0.79557E-04	0.13767E-08
30	0.11366E-05	0.77319E-04	0.13379E-08
31	0.11044E-05	0.75130E-04	0.13001E-08
32	0.10724E-05	0.72953E-04	0.12624E-08
33	0.10413E-05	0.70834E-04	0.12257E-08
34	0.10107E-05	0.68758E-04	0.11898E-08
35	0.98084E-06	0.66724E-04	0.11546E-08
36	0.95156E-06	0.64732E-04	0.11201E-08
37	0.92282E-06	0.62777E-04	0.10863E-08
38	0.89466E-06	0.60861E-04	0.10531E-08
39	0.86707E-06	0.58984E-04	0.10207E-08
40	0.83998E-06	0.57141E-04	0.98878E-09
41	0.81348E-06	0.55339E-04	0.95759E-09
42	0.78741E-06	0.53566E-04	0.92690E-09
43	0.76191E-06	0.51830E-04	0.89688E-09
44	0.73686E-06	0.50126E-04	0.86739E-09
45	0.71224E-06	0.48451E-04	0.83841E-09
46	0.68809E-06	0.46809E-04	0.80998E-09
47	0.66441E-06	0.45198E-04	0.78211E-09
48	0.64113E-06	0.43615E-04	0.75471E-09
49	0.61830E-06	0.42061E-04	0.72783E-09
50	0.59583E-06	0.40533E-04	0.70139E-09
51	0.57378E-06	0.39033E-04	0.67543E-09
52	0.55209E-06	0.37557E-04	0.64989E-09
53	0.53072E-06	0.36103E-04	0.62474E-09

48	48	5.51E-01
49	49	5.30E-01
50	50	5.09E-01
51	51	4.89E-01
52	52	4.69E-01
53	53	4.49E-01
54	54	4.30E-01
55	55	4.12E-01
56	56	3.93E-01
57	57	3.75E-01
58	58	3.58E-01
59	59	3.40E-01
60	60	3.23E-01
61	61	3.07E-01
62	62	2.90E-01
63	63	2.74E-01
64	64	2.58E-01
65	65	2.43E-01
66	66	2.27E-01
67	67	2.12E-01
68	68	1.97E-01
69	69	1.82E-01
70	70	1.68E-01
71	71	1.53E-01
72	72	1.39E-01
73	73	1.25E-01
74	74	1.11E-01
75	75	9.67E-02
76	76	8.28E-02
77	77	6.90E-02
78	78	5.52E-02
79	79	4.15E-02
80	80	2.78E-02

```
RMA 93-03 DBCP Transport, 500 years
  1
       0.1       100.        50.       100.
      98.0     .0147      1100.       0.68
Polygon I
        1.      0.25     .00057        1.6       0.40        .25       .005
      .543       -1.   1.69E-04
   80y       100.0
     1     1  3.27E+01
     2     2  6.29E+00
     3     3  3.84E+00
     4     4  3.55E+00
     5     5  3.45E+00
     6     6  3.36E+00
     7     7  3.28E+00
     8     8  3.19E+00
     9     9  3.11E+00
    10    10  3.04E+00
    11    11  2.96E+00
    12    12  2.89E+00
    13    13  2.81E+00
    14    14  2.74E+00
    15    15  2.67E+00
    16    16  2.60E+00
    17    17  2.53E+00
    18    18  2.47E+00
    19    19  2.40E+00
    20    20  2.34E+00
    21    21  2.28E+00
    22    22  2.22E+00
    23    23  2.16E+00
    24    24  2.10E+00
    25    25  2.04E+00
    26    26  1.98E+00
    27    27  1.93E+00
    28    28  1.88E+00
    29    29  1.82E+00
    30    30  1.77E+00
    31    31  1.72E+00
    32    32  1.67E+00
    33    33  1.62E+00
    34    34  1.57E+00
    35    35  1.53E+00
    36    36  1.48E+00
    37    37  1.44E+00
    38    38  1.39E+00
    39    39  1.35E+00
    40    40  1.31E+00
    41    41  1.27E+00
    42    42  1.23E+00
    43    43  1.19E+00
    44    44  1.15E+00
    45    45  1.11E+00
    46    46  1.07E+00
    47    47  1.04E+00
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54	0.50973E-06	0.34675E-04	0.60003E-09
55	0.48912E-06	0.33273E-04	0.57576E-09
56	0.46875E-06	0.31888E-04	0.55179E-09
57	0.44871E-06	0.30525E-04	0.52820E-09
58	0.42902E-06	0.29185E-04	0.50502E-09
59	0.40954E-06	0.27860E-04	0.48209E-09
60	0.39036E-06	0.26555E-04	0.45951E-09
61	0.37148E-06	0.25271E-04	0.43729E-09
62	0.35279E-06	0.23999E-04	0.41529E-09
63	0.33436E-06	0.22746E-04	0.39360E-09
64	0.31615E-06	0.21507E-04	0.37216E-09
65	0.29820E-06	0.20285E-04	0.35102E-09
66	0.28038E-06	0.19073E-04	0.33004E-09
67	0.26278E-06	0.17876E-04	0.30933E-09
68	0.24535E-06	0.16690E-04	0.28881E-09
69	0.22808E-06	0.15515E-04	0.26848E-09
70	0.21101E-06	0.14354E-04	0.24838E-09
71	0.19402E-06	0.13198E-04	0.22839E-09
72	0.17719E-06	0.12054E-04	0.20858E-09
73	0.16050E-06	0.10918E-04	0.18893E-09
74	0.14390E-06	0.97888E-05	0.16939E-09
75	0.12737E-06	0.86643E-05	0.14993E-09
76	0.11093E-06	0.75465E-05	0.13059E-09
77	0.94580E-07	0.64340E-05	0.11134E-09
78	0.78286E-07	0.53256E-05	0.92154E-10
79	0.62045E-07	0.42207E-05	0.73036E-10
80	0.45841E-07	0.31184E-05	0.53962E-10

Time: 100.000 - DBCP - 500 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.23862E-04	0.16233E-02	0.28090E-07
2	0.50196E-05	0.34147E-03	0.59088E-08
3	0.32343E-05	0.22002E-03	0.38073E-08
4	0.30146E-05	0.20508E-03	0.35487E-08
5	0.29368E-05	0.19978E-03	0.34570E-08
6	0.28719E-05	0.19537E-03	0.33806E-08
7	0.28094E-05	0.19112E-03	0.33071E-08
8	0.27474E-05	0.18690E-03	0.32341E-08
9	0.26868E-05	0.18278E-03	0.31628E-08
10	0.26278E-05	0.17876E-03	0.30933E-08
11	0.25691E-05	0.17477E-03	0.30242E-08
12	0.25118E-05	0.17087E-03	0.29568E-08
13	0.24548E-05	0.16699E-03	0.28897E-08
14	0.23991E-05	0.16320E-03	0.28241E-08
15	0.23443E-05	0.15948E-03	0.27596E-08
16	0.22904E-05	0.15581E-03	0.26961E-08
17	0.22372E-05	0.15219E-03	0.26335E-08
18	0.21854E-05	0.14867E-03	0.25725E-08
19	0.21339E-05	0.14516E-03	0.25119E-08
20	0.20836E-05	0.14174E-03	0.24527E-08
21	0.20341E-05	0.13838E-03	0.23945E-08
22	0.19854E-05	0.13506E-03	0.23371E-08
23	0.19374E-05	0.13180E-03	0.22806E-08
24	0.18901E-05	0.12858E-03	0.22250E-08
25	0.18435E-05	0.12541E-03	0.21701E-08
26	0.17976E-05	0.12228E-03	0.21160E-08
27	0.17529E-05	0.11924E-03	0.20634E-08
28	0.17090E-05	0.11626E-03	0.20117E-08
29	0.16651E-05	0.11328E-03	0.19601E-08
30	0.16224E-05	0.11037E-03	0.19098E-08
31	0.15804E-05	0.10751E-03	0.18604E-08
32	0.15390E-05	0.10469E-03	0.18116E-08
33	0.14982E-05	0.10192E-03	0.17636E-08
34	0.14580E-05	0.99181E-04	0.17162E-08
35	0.14189E-05	0.96525E-04	0.16703E-08
36	0.13799E-05	0.93874E-04	0.16244E-08
37	0.13420E-05	0.91294E-04	0.15798E-08
38	0.13041E-05	0.88716E-04	0.15351E-08
39	0.12672E-05	0.86207E-04	0.14917E-08
40	0.12310E-05	0.83741E-04	0.14491E-08
41	0.11952E-05	0.81309E-04	0.14070E-08
42	0.11600E-05	0.78910E-04	0.13655E-08
43	0.11252E-05	0.76544E-04	0.13245E-08
44	0.10909E-05	0.74208E-04	0.12841E-08
45	0.10570E-05	0.71903E-04	0.12442E-08
46	0.10235E-05	0.69628E-04	0.12048E-08
47	0.99112E-06	0.67423E-04	0.11667E-08
48	0.95858E-06	0.65210E-04	0.11284E-08
49	0.92662E-06	0.63035E-04	0.10908E-08
50	0.89516E-06	0.60895E-04	0.10537E-08
51	0.86416E-06	0.58787E-04	0.10172E-08
52	0.83355E-06	0.56704E-04	0.98121E-09
53	0.80335E-06	0.54650E-04	0.94566E-09

48	48	9.99E-01
49	49	9.63E-01
50	50	9.28E-01
51	51	8.94E-01
52	52	8.60E-01
53	53	8.27E-01
54	54	7.94E-01
55	55	7.62E-01
56	56	7.30E-01
57	57	6.99E-01
58	58	6.69E-01
59	59	6.38E-01
60	60	6.08E-01
61	61	5.79E-01
62	62	5.50E-01
63	63	5.21E-01
64	64	4.93E-01
65	65	4.65E-01
66	66	4.37E-01
67	67	4.09E-01
68	68	3.82E-01
69	69	3.55E-01
70	70	3.29E-01
71	71	3.02E-01
72	72	2.76E-01
73	73	2.50E-01
74	74	2.24E-01
75	75	1.98E-01
76	76	1.73E-01
77	77	1.47E-01
78	78	1.22E-01
79	79	9.67E-02
80	80	7.14E-02

```
RMA 93-03 DBCP Transport, 600 years
 1
       0.1       100.        50.       100.
      98.0      .0147      1100.       0.68
Polygon I
        1.       0.25     .00057        1.6        0.40        .25        .005
      .583        -1.   3.08E-04
   80y      100.0
    1     1  3.72E+01
    2     2  7.82E+00
    3     3  5.04E+00
    4     4  4.70E+00
    5     5  4.58E+00
    6     6  4.48E+00
    7     7  4.38E+00
    8     8  4.28E+00
    9     9  4.19E+00
   10    10  4.09E+00
   11    11  4.00E+00
   12    12  3.91E+00
   13    13  3.83E+00
   14    14  3.74E+00
   15    15  3.65E+00
   16    16  3.57E+00
   17    17  3.49E+00
   18    18  3.41E+00
   19    19  3.33E+00
   20    20  3.25E+00
   21    21  3.17E+00
   22    22  3.09E+00
   23    23  3.02E+00
   24    24  2.95E+00
   25    25  2.87E+00
   26    26  2.80E+00
   27    27  2.73E+00
   28    28  2.66E+00
   29    29  2.59E+00
   30    30  2.53E+00
   31    31  2.46E+00
   32    32  2.40E+00
   33    33  2.33E+00
   34    34  2.27E+00
   35    35  2.21E+00
   36    36  2.15E+00
   37    37  2.09E+00
   38    38  2.03E+00
   39    39  1.97E+00
   40    40  1.92E+00
   41    41  1.86E+00
   42    42  1.81E+00
   43    43  1.75E+00
   44    44  1.70E+00
   45    45  1.65E+00
   46    46  1.59E+00
   47    47  1.54E+00
```

54	0.77351E-06	0.52620E-04	0.91054E-09
55	0.74407E-06	0.50617E-04	0.87588E-09
56	0.71496E-06	0.48636E-04	0.84161E-09
57	0.68622E-06	0.46682E-04	0.80778E-09
58	0.65786E-06	0.44752E-04	0.77440E-09
59	0.62974E-06	0.42839E-04	0.74129E-09
60	0.60194E-06	0.40948E-04	0.70857E-09
61	0.57448E-06	0.39080E-04	0.67625E-09
62	0.54729E-06	0.37231E-04	0.64424E-09
63	0.52034E-06	0.35397E-04	0.61252E-09
64	0.49369E-06	0.33584E-04	0.58114E-09
65	0.46726E-06	0.31787E-04	0.55004E-09
66	0.44105E-06	0.30004E-04	0.51918E-09
67	0.41504E-06	0.28234E-04	0.48856E-09
68	0.38927E-06	0.26481E-04	0.45823E-09
69	0.36369E-06	0.24741E-04	0.42812E-09
70	0.33834E-06	0.23016E-04	0.39827E-09
71	0.31309E-06	0.21299E-04	0.36855E-09
72	0.28803E-06	0.19594E-04	0.33906E-09
73	0.26312E-06	0.17899E-04	0.30973E-09
74	0.23832E-06	0.16212E-04	0.28054E-09
75	0.21363E-06	0.14533E-04	0.25148E-09
76	0.18910E-06	0.12864E-04	0.22260E-09
77	0.16461E-06	0.11198E-04	0.19377E-09
78	0.14024E-06	0.95403E-05	0.16509E-09
79	0.11593E-06	0.78864E-05	0.13647E-09
80	0.91667E-07	0.62359E-05	0.10791E-09

Time: 100.000 - DBCP - 600 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.26100E-04	0.17755E-02	0.30724E-07
2	0.58603E-05	0.39866E-03	0.68984E-08
3	0.39243E-05	0.26696E-03	0.46195E-08
4	0.36824E-05	0.25050E-03	0.43347E-08
5	0.35960E-05	0.24463E-03	0.42331E-08
6	0.35245E-05	0.23976E-03	0.41489E-08
7	0.34550E-05	0.23503E-03	0.40671E-08
8	0.33863E-05	0.23036E-03	0.39862E-08
9	0.33191E-05	0.22579E-03	0.39071E-08
10	0.32521E-05	0.22123E-03	0.38282E-08
11	0.31864E-05	0.21676E-03	0.37509E-08
12	0.31216E-05	0.21236E-03	0.36746E-08
13	0.30582E-05	0.20804E-03	0.36000E-08
14	0.29950E-05	0.20374E-03	0.35256E-08
15	0.29325E-05	0.19949E-03	0.34520E-08
16	0.28713E-05	0.19533E-03	0.33799E-08
17	0.28109E-05	0.19122E-03	0.33089E-08
18	0.27513E-05	0.18716E-03	0.32387E-08
19	0.26923E-05	0.18315E-03	0.31693E-08
20	0.26341E-05	0.17919E-03	0.31007E-08
21	0.25765E-05	0.17527E-03	0.30330E-08
22	0.25196E-05	0.17140E-03	0.29660E-08
23	0.24640E-05	0.16762E-03	0.29005E-08
24	0.24092E-05	0.16389E-03	0.28360E-08
25	0.23544E-05	0.16016E-03	0.27715E-08
26	0.23007E-05	0.15651E-03	0.27083E-08
27	0.22478E-05	0.15291E-03	0.26460E-08
28	0.21955E-05	0.14935E-03	0.25845E-08
29	0.21438E-05	0.14584E-03	0.25236E-08
30	0.20934E-05	0.14241E-03	0.24642E-08
31	0.20430E-05	0.13898E-03	0.24049E-08
32	0.19937E-05	0.13563E-03	0.23469E-08
33	0.19445E-05	0.13228E-03	0.22889E-08
34	0.18963E-05	0.12900E-03	0.22322E-08
35	0.18488E-05	0.12577E-03	0.21763E-08
36	0.18019E-05	0.12258E-03	0.21211E-08
37	0.17554E-05	0.11942E-03	0.20664E-08
38	0.17095E-05	0.11629E-03	0.20124E-08
39	0.16641E-05	0.11321E-03	0.19589E-08
40	0.16198E-05	0.11019E-03	0.19068E-08
41	0.15755E-05	0.10718E-03	0.18546E-08
42	0.15322E-05	0.10423E-03	0.18036E-08
43	0.14889E-05	0.10128E-03	0.17526E-08
44	0.14465E-05	0.98399E-04	0.17027E-08
45	0.14046E-05	0.95553E-04	0.16535E-08
46	0.13626E-05	0.92695E-04	0.16040E-08
47	0.13215E-05	0.89899E-04	0.15556E-08
48	0.12809E-05	0.87139E-04	0.15079E-08
49	0.12408E-05	0.84408E-04	0.14606E-08
50	0.12010E-05	0.81703E-04	0.14138E-08
51	0.11623E-05	0.79066E-04	0.13682E-08
52	0.11234E-05	0.76421E-04	0.13224E-08
53	0.10848E-05	0.73793E-04	0.12769E-08

48	48	1.49E+00
49	49	1.44E+00
50	50	1.39E+00
51	51	1.35E+00
52	52	1.30E+00
53	53	1.25E+00
54	54	1.21E+00
55	55	1.16E+00
56	56	1.11E+00
57	57	1.07E+00
58	58	1.03E+00
59	59	9.81E-01
60	60	9.38E-01
61	61	8.95E-01
62	62	8.53E-01
63	63	8.11E-01
64	64	7.69E-01
65	65	7.28E-01
66	66	6.87E-01
67	67	6.47E-01
68	68	6.07E-01
69	69	5.67E-01
70	70	5.27E-01
71	71	4.88E-01
72	72	4.49E-01
73	73	4.10E-01
74	74	3.71E-01
75	75	3.33E-01
76	76	2.95E-01
77	77	2.57E-01
78	78	2.19E-01
79	79	1.81E-01
80	80	1.43E-01

```
RMA 93-03 DBCP Transport, 700 years
  1
       0.1      100.       50.      100.
      98.0     .0147     1100.      0.68
Polygon I
        1.      0.25    .00057       1.6       0.40       .25       .005
      .614       -1.  4.90E-04
   80y      100.0
    1     1  4.07E+01
    2     2  9.13E+00
    3     3  6.11E+00
    4     4  5.74E+00
    5     5  5.60E+00
    6     6  5.49E+00
    7     7  5.38E+00
    8     8  5.28E+00
    9     9  5.17E+00
   10    10  5.07E+00
   11    11  4.97E+00
   12    12  4.86E+00
   13    13  4.77E+00
   14    14  4.67E+00
   15    15  4.57E+00
   16    16  4.47E+00
   17    17  4.38E+00
   18    18  4.29E+00
   19    19  4.20E+00
   20    20  4.10E+00
   21    21  4.01E+00
   22    22  3.93E+00
   23    23  3.84E+00
   24    24  3.75E+00
   25    25  3.67E+00
   26    26  3.59E+00
   27    27  3.50E+00
   28    28  3.42E+00
   29    29  3.34E+00
   30    30  3.26E+00
   31    31  3.18E+00
   32    32  3.11E+00
   33    33  3.03E+00
   34    34  2.95E+00
   35    35  2.88E+00
   36    36  2.81E+00
   37    37  2.74E+00
   38    38  2.66E+00
   39    39  2.59E+00
   40    40  2.52E+00
   41    41  2.46E+00
   42    42  2.39E+00
   43    43  2.32E+00
   44    44  2.25E+00
   45    45  2.19E+00
   46    46  2.12E+00
   47    47  2.06E+00
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54	0.10471E-05	0.71229E-04	0.12325E-08
55	0.10092E-05	0.68655E-04	0.11880E-08
56	0.97160E-06	0.66095E-04	0.11437E-08
57	0.93488E-06	0.63597E-04	0.11005E-08
58	0.89861E-06	0.61130E-04	0.10578E-08
59	0.86209E-06	0.58646E-04	0.10148E-08
60	0.82611E-06	0.56198E-04	0.97245E-09
61	0.79046E-06	0.53773E-04	0.93049E-09
62	0.75515E-06	0.51370E-04	0.88892E-09
63	0.72010E-06	0.48986E-04	0.84766E-09
64	0.68529E-06	0.46618E-04	0.80669E-09
65	0.65077E-06	0.44270E-04	0.76606E-09
66	0.61649E-06	0.41938E-04	0.72570E-09
67	0.58248E-06	0.39625E-04	0.68567E-09
68	0.54868E-06	0.37325E-04	0.64588E-09
69	0.51507E-06	0.35039E-04	0.60631E-09
70	0.48163E-06	0.32764E-04	0.56695E-09
71	0.44842E-06	0.30505E-04	0.52786E-09
72	0.41538E-06	0.28257E-04	0.48896E-09
73	0.38248E-06	0.26019E-04	0.45024E-09
74	0.34972E-06	0.23790E-04	0.41167E-09
75	0.31713E-06	0.21574E-04	0.37331E-09
76	0.28467E-06	0.19366E-04	0.33510E-09
77	0.25231E-06	0.17164E-04	0.29701E-09
78	0.22004E-06	0.14969E-04	0.25902E-09
79	0.18785E-06	0.12779E-04	0.22112E-09
80	0.15572E-06	0.10593E-04	0.18330E-09

Time: 100.000 - DBCP - 700 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.27902E-04	0.18981E-02	0.32844E-07
2	0.65910E-05	0.44837E-03	0.77586E-08
3	0.45411E-05	0.30892E-03	0.53456E-08
4	0.42829E-05	0.29136E-03	0.50417E-08
5	0.41900E-05	0.28503E-03	0.49322E-08
6	0.41132E-05	0.27981E-03	0.48418E-08
7	0.40385E-05	0.27473E-03	0.47539E-08
8	0.39652E-05	0.26974E-03	0.46676E-08
9	0.38921E-05	0.26477E-03	0.45816E-08
10	0.38203E-05	0.25988E-03	0.44970E-08
11	0.37492E-05	0.25505E-03	0.44134E-08
12	0.36783E-05	0.25022E-03	0.43299E-08
13	0.36091E-05	0.24552E-03	0.42485E-08
14	0.35403E-05	0.24083E-03	0.41674E-08
15	0.34720E-05	0.23619E-03	0.40870E-08
16	0.34043E-05	0.23158E-03	0.40074E-08
17	0.33379E-05	0.22707E-03	0.39292E-08
18	0.32723E-05	0.22261E-03	0.38520E-08
19	0.32074E-05	0.21819E-03	0.37755E-08
20	0.31424E-05	0.21377E-03	0.36991E-08
21	0.30786E-05	0.20943E-03	0.36240E-08
22	0.30161E-05	0.20518E-03	0.35504E-08
23	0.29538E-05	0.20094E-03	0.34771E-08
24	0.28919E-05	0.19673E-03	0.34043E-08
25	0.28313E-05	0.19261E-03	0.33329E-08
26	0.27714E-05	0.18853E-03	0.32623E-08
27	0.27114E-05	0.18445E-03	0.31917E-08
28	0.26525E-05	0.18044E-03	0.31224E-08
29	0.25943E-05	0.17648E-03	0.30539E-08
30	0.25366E-05	0.17256E-03	0.29860E-08
31	0.24795E-05	0.16868E-03	0.29188E-08
32	0.24236E-05	0.16487E-03	0.28529E-08
33	0.23677E-05	0.16107E-03	0.27871E-08
34	0.23122E-05	0.15729E-03	0.27218E-08
35	0.22578E-05	0.15359E-03	0.26577E-08
36	0.22040E-05	0.14993E-03	0.25945E-08
37	0.21508E-05	0.14631E-03	0.25318E-08
38	0.20974E-05	0.14268E-03	0.24690E-08
39	0.20450E-05	0.13912E-03	0.24073E-08
40	0.19932E-05	0.13559E-03	0.23463E-08
41	0.19424E-05	0.13214E-03	0.22865E-08
42	0.18917E-05	0.12868E-03	0.22268E-08
43	0.18412E-05	0.12525E-03	0.21674E-08
44	0.17912E-05	0.12185E-03	0.21085E-08
45	0.17422E-05	0.11852E-03	0.20508E-08
46	0.16932E-05	0.11518E-03	0.19931E-08
47	0.16450E-05	0.11190E-03	0.19364E-08
48	0.15974E-05	0.10866E-03	0.18803E-08
49	0.15495E-05	0.10541E-03	0.18240E-08
50	0.15025E-05	0.10221E-03	0.17687E-08
51	0.14560E-05	0.99047E-04	0.17139E-08
52	0.14099E-05	0.95909E-04	0.16596E-08
53	0.13641E-05	0.92794E-04	0.16057E-08

48	48	2.00E+00
49	49	1.93E+00
50	50	1.87E+00
51	51	1.81E+00
52	52	1.75E+00
53	53	1.69E+00
54	54	1.63E+00
55	55	1.57E+00
56	56	1.51E+00
57	57	1.46E+00
58	58	1.40E+00
59	59	1.34E+00
60	60	1.29E+00
61	61	1.23E+00
62	62	1.18E+00
63	63	1.12E+00
64	64	1.07E+00
65	65	1.01E+00
66	66	9.61E-01
67	67	9.08E-01
68	68	8.55E-01
69	69	8.03E-01
70	70	7.50E-01
71	71	6.99E-01
72	72	6.47E-01
73	73	5.96E-01
74	74	5.45E-01
75	75	4.94E-01
76	76	4.44E-01
77	77	3.93E-01
78	78	3.43E-01
79	79	2.93E-01
80	80	2.43E-01

```
RMA 93-03 DBCP Transport, 800 years
  1
       0.1       100.        50.       100.
      98.0      .0147      1100.       0.68
Polygon I
        1.       0.25     .00057        1.6        0.40         .25        .005
      .639        -1.   7.11E-04
   80y      100.0
    1     1  4.35E+01
    2     2  1.03E+01
    3     3  7.08E+00
    4     4  6.67E+00
    5     5  6.53E+00
    6     6  6.41E+00
    7     7  6.29E+00
    8     8  6.18E+00
    9     9  6.06E+00
   10    10  5.95E+00
   11    11  5.84E+00
   12    12  5.73E+00
   13    13  5.62E+00
   14    14  5.52E+00
   15    15  5.41E+00
   16    16  5.30E+00
   17    17  5.20E+00
   18    18  5.10E+00
   19    19  5.00E+00
   20    20  4.90E+00
   21    21  4.80E+00
   22    22  4.70E+00
   23    23  4.60E+00
   24    24  4.51E+00
   25    25  4.41E+00
   26    26  4.32E+00
   27    27  4.23E+00
   28    28  4.13E+00
   29    29  4.04E+00
   30    30  3.95E+00
   31    31  3.86E+00
   32    32  3.78E+00
   33    33  3.69E+00
   34    34  3.60E+00
   35    35  3.52E+00
   36    36  3.43E+00
   37    37  3.35E+00
   38    38  3.27E+00
   39    39  3.19E+00
   40    40  3.11E+00
   41    41  3.03E+00
   42    42  2.95E+00
   43    43  2.87E+00
   44    44  2.79E+00
   45    45  2.71E+00
   46    46  2.64E+00
   47    47  2.56E+00
```

54	0.13186E-05	0.89703E-04	0.15522E-08
55	0.12735E-05	0.86633E-04	0.14991E-08
56	0.12287E-05	0.83586E-04	0.14464E-08
57	0.11848E-05	0.80601E-04	0.13947E-08
58	0.11408E-05	0.77605E-04	0.13429E-08
59	0.10969E-05	0.74620E-04	0.12912E-08
60	0.10539E-05	0.71695E-04	0.12406E-08
61	0.10107E-05	0.68756E-04	0.11898E-08
62	0.96826E-06	0.65868E-04	0.11398E-08
63	0.92556E-06	0.62963E-04	0.10895E-08
64	0.88360E-06	0.60109E-04	0.10401E-08
65	0.84138E-06	0.57237E-04	0.99043E-09
66	0.79994E-06	0.54418E-04	0.94165E-09
67	0.75860E-06	0.51605E-04	0.89298E-09
68	0.71742E-06	0.48804E-04	0.84451E-09
69	0.67649E-06	0.46020E-04	0.79633E-09
70	0.63569E-06	0.43244E-04	0.74830E-09
71	0.59518E-06	0.40488E-04	0.70061E-09
72	0.55479E-06	0.37741E-04	0.65307E-09
73	0.51460E-06	0.35007E-04	0.60576E-09
74	0.47457E-06	0.32284E-04	0.55864E-09
75	0.43467E-06	0.29569E-04	0.51167E-09
76	0.39495E-06	0.26867E-04	0.46491E-09
77	0.35529E-06	0.24169E-04	0.41823E-09
78	0.31578E-06	0.21482E-04	0.37172E-09
79	0.27637E-06	0.18801E-04	0.32533E-09
80	0.23705E-06	0.16126E-04	0.27904E-09

Time: 100.000 - DBCP - 800 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.29399E-04	0.19999E-02	0.34607E-07
2	0.72362E-05	0.49226E-03	0.85181E-08
3	0.50961E-05	0.34667E-03	0.59989E-08
4	0.48240E-05	0.32816E-03	0.56786E-08
5	0.47265E-05	0.32153E-03	0.55637E-08
6	0.46455E-05	0.31602E-03	0.54685E-08
7	0.45665E-05	0.31065E-03	0.53755E-08
8	0.44889E-05	0.30537E-03	0.52841E-08
9	0.44114E-05	0.30010E-03	0.51929E-08
10	0.43350E-05	0.29490E-03	0.51030E-08
11	0.42594E-05	0.28976E-03	0.50140E-08
12	0.41845E-05	0.28466E-03	0.49257E-08
13	0.41101E-05	0.27960E-03	0.48382E-08
14	0.40370E-05	0.27462E-03	0.47521E-08
15	0.39640E-05	0.26966E-03	0.46662E-08
16	0.38914E-05	0.26472E-03	0.45808E-08
17	0.38201E-05	0.25987E-03	0.44968E-08
18	0.37495E-05	0.25507E-03	0.44137E-08
19	0.36795E-05	0.25030E-03	0.43313E-08
20	0.36100E-05	0.24558E-03	0.42495E-08
21	0.35411E-05	0.24089E-03	0.41684E-08
22	0.34728E-05	0.23625E-03	0.40880E-08
23	0.34050E-05	0.23164E-03	0.40083E-08
24	0.33385E-05	0.22711E-03	0.39299E-08
25	0.32719E-05	0.22258E-03	0.38515E-08
26	0.32064E-05	0.21812E-03	0.37744E-08
27	0.31416E-05	0.21371E-03	0.36981E-08
28	0.30766E-05	0.20929E-03	0.36217E-08
29	0.30127E-05	0.20495E-03	0.35464E-08
30	0.29494E-05	0.20064E-03	0.34719E-08
31	0.28866E-05	0.19637E-03	0.33980E-08
32	0.28249E-05	0.19217E-03	0.33254E-08
33	0.27633E-05	0.18798E-03	0.32528E-08
34	0.27020E-05	0.18381E-03	0.31806E-08
35	0.26417E-05	0.17971E-03	0.31097E-08
36	0.25815E-05	0.17561E-03	0.30388E-08
37	0.25222E-05	0.17158E-03	0.29690E-08
38	0.24635E-05	0.16758E-03	0.28999E-08
39	0.24052E-05	0.16362E-03	0.28313E-08
40	0.23474E-05	0.15969E-03	0.27633E-08
41	0.22900E-05	0.15578E-03	0.26957E-08
42	0.22331E-05	0.15191E-03	0.26286E-08
43	0.21765E-05	0.14806E-03	0.25621E-08
44	0.21203E-05	0.14424E-03	0.24960E-08
45	0.20646E-05	0.14045E-03	0.24303E-08
46	0.20098E-05	0.13672E-03	0.23659E-08
47	0.19550E-05	0.13299E-03	0.23013E-08
48	0.19010E-05	0.12932E-03	0.22378E-08
49	0.18469E-05	0.12564E-03	0.21741E-08
50	0.17937E-05	0.12202E-03	0.21114E-08
51	0.17409E-05	0.11843E-03	0.20493E-08
52	0.16885E-05	0.11486E-03	0.19876E-08
53	0.16364E-05	0.11132E-03	0.19262E-08

48	48	2.49E+00
49	49	2.41E+00
50	50	2.34E+00
51	51	2.27E+00
52	52	2.20E+00
53	53	2.13E+00
54	54	2.05E+00
55	55	1.98E+00
56	56	1.91E+00
57	57	1.85E+00
58	58	1.78E+00
59	59	1.71E+00
60	60	1.64E+00
61	61	1.57E+00
62	62	1.51E+00
63	63	1.44E+00
64	64	1.38E+00
65	65	1.31E+00
66	66	1.25E+00
67	67	1.18E+00
68	68	1.12E+00
69	69	1.05E+00
70	70	9.91E-01
71	71	9.27E-01
72	72	8.64E-01
73	73	8.02E-01
74	74	7.39E-01
75	75	6.77E-01
76	76	6.15E-01
77	77	5.54E-01
78	78	4.92E-01
79	79	4.31E-01
80	80	3.69E-01

```
RMA 93-03 DBCP Transport, 900 years
  1
      0.1       100.       50.       100.
     98.0      .0147     1100.       0.68
Polygon I
       1.       0.25    .00057       1.6       0.40       .25       .005
     .660        -1.  9.67E-04
   80y      100.0
    1     1  4.58E+01
    2     2  1.13E+01
    3     3  7.94E+00
    4     4  7.52E+00
    5     5  7.36E+00
    6     6  7.24E+00
    7     7  7.12E+00
    8     8  6.99E+00
    9     9  6.87E+00
   10    10  6.75E+00
   11    11  6.64E+00
   12    12  6.52E+00
   13    13  6.40E+00
   14    14  6.29E+00
   15    15  6.18E+00
   16    16  6.06E+00
   17    17  5.95E+00
   18    18  5.84E+00
   19    19  5.73E+00
   20    20  5.63E+00
   21    21  5.52E+00
   22    22  5.41E+00
   23    23  5.31E+00
   24    24  5.20E+00
   25    25  5.10E+00
   26    26  5.00E+00
   27    27  4.90E+00
   28    28  4.79E+00
   29    29  4.69E+00
   30    30  4.60E+00
   31    31  4.50E+00
   32    32  4.40E+00
   33    33  4.31E+00
   34    34  4.21E+00
   35    35  4.12E+00
   36    36  4.02E+00
   37    37  3.93E+00
   38    38  3.84E+00
   39    39  3.75E+00
   40    40  3.66E+00
   41    41  3.57E+00
   42    42  3.48E+00
   43    43  3.39E+00
   44    44  3.30E+00
   45    45  3.22E+00
   46    46  3.13E+00
   47    47  3.05E+00
```

54	0.15840E-05	0.10775E-03	0.18646E-08
55	0.15324E-05	0.10424E-03	0.18039E-08
56	0.14812E-05	0.10076E-03	0.17436E-08
57	0.14310E-05	0.97348E-04	0.16845E-08
58	0.13806E-05	0.93919E-04	0.16252E-08
59	0.13303E-05	0.90500E-04	0.15660E-08
60	0.12804E-05	0.87099E-04	0.15072E-08
61	0.12306E-05	0.83716E-04	0.14486E-08
62	0.11818E-05	0.80392E-04	0.13911E-08
63	0.11327E-05	0.77053E-04	0.13333E-08
64	0.10843E-05	0.73763E-04	0.12764E-08
65	0.10357E-05	0.70456E-04	0.12192E-08
66	0.98779E-06	0.67197E-04	0.11628E-08
67	0.93960E-06	0.63918E-04	0.11060E-08
68	0.89211E-06	0.60687E-04	0.10501E-08
69	0.84431E-06	0.57436E-04	0.99388E-09
70	0.79726E-06	0.54235E-04	0.93849E-09
71	0.75021E-06	0.51034E-04	0.88310E-09
72	0.70333E-06	0.47845E-04	0.82792E-09
73	0.65668E-06	0.44672E-04	0.77301E-09
74	0.61013E-06	0.41505E-04	0.71821E-09
75	0.56376E-06	0.38351E-04	0.66363E-09
76	0.51754E-06	0.35207E-04	0.60922E-09
77	0.47150E-06	0.32075E-04	0.55502E-09
78	0.42552E-06	0.28947E-04	0.50089E-09
79	0.37968E-06	0.25829E-04	0.44694E-09
80	0.33389E-06	0.22714E-04	0.39304E-09

Time: 100.000 - DBCP - 900 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.30682E-04	0.20872E-02	0.36117E-07
2	0.78087E-05	0.53121E-03	0.91920E-08
3	0.55956E-05	0.38065E-03	0.65868E-08
4	0.53138E-05	0.36148E-03	0.62551E-08
5	0.52117E-05	0.35454E-03	0.61349E-08
6	0.51276E-05	0.34882E-03	0.60360E-08
7	0.50457E-05	0.34324E-03	0.59395E-08
8	0.49639E-05	0.33768E-03	0.58432E-08
9	0.48831E-05	0.33219E-03	0.57482E-08
10	0.48031E-05	0.32674E-03	0.56539E-08
11	0.47242E-05	0.32137E-03	0.55611E-08
12	0.46454E-05	0.31601E-03	0.54683E-08
13	0.45670E-05	0.31068E-03	0.53761E-08
14	0.44898E-05	0.30543E-03	0.52852E-08
15	0.44133E-05	0.30022E-03	0.51951E-08
16	0.43367E-05	0.29501E-03	0.51049E-08
17	0.42611E-05	0.28987E-03	0.50160E-08
18	0.41862E-05	0.28478E-03	0.49278E-08
19	0.41118E-05	0.27972E-03	0.48403E-08
20	0.40386E-05	0.27474E-03	0.47541E-08
21	0.39654E-05	0.26976E-03	0.46679E-08
22	0.38926E-05	0.26480E-03	0.45822E-08
23	0.38209E-05	0.25993E-03	0.44978E-08
24	0.37492E-05	0.25505E-03	0.44134E-08
25	0.36786E-05	0.25024E-03	0.43302E-08
26	0.36085E-05	0.24547E-03	0.42477E-08
27	0.35389E-05	0.24074E-03	0.41658E-08
28	0.34692E-05	0.23600E-03	0.40837E-08
29	0.34004E-05	0.23132E-03	0.40028E-08
30	0.33329E-05	0.22673E-03	0.39233E-08
31	0.32653E-05	0.22213E-03	0.38437E-08
32	0.31981E-05	0.21756E-03	0.37646E-08
33	0.31319E-05	0.21305E-03	0.36867E-08
34	0.30657E-05	0.20855E-03	0.36088E-08
35	0.30004E-05	0.20411E-03	0.35319E-08
36	0.29351E-05	0.19966E-03	0.34550E-08
37	0.28706E-05	0.19528E-03	0.33792E-08
38	0.28068E-05	0.19094E-03	0.33040E-08
39	0.27433E-05	0.18662E-03	0.32293E-08
40	0.26803E-05	0.18233E-03	0.31551E-08
41	0.26176E-05	0.17807E-03	0.30813E-08
42	0.25554E-05	0.17383E-03	0.30080E-08
43	0.24935E-05	0.16962E-03	0.29352E-08
44	0.24320E-05	0.16544E-03	0.28628E-08
45	0.23715E-05	0.16133E-03	0.27916E-08
46	0.23109E-05	0.15720E-03	0.27202E-08
47	0.22511E-05	0.15314E-03	0.26499E-08
48	0.21912E-05	0.14906E-03	0.25794E-08
49	0.21321E-05	0.14504E-03	0.25098E-08
50	0.20729E-05	0.14101E-03	0.24401E-08
51	0.20145E-05	0.13704E-03	0.23714E-08
52	0.19565E-05	0.13310E-03	0.23031E-08
53	0.18989E-05	0.12918E-03	0.22353E-08

48	48	2.96E+00
49	49	2.88E+00
50	50	2.79E+00
51	51	2.71E+00
52	52	2.63E+00
53	53	2.55E+00
54	54	2.47E+00
55	55	2.39E+00
56	56	2.31E+00
57	57	2.23E+00
58	58	2.15E+00
59	59	2.07E+00
60	60	2.00E+00
61	61	1.92E+00
62	62	1.84E+00
63	63	1.76E+00
64	64	1.69E+00
65	65	1.61E+00
66	66	1.54E+00
67	67	1.46E+00
68	68	1.39E+00
69	69	1.32E+00
70	70	1.24E+00
71	71	1.17E+00
72	72	1.10E+00
73	73	1.02E+00
74	74	9.51E-01
75	75	8.78E-01
76	76	8.06E-01
77	77	7.35E-01
78	78	6.63E-01
79	79	5.92E-01
80	80	5.20E-01

```
RMA 93-03 DBCP Transport, 1000 years
  1
       0.1       100.        50.       100.
      98.0      .0147      1100.       0.68
Polygon I
        1.       0.25     .00057        1.6       0.40        .25       .005
      .678        -1.   1.25E-03
   80y      100.0
    1     1  4.78E+01
    2     2  1.22E+01
    3     3  8.72E+00
    4     4  8.28E+00
    5     5  8.12E+00
    6     6  7.99E+00
    7     7  7.86E+00
    8     8  7.73E+00
    9     9  7.61E+00
   10    10  7.48E+00
   11    11  7.36E+00
   12    12  7.24E+00
   13    13  7.12E+00
   14    14  7.00E+00
   15    15  6.88E+00
   16    16  6.76E+00
   17    17  6.64E+00
   18    18  6.52E+00
   19    19  6.41E+00
   20    20  6.29E+00
   21    21  6.18E+00
   22    22  6.07E+00
   23    23  5.95E+00
   24    24  5.84E+00
   25    25  5.73E+00
   26    26  5.62E+00
   27    27  5.51E+00
   28    28  5.41E+00
   29    29  5.30E+00
   30    30  5.19E+00
   31    31  5.09E+00
   32    32  4.98E+00
   33    33  4.88E+00
   34    34  4.78E+00
   35    35  4.68E+00
   36    36  4.57E+00
   37    37  4.47E+00
   38    38  4.37E+00
   39    39  4.27E+00
   40    40  4.18E+00
   41    41  4.08E+00
   42    42  3.98E+00
   43    43  3.89E+00
   44    44  3.79E+00
   45    45  3.70E+00
   46    46  3.60E+00
   47    47  3.51E+00
```

54	0.18416E-05	0.12528E-03	0.21679E-08
55	0.17846E-05	0.12140E-03	0.21007E-08
56	0.17279E-05	0.11754E-03	0.20340E-08
57	0.16715E-05	0.11370E-03	0.19676E-08
58	0.16153E-05	0.10989E-03	0.19015E-08
59	0.15594E-05	0.10608E-03	0.18357E-08
60	0.15044E-05	0.10234E-03	0.17709E-08
61	0.14492E-05	0.98586E-04	0.17059E-08
62	0.13941E-05	0.94838E-04	0.16411E-08
63	0.13393E-05	0.91106E-04	0.15765E-08
64	0.12852E-05	0.87431E-04	0.15129E-08
65	0.12310E-05	0.83739E-04	0.14490E-08
66	0.11774E-05	0.80095E-04	0.13860E-08
67	0.11236E-05	0.76433E-04	0.13226E-08
68	0.10704E-05	0.72817E-04	0.12600E-08
69	0.10176E-05	0.69223E-04	0.11978E-08
70	0.96433E-06	0.65601E-04	0.11352E-08
71	0.91174E-06	0.62023E-04	0.10733E-08
72	0.85944E-06	0.58465E-04	0.10117E-08
73	0.80669E-06	0.54877E-04	0.94960E-09
74	0.75464E-06	0.51336E-04	0.88833E-09
75	0.70262E-06	0.47797E-04	0.82709E-09
76	0.65076E-06	0.44269E-04	0.76604E-09
77	0.59909E-06	0.40755E-04	0.70522E-09
78	0.54750E-06	0.37245E-04	0.64449E-09
79	0.49606E-06	0.33746E-04	0.58394E-09
80	0.44467E-06	0.30250E-04	0.52345E-09

Time: 100.000 - DBCP - 1000 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.31805E-04	0.21636E-02	0.37440E-07
2	0.83264E-05	0.56642E-03	0.98015E-08
3	0.60510E-05	0.41164E-03	0.71230E-08
4	0.57603E-05	0.39186E-03	0.67807E-08
5	0.56551E-05	0.38470E-03	0.66570E-08
6	0.55680E-05	0.37878E-03	0.65544E-08
7	0.54829E-05	0.37299E-03	0.64542E-08
8	0.53984E-05	0.36724E-03	0.63548E-08
9	0.53151E-05	0.36157E-03	0.62567E-08
10	0.52318E-05	0.35591E-03	0.61586E-08
11	0.51495E-05	0.35031E-03	0.60618E-08
12	0.50679E-05	0.34475E-03	0.59656E-08
13	0.49867E-05	0.33923E-03	0.58701E-08
14	0.49061E-05	0.33375E-03	0.57752E-08
15	0.48259E-05	0.32830E-03	0.56809E-08
16	0.47463E-05	0.32288E-03	0.55871E-08
17	0.46671E-05	0.31749E-03	0.54939E-08
18	0.45884E-05	0.31214E-03	0.54013E-08
19	0.45109E-05	0.30686E-03	0.53100E-08
20	0.44333E-05	0.30158E-03	0.52186E-08
21	0.43567E-05	0.29637E-03	0.51284E-08
22	0.42806E-05	0.29120E-03	0.50390E-08
23	0.42045E-05	0.28602E-03	0.49493E-08
24	0.41292E-05	0.28090E-03	0.48607E-08
25	0.40546E-05	0.27582E-03	0.47729E-08
26	0.39804E-05	0.27078E-03	0.46855E-08
27	0.39067E-05	0.26576E-03	0.45987E-08
28	0.38340E-05	0.26082E-03	0.45132E-08
29	0.37613E-05	0.25587E-03	0.44276E-08
30	0.36889E-05	0.25094E-03	0.43423E-08
31	0.36175E-05	0.24609E-03	0.42583E-08
32	0.35460E-05	0.24123E-03	0.41742E-08
33	0.34755E-05	0.23643E-03	0.40912E-08
34	0.34055E-05	0.23167E-03	0.40088E-08
35	0.33359E-05	0.22693E-03	0.39269E-08
36	0.32661E-05	0.22218E-03	0.38447E-08
37	0.31972E-05	0.21750E-03	0.37636E-08
38	0.31288E-05	0.21284E-03	0.36830E-08
39	0.30608E-05	0.20821E-03	0.36030E-08
40	0.29937E-05	0.20366E-03	0.35241E-08
41	0.29266E-05	0.19909E-03	0.34451E-08
42	0.28597E-05	0.19454E-03	0.33663E-08
43	0.27938E-05	0.19006E-03	0.32887E-08
44	0.27278E-05	0.18556E-03	0.32110E-08
45	0.26626E-05	0.18113E-03	0.31342E-08
46	0.25972E-05	0.17668E-03	0.30573E-08
47	0.25327E-05	0.17229E-03	0.29813E-08
48	0.24680E-05	0.16789E-03	0.29052E-08
49	0.24041E-05	0.16355E-03	0.28300E-08
50	0.23407E-05	0.15923E-03	0.27554E-08
51	0.22776E-05	0.15494E-03	0.26811E-08
52	0.22148E-05	0.15067E-03	0.26072E-08
53	0.21523E-05	0.14642E-03	0.25336E-08

48	48	3.41E+00
49	49	3.32E+00
50	50	3.23E+00
51	51	3.14E+00
52	52	3.05E+00
53	53	2.96E+00
54	54	2.87E+00
55	55	2.78E+00
56	56	2.69E+00
57	57	2.60E+00
58	58	2.52E+00
59	59	2.43E+00
60	60	2.34E+00
61	61	2.26E+00
62	62	2.17E+00
63	63	2.09E+00
64	64	2.00E+00
65	65	1.92E+00
66	66	1.83E+00
67	67	1.75E+00
68	68	1.67E+00
69	69	1.59E+00
70	70	1.50E+00
71	71	1.42E+00
72	72	1.34E+00
73	73	1.26E+00
74	74	1.18E+00
75	75	1.09E+00
76	76	1.01E+00
77	77	9.34E-01
78	78	8.53E-01
79	79	7.73E-01
80	80	6.93E-01

```
RMA 93-03 DIMP, First 100 years
  1
       0.1       100.        50.       100.
      60.0    .000082     22000.       0.52
Polygon I
        1.       0.25     .00057        1.6       0.40        .25       .005
      .089        -1.         0.
   80y      100.0
    1    1       0.0
    2    2       0.0
    3    3       0.0
    4    4       0.0
    5    5       0.0
    6    6       0.0
    7    7       0.0
    8    8       0.0
    9    9       0.0
   10   10       0.0
   11   11       0.0
   12   12       0.0
   13   13       0.0
   14   14       0.0
   15   15       0.0
   16   16       0.0
   17   17       0.0
   18   18       0.0
   19   19       0.0
   20   20       0.0
   21   21       0.0
   22   22       0.0
   23   23       0.0
   24   24       0.0
   25   25       0.0
   26   26       0.0
   27   27       0.0
   28   28       0.0
   29   29       0.0
   30   30       0.0
   31   31       0.0
   32   32       0.0
   33   33       0.0
   34   34       0.0
   35   35       0.0
   36   36       0.0
   37   37       0.0
   38   38       0.0
   39   39       0.0
   40   40       0.0
   41   41       0.0
   42   42       0.0
   43   43       0.0
   44   44       0.0
   45   45       0.0
   46   46       0.0
   47   47       0.0
```

54	0.20901E-05	0.14219E-03	0.24604E-08
55	0.20282E-05	0.13797E-03	0.23875E-08
56	0.19666E-05	0.13378E-03	0.23150E-08
57	0.19052E-05	0.12961E-03	0.22427E-08
58	0.18448E-05	0.12549E-03	0.21716E-08
59	0.17841E-05	0.12137E-03	0.21001E-08
60	0.17235E-05	0.11725E-03	0.20288E-08
61	0.16638E-05	0.11318E-03	0.19586E-08
62	0.16039E-05	0.10911E-03	0.18880E-08
63	0.15447E-05	0.10508E-03	0.18183E-08
64	0.14852E-05	0.10103E-03	0.17483E-08
65	0.14264E-05	0.97035E-04	0.16791E-08
66	0.13674E-05	0.93018E-04	0.16096E-08
67	0.13090E-05	0.89049E-04	0.15409E-08
68	0.12510E-05	0.85102E-04	0.14726E-08
69	0.11932E-05	0.81168E-04	0.14045E-08
70	0.11349E-05	0.77206E-04	0.13360E-08
71	0.10773E-05	0.73288E-04	0.12682E-08
72	0.10200E-05	0.69389E-04	0.12007E-08
73	0.96289E-06	0.65503E-04	0.11335E-08
74	0.90592E-06	0.61627E-04	0.10664E-08
75	0.84847E-06	0.57719E-04	0.99878E-09
76	0.79165E-06	0.53854E-04	0.93189E-09
77	0.73532E-06	0.50022E-04	0.86558E-09
78	0.67887E-06	0.46182E-04	0.79914E-09
79	0.62255E-06	0.42350E-04	0.73283E-09
80	0.56633E-06	0.38526E-04	0.66666E-09

```
---------------------------------------------------------------
              VLEACH (Version 2.2, 1995)

                          By:
        Varadhan Ravi and Jeffrey A. Johnson
                 (USEPA Contractors)
        Center for Subsurface Modeling Support
        Robert S. Kerr Environmental Research Laboratory
        U.S. Environmental Protection Agency
        P.O. Box 1198
        Ada, OK 74820

        Based on the original VLEACH (version 1.0)
        developed by CH2M Hill, Redding, California
        for USEPA Region IX
---------------------------------------------------------------

RMA 93-03 DIMP, First 100 years
  1 polygons.
Timestep =   0.10 years.  Simulation length =  100.00 years.
Printout every  50.00 years.  Vertical profile stored every 100.00 years.
Koc =       60.000    ml/g,      0.21189E-02cu.ft./g
Kh =     0.82000E-04 (dimensionless).
Aqueous solubility =      22000.     mg/l,       622.97     g/cu.ft
Free air diffusion coefficient = .52000     sq. m/day,  2043.1     sq.ft./yr


Polygon   1
Polygon I
Polygon area =      1.0000    sq. ft.
 80 cells, each cell  0.250 ft. thick.
Soil Properties:
 Bulk density =      1.6000    g/ml,       45307.    g/cu.ft.
 Porosity = 0.4000 Volumetric water content = 0.2500
 Organic carbon content = 0.00500000
Recharge Rate = 0.00057000 ft/yr
Conc. in recharge water =     0.89000E-01mg/l,      0.25202E-02g/cu.ft
Atmospheric concentration =      -1.0000    mg/l,     -0.28317E-01g/cu.ft
Water table has a fixed concentration of     0.00000    mg/l,      0.00000    g/
   with respect to gas diffusion.
```

48	48	0.0
49	49	0.0
50	50	0.0
51	51	0.0
52	52	0.0
53	53	0.0
54	54	0.0
55	55	0.0
56	56	0.0
57	57	0.0
58	58	0.0
59	59	0.0
60	60	0.0
61	61	0.0
62	62	0.0
63	63	0.0
64	64	0.0
65	65	0.0
66	66	0.0
67	67	0.0
68	68	0.0
69	69	0.0
70	70	0.0
71	71	0.0
72	72	0.0
73	73	0.0
74	74	0.0
75	75	0.0
76	76	0.0
77	77	0.0
78	78	0.0
79	79	0.0
80	80	0.0

Time: 100.000 - DIMP - 100 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.55013E-07	0.67089E-03	0.71077E-08
2	0.81592E-08	0.99503E-04	0.10542E-08
3	0.85479E-09	0.10424E-04	0.11044E-09
4	0.91442E-10	0.11151E-05	0.11814E-10
5	0.30013E-10	0.36601E-06	0.38777E-11
6	0.24649E-10	0.30059E-06	0.31846E-11
7	0.22941E-10	0.27977E-06	0.29639E-11
8	0.21514E-10	0.26237E-06	0.27797E-11
9	0.20184E-10	0.24615E-06	0.26078E-11
10	0.18937E-10	0.23093E-06	0.24466E-11
11	0.17766E-10	0.21666E-06	0.22953E-11
12	0.16668E-10	0.20326E-06	0.21534E-11
13	0.15637E-10	0.19070E-06	0.20203E-11
14	0.14670E-10	0.17891E-06	0.18954E-11
15	0.13763E-10	0.16785E-06	0.17782E-11
16	0.12912E-10	0.15747E-06	0.16683E-11
17	0.12114E-10	0.14773E-06	0.15651E-11
18	0.11365E-10	0.13860E-06	0.14683E-11
19	0.10662E-10	0.13002E-06	0.13775E-11
20	0.10003E-10	0.12198E-06	0.12923E-11
21	0.93838E-11	0.11444E-06	0.12124E-11
22	0.88033E-11	0.10736E-06	0.11374E-11
23	0.82587E-11	0.10072E-06	0.10670E-11
24	0.77476E-11	0.94483E-07	0.10010E-11
25	0.72681E-11	0.88636E-07	0.93904E-12
26	0.68182E-11	0.83149E-07	0.88091E-12
27	0.63960E-11	0.78001E-07	0.82636E-12
28	0.59999E-11	0.73170E-07	0.77519E-12
29	0.56282E-11	0.68637E-07	0.72716E-12
30	0.52795E-11	0.64384E-07	0.68210E-12
31	0.49522E-11	0.60392E-07	0.63982E-12
32	0.46451E-11	0.56647E-07	0.60014E-12
33	0.43569E-11	0.53132E-07	0.56290E-12
34	0.40864E-11	0.49834E-07	0.52796E-12
35	0.38325E-11	0.46738E-07	0.49516E-12
36	0.35943E-11	0.43833E-07	0.46438E-12
37	0.33707E-11	0.41106E-07	0.43549E-12
38	0.31608E-11	0.38547E-07	0.40838E-12
39	0.29638E-11	0.36144E-07	0.38293E-12
40	0.27789E-11	0.33889E-07	0.35903E-12
41	0.26053E-11	0.31772E-07	0.33660E-12
42	0.24422E-11	0.29783E-07	0.31554E-12
43	0.22892E-11	0.27917E-07	0.29576E-12
44	0.21454E-11	0.26164E-07	0.27719E-12
45	0.20104E-11	0.24517E-07	0.25974E-12
46	0.18835E-11	0.22970E-07	0.24335E-12
47	0.17644E-11	0.21517E-07	0.22796E-12
48	0.16524E-11	0.20151E-07	0.21349E-12
49	0.15471E-11	0.18867E-07	0.19989E-12
50	0.14482E-11	0.17661E-07	0.18710E-12
51	0.13551E-11	0.16526E-07	0.17508E-12
52	0.12676E-11	0.15458E-07	0.16377E-12
53	0.11852E-11	0.14453E-07	0.15312E-12

54	0.11076E-11	0.13508E-07	0.14310E-12
55	0.10346E-11	0.12617E-07	0.13367E-12
56	0.96572E-12	0.11777E-07	0.12477E-12
57	0.90082E-12	0.10986E-07	0.11638E-12
58	0.83958E-12	0.10239E-07	0.10847E-12
59	0.78175E-12	0.95336E-08	0.10100E-12
60	0.72711E-12	0.88672E-08	0.93943E-13
61	0.67543E-12	0.82370E-08	0.87266E-13
62	0.62650E-12	0.76403E-08	0.80944E-13
63	0.58012E-12	0.70747E-08	0.74952E-13
64	0.53611E-12	0.65379E-08	0.69265E-13
65	0.49427E-12	0.60277E-08	0.63860E-13
66	0.45445E-12	0.55421E-08	0.58715E-13
67	0.41648E-12	0.50790E-08	0.53809E-13
68	0.38020E-12	0.46366E-08	0.49122E-13
69	0.34547E-12	0.42131E-08	0.44635E-13
70	0.31215E-12	0.38067E-08	0.40330E-13
71	0.28010E-12	0.34158E-08	0.36189E-13
72	0.24919E-12	0.30389E-08	0.32195E-13
73	0.21929E-12	0.26743E-08	0.28332E-13
74	0.19029E-12	0.23206E-08	0.24585E-13
75	0.16206E-12	0.19763E-08	0.20938E-13
76	0.13449E-12	0.16401E-08	0.17376E-13
77	0.10747E-12	0.13106E-08	0.13885E-13
78	0.80883E-13	0.98637E-09	0.10450E-13
79	0.54628E-13	0.66619E-09	0.70578E-14
80	0.28595E-13	0.34872E-09	0.36944E-14

```
RMA 93-03 DIMP, 200 years
  1
      0.1       100.        50.        100.
     60.0    .000082     22000.        0.52
Polygon I
       1.       0.25     .00057         1.6        0.40        .25        .005
     .308        -1.   2.92E-08
   80y       100.0
    1      1  1.08E+01
    2      2  1.60E+00
    3      3  1.68E-01
    4      4  1.80E-02
    5      5  5.90E-03
    6      6  4.84E-03
    7      7  4.51E-03
    8      8  4.23E-03
    9      9  3.97E-03
   10     10  3.72E-03
   11     11  3.49E-03
   12     12  3.28E-03
   13     13  3.07E-03
   14     14  2.88E-03
   15     15  2.70E-03
   16     16  2.54E-03
   17     17  2.38E-03
   18     18  2.23E-03
   19     19  2.09E-03
   20     20  1.97E-03
   21     21  1.84E-03
   22     22  1.73E-03
   23     23  1.62E-03
   24     24  1.52E-03
   25     25  1.43E-03
   26     26  1.34E-03
   27     27  1.26E-03
   28     28  1.18E-03
   29     29  1.11E-03
   30     30  1.04E-03
   31     31  9.73E-04
   32     32  9.13E-04
   33     33  8.56E-04
   34     34  8.03E-04
   35     35  7.53E-04
   36     36  7.06E-04
   37     37  6.62E-04
   38     38  6.21E-04
   39     39  5.82E-04
   40     40  5.46E-04
   41     41  5.12E-04
   42     42  4.80E-04
   43     43  4.50E-04
   44     44  4.22E-04
   45     45  3.95E-04
   46     46  3.70E-04
   47     47  3.47E-04
```

48	48	3.25E-04
49	49	3.04E-04
50	50	2.85E-04
51	51	2.66E-04
52	52	2.49E-04
53	53	2.33E-04
54	54	2.18E-04
55	55	2.03E-04
56	56	1.90E-04
57	57	1.77E-04
58	58	1.65E-04
59	59	1.54E-04
60	60	1.43E-04
61	61	1.33E-04
62	62	1.23E-04
63	63	1.14E-04
64	64	1.05E-04
65	65	9.71E-05
66	66	8.93E-05
67	67	8.18E-05
68	68	7.47E-05
69	69	6.79E-05
70	70	6.13E-05
71	71	5.50E-05
72	72	4.90E-05
73	73	4.31E-05
74	74	3.74E-05
75	75	3.18E-05
76	76	2.64E-05
77	77	2.11E-05
78	78	1.59E-05
79	79	1.07E-05
80	80	5.62E-06

Time: 100.000 - DIMP - 200 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.22999E-06	0.28047E-02	0.29714E-07
2	0.46502E-07	0.56710E-03	0.60081E-08
3	0.73916E-08	0.90141E-04	0.95499E-09
4	0.11174E-08	0.13627E-04	0.14437E-09
5	0.27375E-09	0.33384E-05	0.35368E-10
6	0.16824E-09	0.20518E-05	0.21737E-10
7	0.14906E-09	0.18178E-05	0.19258E-10
8	0.13910E-09	0.16963E-05	0.17971E-10
9	0.13046E-09	0.15910E-05	0.16855E-10
10	0.12239E-09	0.14926E-05	0.15813E-10
11	0.11483E-09	0.14004E-05	0.14836E-10
12	0.10776E-09	0.13142E-05	0.13923E-10
13	0.10109E-09	0.12328E-05	0.13061E-10
14	0.94846E-10	0.11567E-05	0.12254E-10
15	0.88983E-10	0.10852E-05	0.11497E-10
16	0.83514E-10	0.10185E-05	0.10790E-10
17	0.78355E-10	0.95555E-06	0.10123E-10
18	0.73506E-10	0.89641E-06	0.94969E-11
19	0.68956E-10	0.84093E-06	0.89091E-11
20	0.64729E-10	0.78938E-06	0.83630E-11
21	0.60713E-10	0.74040E-06	0.78440E-11
22	0.56970E-10	0.69475E-06	0.73604E-11
23	0.53443E-10	0.65174E-06	0.69048E-11
24	0.50140E-10	0.61146E-06	0.64780E-11
25	0.47056E-10	0.57386E-06	0.60796E-11
26	0.44148E-10	0.53839E-06	0.57038E-11
27	0.41429E-10	0.50523E-06	0.53526E-11
28	0.38863E-10	0.47394E-06	0.50211E-11
29	0.36469E-10	0.44475E-06	0.47118E-11
30	0.34212E-10	0.41722E-06	0.44202E-11
31	0.32085E-10	0.39128E-06	0.41453E-11
32	0.30096E-10	0.36703E-06	0.38884E-11
33	0.28231E-10	0.34428E-06	0.36474E-11
34	0.26481E-10	0.32294E-06	0.34214E-11
35	0.24839E-10	0.30291E-06	0.32092E-11
36	0.23297E-10	0.28411E-06	0.30099E-11
37	0.21849E-10	0.26645E-06	0.28229E-11
38	0.20492E-10	0.24990E-06	0.26475E-11
39	0.19216E-10	0.23434E-06	0.24827E-11
40	0.18020E-10	0.21975E-06	0.23281E-11
41	0.16897E-10	0.20606E-06	0.21830E-11
42	0.15841E-10	0.19319E-06	0.20467E-11
43	0.14851E-10	0.18110E-06	0.19187E-11
44	0.13921E-10	0.16976E-06	0.17985E-11
45	0.13045E-10	0.15908E-06	0.16854E-11
46	0.12222E-10	0.14905E-06	0.15791E-11
47	0.11452E-10	0.13965E-06	0.14796E-11
48	0.10727E-10	0.13081E-06	0.13859E-11
49	0.10044E-10	0.12248E-06	0.12976E-11
50	0.94036E-11	0.11468E-06	0.12149E-11
51	0.87983E-11	0.10730E-06	0.11367E-11
52	0.82309E-11	0.10038E-06	0.10634E-11
53	0.76976E-11	0.93874E-07	0.99453E-12

54	0.71960E-11	0.87756E-07	0.92971E-12
55	0.67203E-11	0.81955E-07	0.86826E-12
56	0.62752E-11	0.76527E-07	0.81075E-12
57	0.58539E-11	0.71389E-07	0.75632E-12
58	0.54567E-11	0.66545E-07	0.70500E-12
59	0.50830E-11	0.61988E-07	0.65672E-12
60	0.47281E-11	0.57659E-07	0.61086E-12
61	0.43932E-11	0.53575E-07	0.56760E-12
62	0.40745E-11	0.49689E-07	0.52642E-12
63	0.37737E-11	0.46020E-07	0.48755E-12
64	0.34869E-11	0.42523E-07	0.45050E-12
65	0.32163E-11	0.39223E-07	0.41554E-12
66	0.29583E-11	0.36077E-07	0.38221E-12
67	0.27119E-11	0.33072E-07	0.35038E-12
68	0.24766E-11	0.30203E-07	0.31998E-12
69	0.22514E-11	0.27456E-07	0.29088E-12
70	0.20351E-11	0.24818E-07	0.26293E-12
71	0.18271E-11	0.22282E-07	0.23607E-12
72	0.16269E-11	0.19840E-07	0.21019E-12
73	0.14330E-11	0.17476E-07	0.18514E-12
74	0.12449E-11	0.15182E-07	0.16084E-12
75	0.10617E-11	0.12947E-07	0.13717E-12
76	0.88294E-12	0.10768E-07	0.11408E-12
77	0.70785E-12	0.86323E-08	0.91453E-13
78	0.53568E-12	0.65326E-08	0.69209E-13
79	0.36546E-12	0.44568E-08	0.47217E-13
80	0.19693E-12	0.24016E-08	0.25443E-13

```
RMA 93-03 DIMP, 300 years
  1
       0.1       100.        50.        100.
      60.0    .000082     22000.        0.52
Polygon I
        1.       0.25     .00057        1.6        0.40        .25        .005
      .432        -1.   1.94E-07
   80y      100.0
     1    1  4.52E+01
     2    2  9.14E+00
     3    3  1.45E+00
     4    4  2.20E-01
     5    5  5.38E-02
     6    6  3.31E-02
     7    7  2.93E-02
     8    8  2.73E-02
     9    9  2.56E-02
    10   10  2.40E-02
    11   11  2.26E-02
    12   12  2.12E-02
    13   13  1.99E-02
    14   14  1.86E-02
    15   15  1.75E-02
    16   16  1.64E-02
    17   17  1.54E-02
    18   18  1.44E-02
    19   19  1.35E-02
    20   20  1.27E-02
    21   21  1.19E-02
    22   22  1.12E-02
    23   23  1.05E-02
    24   24  9.85E-03
    25   25  9.25E-03
    26   26  8.67E-03
    27   27  8.14E-03
    28   28  7.64E-03
    29   29  7.17E-03
    30   30  6.72E-03
    31   31  6.30E-03
    32   32  5.91E-03
    33   33  5.55E-03
    34   34  5.20E-03
    35   35  4.88E-03
    36   36  4.58E-03
    37   37  4.29E-03
    38   38  4.03E-03
    39   39  3.78E-03
    40   40  3.54E-03
    41   41  3.32E-03
    42   42  3.11E-03
    43   43  2.92E-03
    44   44  2.74E-03
    45   45  2.56E-03
    46   46  2.40E-03
    47   47  2.25E-03
```

48	48	2.11E-03
49	49	1.97E-03
50	50	1.85E-03
51	51	1.73E-03
52	52	1.62E-03
53	53	1.51E-03
54	54	1.41E-03
55	55	1.32E-03
56	56	1.23E-03
57	57	1.15E-03
58	58	1.07E-03
59	59	9.99E-04
60	60	9.29E-04
61	61	8.63E-04
62	62	8.01E-04
63	63	7.42E-04
64	64	6.85E-04
65	65	6.32E-04
66	66	5.81E-04
67	67	5.33E-04
68	68	4.87E-04
69	69	4.42E-04
70	70	4.00E-04
71	71	3.59E-04
72	72	3.20E-04
73	73	2.82E-04
74	74	2.45E-04
75	75	2.09E-04
76	76	1.74E-04
77	77	1.39E-04
78	78	1.05E-04
79	79	7.18E-05
80	80	3.87E-05

Time: 100.000 - DIMP - 300 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.43280E-06	0.52781E-02	0.55918E-07
2	0.12502E-06	0.15246E-02	0.16152E-07
3	0.28248E-07	0.34449E-03	0.36497E-08
4	0.56314E-08	0.68676E-04	0.72758E-09
5	0.13220E-08	0.16123E-04	0.17081E-09
6	0.60392E-09	0.73649E-05	0.78026E-10
7	0.47766E-09	0.58251E-05	0.61713E-10
8	0.43705E-09	0.53299E-05	0.56467E-10
9	0.40885E-09	0.49860E-05	0.52824E-10
10	0.38347E-09	0.46765E-05	0.49544E-10
11	0.36012E-09	0.43917E-05	0.46527E-10
12	0.33801E-09	0.41220E-05	0.43670E-10
13	0.31723E-09	0.38686E-05	0.40986E-10
14	0.29744E-09	0.36273E-05	0.38429E-10
15	0.27921E-09	0.34050E-05	0.36074E-10
16	0.26198E-09	0.31949E-05	0.33848E-10
17	0.24587E-09	0.29985E-05	0.31767E-10
18	0.23056E-09	0.28117E-05	0.29788E-10
19	0.21626E-09	0.26373E-05	0.27940E-10
20	0.20303E-09	0.24760E-05	0.26232E-10
21	0.19050E-09	0.23232E-05	0.24613E-10
22	0.17888E-09	0.21814E-05	0.23111E-10
23	0.16786E-09	0.20470E-05	0.21687E-10
24	0.15750E-09	0.19208E-05	0.20349E-10
25	0.14782E-09	0.18027E-05	0.19098E-10
26	0.13868E-09	0.16912E-05	0.17918E-10
27	0.13014E-09	0.15871E-05	0.16814E-10
28	0.12213E-09	0.14894E-05	0 15779E-10
29	0.11461E-09	0.13976E-05	0 14807E-10
30	0.10751E-09	0.13111E-05	0.13890E-10
31	0.10085E-09	0.12299E-05	0 13030E-10
32	0.94612E-10	0.11538E-05	0.12224E-10
33	0.88785E-10	0.10827E-05	0 11471E-10
34	0.83279E-10	0.10156E-05	0 10760E-10
35	0.78128E-10	0.95279E-06	0 10094E-10
36	0.73302E-10	0.89393E-06	0 94706E-11
37	0.68743E-10	0.83832E-06	0 88815E-11
38	0.64497E-10	0.78655E-06	0 83330E-11
39	0.60502E-10	0.73783E-06	0.78168E-11
40	0.56726E-10	0.69178E-06	0 73290E-11
41	0.53193E-10	0.64870E-06	0 68725E-11
42	0.49868E-10	0.60814E-06	0 64429E-11
43	0.46768E-10	0.57034E-06	0.60424E-11
44	0.43858E-10	0.53485E-06	0 56664E-11
45	0.41084E-10	0.50102E-06	0 53080E-11
46	0.38498E-10	0.46949E-06	0.49739E-11
47	0.36077E-10	0.43997E-06	0 46612E-11
48	0.33808E-10	0.41229E-06	0 43679E-11
49	0.31644E-10	0.38590E-06	0.40884E-11
50	0.29643E-10	0.36150E-06	0 38299E-11
51	0.27746E-10	0.33837E-06	0 35848E-11
52	0.25966E-10	0.31666E-06	0 33548E-11
53	0.24269E-10	0.29596E-06	0 31355E-11

54	0.22677E-10	0.27655E-06	0.29299E-11
55	0.21196E-10	0.25848E-06	0.27385E-11
56	0.19786E-10	0.24129E-06	0.25563E-11
57	0.18469E-10	0.22523E-06	0.23861E-11
58	0.17214E-10	0.20993E-06	0.22240E-11
59	0.16041E-10	0.19563E-06	0.20725E-11
60	0.14927E-10	0.18204E-06	0.19286E-11
61	0.13871E-10	0.16916E-06	0.17921E-11
62	0.12873E-10	0.15699E-06	0.16632E-11
63	0.11926E-10	0.14544E-06	0.15409E-11
64	0.11024E-10	0.13444E-06	0.14243E-11
65	0.10169E-10	0.12402E-06	0.13139E-11
66	0.93551E-11	0.11409E-06	0.12087E-11
67	0.85805E-11	0.10464E-06	0.11086E-11
68	0.78406E-11	0.95617E-07	0.10130E-11
69	0.71288E-11	0.86936E-07	0.92103E-12
70	0.64490E-11	0.78646E-07	0.83320E-12
71	0.57942E-11	0.70661E-07	0.74860E-12
72	0.51643E-11	0.62979E-07	0.66722E-12
73	0.45546E-11	0.55544E-07	0.58846E-12
74	0.39626E-11	0.48325E-07	0.51197E-12
75	0.33864E-11	0.41298E-07	0.43753E-12
76	0.28245E-11	0.34445E-07	0.36492E-12
77	0.22715E-11	0.27701E-07	0.29347E-12
78	0.17285E-11	0.21079E-07	0.22332E-12
79	0.11942E-11	0.14564E-07	0.15429E-12
80	0.66455E-12	0.81043E-08	0.85859E-13

```
RMA 93-03 DIMP, 400 years
  1
       0.1      100.       50.      100.
      60.0   .000082    22000.      0.52
Polygon I
        1.      0.25    .00057       1.6      0.40       .25      .005
      .509       -1.  6.31E-07
   80y      100.0
    1     1  8.50E+01
    2     2  2.46E+01
    3     3  5.55E+00
    4     4  1.11E+00
    5     5  2.60E-01
    6     6  1.19E-01
    7     7  9.39E-02
    8     8  8.59E-02
    9     9  8.03E-02
   10    10  7.54E-02
   11    11  7.08E-02
   12    12  6.64E-02
   13    13  6.23E-02
   14    14  5.84E-02
   15    15  5.49E-02
   16    16  5.15E-02
   17    17  4.83E-02
   18    18  4.53E-02
   19    19  4.25E-02
   20    20  3.99E-02
   21    21  3.74E-02
   22    22  3.51E-02
   23    23  3.30E-02
   24    24  3.09E-02
   25    25  2.90E-02
   26    26  2.72E-02
   27    27  2.56E-02
   28    28  2.40E-02
   29    29  2.25E-02
   30    30  2.11E-02
   31    31  1.98E-02
   32    32  1.86E-02
   33    33  1.74E-02
   34    34  1.64E-02
   35    35  1.54E-02
   36    36  1.44E-02
   37    37  1.35E-02
   38    38  1.27E-02
   39    39  1.19E-02
   40    40  1.11E-02
   41    41  1.05E-02
   42    42  9.80E-03
   43    43  9.19E-03
   44    44  8.62E-03
   45    45  8.07E-03
   46    46  7.56E-03
   47    47  7.09E-03
```

48	48	6.64E-03
49	49	6.22E-03
50	50	5.82E-03
51	51	5.45E-03
52	52	5.10E-03
53	53	4.77E-03
54	54	4.46E-03
55	55	4.16E-03
56	56	3.89E-03
57	57	3.63E-03
58	58	3.38E-03
59	59	3.15E-03
60	60	2.93E-03
61	61	2.73E-03
62	62	2.53E-03
63	63	2.34E-03
64	64	2.17E-03
65	65	2.00E-03
66	66	1.84E-03
67	67	1.69E-03
68	68	1.54E-03
69	69	1.40E-03
70	70	1.27E-03
71	71	1.14E-03
72	72	1.01E-03
73	73	8.95E-04
74	74	7.79E-04
75	75	6.65E-04
76	76	5.55E-04
77	77	4.46E-04
78	78	3.40E-04
79	79	2.35E-04
80	80	1.31E-04

Time: 100.000 - DIMP - 400 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.62641E-06	0.76392E-02	0.80932E-07
2	0.23448E-06	0.28595E-02	0.30295E-07
3	0.69072E-07	0.84234E-03	0.89240E-08
4	0.17430E-07	0.21256E-03	0.22520E-08
5	0.44517E-08	0.54289E-04	0.57516E-09
6	0.16736E-08	0.20410E-04	0.21623E-09
7	0.11151E-08	0.13599E-04	0.14407E-09
8	0.97331E-09	0.11870E-04	0.12575E-09
9	0.90270E-09	0.11009E-04	0.11663E-09
10	0.84604E-09	0.10318E-04	0.10931E-09
11	0.79413E-09	0.96845E-05	0.10260E-09
12	0.74523E-09	0.90882E-05	0.96283E-10
13	0.69936E-09	0.85288E-05	0.90357E-10
14	0.65613E-09	0.80016E-05	0.84772E-10
15	0.61609E-09	0.75133E-05	0.79599E-10
16	0.57826E-09	0.70520E-05	0.74711E-10
17	0.54261E-09	0.66172E-05	0.70105E-10
18	0.50914E-09	0.62090E-05	0.65780E-10
19	0.47777E-09	0.58265E-05	0.61728E-10
20	0.44846E-09	0.54690E-05	0.57940E-10
21	0.42075E-09	0.51311E-05	0.54361E-10
22	0.39485E-09	0.48153E-05	0.51015E-10
23	0.37080E-09	0.45220E-05	0.47907E-10
24	0.34783E-09	0.42418E-05	0.44939E-10
25	0.32638E-09	0.39803E-05	0.42169E-10
26	0.30625E-09	0.37348E-05	0.39568E-10
27	0.28768E-09	0.35083E-05	0.37168E-10
28	0.26998E-09	0.32924E-05	0.34881E-10
29	0.25328E-09	0.30887E-05	0.32723E-10
30	0.23761E-09	0.28977E-05	0.30699E-10
31	0.22296E-09	0.27191E-05	0.28807E-10
32	0.20931E-09	0.25525E-05	0.27042E-10
33	0.19624E-09	0.23932E-05	0.25354E-10
34	0.18436E-09	0.22482E-05	0.23819E-10
35	0.17311E-09	0.21111E-05	0.22365E-10
36	0.16227E-09	0.19789E-05	0.20965E-10
37	0.15216E-09	0.18556E-05	0.19659E-10
38	0.14286E-09	0.17422E-05	0.18458E-10
39	0.13401E-09	0.16343E-05	0.17314E-10
40	0.12547E-09	0.15301E-05	0.16211E-10
41	0.11794E-09	0.14383E-05	0.15238E-10
42	0.11053E-09	0.13480E-05	0.14281E-10
43	0.10362E-09	0.12636E-05	0.13387E-10
44	0.97163E-10	0.11849E-05	0.12553E-10
45	0.91055E-10	0.11104E-05	0.11764E-10
46	0.85325E-10	0.10406E-05	0.11024E-10
47	0.79979E-10	0.97535E-06	0.10333E-10
48	0.74934E-10	0.91383E-06	0.96814E-11
49	0.70194E-10	0.85603E-06	0.90690E-11
50	0.65720E-10	0.80146E-06	0.84910E-11
51	0.61529E-10	0.75035E-06	0.79495E-11
52	0.57584E-10	0.70224E-06	0.74398E-11
53	0.53867E-10	0.65691E-06	0.69596E-11

54	0.50368E-10	0.61425E-06	0.65076E-11
55	0.47044E-10	0.57370E-06	0.60780E-11
56	0.43948E-10	0.53595E-06	0.56780E-11
57	0.41021E-10	0.50025E-06	0.52999E-11
58	0.38238E-10	0.46631E-06	0.49403E-11
59	0.35625E-10	0.43445E-06	0.46028E-11
60	0.33153E-10	0.40430E-06	0.42833E-11
61	0.30841E-10	0.37611E-06	0.39846E-11
62	0.28622E-10	0.34905E-06	0.36979E-11
63	0.26506E-10	0.32324E-06	0.34246E-11
64	0.24533E-10	0.29919E-06	0.31697E-11
65	0.22639E-10	0.27608E-06	0.29249E-11
66	0.20834E-10	0.25408E-06	0.26918E-11
67	0.19124E-10	0.23322E-06	0.24708E-11
68	0.17468E-10	0.21303E-06	0.22569E-11
69	0.15889E-10	0.19377E-06	0.20529E-11
70	0.14393E-10	0.17553E-06	0.18596E-11
71	0.12942E-10	0.15783E-06	0.16721E-11
72	0.11521E-10	0.14050E-06	0.14885E-11
73	0.10180E-10	0.12415E-06	0.13153E-11
74	0.88750E-11	0.10823E-06	0.11466E-11
75	0.75978E-11	0.92656E-07	0.98163E-12
76	0.63540E-11	0.77487E-07	0.82093E-12
77	0.51324E-11	0.62590E-07	0.66310E-12
78	0.39346E-11	0.47983E-07	0.50835E-12
79	0.27524E-11	0.33566E-07	0.35561E-12
80	0.15813E-11	0.19284E-07	0.20430E-12

```
RMA 93-03 DIMP, 500 years
  1
       0.1       100.         50.        100.
      60.0    .000082      22000.        0.52
Polygon I
        1.       0.25      .00057         1.6        0.40          .25         .005
      .561        -1.    1.44E-06
   80y      100.0
    1     1  1.23E+02
    2     2  4.61E+01
    3     3  1.36E+01
    4     4  3.42E+00
    5     5  8.75E-01
    6     6  3.29E-01
    7     7  2.19E-01
    8     8  1.91E-01
    9     9  1.77E-01
   10    10  1.66E-01
   11    11  1.56E-01
   12    12  1.46E-01
   13    13  1.37E-01
   14    14  1.29E-01
   15    15  1.21E-01
   16    16  1.14E-01
   17    17  1.07E-01
   18    18  1.00E-01
   19    19  9.39E-02
   20    20  8.81E-02
   21    21  8.27E-02
   22    22  7.76E-02
   23    23  7.29E-02
   24    24  6.83E-02
   25    25  6.41E-02
   26    26  6.02E-02
   27    27  5.65E-02
   28    28  5.30E-02
   29    29  4.98E-02
   30    30  4.67E-02
   31    31  4.38E-02
   32    32  4.11E-02
   33    33  3.86E-02
   34    34  3.62E-02
   35    35  3.40E-02
   36    36  3.19E-02
   37    37  2.99E-02
   38    38  2.81E-02
   39    39  2.63E-02
   40    40  2.47E-02
   41    41  2.32E-02
   42    42  2.17E-02
   43    43  2.04E-02
   44    44  1.91E-02
   45    45  1.79E-02
   46    46  1.68E-02
   47    47  1.57E-02
```

48	48	1.47E-02
49	49	1.38E-02
50	50	1.29E-02
51	51	1.21E-02
52	52	1.13E-02
53	53	1.06E-02
54	54	9.90E-03
55	55	9.24E-03
56	56	8.64E-03
57	57	8.06E-03
58	58	7.51E-03
59	59	7.00E-03
60	60	6.51E-03
61	61	6.06E-03
62	62	5.62E-03
63	63	5.21E-03
64	64	4.82E-03
65	65	4.45E-03
66	66	4.09E-03
67	67	3.76E-03
68	68	3.43E-03
69	69	3.12E-03
70	70	2.83E-03
71	71	2.54E-03
72	72	2.26E-03
73	73	2.00E-03
74	74	1.74E-03
75	75	1.49E-03
76	76	1.25E-03
77	77	1.01E-03
78	78	7.73E-04
79	79	5.41E-04
80	80	3.11E-04

Time: 100.000 - DIMP - 500 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.79802E-06	0.97319E-02	0.10310E-06
2	0.36176E-06	0.44117E-02	0.46739E-07
3	0.13075E-06	0.15945E-02	0.16893E-07
4	0.40011E-07	0.48794E-03	0.51694E-08
5	0.11553E-07	0.14089E-03	0.14926E-08
6	0.40356E-08	0.49215E-04	0.52140E-09
7	0.22543E-08	0.27491E-04	0.29125E-09
8	0.18118E-08	0.22095E-04	0.23408E-09
9	0.16461E-08	0.20075E-04	0.21268E-09
10	0.15369E-08	0.18743E-04	0.19857E-09
11	0.14424E-08	0.17591E-04	0.18636E-09
12	0.13526E-08	0.16495E-04	0.17476E-09
13	0.12692E-08	0.15477E-04	0.16397E-09
14	0.11928E-08	0.14546E-04	0.15411E-09
15	0.11198E-08	0.13657E-04	0.14468E-09
16	0.10528E-08	0.12839E-04	0.13602E-09
17	0.98874E-09	0.12058E-04	0.12774E-09
18	0.92664E-09	0.11301E-04	0.11972E-09
19	0.86952E-09	0.10604E-04	0.11234E-09
20	0.81606E-09	0.99520E-05	0.10544E-09
21	0.76604E-09	0.93419E-05	0.98972E-10
22	0.71901E-09	0.87684E-05	0.92895E-10
23	0.67514E-09	0.82334E-05	0.87228E-10
24	0.63337E-09	0.77240E-05	0.81831E-10
25	0.59438E-09	0.72486E-05	0.76794E-10
26	0.55804E-09	0.68054E-05	0.72098E-10
27	0.52384E-09	0.63883E-05	0.67680E-10
28	0.49160E-09	0.59952E-05	0.63515E-10
29	0.46161E-09	0.56294E-05	0.59640E-10
30	0.43320E-09	0.52829E-05	0.55969E-10
31	0.40646E-09	0.49568E-05	0.52514E-10
32	0.38143E-09	0.46516E-05	0.49280E-10
33	0.35808E-09	0.43669E-05	0.46264E-10
34	0.33601E-09	0.40977E-05	0.43412E-10
35	0.31543E-09	0.38467E-05	0.40753E-10
36	0.29602E-09	0.36101E-05	0.38246E-10
37	0.27767E-09	0.33862E-05	0.35875E-10
38	0.26068E-09	0.31790E-05	0.33679E-10
39	0.24440E-09	0.29805E-05	0.31577E-10
40	0.22933E-09	0.27968E-05	0.29630E-10
41	0.21528E-09	0.26253E-05	0.27814E-10
42	0.20175E-09	0.24604E-05	0.26066E-10
43	0.18934E-09	0.23091E-05	0.24463E-10
44	0.17751E-09	0.21647E-05	0.22934E-10
45	0.16639E-09	0.20291E-05	0.21497E-10
46	0.15605E-09	0.19031E-05	0.20162E-10
47	0.14613E-09	0.17820E-05	0.18879E-10
48	0.13685E-09	0.16689E-05	0.17681E-10
49	0.12830E-09	0.15646E-05	0.16576E-10
50	0.12011E-09	0.14648E-05	0.15519E-10
51	0.11253E-09	0.13723E-05	0.14539E-10
52	0.10526E-09	0.12837E-05	0.13600E-10
53	0.98568E-10	0.12020E-05	0.12735E-10

54	0.92166E-10	0.11240E-05	0.11908E-10
55	0.86095E-10	0.10499E-05	0.11123E-10
56	0.80445E-10	0.98104E-06	0.10393E-10
57	0.75088E-10	0.91571E-06	0.97014E-11
58	0.70011E-10	0.85379E-06	0.90454E-11
59	0.65244E-10	0.79566E-06	0.84295E-11
60	0.60719E-10	0.74048E-06	0.78449E-11
61	0.56481E-10	0.68879E-06	0.72972E-11
62	0.52430E-10	0.63939E-06	0.67739E-11
63	0.48601E-10	0.59270E-06	0.62793E-11
64	0.44970E-10	0.54842E-06	0.58102E-11
65	0.41522E-10	0.50636E-06	0.53646E-11
66	0.38211E-10	0.46598E-06	0.49368E-11
67	0.35093E-10	0.42797E-06	0.45340E-11
68	0.32075E-10	0.39116E-06	0.41441E-11
69	0.29193E-10	0.35601E-06	0.37717E-11
70	0.26460E-10	0.32268E-06	0.34186E-11
71	0.23800E-10	0.29024E-06	0.30750E-11
72	0.21223E-10	0.25882E-06	0.27420E-11
73	0.18769E-10	0.22889E-06	0.24249E-11
74	0.16373E-10	0.19967E-06	0.21153E-11
75	0.14046E-10	0.17129E-06	0.18147E-11
76	0.11792E-10	0.14380E-06	0.15235E-11
77	0.95713E-11	0.11672E-06	0.12366E-11
78	0.73805E-11	0.90006E-07	0.95355E-12
79	0.52240E-11	0.63708E-07	0.67494E-12
80	0.30897E-11	0.37679E-07	0.39919E-12

```
RMA 93-03 DIMP, 600 years
  1
       0.1      100.        50.       100.
      60.0   .000082     22000.       0.52
Polygon I
        1.      0.25     .00057        1.6       0.40       .25       .005
      .600       -1.   2.72E-06
   80y      100.0
    1     1  1.57E+02
    2     2  7.11E+01
    3     3  2.57E+01
    4     4  7.86E+00
    5     5  2.27E+00
    6     6  7.93E-01
    7     7  4.43E-01
    8     8  3.56E-01
    9     9  3.23E-01
   10    10  3.02E-01
   11    11  2.83E-01
   12    12  2.66E-01
   13    13  2.49E-01
   14    14  2.34E-01
   15    15  2.20E-01
   16    16  2.07E-01
   17    17  1.94E-01
   18    18  1.82E-01
   19    19  1.71E-01
   20    20  1.60E-01
   21    21  1.51E-01
   22    22  1.41E-01
   23    23  1.33E-01
   24    24  1.24E-01
   25    25  1.17E-01
   26    26  1.10E-01
   27    27  1.03E-01
   28    28  9.66E-02
   29    29  9.07E-02
   30    30  8.51E-02
   31    31  7.99E-02
   32    32  7.50E-02
   33    33  7.04E-02
   34    34  6.60E-02
   35    35  6.20E-02
   36    36  5.82E-02
   37    37  5.46E-02
   38    38  5.12E-02
   39    39  4.80E-02
   40    40  4.51E-02
   41    41  4.23E-02
   42    42  3.96E-02
   43    43  3.72E-02
   44    44  3.49E-02
   45    45  3.27E-02
   46    46  3.07E-02
   47    47  2.87E-02
```

48	48	2.69E-02
49	49	2.52E-02
50	50	2.36E-02
51	51	2.21E-02
52	52	2.07E-02
53	53	1.94E-02
54	54	1.81E-02
55	55	1.69E-02
56	56	1.58E-02
57	57	1.48E-02
58	58	1.38E-02
59	59	1.28E-02
60	60	1.19E-02
61	61	1.11E-02
62	62	1.03E-02
63	63	9.55E-03
64	64	8.84E-03
65	65	8.16E-03
66	66	7.51E-03
67	67	6.90E-03
68	68	6.30E-03
69	69	5.74E-03
70	70	5.20E-03
71	71	4.68E-03
72	72	4.17E-03
73	73	3.69E-03
74	74	3.22E-03
75	75	2.76E-03
76	76	2.32E-03
77	77	1.88E-03
78	78	1.45E-03
79	79	1.03E-03
80	80	6.07E-04

Time: 100.000 - DIMP - 600 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.94697E-06	0.11548E-01	0.12235E-06
2	0.49612E-06	0.60503E-02	0.64099E-07
3	0.21045E-06	0.25665E-02	0.27190E-07
4	0.75590E-07	0.92183E-03	0.97661E-08
5	0.24754E-07	0.30188E-03	0.31983E-08
6	0.87053E-08	0.10616E-03	0.11247E-08
7	0.42550E-08	0.51890E-04	0.54974E-09
8	0.30684E-08	0.37420E-04	0.39644E-09
9	0.26834E-08	0.32724E-04	0.34669E-09
10	0.24833E-08	0.30284E-04	0.32084E-09
11	0.23245E-08	0.28348E-04	0.30033E-09
12	0.21826E-08	0.26617E-04	0.28199E-09
13	0.20468E-08	0.24961E-04	0.26445E-09
14	0.19219E-08	0.23437E-04	0.24830E-09
15	0.18058E-08	0.22022E-04	0.23331E-09
16	0.16975E-08	0.20702E-04	0.21932E-09
17	0.15932E-08	0.19429E-04	0.20584E-09
18	0.14951E-08	0.18233E-04	0.19317E-09
19	0.14041E-08	0.17123E-04	0.18141E-09
20	0.13165E-08	0.16054E-04	0.17008E-09
21	0.12383E-08	0.15101E-04	0.15999E-09
22	0.11607E-08	0.14155E-04	0.14996E-09
23	0.10913E-08	0.13309E-04	0.14100E-09
24	0.10221E-08	0.12464E-04	0.13205E-09
25	0.96087E-09	0.11718E-04	0.12414E-09
26	0.90326E-09	0.11015E-04	0.11670E-09
27	0.84733E-09	0.10333E-04	0.10947E-09
28	0.79491E-09	0.96940E-05	0.10270E-09
29	0.74619E-09	0.90999E-05	0.96408E-10
30	0.70037E-09	0.85412E-05	0.90488E-10
31	0.65751E-09	0.80184E-05	0.84950E-10
32	0.61726E-09	0.75275E-05	0.79749E-10
33	0.57944E-09	0.70664E-05	0.74864E-10
34	0.54363E-09	0.66297E-05	0.70237E-10
35	0.51039E-09	0.62243E-05	0.65943E-10
36	0.47915E-09	0.58433E-05	0.61906E-10
37	0.44966E-09	0.54837E-05	0.58096E-10
38	0.42185E-09	0.51446E-05	0.54503E-10
39	0.39568E-09	0.48254E-05	0.51122E-10
40	0.37147E-09	0.45301E-05	0.47993E-10
41	0.34856E-09	0.42507E-05	0.45034E-10
42	0.32671E-09	0.39843E-05	0.42211E-10
43	0.30659E-09	0.37389E-05	0.39612E-10
44	0.28766E-09	0.35081E-05	0.37166E-10
45	0.26970E-09	0.32891E-05	0.34846E-10
46	0.25302E-09	0.30856E-05	0.32690E-10
47	0.23696E-09	0.28898E-05	0.30615E-10
48	0.22203E-09	0.27077E-05	0.28686E-10
49	0.20804E-09	0.25370E-05	0.26878E-10
50	0.19487E-09	0.23764E-05	0.25177E-10
51	0.18250E-09	0.22256E-05	0.23578E-10
52	0.17090E-09	0.20841E-05	0.22080E-10
53	0.16006E-09	0.19519E-05	0.20680E-10

54	0.14959E-09	0.18243E-05	0.19328E-10
55	0.13974E-09	0.17042E-05	0.18054E-10
56	0.13058E-09	0.15924E-05	0.16871E-10
57	0.12211E-09	0.14892E-05	0.15777E-10
58	0.11397E-09	0.13898E-05	0.14724E-10
59	0.10601E-09	0.12928E-05	0.13696E-10
60	0.98581E-10	0.12022E-05	0.12737E-10
61	0.91781E-10	0.11193E-05	0.11858E-10
62	0.85251E-10	0.10396E-05	0.11014E-10
63	0.79052E-10	0.96405E-06	0.10214E-10
64	0.73178E-10	0.89241E-06	0.94545E-11
65	0.67578E-10	0.82412E-06	0.87311E-11
66	0.62232E-10	0.75893E-06	0.80403E-11
67	0.57166E-10	0.69715E-06	0.73858E-11
68	0.52274E-10	0.63749E-06	0.67538E-11
69	0.47626E-10	0.58081E-06	0.61533E-11
70	0.43171E-10	0.52647E-06	0.55776E-11
71	0.38883E-10	0.47419E-06	0.50237E-11
72	0.34717E-10	0.42338E-06	0.44855E-11
73	0.30728E-10	0.37473E-06	0.39701E-11
74	0.26858E-10	0.32753E-06	0.34700E-11
75	0.23080E-10	0.28146E-06	0.29819E-11
76	0.19423E-10	0.23687E-06	0.25095E-11
77	0.15820E-10	0.19292E-06	0.20439E-11
78	0.12279E-10	0.14974E-06	0.15864E-11
79	0.88034E-11	0.10736E-06	0.11374E-11
80	0.53421E-11	0.65148E-07	0.69020E-12

```
RMA 93-03 DIMP, 700 years
 1
      0.1       100.        50.       100.
     60.0    .000082     22000.       0.52
Polygon I
       1.       0.25     .00057        1.6      0.40      .25      .005
     .630        -1.   4.55E-06
   80y      100.0
    1     1  1.86E+02
    2     2  9.75E+01
    3     3  4.14E+01
    4     4  1.49E+01
    5     5  4.86E+00
    6     6  1.71E+00
    7     7  8.36E-01
    8     8  6.03E-01
    9     9  5.27E-01
   10    10  4.88E-01
   11    11  4.57E-01
   12    12  4.29E-01
   13    13  4.02E-01
   14    14  3.78E-01
   15    15  3.55E-01
   16    16  3.34E-01
   17    17  3.13E-01
   18    18  2.94E-01
   19    19  2.76E-01
   20    20  2.59E-01
   21    21  2 43E-01
   22    22  2.28E-01
   23    23  2.14E-01
   24    24  2.01E-01
   25    25  1.89E-01
   26    26  1.77E-01
   27    27  1.66E-01
   28    28  1.56E-01
   29    29  1.47E-01
   30    30  1.38E-01
   31    31  1.29E-01
   32    32  1.21E-01
   33    33  1.14E-01
   34    34  1 07E-01
   35    35  1.00E-01
   36    36  9.42E-02
   37    37  8.84E-02
   38    38  8.29E-02
   39    39  7.78E-02
   40    40  7.30E-02
   41    41  6.85E-02
   42    42  6.42E-02
   43    43  6.02E-02
   44    44  5.65E-02
   45    45  5.30E-02
   46    46  4.97E-02
   47    47  4.66E-02
```

48	48	4.36E-02
49	49	4.09E-02
50	50	3.83E-02
51	51	3.59E-02
52	52	3.36E-02
53	53	3.15E-02
54	54	2.94E-02
55	55	2.75E-02
56	56	2.57E-02
57	57	2.40E-02
58	58	2.24E-02
59	59	2.08E-02
60	60	1.94E-02
61	61	1.80E-02
62	62	1.68E-02
63	63	1.55E-02
64	64	1.44E-02
65	65	1.33E-02
66	66	1.22E-02
67	67	1.12E-02
68	68	1.03E-02
69	69	9.36E-03
70	70	8.48E-03
71	71	7.64E-03
72	72	6.82E-03
73	73	6.04E-03
74	74	5.28E-03
75	75	4.54E-03
76	76	3.82E-03
77	77	3.11E-03
78	78	2.41E-03
79	79	1.73E-03
80	80	1.05E-03

Time: 100.000 - DIMP - 700 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.10721E-05	0.13074E-01	0.13851E-06
2	0.62909E-06	0.76719E-02	0.81278E-07
3	0.30398E-06	0.37071E-02	0.39274E-07
4	0.12497E-06	0.15241E-02	0.16146E-07
5	0.45983E-07	0.56077E-03	0.59410E-08
6	0.16950E-07	0.20671E-03	0.21900E-08
7	0.76761E-08	0.93611E-04	0.99174E-09
8	0.49414E-08	0.60261E-04	0.63842E-09
9	0.40820E-08	0.49781E-04	0.52740E-09
10	0.37115E-08	0.45262E-04	0.47952E-09
11	0.34613E-08	0.42210E-04	0.44719E-09
12	0.32463E-08	0.39589E-04	0.41942E-09
13	0.30450E-08	0.37134E-04	0.39341E-09
14	0.28605E-08	0.34884E-04	0.36957E-09
15	0.26869E-08	0.32767E-04	0.34715E-09
16	0.25258E-08	0.30803E-04	0.32633E-09
17	0.23705E-08	0.28908E-04	0.30626E-09
18	0.22258E-08	0.27144E-04	0.28757E-09
19	0.20900E-08	0.25488E-04	0.27003E-09
20	0.19620E-08	0.23927E-04	0.25349E-09
21	0.18416E-08	0.22459E-04	0.23793E-09
22	0.17285E-08	0.21079E-04	0.22332E-09
23	0.16226E-08	0.19788E-04	0.20964E-09
24	0.15238E-08	0.18583E-04	0.19688E-09
25	0.14320E-08	0.17463E-04	0.18501E-09
26	0.13433E-08	0.16382E-04	0.17356E-09
27	0.12602E-08	0.15369E-04	0.16282E-09
28	0.11836E-08	0.14434E-04	0.15292E-09
29	0.11134E-08	0.13579E-04	0.14386E-09
30	0.10461E-08	0.12757E-04	0.13515E-09
31	0.98022E-09	0.11954E-04	0.12664E-09
32	0.91931E-09	0.11211E-04	0.11877E-09
33	0.86439E-09	0.10541E-04	0.11168E-09
34	0.81190E-09	0.99013E-05	0.10490E-09
35	0.76065E-09	0.92763E-05	0.98276E-10
36	0.71479E-09	0.87170E-05	0.92351E-10
37	0.67123E-09	0.81857E-05	0.86722E-10
38	0.62983E-09	0.76809E-05	0.81374E-10
39	0.59108E-09	0.72083E-05	0.76367E-10
40	0.55469E-09	0.67646E-05	0.71666E-10
41	0.52054E-09	0.63481E-05	0.67254E-10
42	0.48819E-09	0.59536E-05	0.63074E-10
43	0.45786E-09	0.55837E-05	0 59155E-10
44	0.42960E-09	0.52390E-05	0.55504E-10
45	0.40303E-09	0.49150E-05	0.52071E-10
46	0.37799E-09	0.46097E-05	0.48837E-10
47	0.35445E-09	0.43225E-05	0.45795E-10
48	0.33199E-09	0.40487E-05	0.42893E-10
49	0.31122E-09	0.37954E-05	0.40209E-10
50	0.29158E-09	0.35558E-05	0 37672E-10
51	0.27321E-09	0.33319E-05	0.35299E-10
52	0.25582E-09	0.31198E-05	0 33052E-10
53	0.23964E-09	0.29224E-05	0.30961E-10

54	0.22402E-09	0.27319E-05	0.28943E-10
55	0.20946E-09	0.25544E-05	0.27062E-10
56	0.19577E-09	0.23874E-05	0.25293E-10
57	0.18284E-09	0.22298E-05	0.23623E-10
58	0.17065E-09	0.20811E-05	0.22048E-10
59	0.15882E-09	0.19368E-05	0.20520E-10
60	0.14795E-09	0.18042E-05	0.19114E-10
61	0.13749E-09	0.16767E-05	0.17764E-10
62	0.12798E-09	0.15608E-05	0.16535E-10
63	0.11850E-09	0.14452E-05	0.15311E-10
64	0.10983E-09	0.13394E-05	0.14190E-10
65	0.10152E-09	0.12380E-05	0.13116E-10
66	0.93366E-10	0.11386E-05	0.12063E-10
67	0.85704E-10	0.10452E-05	0.11073E-10
68	0.78634E-10	0.95895E-06	0.10159E-10
69	0.71649E-10	0.87377E-06	0.92570E-11
70	0.64950E-10	0.79207E-06	0.83915E-11
71	0.58543E-10	0.71394E-06	0.75638E-11
72	0.52340E-10	0.63830E-06	0.67623E-11
73	0.46381E-10	0.56562E-06	0.59924E-11
74	0.40604E-10	0.49517E-06	0.52460E-11
75	0.34981E-10	0.42660E-06	0.45195E-11
76	0.29502E-10	0.35978E-06	0.38117E-11
77	0.24123E-10	0.29418E-06	0.31167E-11
78	0.18825E-10	0.22957E-06	0.24322E-11
79	0.13636E-10	0.16629E-06	0.17617E-11
80	0.84867E-11	0.10350E-06	0.10965E-11

```
RMA 93-03 DIMP, 800 years
  1
       0.1      100.       50.       100.
      60.0   .000082    22000.       0.52
Polygon I
        1.      0.25    .00057        1.6        0.40        .25        .005
      .655       -1.  7.00E-06
   80y      100.0
     1     1  2.11E+02
     2     2  1.24E+02
     3     3  5.97E+01
     4     4  2.46E+01
     5     5  9.04E+00
     6     6  3.33E+00
     7     7  1.51E+00
     8     8  9.71E-01
     9     9  8.02E-01
    10    10  7.29E-01
    11    11  6.80E-01
    12    12  6.38E-01
    13    13  5.98E-01
    14    14  5.62E-01
    15    15  5.28E-01
    16    16  4.96E-01
    17    17  4.66E-01
    18    18  4.37E-01
    19    19  4.11E-01
    20    20  3.86E-01
    21    21  3.62E-01
    22    22  3.40E-01
    23    23  3.19E-01
    24    24  2.99E-01
    25    25  2.81E-01
    26    26  2.64E-01
    27    27  2.48E-01
    28    28  2.33E-01
    29    29  2.19E-01
    30    30  2.06E-01
    31    31  1.93E-01
    32    32  1.81E-01
    33    33  1.70E-01
    34    34  1.60E-01
    35    35  1.49E-01
    36    36  1.40E-01
    37    37  1.32E-01
    38    38  1.24E-01
    39    39  1.16E-01
    40    40  1.09E-01
    41    41  1.02E-01
    42    42  9.59E-02
    43    43  9.00E-02
    44    44  8.44E-02
    45    45  7.92E-02
    46    46  7.43E-02
    47    47  6.96E-02
```

48	48	6.52E-02
49	49	6.12E-02
50	50	5.73E-02
51	51	5.37E-02
52	52	5.03E-02
53	53	4.71E-02
54	54	4.40E-02
55	55	4.12E-02
56	56	3.85E-02
57	57	3.59E-02
58	58	3.35E-02
59	59	3.12E-02
60	60	2.91E-02
61	61	2.70E-02
62	62	2.51E-02
63	63	2.33E-02
64	64	2.16E-02
65	65	1.99E-02
66	66	1.83E-02
67	67	1.68E-02
68	68	1.55E-02
69	69	1.41E-02
70	70	1.28E-02
71	71	1.15E-02
72	72	1.03E-02
73	73	9.11E-03
74	74	7.98E-03
75	75	6.87E-03
76	76	5.80E-03
77	77	4.74E-03
78	78	3.70E-03
79	79	2.68E-03
80	80	1.67E-03

Time: 100.000 - DIMP - 800 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.11794E-05	0.14383E-01	0.15238E-06
2	0.75741E-06	0.92367E-02	0.97857E-07
3	0.40640E-06	0.49560E-02	0 52506E-07
4	0.18703E-06	0.22808E-02	0.24164E-07
5	0.76553E-07	0.93358E-03	0.98906E-08
6	0.30128E-07	0.36741E-03	0.38925E-08
7	0.13283E-07	0.16199E-03	0.17162E-08
8	0.77532E-08	0.94552E-04	0.10017E-08
9	0.59593E-08	0.72675E-04	0.76994E-09
10	0.52639E-08	0.64194E-04	0.68010E-09
11	0.48686E-08	0.59373E-04	0.62902E-09
12	0.45581E-08	0.55587E-04	0.58890E-09
13	0.42747E-08	0.52131E-04	0.55229E-09
14	0.40149E-08	0.48962E-04	0.51872E-09
15	0.37720E-08	0.46000E-04	0.48734E-09
16	0.35436E-08	0.43214E-04	0.45783E-09
17	0.33292E-08	0.40600E-04	0.43013E-09
18	0.31248E-08	0.38108E-04	0.40372E-09
19	0.29365E-08	0.35811E-04	0.37939E-09
20	0.27587E-08	0.33642E-04	0.35642E-09
21	0.25893E-08	0.31577E-04	0.33454E-09
22	0.24315E-08	0.29653E-04	0.31415E-09
23	0.22826E-08	0.27836E-04	0.29491E-09
24	0.21414E-08	0.26114E-04	0.27666E-09
25	0.20112E-08	0.24527E-04	0.25985E-09
26	0.18895E-08	0.23043E-04	0.24412E-09
27	0.17750E-08	0.21647E-04	0.22933E-09
28	0.16676E-08	0.20336E-04	0.21545E-09
29	0.15670E-08	0.19110E-04	0.20245E-09
30	0.14732E-08	0.17965E-04	0.19033E-09
31	0.13823E-08	0.16857E-04	0.17859E-09
32	0.12968E-08	0.15815E-04	0.16755E-09
33	0.12177E-08	0.14849E-04	0.15732E-09
34	0.11448E-08	0.13961E-04	0.14791E-09
35	0.10709E-08	0.13060E-04	0.13836E-09
36	0.10046E-08	0.12251E-04	0.12980E-09
37	0.94523E-09	0.11527E-04	0.12212E-09
38	0.88839E-09	0.10834E-04	0.11478E-09
39	0.83275E-09	0.10155E-04	0.10759E-09
40	0.78172E-09	0.95332E-05	0.10100E-09
41	0.73272E-09	0.89356E-05	0.94667E-10
42	0.68802E-09	0.83905E-05	0.88891E-10
43	0.64586E-09	0.78764E-05	0.83445E-10
44	0.60592E-09	0.73893E-05	0.78285E-10
45	0.56852E-09	0.69332E-05	0.73453E-10
46	0.53338E-09	0.65046E-05	0.68912E-10
47	0.49998E-09	0.60973E-05	0.64597E-10
48	0.46854E-09	0.57138E-05	0.60534E-10
49	0.43947E-09	0.53593E-05	0.56779E-10
50	0.41177E-09	0.50216E-05	0.53201E-10
51	0.38583E-09	0.47052E-05	0.49849E-10
52	0.36142E-09	0.44076E-05	0.46696E-10
53	0.33844E-09	0.41273E-05	0.43726E-10

54	0.31647E-09	0.38594E-05	0.40888E-10
55	0.29611E-09	0.36111E-05	0.38258E-10
56	0.27682E-09	0.33758E-05	0.35765E-10
57	0.25837E-09	0.31509E-05	0.33381E-10
58	0.24108E-09	0.29401E-05	0.31148E-10
59	0.22468E-09	0.27400E-05	0.29029E-10
60	0.20942E-09	0.25539E-05	0.27057E-10
61	0.19464E-09	0.23737E-05	0.25148E-10
62	0.18085E-09	0.22055E-05	0.23366E-10
63	0.16787E-09	0.20471E-05	0.21688E-10
64	0.15558E-09	0.18974E-05	0.20101E-10
65	0.14361E-09	0.17514E-05	0.18555E-10
66	0.13219E-09	0.16121E-05	0.17079E-10
67	0.12140E-09	0.14804E-05	0.15684E-10
68	0.11160E-09	0.13610E-05	0.14419E-10
69	0.10182E-09	0.12417E-05	0.13155E-10
70	0.92432E-10	0.11272E-05	0.11942E-10
71	0.83251E-10	0.10153E-05	0.10756E-10
72	0.74545E-10	0.90908E-06	0.96311E-11
73	0.66073E-10	0.80577E-06	0.85366E-11
74	0.57923E-10	0.70638E-06	0.74836E-11
75	0.49981E-10	0.60952E-06	0.64575E-11
76	0.42273E-10	0.51553E-06	0.54617E-11
77	0.34698E-10	0.42314E-06	0.44829E-11
78	0.27250E-10	0.33232E-06	0.35207E-11
79	0.19929E-10	0.24304E-06	0.25748E-11
80	0.12690E-10	0.15476E-06	0.16396E-11

```
RMA 93-03 DIMP, 900 years
  1
       0.1       100.       50.       100.
      60.0    .000082    22000.       0.52
Polygon I
        1.       0.25    .00057        1.6        0.40        .25        .005
      .675        -1.  1.02E-06
   80y      100.0
    1     1  2.32E+02
    2     2  1.49E+02
    3     3  7.99E+01
    4     4  3.68E+01
    5     5  1.50E+01
    6     6  5.92E+00
    7     7  2.61E+00
    8     8  1.52E+00
    9     9  1.17E+00
   10    10  1.03E+00
   11    11  9.57E-01
   12    12  8.96E-01
   13    13  8.40E-01
   14    14  7.89E-01
   15    15  7.41E-01
   16    16  6.96E-01
   17    17  6.54E-01
   18    18  6.14E-01
   19    19  5.77E-01
   20    20  5.42E-01
   21    21  5.09E-01
   22    22  4.78E-01
   23    23  4.49E-01
   24    24  4.21E-01
   25    25  3.95E-01
   26    26  3.71E-01
   27    27  3.49E-01
   28    28  3.28E-01
   29    29  3.08E-01
   30    30  2.89E-01
   31    31  2.72E-01
   32    32  2.55E-01
   33    33  2.39E-01
   34    34  2.25E-01
   35    35  2.10E-01
   36    36  1.97E-01
   37    37  1.86E-01
   38    38  1.75E-01
   39    39  1.64E-01
   40    40  1.54E-01
   41    41  1.44E-01
   42    42  1.35E-01
   43    43  1.27E-01
   44    44  1.19E-01
   45    45  1.12E-01
   46    46  1.05E-01
   47    47  9.82E-02
```

48	48	9.21E-02
49	49	8.64E-02
50	50	8.09E-02
51	51	7.58E-02
52	52	7.10E-02
53	53	6.65E-02
54	54	6.22E-02
55	55	5.82E-02
56	56	5.44E-02
57	57	5.08E-02
58	58	4.74E-02
59	59	4.41E-02
60	60	4.12E-02
61	61	3.82E-02
62	62	3.55E-02
63	63	3.30E-02
64	64	3.06E-02
65	65	2.82E-02
66	66	2.60E-02
67	67	2.39E-02
68	68	2.19E-02
69	69	2.00E-02
70	70	1.82E-02
71	71	1.64E-02
72	72	1.46E-02
73	73	1.30E-02
74	74	1.14E-02
75	75	9.82E-03
76	76	8.31E-03
77	77	6.82E-03
78	78	5.35E-03
79	79	3.92E-03
80	80	2.49E-03

Time: 100.000 - DIMP - 900 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.12690E-05	0.15476E-01	0.16396E-06
2	0.87522E-06	0.10673E-01	0.11308E-06
3	0.51330E-06	0.62598E-02	0.66318E-07
4	0.26007E-06	0.31716E-02	0.33601E-07
5	0.11681E-06	0.14246E-02	0.15092E-07
6	0.49381E-07	0.60221E-03	0.63800E-08
7	0.21936E-07	0.26752E-03	0.28342E-08
8	0.11935E-07	0.14554E-03	0.15419E-08
9	0.84900E-08	0.10354E-03	0.10969E-08
10	0.71928E-08	0.87717E-04	0.92930E-09
11	0.65712E-08	0.80136E-04	0.84899E-09
12	0.61316E-08	0.74776E-04	0.79220E-09
13	0.57473E-08	0.70088E-04	0.74254E-09
14	0.53963E-08	0.65809E-04	0.69720E-09
15	0.50686E-08	0.61812E-04	0.65486E-09
16	0.47613E-08	0.58064E-04	0.61516E-09
17	0.44737E-08	0.54557E-04	0.57800E-09
18	0.42018E-08	0.51241E-04	0.54287E-09
19	0.39479E-08	0.48145E-04	0.51007E-09
20	0.37090E-08	0.45232E-04	0.47920E-09
21	0.34840E-08	0.42488E-04	0.45013E-09
22	0.32724E-08	0.39907E-04	0.42279E-09
23	0.30740E-08	0.37488E-04	0.39716E-09
24	0.28850E-08	0.35183E-04	0.37274E-09
25	0.27076E-08	0.33020E-04	0.34983E-09
26	0.25428E-08	0.31010E-04	0.32853E-09
27	0.23905E-08	0.29152E-04	0.30885E-09
28	0.22468E-08	0.27400E-04	0.29029E-09
29	0.21106E-08	0.25739E-04	0.27269E-09
30	0.19814E-08	0.24164E-04	0.25600E-09
31	0.18629E-08	0.22719E-04	0.24069E-09
32	0.17487E-08	0.21326E-04	0.22593E-09
33	0.16403E-08	0.20003E-04	0.21192E-09
34	0.15420E-08	0.18804E-04	0.19922E-09
35	0.14440E-08	0.17609E-04	0.18656E-09
36	0.13540E-08	0.16512E-04	0.17493E-09
37	0.12748E-08	0.15546E-04	0 16470E-09
38	0.11995E-08	0.14628E-04	0.15497E-09
39	0.11257E-08	0.13728E-04	0.14544E-09
40	0.10568E-08	0.12888E-04	0.13654E-09
41	0.99009E-09	0.12074E-04	0.12792E-09
42	0.92819E-09	0.11319E-04	0.11992E-09
43	0.87202E-09	0.10634E-04	0.11266E-09
44	0.81805E-09	0.99762E-05	0 10569E-09
45	0.76874E-09	0.93749E-05	0 99321E-10
46	0.72136E-09	0.87971E-05	0.93200E-10
47	0.67561E-09	0.82392E-05	0.87288E-10
48	0.63334E-09	0.77236E-05	0.81827E-10
49	0.59400E-09	0.72438E-05	0 76744E-10
50	0.55656E-09	0.67873E-05	0.71907E-10
51	0.52146E-09	0.63593E-05	0 67372E-10
52	0.48847E-09	0.59570E-05	0.63111E-10
53	0.45749E-09	0.55792E-05	0 59107E-10

54	0.42810E-09	0.52207E-05	0.55310E-10
55	0.40052E-09	0.48844E-05	0.51747E-10
56	0.37445E-09	0.45665E-05	0.48379E-10
57	0.34978E-09	0.42656E-05	0.45191E-10
58	0.32645E-09	0.39811E-05	0.42178E-10
59	0.30409E-09	0.37084E-05	0.39288E-10
60	0.28364E-09	0.34591E-05	0.36646E-10
61	0.26359E-09	0.32145E-05	0.34056E-10
62	0.24486E-09	0.29861E-05	0.31636E-10
63	0.22744E-09	0.27736E-05	0.29385E-10
64	0.21089E-09	0.25718E-05	0.27246E-10
65	0.19470E-09	0.23744E-05	0.25155E-10
66	0.17946E-09	0.21885E-05	0.23186E-10
67	0.16499E-09	0.20121E-05	0.21317E-10
68	0.15120E-09	0.18440E-05	0.19536E-10
69	0.13807E-09	0.16838E-05	0.17838E-10
70	0.12557E-09	0.15313E-05	0.16223E-10
71	0.11332E-09	0.13820E-05	0.14641E-10
72	0.10121E-09	0.12342E-05	0.13076E-10
73	0.89923E-10	0.10966E-05	0.11618E-10
74	0.78954E-10	0.96286E-06	0.10201E-10
75	0.68169E-10	0.83133E-06	0.88074E-11
76	0.57731E-10	0.70404E-06	0.74588E-11
77	0.47503E-10	0.57930E-06	0.61373E-11
78	0.37426E-10	0.45641E-06	0.48354E-11
79	0.27555E-10	0.33604E-06	0.35601E-11
80	0.17755E-10	0.21653E-06	0.22940E-11

```
RMA 93-03 DIMP, 1000 years
  1
      0.1      100.       50.       100.
     60.0    .000082    22000.      0.52
Polygon I
       1.       0.25    .00057       1.6       0.40       .25       .005
     .693        -1.  1.40E-06
   80y     100.0
    1    1  2.49E+02
    2    2  1.72E+02
    3    3  1.01E+02
    4    4  5.11E+01
    5    5  2.30E+01
    6    6  9.70E+00
    7    7  4.31E+00
    8    8  2.35E+00
    9    9  1.67E+00
   10   10  1.41E+00
   11   11  1.29E+00
   12   12  1.20E+00
   13   13  1.13E+00
   14   14  1.06E+00
   15   15  9.96E-01
   16   16  9.36E-01
   17   17  8.79E-01
   18   18  8.26E-01
   19   19  7.76E-01
   20   20  7.29E-01
   21   21  6.85E-01
   22   22  6.43E-01
   23   23  6.04E-01
   24   24  5.67E-01
   25   25  5.32E-01
   26   26  5.00E-01
   27   27  4.70E-01
   28   28  4.41E-01
   29   29  4.15E-01
   30   30  3.89E-01
   31   31  3 66E-01
   32   32  3.44E-01
   33   33  3.22E-01
   34   34  3.03E-01
   35   35  2.84E-01
   36   36  2.66E-01
   37   37  2.50E-01
   38   38  2.36E-01
   39   39  2.21E-01
   40   40  2.08E-01
   41   41  1.95E-01
   42   42  1.82E-01
   43   43  1.71E-01
   44   44  1.61E-01
   45   45  1.51E-01
   46   46  1.42E-01
   47   47  1.33E-01
```

48	48	1.24E-01
49	49	1.17E-01
50	50	1.09E-01
51	51	1.02E-01
52	52	9.60E-02
53	53	8.99E-02
54	54	8.41E-02
55	55	7.87E-02
56	56	7.36E-02
57	57	6.87E-02
58	58	6.41E-02
59	59	5.98E-02
60	60	5.57E-02
61	61	5.18E-02
62	62	4.81E-02
63	63	4.47E-02
64	64	4.14E-02
65	65	3.83E-02
66	66	3.53E-02
67	67	3.24E-02
68	68	2.97E-02
69	69	2.71E-02
70	70	2.47E-02
71	71	2.23E-02
72	72	1.99E-02
73	73	1.77E-02
74	74	1.55E-02
75	75	1.34E-02
76	76	1.13E-02
77	77	9.33E-03
78	78	7.35E-03
79	79	5.41E-03
80	80	3.49E-03

Time: 100.000 - DTMP - 1000 Years

Cell	Cgas(g/cu.ft)	Cliq(g/cu.ft)	Csol(g/g)
1	0.13428E-05	0.16375E-01	0.17349E-06
2	0.98094E-06	0.11963E-01	0.12674E-06
3	0.62048E-06	0.75669E-02	0.80166E-07
4	0.34140E-06	0.41634E-02	0.44109E-07
5	0.16707E-06	0.20374E-02	0.21585E-07
6	0.75720E-07	0.92341E-03	0.97830E-08
7	0.34559E-07	0.42145E-03	0.44649E-08
8	0.18091E-07	0.22062E-03	0.23374E-08
9	0.11964E-07	0.14591E-03	0.15458E-08
10	0.96313E-08	0.11745E-03	0.12444E-08
11	0.86047E-08	0.10494E-03	0.11117E-08
12	0.79602E-08	0.97076E-04	0.10285E-08
13	0.74652E-08	0.91039E-04	0.96450E-09
14	0.70083E-08	0.85467E-04	0.90547E-09
15	0.65839E-08	0.80291E-04	0.85063E-09
16	0.61871E-08	0.75452E-04	0.79937E-09
17	0.58124E-08	0.70883E-04	0.75096E-09
18	0.54616E-08	0.66605E-04	0.70564E-09
19	0.51318E-08	0.62583E-04	0.66303E-09
20	0.48217E-08	0.58801E-04	0.62296E-09
21	0.45308E-08	0.55254E-04	0.58537E-09
22	0.42552E-08	0.51893E-04	0.54977E-09
23	0.39972E-08	0.48746E-04	0.51643E-09
24	0.37538E-08	0.45779E-04	0.48499E-09
25	0.35240E-08	0.42975E-04	0.45530E-09
26	0.33109E-08	0.40377E-04	0.42777E-09
27	0.31119E-08	0.37950E-04	0.40205E-09
28	0.29221E-08	0.35635E-04	0.37753E-09
29	0.27474E-08	0.33505E-04	0.35496E-09
30	0.25788E-08	0.31449E-04	0.33318E-09
31	0.24240E-08	0.29561E-04	0.31318E-09
32	0.22785E-08	0.27786E-04	0.29438E-09
33	0.21366E-08	0.26056E-04	0.27605E-09
34	0.20079E-08	0.24486E-04	0.25942E-09
35	0.18844E-08	0.22980E-04	0.24346E-09
36	0.17667E-08	0.21545E-04	0.22826E-09
37	0.16591E-08	0.20233E-04	0.21436E-09
38	0.15628E-08	0.19058E-04	0.20191E-09
39	0.14669E-08	0.17888E-04	0.18952E-09
40	0.13788E-08	0.16814E-04	0.17814E-09
41	0.12941E-08	0.15781E-04	0.16719E-09
42	0.12108E-08	0.14766E-04	0.15644E-09
43	0.11360E-08	0.13854E-04	0.14678E-09
44	0.10682E-08	0.13027E-04	0.13801E-09
45	0.10028E-08	0.12229E-04	0.12956E-09
46	0.94219E-09	0.11490E-04	0.12173E-09
47	0.88356E-09	0.10775E-04	0.11416E-09
48	0.82589E-09	0.10072E-04	0.10670E-09
49	0.77630E-09	0.94671E-05	0.10030E-09
50	0.72602E-09	0.88539E-05	0.93801E-10
51	0.67926E-09	0.82837E-05	0.87760E-10
52	0.63777E-09	0.77777E-05	0.82400E-10
53	0.59779E-09	0.72901E-05	0.77234E-10

54	0.55951E-09	0.68234E-05	0.72289E-10
55	0.52355E-09	0.63847E-05	0.67642E-10
56	0.48965E-09	0.59714E-05	0.63263E-10
57	0.45735E-09	0.55774E-05	0.59089E-10
58	0.42683E-09	0.52053E-05	0.55147E-10
59	0.39818E-09	0.48559E-05	0.51445E-10
60	0.37102E-09	0.45246E-05	0.47935E-10
61	0.34520E-09	0.42098E-05	0.44600E-10
62	0.32070E-09	0.39110E-05	0.41434E-10
63	0.29784E-09	0.36322E-05	0.38481E-10
64	0.27600E-09	0.33659E-05	0.35659E-10
65	0.25531E-09	0.31135E-05	0.32985E-10
66	0.23546E-09	0.28714E-05	0.30421E-10
67	0.21633E-09	0.26382E-05	0.27950E-10
68	0.19827E-09	0.24179E-05	0.25616E-10
69	0.18099E-09	0.22072E-05	0.23383E-10
70	0.16475E-09	0.20092E-05	0.21286E-10
71	0.14891E-09	0.18160E-05	0.19239E-10
72	0.13323E-09	0.16248E-05	0.17214E-10
73	0.11841E-09	0.14440E-05	0.15298E-10
74	0.10391E-09	0.12672E-05	0.13426E-10
75	0.89908E-10	0.10964E-05	0.11616E-10
76	0.76094E-10	0.92798E-06	0.98313E-11
77	0.62837E-10	0.76630E-06	0.81185E-11
78	0.49743E-10	0.60662E-06	0.64267E-11
79	0.36845E-10	0.44932E-06	0.47603E-11
80	0.24091E-10	0.29380E-06	0.31126E-11

WIND EROSION CALCULATION SUPPORTING INFORMATION

Exhibit 502.61(a)

Wind Erodibility Groups
and Soil Erodibility Index

Predominant Soil Texture Class of Surface Layer	Wind Erodibility Group (WEG)	Soil Erodibility Index (I) (T/Ac/Yr)1/
Very fine sand, fine sand, sand, or coarse sand.	1	310 2/ 250 220 180 160
Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric organic soil materials.	2	134
Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam.	3	86
Clay, silty clay, noncalcareous clay loam, or silty clay loam with more than 35 percent clay.	4	86
Calcareous loam and silt loam, or calcareous clay loam and silty clay loam.	4L	86
Noncalcareous loam and silt loam with less than 20 percent clay, or sandy clay loam, sandy clay, and hemic organic soil materials.	5	56
Noncalcareous loam and silt loam with more than 20 percent clay, or non-calcareous clay loam with less than 35 percent clay.	6	48
Silt, noncalcareous silty clay loam with less than 35 percent clay, and fibric organic soil material.	7	38
Soils not susceptible to wind erosion due to coarse surface fragments or wetness.	8	—

1/ The soil erodibility index is based on the relationship of dry soil aggregates greater than .84 mm to potential soil erosion. See exhibit 502.61(b).

2/ The "I" factors for WEG 1 vary from 160 for coarse sands to 310 for very fine sands. Use an I of 220 as an average figure. For coarse sand with gravel, use a low figure. For no gravel and very fine sand, use a higher figure.

Table A-2. VALUES OF K, L AND V FOR COMMON FIELD CROPS

Crop	K	L, ft.	V, lb/acre
Alfalfa	1.0	1000	3000
Barley	0.6	2000	1100
Beans	0.5	1000	250
Corn	0.6	2000	500
Cotton	0.5	2000	250
Grain Hays	0.8	2000	1250
Oats	0.8	2000	1250
Peanuts	0.6	1000	250
Potatoes	0.8	1000	400
Rice	0.8	1000	1000
Rye	0.6	2000	1250
Safflower	1.0	2000	1500
Sorghum	0.5	2000	900
Soybeans	0.6	2000	250
Sugar Beets	0.6	1000	100
Vegetables	0.6	500	100
Wheat	0.6	2000	1350

SOURCE: "DEVELOPMENT OF EMISSION FACTORS FOR FUGITIVE DUST SOURCES" EPA-450/3-74-037 JUNE, 1974

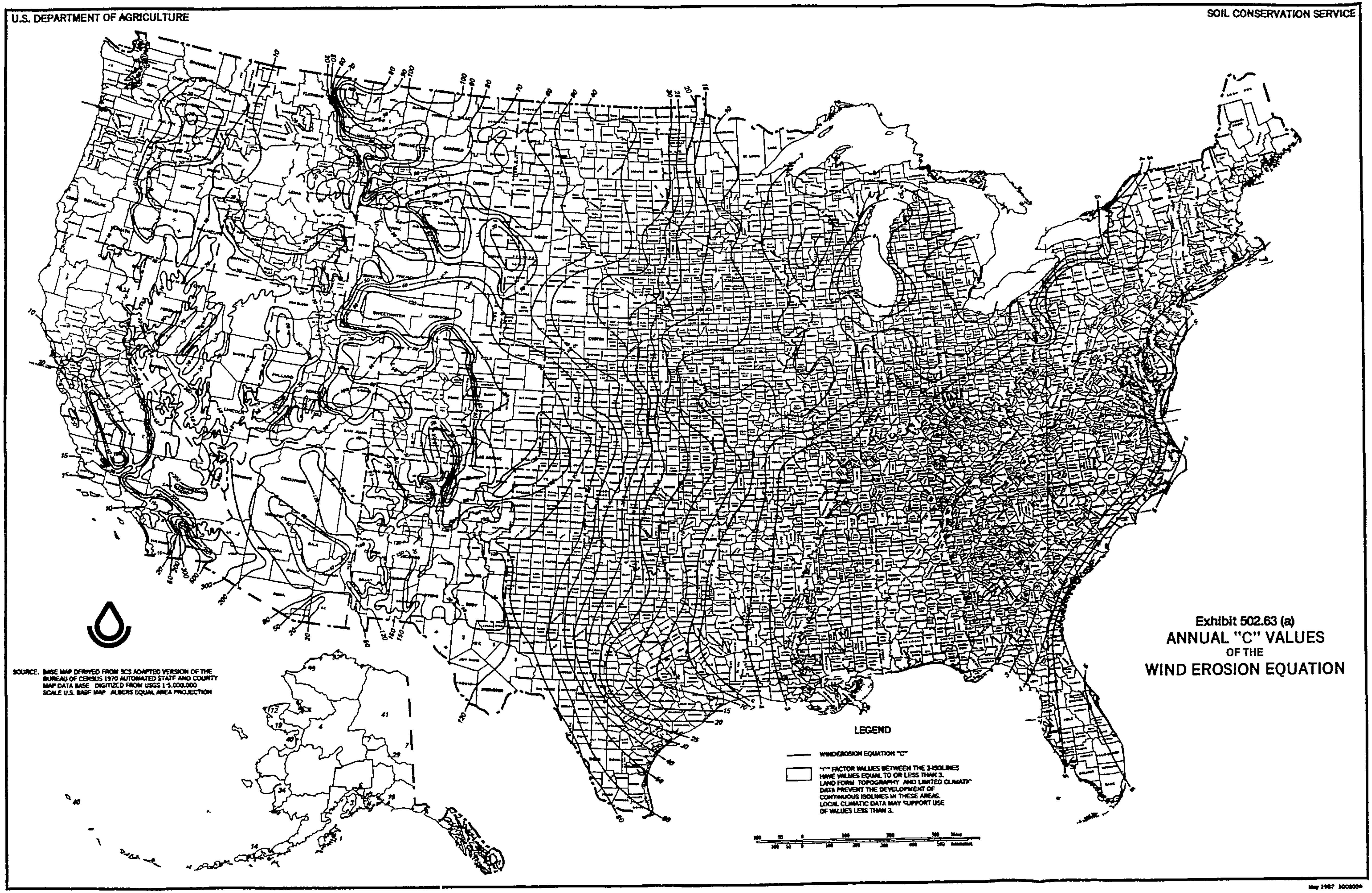

Exhibit 502.63 (a)

ANNUAL "C" VALUES OF THE WIND EROSION EQUATION

GULLY EROSION CALCULATIONS AND RUSLE RESULTS

Harding Lawson Associates
Engineering and
Environmental Services

SHEET 1 OF 4
JOB NO 21907-708010
DATE 1-10-96
PROJECT RMA 9303 CAMU D.D.
COMPUTED BY SES
SUBJECT GULLY EROSION - COVER SIDE SLOPES
CHECKED BY ECA

OBJECTIVE: TO DETERMINE THE REQUIRED PARTICLE DIAMETER (D_{50}) TO RESIST GULLY EROSION ON THE SIDE SLOPES OF THE FINAL COVER.

ASSUMPTIONS. 1) 200' LONG TOP SLOPE
2) 100' LONG SIDE SLOPE

REFERENCES: 1. PRECIPITATION-FREQUENCY ATLAS OF THE WESTERN U.S, VOL. III - COLORADO. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA) ATLAS 2.

2. FINAL STAFF TECHNICAL POSITION DESIGN OF EROSION PROTECTION COVERS FOR STABILIZATION OF URANIUM MILL TAILINGS SITES, AUG. 1990. U.S. NUCLEAR REGULATORY COMMISSION

3. METHODOLOGIES FOR EVALUATING LONG-TERM STABILIZATION DESIGNS OF URANIUM MILL TAILINGS IMPOUNDMENTS JUNE 1986, U.S. NUCLEAR REGULATORY COMMISSION.

DETERMINE RAINFALL INTENSITY:

FROM NOAA ATLAS NO. 2 (Ref. 1)

$X_{24} \Rightarrow$ 100 yr, 24 hr. = 5 in

$X_6 \rightarrow$ 100 yr., 6 hr = 3.6 in.

$X_1 \Rightarrow$ 100 yr., 1 hr. $\Rightarrow y_{100} = 1.897 + 0.439\left[X_6\left(\frac{X_6}{X_{24}}\right)\right] - 0.008\,Z$

WHERE Z - ELEVATION IN HUNDREDS OF FEET
ASSUME FOR RMA Z = 52.80

$X_1 = 1.897 + 0.439\left[3.6\left(\frac{3.6}{5}\right)\right] - 0.008(52.80) = 2.6"$

USE % 1 hr FROM NRC/CR-4620 (REF. 3) THEN CONVERT TO INTENSITY: $i = P_t\left(\frac{60}{t}\right)$

time (t) (minutes)	% of 1 Hr PRECIP.	PRECIP (P_t) For t (in.)	INTENSITY @ TIME (t) (in/hr)
2.5	27.5	0.72	17.28
5	45	1.17	14.04
10	62	1.61	9.66
15	74	1.92	7.68
20	82	2.13	6.40
30	89	2.31	4.62
45	95	2.47	3.29
60	100	2.6	2.60

for time t_c = 2.5 min i = 17.28 in/hr.

DETERMINE THE DRAINAGE AREA FOR AN ASSUMED SIDE SLOPE SITUATION (IN ACRES) FOR A UNIT WIDTH OF 1':

$$A_{TOPSLOPE} = \frac{200'(1')}{43560 \; ft^2/ac.} = 0.00459 \text{ Ac.}$$

$$A_{SIDESLOPE} = \frac{100'(1')}{43560 \; ft^2/ac} = 0.00230 \text{ Ac.}$$

CALCULATE THE TIME OF CONSENTRATION USING THE KIRPICH METHOD: (REF. 2)

$$t_c = \left[\frac{11.9 L^3}{H}\right]^{0.385}$$

L in miles
H in feet

$$t_{c_{TOP}} = \left[\frac{11.9 \; (0.038)^3}{10'}\right]^{0.385}$$

$L = 200/5280 = 0.038 mi$
$H = 0.05 \times 200 = 10'$

$$= 0.0245 \text{ hr.} = 1.47 \text{ min.}$$

$$t_{c_{SIDE}} = \left[\frac{11.9 \; (0.0189)^3}{20}\right]^{0.385}$$

$L = \frac{100}{5280} = 0.0189 mi$
$H = 100(.2) = 20'$

$$= 0.00837 \text{ hr} = 0.50 \text{ min}$$

$$\text{TOTAL } T_c = 1.47 + 0.50 = 1.97 \text{ min}$$

$\boxed{\text{USE 2.5 minutes minimum}}$

Harding Lawson Associates
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SHEET 4 OF 4
JOB NO 21907-70810
DATE 1-10-96
PROJECT KMA 9503 CAMU A.D.
COMPUTED BY SES
SUBJECT GULLY EROSION - COVER SIDE SLOPES
CHECKED BY EGA

DETERMINE PEAK FLOW RATE USING THE RATIONAL FORMULA:

$$Q = CiA$$

ASSUME A RUNOFF COEFFICIENT (C) OF 0.8

$$Q_{TOPSLOPE} = 0.8(17.28)(0.0046) = 0.0636 \text{ cfs}$$

$$Q_{SIDESLOPE} = 0.8(17.28)(0.0023) = \underline{0.0318 \text{ cfs}}$$

$$0.0954 \text{ cfs}$$

FROM THE GRAPH SHOWN IN ATTACHMENT A

FOR A $Q = 0.10$ $D_{50} = 0.8$ in for a 20% slope.

DETERMINE TOTAL THICKNESS OF ARMOR LAYER.

$$t_r = 1.5 D_s \quad \text{WHERE } D_s = D_{50}$$

$$= 1.5(0.8) = 1.2 \text{ inches thick.}$$

USE MIN. OF 3 inches due to difficulty of placement & QA/QC.

$$\boxed{d_{50} = 0.8 \text{ in} \ @ \ 3 \text{ in thick}}$$

NOTE:
IT SHOULD BE EVALUATED DURING DESIGN WHETHER A SOIL/GRAVEL ADMIX WITH A D_{50} OF 0.8 in WOULD BE SUITABLE (ie could it support THE SELECTED VEGETATION SPECIES.

ATTACHMENT A

REF. "DEVELOPMENT OF RIPRAP DESIGN CRITERIA BY RIPRAP TESTING IN FLUMES PHASE II" [34]
NUREG/CR-4651 (Sept 1988)
U.S. NUCLEAR REGULATORY COMMISSION

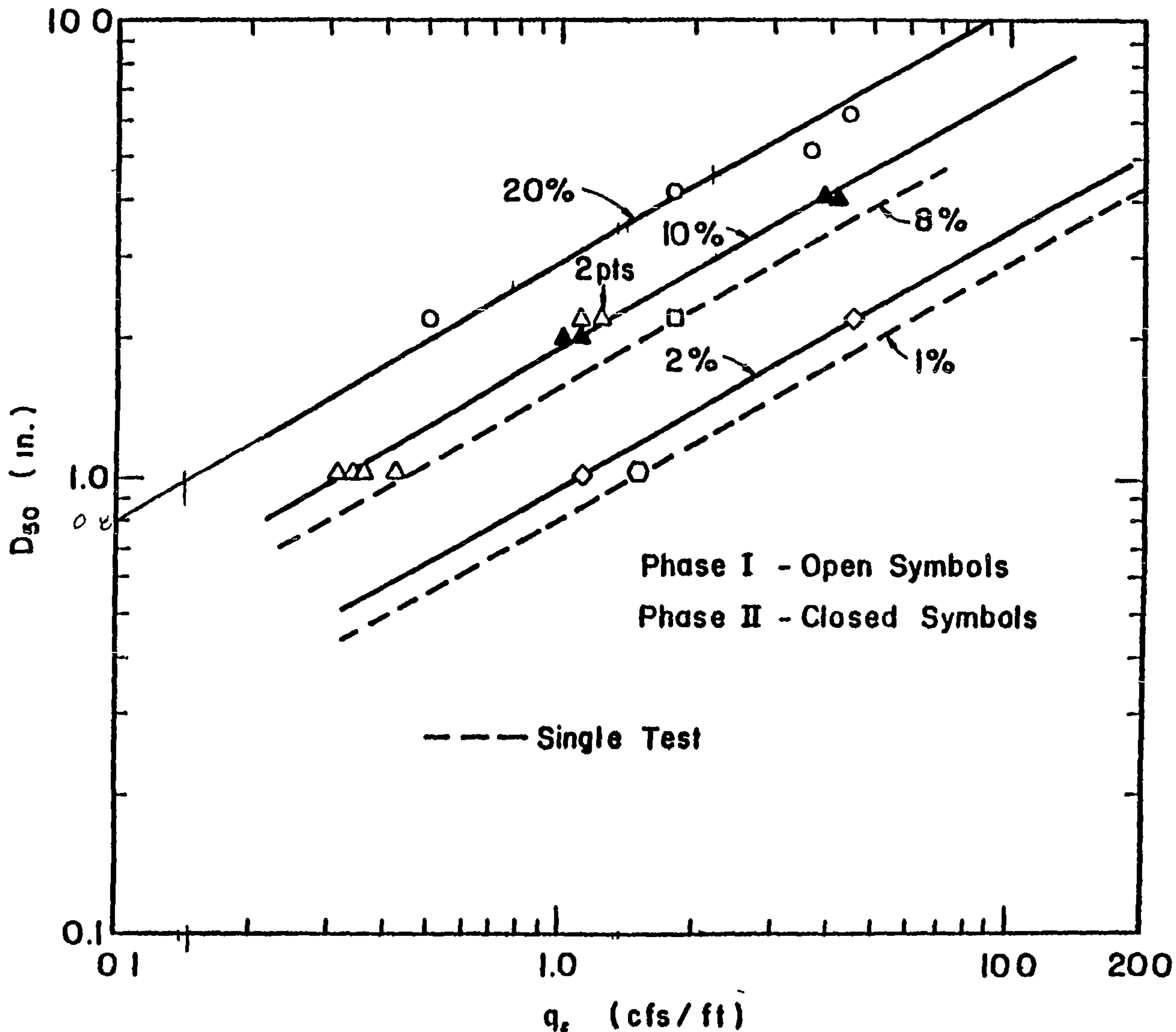

Figure 4.1. Comparison of unit discharge and median stone size relationship at failure for Phase II tests with Phase I tests at 10% slope.

Harding Lawson Associates
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SHEET 1 OF 8
JOB NO. 21907-708010
DATE 12-19-95
COMPUTED BY SES
CHECKED BY KAJ

PROJECT RMA 9303 CAMU D.D.
SUBJECT GULLY EROSION - COVER TOP SLOPES

OBJECTIVE: TO DETERMINE THE EROSION RESISTANCE OF THE VEGETATED TOPSLOPES OF THE ENGINEERED COVER AGAINST THE EROSIVE VELOCITIES OF STORMWATER RUNOFF RESULTING FROM A PROBABLE MAXIMUM PRECIPITATION (PMP) STORM EVENT FOR A FULLY VEGETATED COVER AND A 100-YEAR STORM EVENT FOR AN UNVEGETATED COVER

ASSUMPTIONS:

1) DESIGN LIFE OF 1,000 YEARS. USE THE PMP STORM, WHICH IS GENERALLY CONSIDERED TO BE IN THE 100,000 YEAR RECURRANCE RANGE, TO DEMONSTRATE THAT THE COVER WILL BE STABLE FOR 1,000 YEARS (REF. 1)

2) ASSUME THE SOIL PROPERTIES OF INSITU TOPSOILS WHICH ARE PRIMARILY SANDY LOAMS. SEE ATACHMENT 2 FOR THE SCS INFORMATION ON THESE SOILS.

3) ASSUME A 40% GRAVEL ADMIXTURE TO THE EXISTING SOILS TO ENHANCE THE EROSION RESISTANCE OVER THE 1000-YEAR DURATION. USE 1/2" MINUS FOR THE ADMIX

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SHEET 2 OF 8
JOB NO 21907-70801D
DATE 12-19-95
PROJECT RMA 93-03 CAMU DD
COMPUTED BY SES
SUBJECT GULY EROSION - COVER TOP SLOPES
CHECKED BY KAT

REFERENCES:

1) U.S. Nuclear Regulatory Commission, August 1990. Final Staff technical Position Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites.

2) U.S. Department of Agriculture, Soil Conservation Service. Soil Survey of Adams County, Colorado. (October 1974)

3) U.S. Department of Energy, December 1989. Technical Approach Document, Revision 2.

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SHEET 3 OF 8
JOB NO 21907-708010
DATE 12-19-95
COMPUTED BY SES
CHECKED BY RAT

PROJECT RMA 9303 CAMU DD
SUBJECT GULLY EROSION - COVER TOPSLOPES

CALCULATIONS:

USE THE ANALYTICAL/EMPIRICAL METHOD (REF 3) OR TRACTIVE FORCE METHOD TO COMPARE THE TRACTIVE FORCE PRODUCED BY THE FLOW TO THE ALLOWABLE TRACTIVE FORCES THE SOIL CAN WITHSTAND.

NOTE: THIS ANALYSIS IS FOR SLOPES NO GREATER THAN FIVE PERCENT.

1) DETERMINE THE ALLOWABLE TRACTIVE SHEAR STRESS OF THE TOPSOIL ONLY BY THE TEMPLE METHOD (REF. 1&3), NOTE: FOR NONCOHESIVE GRANULAR SOILS ONLY

$$\tau_{ALLOWABLE} = 0.4\, d_{75}$$

☐ ASSUME $d_{75} = 0.02185$ inches (ATTACHMENT A)

$$\tau_{ALL.} = 0.00874 \text{ PSF}$$

2) CALCULATE THE ACTUAL TRACTIVE SHEAR STRESS THAT THE TOPSOIL MUST WITHSTAND FOR THE GIVEN PRECIPITATION EVENTS

DETERMINE THE UNIT DISCHARGE RATE q FOR BOTH THE 100-YEAR AND PMP EVENTS.

$$q = F_{cu} \times I \times L \qquad \text{(REF. 1)}$$

$$F_{cu} = 3 \times C_r \qquad \text{(REF. 1)}$$

☐ ASSUME $C_r = 0.3$ (REF 3, pg. 103)

□ ASSUME $L_{MAX} = 200$ FEET

□ ASSUME: $I_{100\text{-}yr.} = 2.7 \frac{in}{hr}$ (ATTACHMENT D)

$I_{PMP} = 10.7 \frac{in}{hr.}$ (ATTACHMENT D)

$\therefore q_{100\text{-}yr} = (3 \times 0.3) \times \dfrac{2.7 \frac{in}{hr}}{43{,}200 \frac{in/hr}{ft/sec}} \times 200 \text{ Feet} = 0.01125$

$q_{pmp} = (3 \times 0.3) \times \dfrac{10.7}{43{,}200} \times 200 = 0.04458$

□ ASSUME MANNING'S ROUGHNESS COEFFICIENT FOR A DISTURBED UNVEGETATED SLOPE

$\therefore n = 0.022$ (ATTACHMENT E)

DETERMINE DEPTH OF SHEET FLOW FOR 100-YR EVENT:

BY MANNING'S EQUATION:

$V = \dfrac{1.486}{n} \times D^{2/3} \times S^{1/2}$ (REF. 3)

FROM CONTINUITY:

$V = q/D$ (REF. 3)

$\therefore \dfrac{q_{100}}{D} = \dfrac{1.486}{n} \times D^{2/3} \times S^{1/2}$ ⇒ SOLVE FOR D (USE FACTORED $q \times F_a$)

$D = \left[q_{100} F_a \left(\dfrac{n}{1.486} \right) \left(\dfrac{1}{S^{1/2}} \right) \right]^{3/5}$

☐ ASSUME MAX SLOPE = 5% ∴ S = 0.05

$$D = \left[(0.01125)(0.9)\left(\frac{0.022}{1.486}\right)\left(\frac{1}{\sqrt{0.05}}\right)\right]^{3/5} = 0.0125 \text{ FEET}$$

CALCULATE ACTUAL TRACTIVE SHEAR STRESS BY DUBOY'S FORMULA (REF. 3)

$\tau_{ACT} = \gamma' DS$ ☐ ASSUME $\gamma' = 62.4$ PCF

$= (62.4 \text{ PCF})(0.0125')(0.05 \frac{\text{FEET}}{\text{FOOT}}) = 0.0389$ PSF

$\boxed{\tau_{ACTUAL} > \tau_{ALLOWABLE}}$

0.0389 PSF > 0.00874 PSF

THEREFORE, AN UNVEGETATED SLOPE UNDER THE GIVEN CONDITIONS WOULD NOT RESIST EROSIVE FORCES.

3) DETERMINE THE ACTUAL TRACTIVE SHEAR STRESS FOR A VEGETATED SLOPE.

☐ ASSUME : $C_I = 5.60$, $C_F = 0.75$ } (Ref 3, pg 10.5)

DETERMINE NEW MANNING'S COEFFICIENTS FOR VEGETATED SLOPES

CALCULATE THE FLOW RESISTANCE COEFFICIENT (n_r) FOR VEGETAL CONDITIONS WITHIN THE FLOW FIELD:

$$n_r = e^{[0.01329\, C_I [\ln(RV)]^2 - 0.09543\, C_I \ln(RV) + 0.2971\, C_I - 4.16]}$$

(REF. 3) ☐ ASSUME $RV = q_{pmp}$ (REF. 3)

$$n_r = e^{0.01329(5.6)[\ln(0.0446)]^2 - 0.09543(5.6)\ln(0.0446) + 0.2971(5.6) - 4.16}$$

$$n_r = e^{-0.114} = 0.89$$

CALCULATE NEW ROUGHNESS COEFFICIENT (n_s) FOR SOIL GRAIN ROUGHNESS AT SOIL/WATER BOUNDARY:

$$n_s = \frac{d_{75}^{1/6}}{39} = 0.01356$$

CALCULATE n_v' FOR THE COMBINED INFLUENCE OF VEGETATION AND SOIL ROUGHNESS

$$n_v' = \left[n_r^2 - (0.0156)^2 + n_s^2\right]^{1/2}$$

$$= \left[(0.89)^2 - (0.0156)^2 + (0.01356)^2\right]^{1/2} = 0.89$$

COMPUTE THE FLOW DEPTH DOWN THE VEGETATED SLOPE USING THE MANNING'S COEFFICIENT OF RESISTANCE ON A VEGETATED SLOPE AND THE UNIT DISCHARGE FROM THE PMP EVENT.

$$D = \left[q_{PMP} F_{ci} \left(\frac{n}{1.486}\right)\left(\frac{1}{S^{1/2}}\right)\right]^{3/5} = \left[0.0446(.9)\left(\frac{0.89}{1.486}\right)\left(\frac{1}{\sqrt{0.05}}\right)\right]^{3/5}$$

$$D = 0.2623 \text{ FEET}$$

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SHEET 7 OF 8
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SUBJECT GULLY EROSION - COVER TOPSLOPES
COMPUTED BY SBS
CHECKED BY KGJ

CALCULATE THE COEFFICIENT OF VEGETAL RESISTANCE (K_V)

$$K_V = (1 - C_F)\left(\frac{n_s}{n_v'}\right)^2 = (1-0.75)\left(\frac{0.01356}{0.89}\right)^2$$

$$K_V = 0.000058$$

DETERMINE THE ACTUAL SHEAR STRESS FOR THE GIVEN FLOW DEPTH FOR THE PMP EVENT

$$\tau_{ACT} = \gamma D S = (62.4\ PCF)(0.2623')(0.05\ \tfrac{ft}{ft})$$

$$\tau_{ACT} = 0.818\ PSF$$

CALCULATE THE EFFECTIVE ACTUAL TRACTIVE SHEAR STRESS, τ_e, APPLIED TO THE VEGETATED SLOPE AT THE SOIL/WATER BOUNDARY:

$$\tau_e = \tau_{ACT} \times K_V = 0.818\ PSF \times 0.000058$$

$$\boxed{\tau_e = 0.0000474\ PSF \ll \tau_{ALLOWABLE}}$$

$\therefore$ EXISTING SOILS WILL BE ADEQUATE FOR COVER TOP SLOPES UNDER VEGETATED CONDITIONS, BUT MUST BE ENHANCED FOR UNVEGETATED CONDITIONS.

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SHEET 8 OF 8
JOB NO 21907-708070
DATE 12-19-95
COMPUTED BY SES
CHECKED BY RGJ

PROJECT RMA 93-03 CAMU DD
SUBJECT GULLY EROSION - COVER TOP SLOPES

4) DETERMINE THE REQUIRED d_{75} OF AN ENHANCED SOIL MIX TO ACHIEVE τ_{actual} FOR UNVEGETATED SITUATIONS.

$\tau_{actual} = 0.0389$ PSF

$\tau = 0.4 d_{75}$

$d_{75} = \dfrac{0.0389}{0.4} = 0.09725$ inches SAY #8 SIEVE

d_{75} FOR A 30% GRAVEL ADMIXTURE IS APPROXIMATELY $\underline{0.315''}$, AND THEREFORE WOULD SUFFICE

ATTACHMENT A

TABLE 6.—*Estimated properti*

[An asterisk in the first column indicates that at least one mapping unit in the series is made up of two or more kinds of soil The sc for referring to the other series that appear in the first col

Soil series and map symbols	Depth from surface	Classification: USDA texture	Classification: Unified	Classification: AASH(
	Inches			
*Adena. AaB, AaC, AcC, AcD. For properties of Colby soils in AcC and AcD, refer to Colby series.	0–11	Loam, clay loam, silty clay loam	ML or CL	A–4 or A-
	11–60	Silty clay loam, silt loam	ML or CL	A–4 or A-
Arvada AdB	0–4	Loam, sandy loam	SM or ML	A–4 or A-
	4–28	Clay, sandy clay	CL or CH	A–7
	28–60	Sandy loam	SM	A–2 or A-
*Ascalon ArB, ArC, AsB, AsC, AsD, At, AvC. For properties of Platner soils in At and Vona soils in AvC, refer to their respective series	0–21	Loamy sand, sandy loam, and sandy clay loam	SM or SC	A–2 or A-
	21–60	Sandy loam	SM	A–2 or A-
*Blakeland BoD, Bt. For properties of Truckton soils in Bt, refer to Truckton series.	0–60	Loamy sand and sand	SP–SM or SM	A–2 or A-
Colby CbE	0–60	Loam and fine sandy loam	ML	A–4
Dacono DaA, DaB	0–9	Loam	ML	A–4
	9–17	Clay	CH	A–7
	17–26	Sandy clay loam	SC	A–4
	26–60	Very coarse loamy sand, sand, and gravel.	SP or SM, SP–SM, or GP–GM	A–1
Deertrail. Mapped only in a complex with Weld soils.	0–9	Very fine sandy loam and loam	ML	A–4
	9–21	Clay	CH	A–7
	21–60	Silty clay loam and loam	CL or ML	A–4 or A-
Gravelly land-Shale outcrop complex Gr. Properties too variable to be estimated.				
Gullied land Gu. Properties too variable to be estimated				
Heldt HlB, HlD	0–32	Clay	CH	A–7
	32–60	Silty clay loam, sandy clay loam.	CL	A–6
Loamy alluvial land: Lu	0–60	Loam, silt loam, and clay loam	ML or CL	A–4 or A
Lv	0–20	Stratified loam	ML	A–4
	20–60	Sand and gravel	SP or GP	A–1
Lw	0–36	Loam, clay, and stratified loam	ML or CL	A–4 or A
	36	Gravel	GP	A–1
Nunn. NlA, NlB	0–9	Loam and clay loam	ML	A–4 or A
	9–23	Clay	CH	A–7
	23–60	Loam and silt loam	CL or ML	A–4
NuA, NuB	0–9	Clay loam	CL	A–6
	9–23	Clay	CH	A–7
	23–60	Loam and silt loam	CL or ML	A–6 or A
Platner PlB, PlC	0–9	Loam	ML	A–4
	9–18	Clay	CH	A–7
	18–60	Clay loam, loam, and sandy loam	SM, ML, or CL	A–6 or A
Renohill ReB, ReD	0–9	Loam and clay loam	ML or CL	A–6
	9–28	Clay and clay loam	CH	A–7
	28	Shale and sandstone		

ATTACHMENT A
CONTINUED

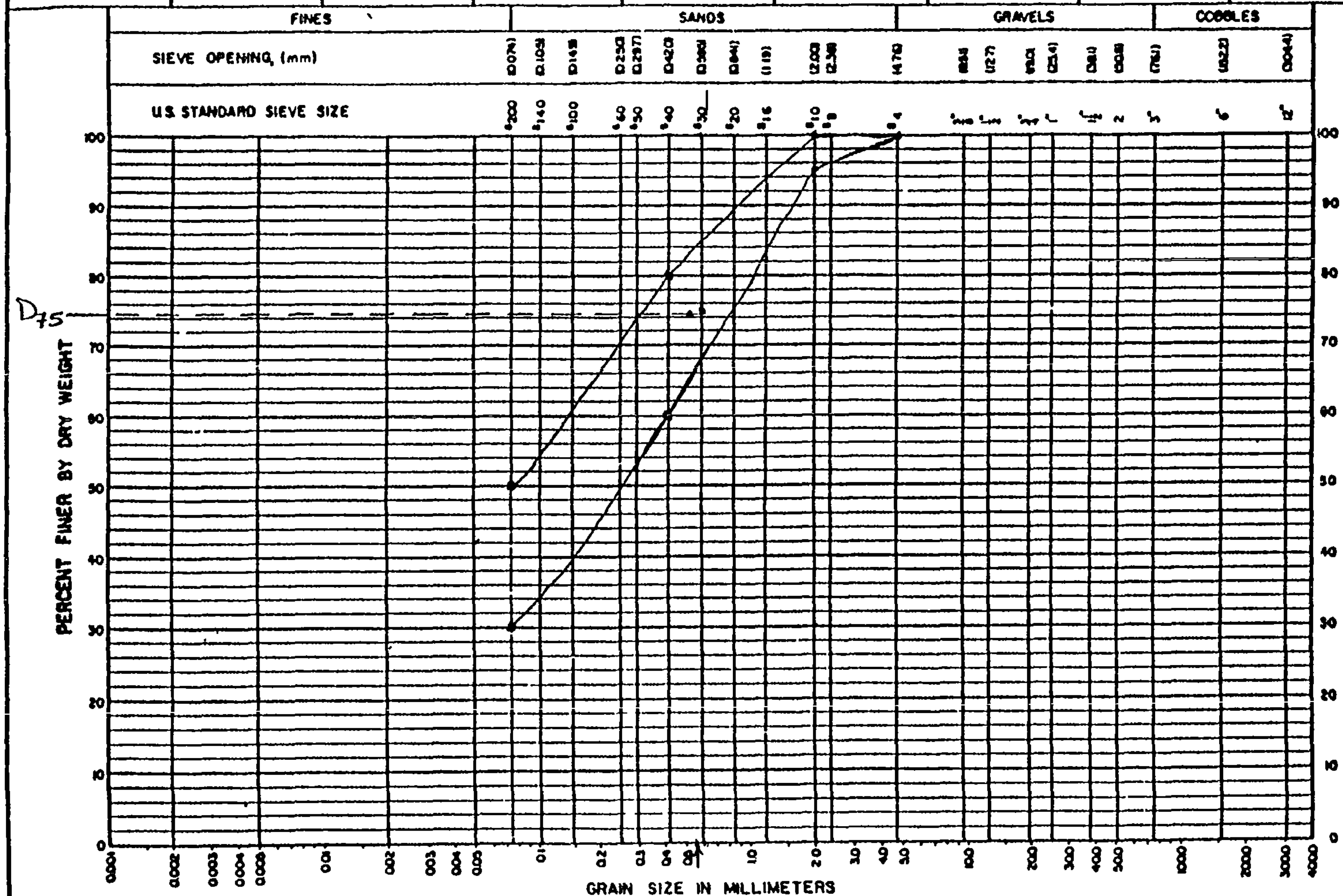
soils significant to engineering

such mapping units may have different properties and limitations, and for this reason it is necessary to follow carefully the instructio
The sign > means more than, and the sign < means less than]

Percentage passing sieve—				Permeability	Available water capacity	Reaction	Salinity	Shrink-swell potential
No 4 (4 7 mm)	No 10 (2 0 mm)	No 40 (0 42 mm)	No 200 (0 074 mm)					
				Inches per hour	*Inches per inch of soil*	*pH*	*Mmhos /cm. at 25° C*	
100	100	85–95	70–85	0 06–0 20	0. 19–0 21	6 6–7 8	0–4	Moderate
100	100	90–100	70–90	0 63–2 0	0 19–0 21	7 9–9 0	0–4	Low to moderate
100	100	60–90	30–60	0 63–6. 3	0 11–0 18	7 9–8. 4	0–8	Low
100	100	90–100	80–90	<0 06	0 04–0 06	7 9–10 0	8–15	High
100	95–100	60–70	30–40	2 0–6. 3	0 04–0 06	7 9–9 0	4–15	Low
100	95–100	60–80	30–50	0 63–2 0	0 13–0 15	6 6–7 8	0–4	Low to moderate
100	95–100	60–70	30–40	2 0–6 3	0 11–0 13	7 9–9 0	0–4	Low
100	100	50–75	5–15	6 3–20 0	0 06–0 08	6 1–7 3	0–2	Low
100	100	80–95	50–80	0 63–2. 0	0 16–0 18	7 9–8. 4	0–4	Low to moderate
90–100	85–100	80–90	60–70	0 63–2 0	0 16–0 18	6 6–7 3	0–1	Low
90–100	85–100	80–100	70–80	0 06–0 20	0 14–0 16	7 4–7. 8	0–1	High
90–100	85–100	80–90	35–50	0 63–2 0	0 14–0 16	7 9–8 4	0–2	Moderate
50–65	25–35	15–25	0–15	>20. 0	0 03–0 05	7 9–8. 4	0–2	Low
100	100	85–95	60–70	0 63–2 0	0 15–0 17	6 6–7 8	0–4	Low.
100	100	85–95	70–80	0 06–0. 20	0. 04–0 06	7 9–10 0	0–8	High.
100	100	90–100	75–85	0 63–2 0	0 04–0 06	7 9–10 0	4–8	Low to moderate
100	100	95–100	80–95	0. 06–0 20	0. 14–0 16	7 9–8. 4	0–2	High
100	100	90–100	70–90	0 20–0 63	0 16–0 18	7 9–8 4	0–2	Moderate
100	100	85–100	60–80	0 20–2 0	0 16–0 20	---------------	4–8	Low to moderate.
100	95–100	85–95	50–80	0 63–2. 0	0 16–0 18	---------------	0–8	Low.
30–40	25–35	15–25	0–5	>20. 0	0 03–0 05	---------------	0–2	Low.
100	100	85–95	50–80	0 20–2 0	0 16–0 20	---------------	0–8	Low to moderate.
30–40	25–35	15–25	0–5	>20 0	0 03–0 05	---------------	0–2	Low.
100	90–100	80–90	60–80	0 63–2. 0	0 16–0 18	6. 6–7 3	0–2	Moderate
100	100	90–100	75–85	0 2–0 63	0 14–0 16	7 4–7 8	0–2	High.
100	90–100	80–90	60–80	0 63–0 20	0 18–0 20	7 9–8 4	0–4	Moderate
100	90–100	80–90	60–80	0 20–0 63	0 19–0 21	6 6–7 3	0–2	Moderate
100	90–100	80–90	75–85	0 06–0 20	0 14–0 16	7 4–7 8	0–2	High.
100	90–100	80–90	50–70	0 20–2 0	0 18–0 20	7 9–8. 4	0–4	Moderate
100	100	85–95	60–70	0 63–2. 0	0 16–0 18	6 6–7 3	0–2	Moderate
100	100	90–100	75–85	0 06–0 20	0 14–0 16	6 6–7 3	0–4	High.
100	90–100	75–85	40–75	0 63–2. 0	0 16–0 18	7 9–8. 0	0–4	Low to moderate
100	100	85–95	70–80	0 2–0 63	0 18–0. 20	7 4–8. 4	0–2	Moderate
100	100	90–100	70–95	0 06–0 20	0. 15–0. 17	7 9–9 0	0–2	High

GRAIN SIZE DISTRIBUTION

D_{10}	D_{15}	D_{30}	D_{50}	D_{60}	D_{85}	D_{MAX}	C_u	C_c



SPECIFIC GRAVITY (G_s)		ATTERBERG LIMITS						SOLUBLE SALTS	SHRINKAGE LIMIT	UNDISTURBED CONDITION	
		NATURAL MOISTURE		AIR DRY		OVEN DRY				MOISTURE	DRY UNIT WEIGHT
(-) #4	(+) #4	LL	PI	LL	PI	LL	PI	%	%	%	g/cc pcf

REMARKS

SANDY LOAMS & LOAMY SANDS

SCS-ENG-353 (REV. 3-70)
FILE CODE ENG-22

SOIL CLASSIFICATION

RMA 9303 SOILS NATIVE TO
21907-70800 THE PROJECT SITE

PROJECT and STATE: ROCKY MOUNTAIN ARSENAL

FIELD SAMPLE NO.

DEPTH

GEOLOGIC ORIGIN

SAMPLE LOCATION

TYPE OF SAMPLE

TESTED AT

APPROVED BY: SES

DATE: 11-28-95

SYMBOL: SM or SC

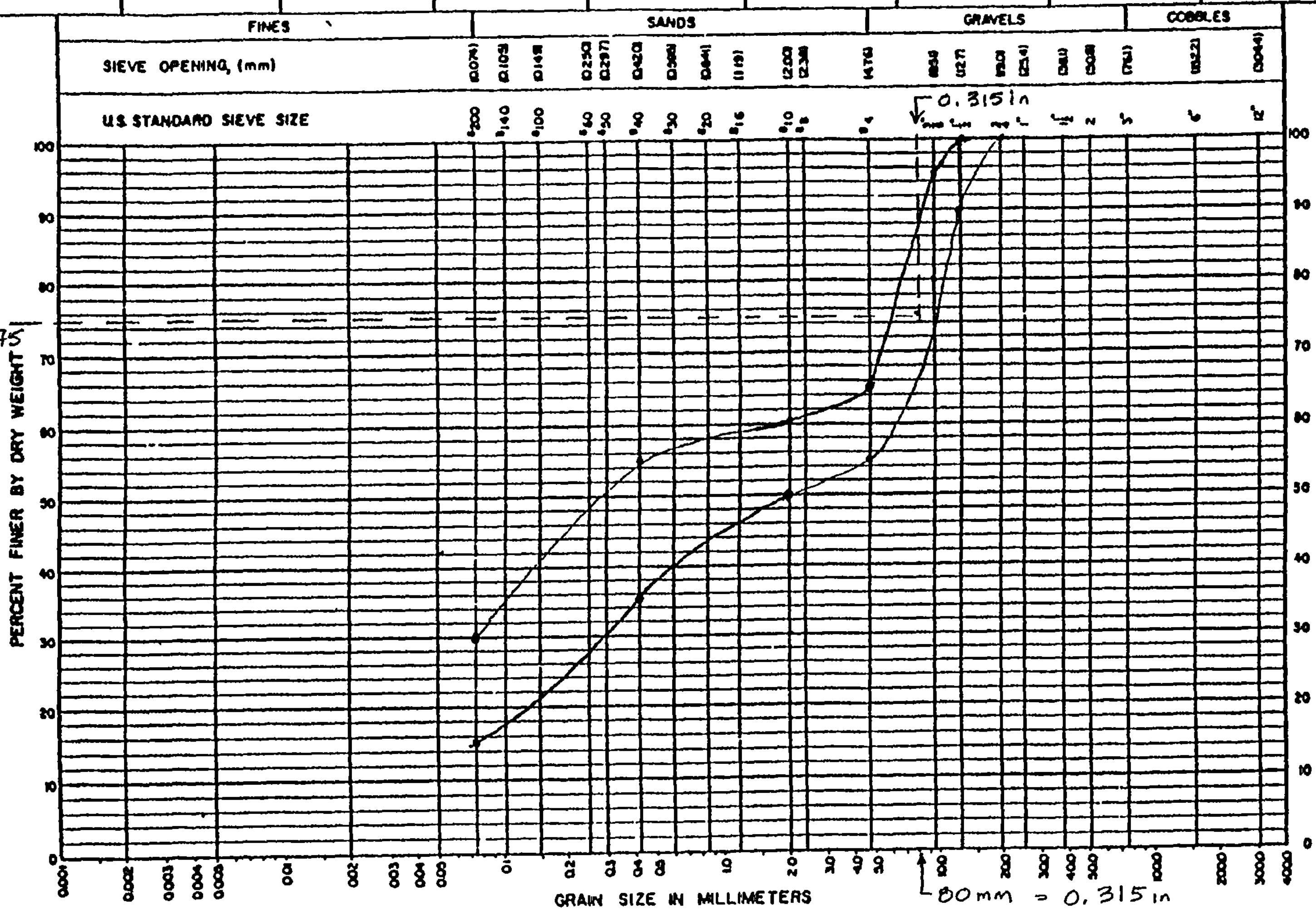
DESCRIPTION: ASCALON SERIES - GRADATION PER SCS

LABORATORY NO.

ATTACHMENT B

GRAIN SIZE DISTRIBUTION

D_{10}	D_{15}	D_{30}	D_{50}	D_{60}	D_{85}	D_{MAX}	C_u	C_c



SPECIFIC GRAVITY (G_s)		ATTERBERG LIMITS						SOLUBLE SALTS	SHRINKAGE LIMIT	UNDISTURBED CONDITION	
		NATURAL MOISTURE		AIR DRY		OVEN DRY				MOISTURE	DRY UNIT WEIGHT
(-) #4	(+) #4	LL	PI	LL	PI	LL	PI	%	%	%	g/cc pcf

REMARKS

GRAVELLY SANDY LOAMS OR GRAVELLY LOAMY SANDS

SCS-ENG-353 (REV. 3-70)
FILE CODE ENG-22

SOIL CLASSIFICATION

LABORATORY NO. ATTACHMENT C

PROJECT and STATE: RMA 9303 21907-708010 NATIVE SOILS W/ 30% GRAVEL ADMIX

SAMPLE LOCATION

FIELD SAMPLE NO.

DEPTH

GEOLOGIC ORIGIN

TYPE OF SAMPLE

TESTED AT

APPROVED BY: SES

DATE: 11-28-95

SYMBOL

DESCRIPTION

ATTACHMENT D

Table 1
Precipitation Values for the RFP → ROCKY FLATS PLANT
(in inches) (DENVER AREA)

RECURRENCE INTERVAL
(Probability of Occurrence)

DURA-TION	2-yr (50%)	5-yr (20%)	10-yr (10%)	25-yr (4%)	50-yr (2%)	100-yr (1%)	500 yr (0.2%)	$\boxed{\text{PMP(L)}}$	PMP(G)	REFERENCE APPENDIX TABLE
5-min	0.3	0.4	0.5	0.6	0.7	0.8	–	–	–	
10-min	0.5	0.6	0.8	1.0	1.1	1.2	–	–	–	
15-min	0.6	0.8	1.0	1.2	1.4	1.5	–	–	–	
30-min	0.8	1.2	1.4	1.7	1.9	2.1	–	–	–	
1-hr	1.0	1.5	1.8	2.1	2.4	2.7	3.3	10.7	13	B-4
2-hr	1.2	1.6	2.0	2.4	2.8	3.0	3.8	–	15	
6-hr	1.6	2.0	2.5	3.0	3.4	3.8	4.8	14.5	24	B-1
24-hr	2.2	2.8	3.2	4.0	4.4	5.2	6.5	–	35	B-2
72-hr	2.9	3.3	3.8	5.0	5.5	6.3	8.1	–	43	B-3

PMP(L) = Local Storm PMP

PMP(G) = General Storm PMP

STANDARD HANDBOOK FOR CIVIL ENGINEERS 2nd EDITION

ATTACHMENT F

Table 21-11. Values of the Roughness Coefficient n for Use in the Manning Equation

	Min	Avg	Max
A Open-channel flow in closed conduits			
1 Corrugated-metal storm drain	0.021	0.024	0.030
2 Cement-mortar surface	0.011	0.013	0.015
3 Concrete (unfinished)			
a Steel form	0.012	0.013	0.014
b Smooth wood form	0.012	0.014	0.016
c Rough wood form	0.015	0.017	0.020
B Lined channels			
1 Metal			
a Smooth steel (unpainted)	0.011	0.012	0.014
b Corrugated	0.021	0.025	0.030
2 Wood			
a Planed, untreated	0.010	0.012	0.014
3 Concrete			
a Float finish	0.013	0.015	0.016
b Gunite, good section	0.016	0.019	0.023
c Gunite, wavy section	0.018	0.022	0.025
4 Masonry			
a Cemented rubble	0.017	0.025	0.030
b Dry rubble	0.023	0.032	0.035
5 Asphalt			
a Smooth	0.013	0.013	
b Rough	0.016	0.016	
C Unlined channels			
1 Excavated earth straight and uniform			
a Clean, after weathering	0.018	0.022	0.025
b With short grass, few weeds	0.022	0.027	0.033
c Dense weeds, high as flow depth	0.050	0.080	0.120
d Dense brush, high stage	0.080	0.100	0.140
2 Dredged earth			
a No vegetation	0.025	0.028	0.033
b Light brush on banks	0.035	0.050	0.060
3 Rock cuts			
a Smooth and uniform	0.025	0.035	0.040
b Jagged and irregular	0.035	0.040	0.050

Shallow flow in an unlined channel will result in an increase in the effective n value if the channel bottom is covered with large boulders or ridges of silt, since these projections would then have a larger influence on the flow than for deep flow A deeper-than-normal flow will also result in an increase in the effective n value if there is a dense growth of brush along the banks within the path of flow When channel banks are overtopped during a flood, the effective n value increases as the flow spills into heavy growth bordering the channel The roughness of a lined channel experiences change with age, because of both deterioration of the surface and accumulation of foreign matter, therefore, the average n values given in Table 21-11 are recommended only for well-maintained channels (See also Art 21-9 and Table 21-4)

21-26. Water-Surface Profiles for Gradually Varied Flow. Examples of various surface curves possible with gradually varied flow are shown in Fig 21-46 These surface profiles represent backwater curves that form under the conditions illustrated in examples (*a*) through (*r*)

These curves are divided into five groups according to the slope of the channel in which they appear (Art 21-23) Each group is labeled with a letter descriptive of the slope M for mild (subcritical), S for steep (supercritical), C for critical, H for horizontal, and A for adverse The two dashed lines that appear in the left-hand figure for each of these classes are the *normal-depth line* N D L and the *critical-depth line* C D L The N D L and C D.L are identical for a channel of critical slope, and the N D L is replaced by a horizontal line, at an arbitrary elevation, for the channels of horizontal or adverse slope

There are three types of surface-profile curves possible in channels of mild or steep slope, and for channels of critical, horizontal, and adverse slope

Harding Lawson Associates
Engineering and Environmental Services

SHEET 1 OF 9
JOB NO 21907-708010
DATE 2-22-96
PROJECT RMA 9303 - LANDFILL COVERS
COMPUTED BY SES
SUBJECT SHEET & RILL EROSION OF COVERS (RUSLE ANALYSIS)
CHECKED BY [illegible]

OBJECTIVE:

DETERMINE HOW MUCH SOIL LOSS WILL OCCUR TO THE PROPOSED ENGINEERED COVERS DUE TO SHEET AND RILL EROSION CAUSED BY OVERLAND RUNOFF OVER THE 1,000 YEAR DESIGN LIFE.

ASSUMPTIONS:

1) USE RUSLE MODEL VERSION 1.04 (MOST CURRENT AVAILABLE), DEVELOPED BY THE SOIL AND WATER CONSERVATION SOCIETY TO REVISE THE USLE EQUATION ORIGINALLY DEVELOPED BY THE SCS.

2) IT SHOULD BE NOTED THAT NO ACTUAL LAB OR FIELD TESTS WERE PERFORMED FOR THIS ANALYSIS. GENERAL SOILS TYPICAL TO THE LANDFILL AREA WHERE USED FOR BASIC PROPERTY INFORMATION. IT IS ASSUMED THAT SOILS EXCAVATED DURING CONSTRUCTION OF THE LANDFILLS WILL BE STOCKPILED AND REUSED FOR THE ENGINEERED COVER CONSTRUCTION.

3) ASSUME GENERAL ASCALON SERIES SOILS (SCS) ATTACHMENT A WHICH ARE SANDY LOAMS, LOAMY SANDS AND SANDY CLAY LOAMS, SM or SC.

4) ASSUME RMA IS A SEMI-ARID CLIMATE. THE VEGETATIVE COVER (CANOPY) IS ASSUMED TO BE APPROXIMATELY 30 PERCENT, BASED ON SIMILAR VEGETATION INDEGINOUS TO THE AREA (CONSERVATIVE)

5) AS NOTED WITHIN CALCULATIONS & MODEL.

RUSLE COMPUTER ANALYSIS
(SWCS1.04)

SUMMARY TABLE

File Exit Help Screen

< RUSLE SWCS1.04 >

Conservation Planning Alternatives - Soil Loss Computation Worksheet

filename	R	x	K	x	LS	x	C	x	P	=	A (TONS/AC)
TRIAL-SO	40		0.29		6.09		0.135		1.00	=	9.5
TRIAL-VG	40		0.29		6.09		0.052		1.00	=	3.6
TRIAL-GA	40		0.18		6.09		0.045		1.00	=	2
TRIAL-GV	40		0.18		6.09		0.025		1.00	=	1.1
	0		0		0		0		0	=	0
	0		0		0		0		0	=	0
	0		0		0		0		0	=	0
	0		0		0		0		0	=	0
	0		0		0		0		0	=	0
	0		0		0		0		0	=	0

TRIAL-SO ASSUMES SOIL ONLY CONDITIONS, NO GRAVEL ADMIX AND NO ABOVE GROUND VEGETATION OR ROOTMASS (VEGETATION NEVER PLANTED) ← THIS IS NOT LIKELY, AS NATURAL VEGETATION WILL EVENTUALLY SEED & ESTABLISH.

TRIAL-VG ASSUMES SOIL W/O GRAVEL ADMIX, WITH NORMAL VEGETATION AND ROOTMASS.

TRIAL-GA ASSUMES SOIL W/GRAVEL ADMIX WITH ROOT MASS, BUT NO ABOVE GRADE VEGETATION (IN CASE OF FIRE, DROUGHT, etc.)

TRIAL-GV ASSUMES SOIL W/GRAVEL ADMIX WITH ABOVE GRADE VEGETATION & ROOT MASS

THESE FOUR SCENARIOS REPRESENT A RANGE OF POSSIBLE CONDITIONS. CONSIDERING THE 1,000 YEAR DESIGN LIFE OF THIS COVER THE POSSIBILITY THAT VEGETATION MAY BE DESTROYED AT SOME TIME SHOULD BE CONSIDERED ONCE VEGETATION IS ESTABLISHED (@CONSTRUCTION). HOWEVER, ROOT MASS WILL BE PRESENT EVEN IF VEG. IS DESTROYED.

Harding Lawson Associates Engineering and Environmental Services	SHEET 3 OF 9
	JOB NO 21907
	DATE 2-22-96
PROJECT RMA 9303	COMPUTED BY SES
SUBJECT RUSLE ANALYSIS	CHECKED BY ECA

RAINFALL FACTOR (R) - FOR ALL 4 SCENARIOS

```
        File              Exit              Help              Screen
Õááááááááááááááááááááááááá< Rainfall Factor SWCS1.04 >áááááááááááááááááááááááááá¢

                       city code: 6001    DENVER                       CO
                 Initial R value: 40
                    field slope %: 14.8 Õáááááááááááááá¢
             adjust for ponding?: 1        °  1. yes°
                                       °  2. no  °
                                      âááááááááááááááì

          Õáááááááááááááááááááááááááááááááááááááááááááááááááá¢
          ° Should the program adjust the R factor for the   °
          ° effect of ponded water absorbing rainfall impact? °
          °   Answer yes UNLESS the surface is very rough or  °
          ° has been formed into moderate to high ridges.     °
          âááááááááááááááááááááááááááááááááááááááááááááááááááì

âáááááááááááááááááááááááááá< F3 When Questions Answered >áááááááááááááááááááááááì
```

SLOPE LENGTH FACTOR (LS) - FOR ALL 4 SCENARIOS

```
        File              Exit              Help              Screen
Õááááááááááááááááááááááááááá< LS Factor SWCS1.04 >áááááááááááááááááááááááááááááá

°   number of segments: 2          segment lengths are measured: 2
°         segments are: 1
°         use LS table: 3
°
°ááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááá
°                            1          2
° Gradient (%) of Segment    5          20
° Length of Segment (ft)     200        140
° Segment LS                1.017      13.344
°ááááÕááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááá¢ááááááá
°    ° overall LS = 6.09; equiv. slope = 14.9 %; horiz. length = 340 ft°
°    âááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááì

âááááááááááááááááááááááááááááá< Esc exits >ááááááááááááááááááááááááááááááá
```

Harding Lawson Associates
Engineering and
Environmental Services

SHEET 4 OF 9
JOB NO 21907
DATE 2-22-94
COMPUTED BY SES
CHECKED BY ECR

PROJECT RMA 9303
SUBJECT RUSLE ANALYSIS

SOIL ONLY
NO GRAVEL ADMIX

K-FACTOR → FOR FIRST TWO SCENARIOS W/SOIL & NO GRAVEL ADMIX

```
     File              Exit              Help              Screen
Õáááááááááááááááááá< Seasonally Variable K Factor SWCS1.04 >áááááááááááááááááááááá¢
°     city code: 6001_    DENVER                 CO        estimated K: 0.24      °
° % rock cover: 0    # yrs to consolidate: 7    hyd. group: 2                    °
° soil series: ascalon                surface texture: sl                        °
°ááááDATEááááááááááá%EIáááááááááKáááááááá°áááááDATEáááááááááááááá%EIááááááááááKáááááá°
°  1/1-1/15          0.0        0.188      °   7/1-7/15             14.5        0.297   °
°  1/16-1/31         0.1        0.216      °   7/16-7/31            16.0        0.246   °
°  2/1-2/15          0.0        0.249      °   8/1-8/15             15.1        0.202   °
°  2/16-2/28         0.1        0.285      °   8/16-8/31             7.7        0.167   °
°  3/1-3/15          0.1        0.32       °   9/1-9/15              4.8        0.137   °
°  3/16-3/31         0.3        0.367      °   9/16-9/30             1.8        0.113   °
°  4/1-4/15          1.1        0.423      °   10/1-10/15            1.0        0.094   °
°  4/16-4/30         3.2        0.485      °   10/16-10/31           0.4        0.094   °
°  5/1-5/15          5.0        0.64       °   11/1-11/15            0.2        0.109   °
°  5/16-5/31         9.6        0.53       °   11/16-11/30           0.0        0.125   °
°  6/1-6/15          7.7        0.434      °   12/1-12/15            0.1        0.142   °
°  6/16-6/30        11.1        0.359      °   12/16-12/31           0.1        0.163   °
° NOTE:  upward adjustment of K reached the limit of 1.2 * Knom         -----    °
°   EI DIST.: 84          FREEZE-FREE DAYS: 160    AVERAGE ANNUAL K:   0.288     °
°    R VALUE: 40     Kmin = 0.087 on 10/14    Kmax = 0.648 on 5/7                °
ááááááááááááááááááááááááááááááááááááá< Esc exits >áááááááááááááááááááááááááááááááááááááá¾
```

SOIL WITH
30% GRAVEL ADMIX

K-FACTOR → FOR LAST TWO SCENARIOS W/GRAVEL ADMIX

```
     File              Exit              Help              Screen
Õáááááááááááááááááá< Seasonally Variable K Factor SWCS1.04 >áááááááááááááááááááááá¢
°     city code: 6001_    DENVER                 CO        estimated K: 0.15      °
° % rock cover: 30   # yrs to consolidate: 7    hyd. group: 2                    °
° soil series: ascalon                surface texture: sl                        °
°ááááDATEááááááááááá%EIáááááááááKáááááááá°áááááDATEáááááááááááááá%EIááááááááááKáááááá°
°  1/1-1/15          0.0        0.118      °   7/1-7/15             14.5        0.186   °
°  1/16-1/31         0.1        0.135      °   7/16-7/31            16.0        0.154   °
°  2/1-2/15          0.0        0.156      °   8/1-8/15             15.1        0.126   °
°  2/16-2/28         0.1        0.178      °   8/16-8/31             7.7        0.104   °
°  3/1-3/15          0.1        0.2        °   9/1-9/15              4.8        0.085   °
°  3/16-3/31         0.3        0.229      °   9/16-9/30             1.8        0.071   °
°  4/1-4/15          1.1        0.265      °   10/1-10/15            1.0        0.059   °
°  4/16-4/30         3.2        0.303      °   10/16-10/31           0.4        0.059   °
°  5/1-5/15          5.0        0.4        °   11/1-11/15            0.2        0.068   °
°  5/16-5/31         9.6        0.331      °   11/16-11/30           0.0        0.078   °
°  6/1-6/15          7.7        0.271      °   12/1-12/15            0.1        0.089   °
°  6/16-6/30        11.1        0.224      °   12/16-12/31           0.1        0.102   °
° NOTE:  upward adjustment of K reached the limit of 1.2 * Knom         -----    °
°   EI DIST.: 84          FREEZE-FREE DAYS: 160    AVERAGE ANNUAL K:   0.18      °
°    R VALUE: 40     Kmin = 0.054 on 10/14    Kmax = 0.405 on 5/7                °
ááááááááááááááááááááááááááááááááááááá< Esc exits >áááááááááááááááááááááááááááááááááááááá¾
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SHEET 5 OF 9
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PROJECT RMA 9303
SUBJECT RUSLE ANALYSIS

C-FACTOR
TRIAL - SO - SOIL ONLY W/NO VEG. OR ROOTMASS

```
        File             Exit            Help            Screen
Õááááááááááááááááááááááá< Time-invariant C SWCS1.04 >áááááááááááááááááááááááááá¢
°       where get vegetation information?: 3                                   °
°                                                                              °
°                                                 Õááááááááááááááááááááááá¢    °
°                                                 ° CA ann. grassland   .3 °   °
°   effective root mass (lb/ac) in top 4": 0      ° tallgrass prairie   .3 °   °
°                        % canopy cover: 0        ° clipped & bare      .6 °   °
°                  average fall height (ft): 0    ° pinyon/jun. inter.  .6 °   °
° roughness value for the field condition: 1      ° cleared             .7 °   °
°   has there been mechanical disturbance: 1      ° natural shrub       .8 °   °
°                                                 ° shortgrass desert   .8 °   °
°                                                 ° cleared & pitted   1.0 °   °
° total % ground cover (rock and residue): 20     ° mixed grass prar.  1.0 °   °
°     % surface covered by rock fragments: 0      ° pitted             1.1 °   °
°      % vegetative residue surface cover: 20     ° sagebrush          1.1 °   °
°    surface cover function; B-value code: 1      ° root plow          1.3 °   °
°                                                 ááááááááááááááááááááááááì    °
°                                                                              °
°                                    C=0.132                                   °
° enter avg. annual values!                                                    °
  ááááááááááááááááááááááá< F3 When Questions Answered >ááááááááááááááááááááááááì
```

C-FACTOR
TRIAL - VG - SOIL W/VEGETATION & ROOT MASS

```
        File             Exit            Help            Screen
Õááááááááááááááááááááááá< Time-invariant C SWCS1.04 >áááááááááááááááááááááááááá¢
°       where get vegetation information?: 3                                   °
°                                                                              °
°                                                 Õááááááááááááááááááááááá¢    °
°                                                 ° CA ann. grassland   .3 °   °
°   effective root mass (lb/ac) in top 4": 950    ° tallgrass prairie   .3 °   °
°                        % canopy cover: 30       ° clipped & bare      .6 °   °
°                  average fall height (ft): 1    ° pinyon/jun. inter.  .6 °   °
° roughness value for the field condition: 0.3    ° cleared             .7 °   °
°   has there been mechanical disturbance: 1      ° natural shrub       .8 °   °
°                                                 ° shortgrass desert   .8 °   °
°                                                 ° cleared & pitted   1.0 °   °
° total % ground cover (rock and residue): 30     ° mixed grass prar.  1.0 °   °
°     % surface covered by rock fragments: 0      ° pitted             1.1 °   °
°      % vegetative residue surface cover: 30     ° sagebrush          1.1 °   °
°    surface cover function; B-value code: 1      ° root plow          1.3 °   °
°                                                 ááááááááááááááááááááááááì    °
°                                                                              °
°                                    C=0.052                                   °
° enter avg. annual values!                                                    °
ááááááááááááááááááááááááá< F3 When Questions Answered >ááááááááááááááááááááááááì
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C-FACTOR
TRIAL - GA SOIL W/GRAVEL ADMIX, ROOTMASS W/NO. VEG.

```
      File          Exit         Help         Screen
Õááááááááááááááááááááááááá< Time-invariant C SWCS1.04 >áááááááááááááááááááááááááááá¢
°       where get vegetation information?: 3                                        °
°                                                                                   °
°                                                   Õááááááááááááááááááááááááá¢     °
°                                                   ° CA ann. grassland  .3 °       °
°   effective root mass (lb/ac) in top 4": 950      ° tallgrass prairie  .3 °       °
°                          % canopy cover: 0        ° clipped & bare     .6 °       °
°                average fall height (ft): 0        ° pinyon/jun. inter. .6 °       °
° roughness value for the field condition: 1        ° cleared            .7 °       °
°   has there been mechanical disturbance: 1        ° natural shrub      .8 °       °
°                                                   ° shortgrass desert  .8 °       °
°                                                   ° cleared & pitted  1.0 °       °
° total % ground cover (rock and residue): 30       ° mixed grass prar. 1.0 °       °
°     % surface covered by rock fragments: 30       ° pitted            1.1 °       °
°      % vegetative residue surface cover: 0        ° sagebrush         1.1 °       °
°    surface cover function; B-value code: 1        ° root plow         1.3 °       °
°                                                   áááááááááááááááááááááááááì      °
°                                                                                   °
°                                      C=0045                                       °
° enter avg. annual values!                                                         °
ááááááááááááááááááááááááááá< F3 When Questions Answered >áááááááááááááááááááá      ì
```

C-FACTOR
TRIAL-GV -SOIL W/GRAVEL ADMIX, W/VEG & ROOTMAS

```
      File          Exit         Help         Screen
Õááááááááááááááááááááááááá< Time-invariant C SWCS1.04 >áááááááááááááááááááááááááááá¢
°       where get vegetation information?: 3                                        °
°                                                                                   °
°                                                   Õááááááááááááááááááááááááá¢     °
°                                                   ° CA ann. grassland  .3 °       °
°   effective root mass (lb/ac) in top 4": 950      ° tallgrass prairie  .3 °       °
°                          % canopy cover: 30       ° clipped & bare     .6 °       °
°                average fall height (ft): 1        ° pinyon/jun. inter. .6 °       °
° roughness value for the field condition: 0.3      ° cleared            .7 °       °
°   has there been mechanical disturbance: 1        ° natural shrub      .8 °       °
°                                                   ° shortgrass desert  .8 °       °
°                                                   ° cleared & pitted  1.0 °       °
° total % ground cover (rock and residue): 51       ° mixed grass prar. 1.0 °       °
°     % surface covered by rock fragments: 30       ° pitted            1.1 °       °
°      % vegetative residue surface cover: 30       ° sagebrush         1.1 °       °
°    surface cover function; B-value code: 1        ° root plow         1.3 °       °
°                                                   áááááááááááááááááááááááááì      °
°                                                                                   °
°                                     C=0.025                                       °
° enter avg. annual values!                                                         °
ááááááááááááááááááááááááááá< F3 When Questions Answered >áááááááááááááááááááá      ì
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PROJECT RMA 9303	SHEET 7 OF 9
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CROPLAND FACTOR (P) - FOR ALL 4 SCENARIOS

```
        File             Exit             Help             Screen
Õáááááááááááááááááááááááá< P Factor - Cropland SWCS1.04 >áááááááááááááááááááááááá¢
°                                                                                °
°                                                                                °
°     contoured   strip    terraced  subsurface               P factor           °
°               cropped              drained                                     °
°   Õáááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááá¢       °
°   °  1____      1         1         1                   =  1          °       °
°   âááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááì       °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
°                                                                                °
  ááááááááááááááá< F4 Calls Routine, Esc Returns to P Main Menu >ááááááááááááááál
```

ASSUME THE CROPLAND FACTOR P IS 1 FOR NON-FARMLAND.
(SEE REF. 1)

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PROJECT RMA 9303
SUBJECT RUSLE ANALYSIS

CALCULATE DEPTH OF SOIL LOSS

☐ ASSUME SOIL ONLY DENSITY OF 105 lb/ft3

TRIAL - SO

$$\underset{1\text{-}YR}{\text{Depth}} = 9.5 \frac{\text{TONS}}{\text{Ac}} \times \frac{1\text{Ac}}{43{,}560\text{ft}^2} \times \frac{2000\text{ lb}}{\text{TON}} \times \frac{1\text{ft}^3}{105\text{ lb}} \times \frac{12\text{ in}}{1\text{ft}} = 0.0498\text{ in}$$

$$\underset{1000yr}{\text{Depth}} = 0.0498\text{ in} \times 1000\text{ yr} = \boxed{49.8\text{ inches}}$$

TRIAL - VG

$$\underset{1000yr}{\text{Depth}} = \frac{3.6 \times 1 \times 2000 \times 1 \times 12 \times 1000}{43560 \times 1 \times 105} = \boxed{18.89\text{ inches}}$$

☐ ASSUME SOIL/GRAVEL DENSITY OF 135 lb/ft³

TRIAL - GA

$$\underset{1000yr}{\text{Depth}} = \frac{2.0 \times 1 \times 2000 \times 1 \times 12 \times 1000}{43{,}560 \times 1 \times 135} = \boxed{8.16\text{ inches}}$$

TRIAL - GV

$$\underset{1000yr}{\text{Depth}} = \frac{1.1 \times 1 \times 2000 \times 1 \times 12 \times 1000}{43560 \times 1 \times 135} = \boxed{4.5\text{ inches}}$$

RUN SCENARIO → "TRIAL - SR" for SOIL w/ROOTMASS BUT NO ABOVE GROUND VEGETATION (COVER WAS VEGETATED BUT BY FIRE, DROUGHT, ETC. VEG. WAS DESTROYED). (NO GRAVEL ADMIX)

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TRIAL-SR

```
        File              Exit              Help              Screen
Õááááááááááááááááááááááááááááá< RUSLE SWCS1.04 >áááááááááááááááááááááááááááááááá¢
°      Conservatıon Plannıng Alternatives - Soil Loss Computatıon Worksheet     °
°                                                                               °
° fılename              R     x     K     x     LS    x     C     x     P     = A   °
°ááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááááá°
° TRIAL-SR             40          0.29        6.093       0.063       1.00   = 4.5 °
°                       0           0           0           0           0     = 0   °
°                       0           0           0           0           0     = 0   °
°                       0           0           0           0           0     = 0   °
        File              Exit              Help              Screen
Õáááááááááááááááááááááááá< Time-invariant C SWCS1.04 >áááááááááááááááááááááááá¢
°        where get vegetation information?: 3                                  °
°                                                                              °
°                                                    Õááááááááááááááááááááááá¢  °
°                                                    ° CA ann. grassland  .3 °  °
°    effective root mass (lb/ac) in top 4": 950      ° tallgrass prairie  .3 °  °
°                              % canopy cover: 0     ° clipped & bare     .6 °  °
°                     average fall height (ft): 0    ° pinyon/jun. inter. .6 °  °
° roughness value for the field condition: 1         ° cleared            .7 °  °
°   has there been mechanical disturbance: 1         ° natural shrub      .8 °  °
-                                                    ° shortgrass desert  .8 °  °
                                                     ° cleared & pıtted   1.0 ° °
° total % ground cover (rock and residue): 20        ° mıxed grass prar.  1.0 ° °
°     % surface covered by rock fragments: 0         ° pıtted             1.1 ° °
°      % vegetative resıdue surface cover: 20        ° sagebrush          1.1 ° °
°    surface cover function; B-value code: 1         ° root plow          1.3 ° °
°                                                    âááááááááááááááááááááááıı  °
°                                                                               °
°                                                                               °
° enter avg. annual values!                                                     °
âáááááááááááááááááááááááááááá< F3 When Questions Answered >áááááááááááááááááááááááı
```

$$\frac{\text{DEPTH}}{1000\ \text{YR}} = \frac{4.5 \times 1 \times 2000 \times 1 \times 12 \times 1000}{43560 \times 1 \times 105} = \boxed{23.61 \text{ inches}}$$

Since it is not anticipated that a consistent vegetative condition would be maintained over the entire 1000-year design life of the cover, it is suggested that the design of the uppermost soil layer be designed to account for an unvegetated condition. The inclusion of the gravel admix into the topsoil layer greatly reduces the total required depth of this layer (23 61 inches vs 8.16 inches) However, a cover of soil with vegetation (no gravel admix) may be suitable for the 1,000 year design life with appropriate final slope lengths and angles These conceptual calculations were based on assumed slope angles and lengths which may change during design. Based on these conceptual calculations, it suggested that the Trial-GA (soil/gravel admix with root mass, but no above grade vegetation) scenario be used, which would yield a minimum topsoil/gravel admix layer thickness of 10 inches (to allow for some remaining functional layer after the 1000 year period).

ATTACHMENT A

TABLE 6.—*Estimated properties*

[An asterisk in the first column indicates that at least one mapping unit in the series is made up of two or more kinds of soil. The soil ... for referring to the other series that appear in the first colu...

Soil series and map symbols	Depth from surface	Classification: USDA texture	Classification: Unified	Classification: AASHO
	Inches			
*Adena: AaB, AaC, AcC, AcD. For properties of Colby soils in AcC and AcD, refer to Colby series.	0–11	Loam, clay loam, silty clay loam.	ML or CL	A–4 or A–6
	11–60	Silty clay loam, silt loam	ML or CL	A–4 or A–6
Arvada: AdB	0–4	Loam, sandy loam	SM or ML	A–4 or A–2
	4–28	Clay, sandy clay	CL or CH	A–7
	28–60	Sandy loam	SM	A–2 or A–4
*Ascalon: ArB, ArC, AsB, AsC, AsD, At, AvC. For properties of Platner soils in At and Vona soils in AvC, refer to their respective series.	0–21	Loamy sand, sandy loam, and sandy clay loam.	SM or SC	A–2 or A–4
	21–60	Sandy loam	SM	A–2 or A–4
*Blakeland: BoD, Bt. For properties of Truckton soils in Bt, refer to Truckton series.	0–60	Loamy sand and sand	SP–SM or SM	A–2 or A–3
Colby: CbE	0–60	Loam and fine sandy loam	ML	A–4
Dacono: DaA, DaB	0–9	Loam	ML	A–4
	9–17	Clay	CH	A–7
	17–26	Sandy clay loam	SC	A–4
	26–60	Very coarse loamy sand, sand, and gravel.	SP or SM, SP–SM, or GP–GM	A–1
Deertrail. Mapped only in a complex with Weld soils.	0–9	Very fine sandy loam and loam	ML	A–4
	9–21	Clay	CH	A–7
	21–60	Silty clay loam and loam	CL or ML	A–4 or A–6
Gravelly land-Shale outcrop complex: Gr. Properties too variable to be estimated.				
Gullied land: Gu. Properties too variable to be estimated.				
Heldt: HIB, HID	0–32	Clay	CH	A–7
	32–60	Silty clay loam, sandy clay loam.	CL	A–6
Loamy alluvial land:				
Lu	0–60	Loam, silt loam, and clay loam	ML or CL	A–4 or A–6
Lv	0–20	Stratified loam	ML	A–4
	20–60	Sand and gravel	SP or GP	A–1
Lw	0–36	Loam, clay, and stratified loam	ML or CL	A–4 or A–6
	36	Gravel	GP	A–1
Nunn:				
NIA, NIB	0–9	Loam and clay loam	ML	A–4 or A–6
	9–23	Clay	CH	A–7
	23–60	Loam and silt loam	CL or ML	A–4
NuA, NuB	0–9	Clay loam	CL	A–6
	9–23	Clay	CH	A–7
	23–60	Loam and silt loam	CL or ML	A–6 or A–4
Platner: PIB, PIC	0–9	Loam	ML	A–4
	9–18	Clay	CH	A–7
	18–60	Clay loam, loam, and sandy loam.	SM, ML, or CL	A–6 or A–4
Renohill: ReB, ReD	0–9	Loam and clay loam	ML or CL	A–6
	9–28	Clay and clay loam	CH	A–7
	28	Shale and sandstone.		

ATTACHMENT A.
(CONTINUED)

soils significant to engineering

such mapping units may have different properties and limitations, and for this reason it is necessary to follow carefully the instructio
The sign > means more than, and the sign < means less than]

Percentage passing sieve— No 4 (4 7 mm)	No 10 (2 0 mm)	No 40 (0.42 mm.)	No 200 (0 074 mm)	Permeability	Available water capacity	Reaction	Salinity	Shrink-swell potential
				Inches per hour	*Inches per inch of soil*	*pH*	*Mmhos./cm. at 25° C*	
100	100	85–95	70–85	0. 06–0 20	0. 19–0. 21	6. 6–7. 8	0–4	Moderate.
100	100	90–100	70–90	0. 63–2. 0	0 19–0. 21	7. 9–9 0	0–4	Low to moderate
100	100	60–90	30–60	0. 63–6. 3	0. 11–0 18	7 9–8. 4	0–8	Low
100	100	90–100	80–90	<0 06	0. 04–0 06	7 9–10 0	8–15	High.
100	95–100	60–70	30–40	2 0–6. 3	0. 04–0. 06	7 9–9 0	4–15	Low.
100	95–100	60–80	30–50	0 63–2. 0	0. 13–0 15	6. 6–7 8	0–4	Low to moderate
100	95–100	60–70	30–40	2 0–6. 3	0. 11–0 13	7 9–9 0	0–4	Low
100	100	50–75	5–15	6 3–20 0	0 06–0 08	6. 1–7 3	0–2	Low
100	100	80–95	50–80	0 63–2. 0	0 16–0 18	7. 9–8. 4	0–4	Low to moderate
90–100	85–100	80–90	60–70	0. 63–2. 0	0. 16–0. 18	6. 6–7. 3	0–1	Low
90–100	85–100	80–100	70–80	0. 06–0. 20	0. 14–0 16	7. 4–7 8	0–1	High.
90–100	85–100	80–90	35–50	0. 63–2. 0	0. 14–0. 16	7. 9–8. 4	0–2	Moderate
50–65	25–35	15–25	0–15	>20. 0	0. 03–0 05	7. 9–8. 4	0–2	Low.
100	100	85–95	60–70	0 63–2. 0	0 15–0 17	6. 6–7 8	0–4	Low
100	100	85–95	70–80	0. 06–0 20	0. 04–0 06	7. 9–10. 0	0–8	High
100	100	90–100	75–85	0. 63–2. 0	0. 04–0 06	7. 9–10 0	4–8	Low to moderate.
100	100	95–100	80–95	0 06–0 20	0 14–0 16	7 9–8. 4	0–2	High.
100	100	90–100	70–90	0 20–0 63	0 16–0 18	7 9–8. 4	0–2	Moderate
100	100	85–100	60–80	0. 20–2. 0	0 16–0. 20	----------	4–8	Low to moderate.
100	95–100	85–95	50–80	0. 63–2. 0	0 16–0 18	----------	0–8	Low.
30–40	25–35	15–25	0–5	>20. 0	0 03–0 05	----------	0–2	Low.
100	100	85–95	50–80	0. 20–2. 0	0. 16–0 20	----------	0–8	Low to moderate
30–40	25–35	15–25	0–5	>20. 0	0. 03–0. 05	----------	0–2	Low.
100	90–100	80–90	60–80	0 63–2. 0	0 16–0 18	6. 6–7. 3	0–2	Moderate.
100	100	90–100	75–85	0. 2–0 63	0. 14–0 16	7 4–7 8	0–2	High
100	90–100	80–90	60–80	0 63–0 20	0. 18–0 20	7. 9–8. 4	0–4	Moderate.
100	90–100	80–90	60–80	0. 20–0 63	0 19–0 21	6 6–7 3	0–2	Moderate
100	90–100	80–90	75–85	0. 06–0 20	0 14–0 16	7. 4–7. 8	0–2	High
100	90–100	80–90	50–70	0. 20–2. 0	0. 18–0 20	7. 9–8. 4	0–4	Moderate
100	100	85–95	60–70	0. 63–2. 0	0. 16–0 18	6. 6–7. 3	0–2	Moderate
100	100	90–100	75–85	0 06–0 20	0. 14–0 16	6 6–7 3	0–4	High.
100	90–100	75–85	40–75	0. 63–2. 0	0. 16–0 18	7. 9–8. 0	0–4	Low to moderate
100	100	85–95	70–80	0. 2–0. 63	0. 18–0 20	7 4–8. 4	0–2	Moderate.
100	100	90–100	70–95	0. 06–0. 20	0. 15–0. 17	7. 9–9 0	0–2	High.

ATTACHMENT B
(RUSLE MANUAL)

Table 8.

Typical Root Mass Values for Established Forage Stands.[1]

(Source: USDA Agriculture Handbook 703.)

Common Name	Root mass in top 4 in. (lb ac^{-1})	Yield (tons/acre)
Grasses:		
Bahiagrass	1,900	-
Bermudagrass, Coastal	3,900	-
Bermudagrass, Common	2,400	-
Bluegrass, Kentucky	4,800	-
Bromegrass, Smooth	4,500	2.5
Dallisgrass	2,500	-
Fescue, Tall	7,000	1.5
Orchardgrass	5,900	2.5
Timothy	2,900	2.5
Legumes:		
Alfalfa	3,500	1.75
Clover, Ladino	1,400	-
Clover, Red	2,100	1.25
Clover, Sweet	1,200	-
Clover, White	1,900	-
Lespedeza, Sericea	1,900	-
Trefoil, Birdsfoot	2,400	-

[1]These values are for mature, full pure stands on well drained nonirrigated soils with moderate to high available water-holding capacity. These values hold for the species shown only within their range of adaptation. Except for biennials, most forages do not attain a fully-developed root system until the end of the second growing season. Root mass values listed can be reduced by as much as half on excessively drained or shallow soils and in areas where rainfall during the growing season is less than 18 inches.

ASSUME HALF OF LOWEST VALUE (CONSERVATIVE)

USE $\frac{1,900}{2} = 950 \frac{lb}{ac}$

STENSENG ATTACHMENT

United States
Environmental Protection
Agency

Office of Solid Waste
and Emergency Response
Washington DC 20460

SW-867
September 1982
Revised Edition

Evaluating Cover Systems for Solid and Hazardous Waste

PB87-154894

ATTCH. C
(CONT.)

is erosion objectionable in itself but erosion can degrade the seriously reduce its effectiveness.

uate Erosion Potential **Step 19**

The USDA universal soil loss equation (USLE) is a convenient tool for use in evaluating erosion potential. The USLE predicts average annual soil loss as the product of six quantifiable factors. The equation is:

$$A = R\,K\,L\,S\,C\,P$$

where A = average annual soil loss, in tons/acre
R = rainfall and runoff erosivity index
K = soil erodibility factor, tons/acre
L = slope-length factor
S = slope-steepness factor
C = cover-management factor
P = practice factor

The data necessary as input to this equation are available to the evaluator in a figure and tables included below. Note that the evaluations in Step 8 on soil composition and Steps 25-32 on vegetation all impact on the evaluation of erosion also.

Factor R in the USLE can be calculated empirically from climatological data. For average annual soil loss determinations, however, R can be obtained directly from Figure 20. Factor K, the average soil loss for a given

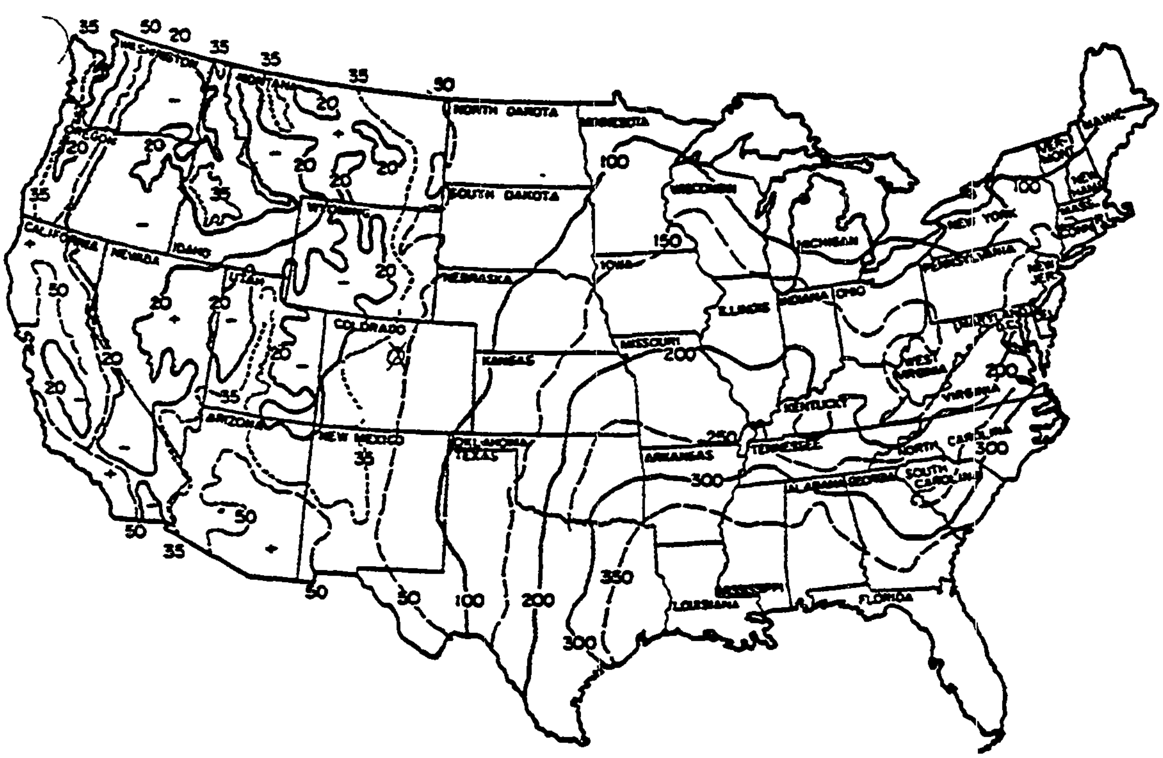


Figure 20. Average annual values of rainfall-erosivity factor R.[11]

ATTACH. C
(CONT.)

soil in a unit plot, pinpoints differences in erosion according to differences in soil type. Long-term plot studies under natural rainfall have produced K values generalized in Table 5 for the USDA soil types.

TABLE 5. APPROXIMATE VALUES OF FACTOR K FOR USDA TEXTURAL CLASSES[11]

Texture class	Organic matter content		
	<0.5%	2%	4%
	K	K	K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sandy loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

CONSERVATIVE

The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

The evaluator must next consider the shape of the slope in terms of length and inclination. The appropriate LS factor is obtained from Table 6. A nonlinear slope may have to be evaluated as a series of segments, each with uniform gradient. Two or three segments should be sufficient for most engineered landfills, provided the segments are selected so that they are also of equal length (Table 6 can be used, with certain adjustments). Enter Table 6 with the total slope length and read LS values corresponding to the percent slope of each segment. For three segments, multiply the chart LS values for the upper, middle, and lower segments by 0.58, 1.06, and 1.37, respectively. The average of the three products is a good estimate of the

ATTCH. C
(CONT)

are listed in Table 8. These values are based on rather limited field data, but P has a narrower range of possible values than the other five factors.

TABLE 8. VALUES OF FACTOR P[11]

Practice	Land slope (percent) 1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
	(Factor P)				
Contouring (P_c)	0.60	0.50	0.60	0.80	0.90
Contour strip cropping (P_{sc})					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting (P_{cl})	0.30	0.25	0.30	0.40	0.45
Contour terracing (P_t)[2]	[3] $0.6/\sqrt{n}$	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$
No support practice	1.0	1.0	1.0	1.0	1.0

[1] R = rowcrop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that rowcrop strips are always separated by a meadow or winter-grain strip.

[2] These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2.

[3] n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

Example: An owner/operator proposes to close one section of his small landfill with a sandy clay subsoil cover having the surface configuration shown in Figure 21. The factor R has been established as 200 for this locality. The evaluator questions anticipated erosion along the steep side and assigns the following values to the other factors in the USLE after inspecting Tables 5 through 8:

K = 0.14   LS = 8.3   C = 1.00   P = 0.90

The rate of erosion for the steep slope of the landfill is calculated as follows:

A = 200 (0.14 tons/acre) (8.3) (1.00) (0.90)
= 209 tons/acre

This erosion not only exceeds a limit recommended by the permitting authority but also indicates a potential

Attachment A3

AQUIFER TESTING PROGRAM RESULTS

CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

This attachment presents the data, analysis, and results of the aquifer testing program conducted by Harding Lawson Associates (HLA) in the western portion of Section 25 at Rocky Mountain Arsenal (RMA) The aquifer testing program was performed in support of Task 93-03 Feasibility Study Soils Support Program as described in the Draft Final Work Plan for the Hydrogeologic and Geotechnical Program (HLA, 1995a) The purpose of the aquifer testing program was to evaluate the hydraulic properties such as hydraulic conductivity and transmissivity of the hydrostatic units in the western portion of Section 25

The western portion of Section 25 has been selected as the proposed site of the hazardous waste landfill that is part of the overall conceptual remedy for the Onpost Operable Unit at RMA (Program Manager for Rocky Mountain Arsenal [PMRMA], 1995) As discussed in the Landfill Site Feasibility Report (HLA, 1995b), the hydrogeology of the proposed landfill site had not been studied in detail To facilitate the designation of the landfill site, as well as the design of future groundwater monitoring programs proposed for the area, further characterization of the hydrostratigraphic units at the proposed site was necessary

1.1 Geology and Hydrogeology of Section 25

A detailed discussion of the geologic setting of the proposed site was presented in the Landfill Site Feasibility Report (HLA, 1995b) and is not included here for brevity In general, the site is immediately underlain by the Quaternary surficial deposits commonly called the Quaternary alluvium The alluvium is composed of primarily clay, silt, and fine- to medium-grained sand with some coarse-grained sand and gravel Underlying the alluvium is the Cretaceous-Tertiary Age Denver Formation (Fm) The Denver Fm is composed primarily of claystone with interbedded siltstone, sandstone, and lignite

Groundwater in the western portion of Section 25 occurs under both unconfined and confined conditions The Quaternary alluvium and the uppermost weathered portion of the Denver Fm form a generally continuous unconfined groundwater system This flow system is referred to as the unconfined flow system (UFS) Confining strata inhibit groundwater interaction between the UFS and the deeper, more permeable zones, such as sandstones, siltstones, and lignites in the Denver Fm, causing confining conditions to exist The confined groundwater underlying the UFS is referred to as the confined flow system (CFS)

1.2 Test Methods and Data Analysis

For the aquifer testing program in Section 25, aquifer tests were conducted in both the UFS and CFS flow systems In western portion of Section 25, the UFS occurs within the weathered Denver Fm and the alluvium in the area is predominantly unsaturated The aquifer testing program, therefore, was designed to evaluate the hydraulic properties of the two Denver Fm flow systems (UFS and CFS) Because the hydraulic properties of each flow system are different, different approaches for the test methods and data analysis were selected and implemented

Unconfined Flow System Aquifer Tests

The Denver Fm UFS tests consisted of single-well hydraulic tests (rising head slug tests) at five well locations (25022, 25027, 25028, 25065, and 25066) The tests were conducted between November 20 and 22, 1995, and the well locations are illustrated in Figure A3 1

A slug test provides water-level response data following the rapid removal of a small volume of water The water-level response data can be used to estimate the hydraulic conductivity of the aquifer Due to the small volume of water removed, a slug test has a much smaller area of influence than an aquifer pumping test, and therefore provides an estimate of hydraulic conductivity near the well bore Slug tests from a number of wells in an area provide an indication of the hydraulic conductivity variability across an area as the lithology of the aquifer changes This is especially useful in Section 25 where the UFS occurs in a variety of lithology including Denver Fm claystone, sandstone, and siltstone HLA chose to perform slug tests in a number of wells in the UFS rather than an aquifer pumping test for the following reasons

- Well development data in the proposed testing area indicated a relatively low hydraulic conductivity and a thin saturated interval Both of these conditions would indicate that a pumping test of the aquifer would be unsatisfactory because the well would likely dewater before significant response could be measured in nearby wells
- Estimates of hydraulic conductivity at several well locations within the weathered Denver Fm were considered more useful than a single pumping test result because of the variability in the hydraulic conductivity of the UFS throughout the area

The Denver Fm UFS slug tests were analyzed using the Hvorslev method and Bouwer and Rice method Both of these methods represent standard procedures for slug test data analysis and are described in further detail in this attachment

Confined Flow System Aquifer Test

The Denver CFS test consisted of one 72-hour aquifer pumping test conducted at Well 25064 between November 13 and 20, 1995 The aquifer pumping test location, including observations wells monitored during the aquifer pumping test, is shown in Figure A3 1 An aquifer pumping test is a standard method used to estimate the hydraulic properties of an aquifer such as hydraulic conductivity and transmissivity

The Denver Fm CFS aquifer test data were analyzed using three methods

- Theis type-curve method
- Cooper and Jacob semilogarithmic method
- Theis recovery method

These three methods represent standard procedures for aquifer test analysis and are described in further detail in the following sections

2.0 SINGLE-WELL HYDRAULIC TESTING

Single-well hydraulic tests (rising head slug tests) were performed at five monitoring wells located in Section 25 at RMA (Figure A3 1) between November 20 and 22, 1995 The objective of the slug testing was to provide site-specific hydraulic conductivity data from monitoring wells located near the proposed landfill site The five monitoring wells identified for testing (25022, 25027, 25028, 25065, and 25066) are screened across the Denver Fm UFS Well 25022 is screened across the contact of weathered sandstone and weathered claystone of the Denver Fm Well 25027 is screened in the weathered sandstone of the Denver Fm Wells 25028, 25065, and 25066 are screened in the weathered claystone of the Denver Fm

2.1 Equipment and Procedures

The equipment used during the slug testing varied due to well diameter (4-inch-diameter or 2-inch-diameter) and casing thickness (Schedule 40 or Schedule 80) During the test, a slug of water was removed from the well using a bailer Two different sizes of bailers were used for the tests a 1 65-inch-diameter stainless steel bailer, and a 1 80-inch-diameter stainless steel bailer For two of the wells (25022 and 25066), a 4-foot-long bailer length was used and for three wells (25027, 25028, and 25065), shorter bailer lengths (2 feet, 1 foot, and 3 feet, respectively) were used due to restrictive bends in the well casings Water levels were measured during pretest monitoring and during the test using a Solinst electronic water-level indicator

The field procedures used during slug testing were as follows

- Bailers and measuring devices were decontaminated before each test
- Upon arrival at the well to be tested, the static water level was measured and recorded
- The bailer was lowered to just below the top of the water column in the well for Wells 25066, 25027, 25028, and 25065 The water level within the well was then allowed to reequilibrate until it recovered to static water level
- For Well 25022 and a second test for Well 25065, the bailer was submerged and withdrawn "instantaneously" and no equilibration time was necessary

- To begin the test, the bailer was "instantaneously" removed and the volume of water removed was recorded
- The time that the slug was pulled above the water column was recorded as the initial time Times and water-level measurements were then recorded with the Solinst water-level indicator at sufficient frequency to accurately monitor the recovery Measurements were taken until the well had reequilibrated to static conditions or until a minimum of 60 minutes had passed since the slug was removed
- After completion of the test, the data was entered into spreadsheets for subsequent data reduction
- Water removed from the well and decontamination water was containerized and transported to the North Boundary Treatment System (NBTS) for treatment

2.2 Data Analysis and Evaluation

The first step of slug test data analysis consisted of plotting the time and water-level data obtained during slug testing in the form of a water-level hydrograph for each test The purpose of the hydrograph is to evaluate the consistency of the data and to confirm that static water-level conditions existed prior to testing Hydrographs for each slug test (including the first and second tests of Well 25065) are presented in Figures A3 2 through A3 7

Hvorslev Method

A semilogarithmic plot was prepared for the rising-head (withdrawal) portion of each hydrograph Values plotted are the log of drawdown (withdrawal) versus arithmetic elapsed time The semiloga-rithmic withdrawal plot was then analyzed using a semilogarithmic analysis that is consistent with the Bouwer (1989) "slope" method The slug test analysis was based on the following equation, which describes the transient change in hydraulic drawdown after the slug is initiated (Hvorslev, 1951)

$$T = \frac{2\ 303\ C\ A}{2\pi(t_2 - t_1)} \log(s_1/s_2)$$

where

T = aquifer transmissivity (feet^2/day)

C = dimensionless shape factor (related to the geometry of the well completion interval)

A = cross-sectional area of well at water surface (including sandpack porosity for alluvial wells that are sandpacked above the water table) (feet^2)

s = hydraulic drawdown (feet)

t = elapsed time (day)

In the previous equation, subscripts identify contemporaneous time-drawdown measurements (i e , s_1 is the drawdown occurring at time t_1) Hvorslev (1951) defines the shape factor as follows

$$C = \ell\eta \left[\frac{L}{D} + \sqrt{1 + \left[\frac{L}{D} \right]^2} \right]$$

where

L = length of test interval (feet)

D = borehole diameter (feet)

The equation for transmissivity predicts that a semilogarithmic plot of arithmetic time versus log drawdown should be a straight line If one considers a period of time over which the drawdown changes by a factor of 10, the following equation results

$$T = \frac{2\ 303\ C\ A}{2\pi\ \Delta t_{90}}$$

where

t_{90} = change in time over one log cycle of drawdown (minutes)

The change in time over one log cycle of drawdown is interpreted from a semilogarithmic plot as described by Bouwer (1989)

The semilogarithmic method is based on the assumption of quasi-steady-state flow near the borehole (i e , a succession of steady-state flow conditions) Fully transient solutions predict that quasi-steady-state conditions tend to be achieved at late recovery times Thus, in applying the semilogarithmic method to slug test data, preference is generally given to fitting the straight line to later-time data

The average hydraulic conductivity computation for the test interval is as follows

$$K = \frac{T}{B}$$

where

K = average hydraulic conductivity (feet/day)

B = test interval thickness (saturated thickness) (feet)

K (cm/s) = K (ft/day) x 3 53 x 10^{-4}

Bouwer and Rice Method

The Bouwer and Rice method uses the following equation

$$K = (r_c^2 (\ln(R_e/R))/2L_e)*(1/t)\ln(s/s_o)$$

where

K = hydraulic conductivity (feet/day)

r_c = the radius of the well casing

R = the radius of the gravel envelope

R_e = the effective radial distance over which head is dissipated (feet)

L_e = the length of screen or open section of the well through which water can enter

s_o = the drawdown at time t=0 (feet)

s_t = the drawdown at time t=t (feet)

t = the time since s_o=s

To calculate the ratio of the effective radial distance (Re) to the radius of the gravel envelope (R), Bouwer and Rice (1976) provide the following equation

$$\ln(R_e/R)=[(1\ 1/\ln(L_w/R))+(C/(L_e/R))]^{-1}$$

where

C = a shape factor obtained from Bouwer, 1989

L_w = the length from the water table to the bottom of the sandpack

The drawdown is plotted versus time on semilogarithmic paper and the slope of the line through that data is calculated The value of $(1/t)\ln(s_o/s_t)$ may be obtained from two points picked on that straight line At one point, $t=t_1$ and $s=s_1$, and at the second point, $t=t_2$, and $s=s_2$ (Fetter, 1988) Under these conditions $(1/t)\ln(s_o/s_t)=(1/(t_2-t_1))\ln(s_1/s_2)$ hydraulic conductivity can then be calculated using the equation listed above

2.3 Single-well Hydraulic Test Results

The results of the slug testing are summarized in Table A3 1, the results presented graphically in Figures A3 8 through A3 13, and the calculation sheets are included as Tables A3 2, A3 3, and A3 4 For each of the five wells (25022, 25027, 25028, 25065, and 25066), calculations of hydraulic conductivity were performed using the Hvorslev method and the Bouwer and Rice method The results of the two data sets were then compared to verify the accuracy of the analysis For each of the five wells, the two methods yield similar hydraulic conductivity values Based on the slug test results for the wells located in Section 25, the three wells in the weathered sandy claystone of the unconfined Denver Fm (Wells 25028, 25065, and 25066) yielded a hydraulic conductivity that ranged from 3 3 x 10^{-6} centimeters per second to 1 9 x 10^{-5} cm/s (9 4 x 10^{-3} feet per day (ft/day) to 5 4 x 10^{-2} ft/day)

Based on the slug tests, the estimated transmissivity of the weathered claystone present at Wells 25028, 25065, and 25066 ranged from 0 11 ft^2/day to 0 68 ft^2/day with a geometric mean of 0 30 ft^2/day The estimated transmissivity of the Denver Fm sandstone at Well 25027 ranges between 24 to 29 ft^2/day with a geometric mean of 27 ft^2/day The estimated transmissivity of the Denver Fm sandstone at Well 25022 ranged from 7 2 ft^2/day to 8 8 ft^2/day with a geometric mean of 8 0 ft^2/day

For Well 25065, the two tests were run due to mechanical difficulty during the first test The two tests yielded similar results The value from the first test was not used in the final analysis of the geometric mean of the data set because the first few minutes of data were not properly recorded (Figure A3 11)

For Well 25027, which is in the Denver Fm weathered sandstone, the geometric mean hydraulic conductivity was calculated to be 1 71 x 10^{-3} cm/s (4 9 ft/day) This value may reflect some contribution from the sandpack because a smaller volume of water was removed than originally desired due to the thin saturated zone For Well 25022, the hydraulic conductivity was calculated to be 4 0 x 10^{-4} cm/s (1 12 ft/day) This, too, may reflect some influence of the sandpack because a smaller diameter bailer was required to pass a blockage at ground surface in the well

3.0 AQUIFER PUMPING TEST

An aquifer pumping test of the Denver Fm CFS was conducted between November 13 and 20, 1995 The well array at the test site consisted of a pumping well (25064), two observation wells (25009 and 25063) completed in the same flow system, one well (25008) completed in the overlying UFS, and one well (25010) completed in the underlying Denver Fm CFS The locations of these wells are shown in Figure A3 1 Eight additional wells, four completed in the UFS and four completed in the Denver CFS, were monitored for background water-level trends as part of the test The locations of these background wells relative to the test site are also shown in Figure A3 1 Water levels were also measured (twice before and once after the pumping test) in the 13 previously mentioned wells (background well network and test site wells) and in 25 additional wells (secondary background well network) The secondary background well network is also shown in Figure A3 1 The sequence of aquifer testing activities is summarized in Table A3 5

3.1 Equipment and Methods

Pretest water-level monitoring was conducted using an electronic water-level indicator Water levels at the site and in the surrounding well network were measured and recorded from October 30, 1995, until the aquifer pumping test began on November 13, 1995 The wells at the site were also monitored with electronic transducers beginning on November 12, 1995

Pumping was accomplished using a 2-inch-diameter Bennett™ pump operating on a compressed air supply The pump supplied sufficient pressure at ground surface to allow the water to flow up into a 300-gallon tank used for temporary water storage A Little Giant™ submersible pump was used to transfer the water into a truck-mounted 1,800-gallon tank for transport to the onsite treatment facility at the North Boundary of RMA

Flow rates were measured during the pumping test using an in-line variable area flowmeter, and manually using a calibrated 5-gallon bucket and a stopwatch Flow rate was controlled using both a needle valve connected to the discharge line and the air pressure regulators connected to the Bennett™ pump and compressed air bottles

Water levels were measured in the pumping and observation wells using electronic pressure transducers interfaced to a multiple-channel datalogger with internal memory for data acquisition and manually with an electronic water-level indicator The datalogger provided real-time digital readouts of water levels in the monitoring wells and the pumping well so that field personnel could monitor the operation and progress of the aquifer pumping test

3.2 Data Evaluation

To verify that the aquifer test measurements were recorded correctly and to make any necessary corrections for external influences such as barometric pressure and/or water-table elevation changes the following methods were used to evaluate the aquifer test data

- Hydrograph Evaluation
  - Compare manual measurements to electronic measurements to verify the electronic data
  - Review water-level hydrographs for test site wells and background monitoring wells for regional (background) water-level changes over time
  - Compare water-level data to barometric data to correct for barometric influences
- Flow Rate Evaluation
  - Compare manual measurements to electronic flow measurements recorded from the Bennett™ pump flowmeter to verify the flowmeter readings
  - Review the variability in flow rates recorded during the aquifer test period

Hydrograph Evaluation

Hydrographs (including both transducer measurements and hand measurements where appropriate) of the pumping well, observation piezometers, and background wells are presented in Figures A3 14 through A3 31 Where appropriate, hydrographs for both transducer reading and hand measurements were plotted Also, on each hydrograph, the measurements are illustrated as raw and corrected for barometric pressure changes The procedure for correcting for barometric effects is described in the following section

Observation well hydrographs indicate that water levels at the site were relatively stable for one day before the pumping test Because hydrographs for the background wells show no regional trend, background trend corrections were not applied to drawdown data before analysis

Barometric Pressure Corrections

Barometric corrections were made on water-level data obtained from aquifer test monitoring wells Figure A3 32 illustrates the barometric pressure changes over the aquifer test time period The following equation was added to or subtracted from the raw pressure head to correct for barometric effects

$$COR = \left[\frac{Dm}{12\ Dw} (Bo - Ba) \right] \frac{BE}{100}$$

where

COR = barometric correction value (feet)

Dm = density of mercury (13 55 grams per cubic centimeter [g/cm^3])

Dw = density of water (1 0 g/cm^3)

Bo = standard barometric pressure used as a datum (inches of mercury)

Ba = barometric pressure at the time of measurement (inches of mercury)

BE = barometric efficiency (percent)

In the equation, the term in brackets is a standard correction for a nonvented transducer that provides a true gauge pressure reading Barometric efficiency (BE) is related to the formation response caused by barometric pressure variations (McWhorter and Sunada, 1977)

In general, values for BE were estimated through a calibration procedure The barometric efficiency was estimated at 80 percent through calibration and barometric induced water-level fluctuations were dampened out The BE for two wells (25008 and 25010) was estimated at 20 percent because the hydrographs displayed very little effect from barometric influence

Flow Rate Corrections

Corrections associated with variations in flow rate were not applied to test data because, where feasible, test logistics were modified to reduce the significance of these effects For example, for this pumping test, a high priority was placed on holding the discharge flow rate as uniform as possible This was accomplished using an in-line flowmeter, corroborative flow rate measurements using the calibrated 5-gallon bucket and stopwatch method, and a control valve that could be used to adjust the flow rate as required Diligent flow rate monitoring and control eliminated the need for flow rate corrections and therefore, significantly reduced the uncertainty of subsequent test analyses
Figure A3 33 illustrates the flow rate measurements throughout the test

3.3 Data Analysis Methods and Assumptions

The conceptual model used to analyze results at the pumping site assumes that the CFS can be conceptualized as an ideal confined aquifer with no leakage from underlying or overlying aquitards Water-level data obtained from the pumping and recovery periods were analyzed using the following three methods

- Theis type-curve method
- Cooper and Jacob semilogarithmic method
- Theis recovery method

These methods are described in the literature and represent standard procedures for aquifer test analysis All three methods were used to compute transmissivity and average hydraulic conductivity of the aquifer In addition, the first two methods provided a means for estimating the aquifer storage coefficient These methods of analysis were used to provide semi-independent estimates of aquifer characteristics at the test site The Theis type-curve method relies heavily on early-time pumping data, and the Jacob method gives preference to mid- to late-time pumping data The Theis recovery method is based on analysis of well recovery after termination of pumping The analysis for each method is described below

The analytical solutions presented in this section are based on the pumping test response of an ideal aquifer, which is illustrated in Figure A3 34 These methods rely on a number of simplifying assumptions The degree to which computed aquifer parameters represent actual conditions depends on the extent to which the simplifying assumptions are met Assumptions that form the basis of the Theis type-curve method, Theis recovery method, and the Cooper and Jacob semilogarithmic method are as follows

1 The aquifer is uniform in hydraulic properties and the hydraulic conductivity is nondirectional (i e , aquifer properties are homogeneous-isotropic)

2 The formation is uniform in thickness and "seemingly" infinite in areal extent

3 The aquifer receives no recharge and contains no internal sources or sinks (with exception of the pumping well)

4 The pumping well penetrates and receives water from the full thickness of the water-bearing formation

5 The water removed from storage is discharged instantaneously when the head is lowered

6 All water removed from the well is derived from aquifer storage

These assumptions are rarely met in field tests due to the natural heterogeneities of a formation However, slight deviations from the above assumptions do not prohibit successful application of Theis and similar methods In some cases, it can be shown that certain violations of the governing assumptions still allow a portion of the test data to be analyzed using ideal aquifer solutions For example, the assumption of an aquifer of seemingly infinite areal extent is frequently violated because of the presence of impermeable and/or recharge boundaries However, in the presence of such boundaries, it is usually possible to analyze early-time data using an ideal aquifer solution

Theis Type-Curve Method

The Theis type-curve method analysis is performed by plotting field data (corrected drawdown versus time) on log-log paper having the same scale as the Theis type-curve This data plot is placed over the type-curve and, while keeping the coordinate axes of both plots parallel, the data plot is translated horizontally and vertically until a best fit with the type-curve is attained (see Figure A3 35) An arbitrary match point is selected, and W(u)* and (1/u)* are read from the type-curve and s* and t* are read from the data plot The transmissivity is then calculated using the following equation

$$T = \frac{Q}{4\pi} \frac{W(u)^*}{s^*}$$

where

T = aquifer transmissivity

Q = pumping flow rate

W(u)* = match point value on type-curve

s* = match point value for drawdown on data plot

The storage coefficient is calculated as follows

$$S = \frac{4T}{r^2} \frac{t^*}{(1/u^*)}$$

where

S = storage coefficient

t* = match point value for time on data plot

r = radial distance from pumping well to observation well

u* = match point value on type-curve

Aquifer parameters are assessed from data obtained at observation wells The Theis method cannot be used to analyze pumping well data

Cooper and Jacob (1946) Semilogarithmic Method

The Cooper and Jacob (1946) semilogarithmic method involves analyzing the pumping data from both the observation wells and the pumping well, although data obtained from the pumping well is usually subject to greater uncertainty In using the method, a plot of drawdown(s) versus the logarithm of time (t) is prepared as shown in Figure A3 36 A "best-fit" straight line is drawn through the data, and transmissivity is calculated as follows

$$T = \frac{2\ 303\ Q}{4\pi\ \Delta s}$$

where

T = aquifer transmissivity

Q = pumping flow rate

Δs = change in drawdown per log cycle of time (determined from the slope of the semi-logarithmic straight line)

From observation well data, the aquifer storage coefficient is computed by

$$S = \frac{2\ 24\ T\ t_o}{r^2}$$

where

S = storage coefficient

t_o = intercept of semilogarithmic straight line with time axis ($s = 0$)

r = radial distance from pumping well to observation well

The storage coefficient is estimated from data obtained at observation wells and cannot be reliably computed from pumping well data

Traditionally, the Cooper and Jacob analysis has been considered applicable for data where u is less than 0 01 in the following equation

$$u = \frac{Sr^2}{4Tt}$$

However, for practical considerations, it is only necessary for u to be less than 0 1

Theis Recovery Method

The Theis recovery method involves analysis of residual drawdown data obtained from both observation wells and the pumping well A semilogarithmic plot of residual drawdown (s′) versus the log of (t/t′) is prepared where

t = time since initiation of pumping

t′ = time since initiation of recovery

A "best-fit" straight line is drawn through the plotted points giving preference to intermediate- and later-time data (see Figure A3 37) Aquifer transmissivity is calculated using the following equation

$$T = \frac{2\ 303\ Q}{4\pi\ \Delta s'}$$

where

T = aquifer transmissivity

Q = flow rate during pumping

Δs′ = change in drawdown per log cycle of (t/t′), based on the slope of semilogarithmic straight line

The aquifer storage coefficient cannot be computed using the Theis recovery method

3.4 Results of the Aquifer Pumping Test

Field Results

A 72-hour pumping test of the Denver Fm CFS was conducted at the test site between November 13 and November 16, 1995 The average pumping rate during the pumping test was 1 8 gallons per minute (gpm) and ranged from 1 6 to 2 0 gpm A graph of flow rate versus time is presented in Figure A3 33

At the end of the 72-hour pumping period, the pumping well (25064) exhibited 5 70 feet of drawdown (14 2 percent of the 40 feet of available drawdown) The closest observation well (25009), which was located a radial distance of 24 4 feet from the pumping well, exhibited 1 72 feet of drawdown Well 25063, located a radial distance of 29 0 feet from the pumping well, exhibited 1 51 feet of drawdown Wells 25008 (completed in the UFS) and 25010 (completed in the deeper CFS), located at radial distances of 10 8 and 19 68 feet, respectively, from the pumping well, exhibited no discernible response due to pumping

Following the pumping portion of the test, water-level recovery was monitored for 96 hours Post-test recovery monitoring with the transducers was concluded on November 20, 1995 At that time, the residual drawdown in the pumping well after correction for barometric pressure influence was 0 22 foot Residual drawdowns in nearby observation wells (25009 and 25063) after correction for barometric pressure influences were 0 26 foot and 0 19 foot, respectively

Theis Type-Curve Results

The Theis type-curve method is presented graphically by well in Figures A3 38 and A3 39 Transmissivity, hydraulic conductivity, and storage coefficient results obtained using this method are very consistent between wells The Theis curve plot for Well 25009 (Figure A3 38) shows a standard Theis curve with an inflection point at approximately t = 2,000 seconds (33 minutes) After this point, the drawdown continues to increase with time Both the early time portion of the curve can be fitted to the Theis type-curve and the later-time portion of the curve can be fitted to the Theis type-curve Although there are many possible causes for a response curve of this shape, HLA believes the likely cause may be a small overdeveloped zone immediately surrounding the pumping well or due to localized aquifer heterogeneity near the test site The same curve shape is shown in the Theis curve plot for Well 25063 During analysis, a greatest significance was placed on the later-tıme data   The values presented for the Theıs analysıs are based on a Theıs curve fitted to the later-time data

Cooper-Jacob Results

Results from Cooper and Jacob's semılogarıthmıc method were consıstent between wells and compared favorably wıth results of the two types of Theis analyses   Graphs used for the Cooper and Jacob semılogarıthmıc analysıs are presented ın Fıgures A3 40 and A3 41   Results obtaıned from both observatıon Wells 25009 and 25063 met the u $\leq$0 1 crıterıon for applıcatıon of the Cooper and Jacob semılogarıthmıc analysıs and are therefore consıdered valıd

Theis Recovery Results

The Theıs recovery method yıelded consıstent values of transmıssıvıty and hydraulıc conductıvıty between wells   Graphs used for the Theıs recovery analysıs are presented ın Fıgures A3 42 through A3 44

4.0 AQUIFER TESTING PROGRAM SUMMARY AND CONCLUSIONS

The results of the slug tests are presented in Table A3 1 The results of the slug tests indicate that the transmissivity and hydraulic conductivity of the Denver Fm claystone units are approximately two orders of magnitude lower than those measured in the Denver Fm sandstone units For example, the mean hydraulic conductivity for the claystone units is 6 8 x 10^{-6} cm/s whereas within the sandstone units the mean hydraulic conductivity is 9 1 x 10^{-4} cm/s

The results of the aquifer pumping test are presented in Table A3.6 The hydraulic conductivity of the confined Denver Fm sandstone is estimated at 7 61 x 10^{-4} cm/s The transmissivity and storativity were estimated at 75 5 square feet per day and 6 47 x 10^{-3}, respectively It should be noted that throughout the pumping test, no measurable response was noted in the observation wells completed within the overlying and underlying aquifers (25008 and 25010) This indicates that the confining units separating the aquifers do inhibit groundwater flow between the aquifers

In conclusion, five slug tests in the UFS and one aquifer pumping test in the CFS were completed in the western portion of Section 25 The test results confirm that the Denver Fm weathered claystone units have significantly lower hydraulic conductivities than the Denver Fm weathered sandstone units The test results provide specific information on the hydraulic conductivity and transmissivity of the hydrostratigraphic units within the proposed landfill area that can be used in future hydrogeologic investigations including the proposed groundwater monitoring program for the proposed landfill area

5.0 REFERENCES

Bouwer, H 1989 *The Bouwer and Rice slug test - an update* Ground Water, v 27, no 3

Bouwer, H , and R C Rice 1976 *A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells* American Geophysical Union, June

Cooper, H H , Jr , and C.E Jacob 1946 *A generalized graphical method for evaluating formation constants and summarizing well-field history* Transactions, American Geophysical Union, v.27, no IV, August

Fetter, C L 1988 *Applied Hydrogeology* New Jersey Prentice-Hall, Inc

Harding Lawson Associates. 1995a *Draft final work plan for the hyrdogeologic and geotechnical program, feasibility study soils support program, Rocky Mountain Arsenal, Commerce City, Colorado* October

Harding Lawson Associates 1995b *Landfill site feasibility report, feasibility study soils support program, Rocky Mountain Arsenal, Commerce City, Colorado*, July

Hvorslev, M J 1951 *Time lag and soil permeability in ground-water observations* U S Army Corps of Engineers, Waterways Experiment Station, Bulletin No 36

McWhorter, D B and D K Sunada 1977 *Ground-water hydrology and hydraulics* Water Resources Publications, Fort Collins, Colo 290

Program Manager for Rocky Mountain Arsenal 1995 *Proposed plan for the Rocky Mountain Arsenal On-Post Operable Unit*, October

Table A3.1: Summary of Results of Single Well Hydraulic Test Analyses

Well Number	Hvorslev Transmissivity (ft^2/day)	Hvorslev Hydraulic Conductivity (cm/s)	Bouwer and Rice Transmissivity (ft^2/day)	Bouwer and Rice Hydraulic Conductivity (cm/s)	Geometric Mean Transmissivity (ft^2/day)	Geometric Mean Hydraulic Conductivity (cm/s)	Test Interval Description
25022	8 8	$4\ 3 \times 10^{-4}$	7 2	$3\ 6 \times 10^{-4}$	8 0	$4\ 0 \times 10^{-4}$	Unconfined Flow System, Denver Fm, sandstone
25027	29	$1\ 9 \times 10^{-3}$	24	$1\ 6 \times 10^{-3}$	27	$1\ 7 \times 10^{-3}$	Unconfined Flow System, Denver Fm, sandstone
25028	0 27	$5\ 5 \times 10^{-6}$	0 21	$4\ 4 \times 10^{-6}$	0 24	$4\ 9 \times 10^{-6}$	Unconfined Flow System, Denver Fm, claystone
25065	0 79	$2\ 2 \times 10^{-5}$	0 59	$1\ 7 \times 10^{-5}$	0 68	$1\ 9 \times 10^{-5}$	Unconfined Flow System, Denver Fm, claystone
25066	0 13	$3\ 8 \times 10^{-6}$	0 10	$2\ 8 \times 10^{-6}$	0 11	$3\ 3 \times 10^{-6}$	Unconfined Flow System, Denver Fm, claystone

cm/s Centimeters per second
Fm Formation
ft Feet

Table A3.2

RISING HEAD SLUG TEST CALCULATION SHEET
HVORSLEV ANALYSIS

Drawdown calculations

Well Number	Log Drawdown Line	Time at t1 (minutes)	Time at t2 (minutes)	Drawdown s1 at t1 (feet)	Drawdown s2 at t2 (feet)	Log s1	Log s2	Calculated dt (minutes)
25022	A-A'	2 75	6 28	0 19	0 11	-0 721	-0 959	14 87
25027	A-A'	0 53	1 08	0 19	0 14	-0 721	-0 854	4 15
25028	A-A'	6 35	20 6	0 72	0 62	-0 143	-0 208	219 43
25028	B-B'	32 3	50	0 58	0 54	-0 237	-0 268	570 34
25065	A-A'	55	71 7	2 33	2 08	0 367	0 318	338 79
25066	A-A'	25	50	0 68	0 66	-0 167	-0 180	1928 27
25066	B-B'	123 9	219 5	0 62	0 58	-0 208	-0 237	3300 68
25065 (2)	A-A"	14 6	48 5	0 85	0 65	-0 071	-0 187	290 97

Well Number	Log Drawdown Line	dt (min)	Well Diameter (inches)	Borehole Diameter (inches)	Equivalent Free Water Area (ft2)	Depth to Ground Water (ft bgs)	Depth to bottom Sandpack (ft bgs)	Test Length Interval (ft)	Borehole Diameter (feet)	Shape factor C	Trans-missivity (ft^2/d)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/s)
25022	A-A'	14 87	2	6	0 0742	47 89	55	7 11	0 50	3 35	8 8	1 240	4 4E-04
25027	A-A'	4 15	2	6	0 0742	43 51	49	5 49	0 50	3 09	29	5 316	1 9E-03
25028	A-A'	219 43	2	5 625	0 0670	43 78	62	17 00	0 47	4 28	0 69	0 041	1 4E-05
25028	B-B'	570 34	2	5 625	0 0670	43 78	62	17 00	0 47	4 28	0 27	0 016	5 5E-06
25065	A-A'	338 79	2	8	0 1200	41 92	58 5	12 50	0 67	3 63	0 68	0 054	1 9E-05
25066	A-A'	1928 272	4	10 625	0 2458	42 1	58	12 00	0 89	3 30	0 22	0 019	6 5E-06
25066	B-B'	3300 68	4	10 625	0 2458	42 1	58	12 00	0 89	3 30	0 13	0 011	3 8E-06
25065 (2)	A-A'	290 97	2	8	0 1200	41 89	58 5	12 50	0 67	3 63	0 79	0 063	2 2E-05

Table A3.3

RISING HEAD SLUG TEST CALCULATION SHEET
BOUWER AND RICE ANALYSIS

Slope Calculations

Well Number	Log Drawdown Line	Hvorslev dt (min)	Slug Test Start Time t0 (min)	Time at t1 (min)	Time at t2 (min)	Elapsed Time t1-t0 (sec)	Elapsed Time t2-t0 (sec)	Draw-down s1 at t1 (feet)	Draw-down s2 at t2 (feet)	Log s1	Log s2	Slope m = s2-s1/t2-t1	Log of Initial Drawdown = log(s1)-mx1	Calculated s0 at t0
25022	A-A'	14 872	0	2 75	6 28	165	376 8	0 19	0 11	-0 72	-0 96	-0 07	-0 54	0 29
25027	A-A'	4 147	0	0 53	1 08	31 8	64 8	0 19	0 14	-0 72	-0 85	-0 24	-0 59	0 26
25028	A-A'	219 431	0	6 35	20 6	381	1236	0 72	0 62	-0 14	-0 21	0 00	-0 11	0 77
25028	B-B'	570 338	0	32 3	50	1938	3000	0 58	0 54	-0 24	-0 27	0 00	-0 18	0 66
25065	A-A'	338 793	0	55	71 1	3300	4266	2 33	2 08	0 37	0 32	0 00	0 54	3 43
25066	A-A'	1928 272	0	25	50	1500	3000	0 68	0 66	-0 17	-0 18	0 00	-0 15	0 70
25066	B-B'	3300 684	0	123 9	219 5	7434	13170	0 62	0 58	-0 21	-0 24	0 00	-0 17	0 68
25065 (2)	A-A'	290 973	0	14 6	48 5	876	2910	0 85	0 65	-0 07	-0 19	0 00	-0 02	0 95

Well Number	Log Draw-down Line	Hvorslev dt (min)	Test Interval Length (feet)	Diameter of Well Casing (inches)	Radius of Borehole (feet)	Le/Rw	C from B&R 1989, fig 2	Ln(Re/Rw) from Equation 5 B&R 1989	Calculated Drawdown at Time t0 (feet)	Elapsed Time t2-t0 (sec)	Drawdown at Time t2 (feet)	Equivalent Free Water Surface Radius Rc (feet)	Transmissivity (ft^2/day)	Hydraulic Conductivity (cm/sec)
25022	A-A'	0	7 11	2	0 250	28 440	1	2 749	0	0	0 11	0 153659	7 24	3 59E-04
25027	A-A'	0	5 49	2	0 250	21 960	0 7	2 578	0	0	0 14	0 153659	24 33	1 56E-03
25028	A-A'	0	17	2	0 234	72 533	2 8	3 386	0	0	0 62	0 146084	0 55	1 13E-05
25028	B-B'	0	17	2	0 234	72 533	2 8	3 386	0	0	0 54	0 146084	0 21	4 36E-06
25065	A-A'	0	12 5	2	0 333	37 500	2 4	2 721	0	0	2 08	0 195434	0 53	1 49E-05
25066	A-A'	0	12	4	0 443	27 106	2	2 456	0	0	0 66	0 279717	0 17	4 86E-06
25066	B-B'	0	12	4	0 443	27 106	2	2 456	0	0	0 58	0 279717	0 10	2 84E-06
25065 (2)	A-A'	0	12 5	2	0 333	37 500	2 4	2 721	0	0	0 65	0 195434	0 59	1 67E-05

Table A3.4

RISING HEAD SLUG TEST COMPARISON OF ANALYTICAL METHODS

Well Number	Log Drawdown Line	Bouwer & Rice T (ft^2/day)	Hvorslev T (ft^2/day)	Geometric Mean T (ft^2/day)	Bouwer & Rice K (ft/day)	Bouwer & Rice K (ft/day)	Hvorslev K (cm/s)	Hvorslev K (ft/day)	Geometric Mean K (cm/s)	Geometric Mean K (ft/day)	Comments
25022	A-A'	7 236	8 817	7 987	3 59E-04	1 018	4 38E-04	1 240	3 96E-04	1.12	unconfined flow system, Denver Fm sandstone
25027	A-A'	24.330	29 184	26 647	1 56E-03	4 432	1 88E-03	5 316	1.71E-03	4 86	unconfined flow system, Denver Fm sandstone
25028	A-A'	0 546	0 691	0 614	1 13E-05	0 032	1 43E-05	0 041	1 27E-05	0 04	unconfined flow system, Denver Fm claystone
25028	B-B'	0 210	0 266	0 236	4 36E-06	0 012	5 52E-06	0 016	4 90E-06	0 01	unconfined flow system, Denver Fm claystone
25065	A-A'	0 528	0 678	0 598	1 49E-05	0 042	1 91E-05	0 054	1 69E-05	0 05	unconfined flow system, Denver Fm claystone
25066	A-A'	0 165	0 222	0 192	4 86E-06	0.014	6 53E-06	0 019	5.63E-06	0 02	unconfined flow system, Denver Fm claystone
25066	B-B'	0 097	0.130	0.112	2.84E-06	0.008	3 82E-06	0 011	3 29E-06	0 01	unconfined flow system, Denver Fm claystone
25065 (2)	A-A'	0 592	0 789	0 684	1 67E-05	0 047	2 23E-05	0 063	1 93E-05	0 05	unconfined flow system, Denver Fm claystone

T = Transmissivity
K = Hydraulic conductivity
ft = feet
cm = centimeters
s = seconds

Table A3.5: Sequence of Aquifer Testing Activities

Date	Activities
10/30/95	Begin pretest monitoring, first round of water-level measurements
11/07/95	Second round of water-level measurements
11/12/95	Begin monitoring aquifer pumping and observation wells with transducers
11/13/95	Begin aquifer pumping test at 12 10 p m
11/16/95	End aquifer pumping test at 12 10 p m., begin recovery monitoring
11/20/95	End recovery monitoring of aquifer pumping test wells, begin slug tests
11/21/95	Continue slug tests
11/22/95	Complete slug tests, post-test round of water-level measurements

Table A3.6: Summary of Results of Aquifer Pumping Test Analyses

Well Number	Transmissivity (ft^2/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/s)	Storativity (unitless)
Summary of Theis Type-Curve Method Results				
25009	76 8	2 19	7 74 x 10^{-4}	6 27 x 10^{3}
25063	79.0	2 26	7 96 x 10^{-4}	6 52 x 10^{3}
Summary of Cooper-Jacob Semilogarithmic Method Results				
25009	73.3	2 09	7 39 x 10^{-4}	7 26 x 10^{3}
25063	79 2	2 26	7 98 x 10^{-4}	5 89 x 10^{-3}
Summary of Theis Recovery Method Results				
25009	81 6	2 33	8 23 x 10^{-4}	NA
25063	66 3	1 89	6 69 x 10^{-4}	NA
25064	70 7	2 02	7 13 x 10^{-4}	NA
Geometric mean	75 5	2 16	7 61 x 10^{-4}	6 47 x 10^{-3}

cm/s Centimeters per second
ft Feet

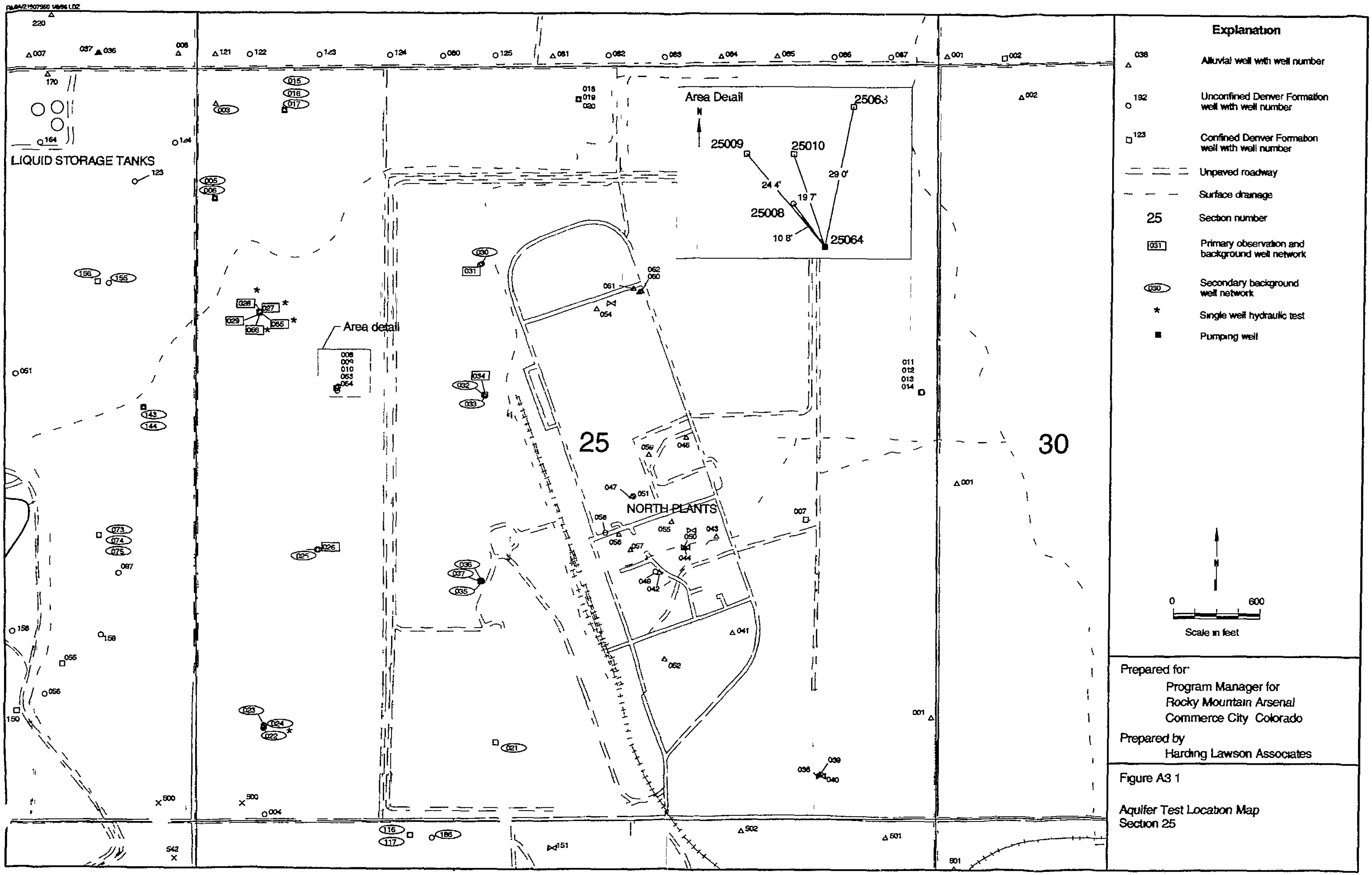


Figure A3 1

Aquifer Test Location Map
Section 25

Figure A3.2

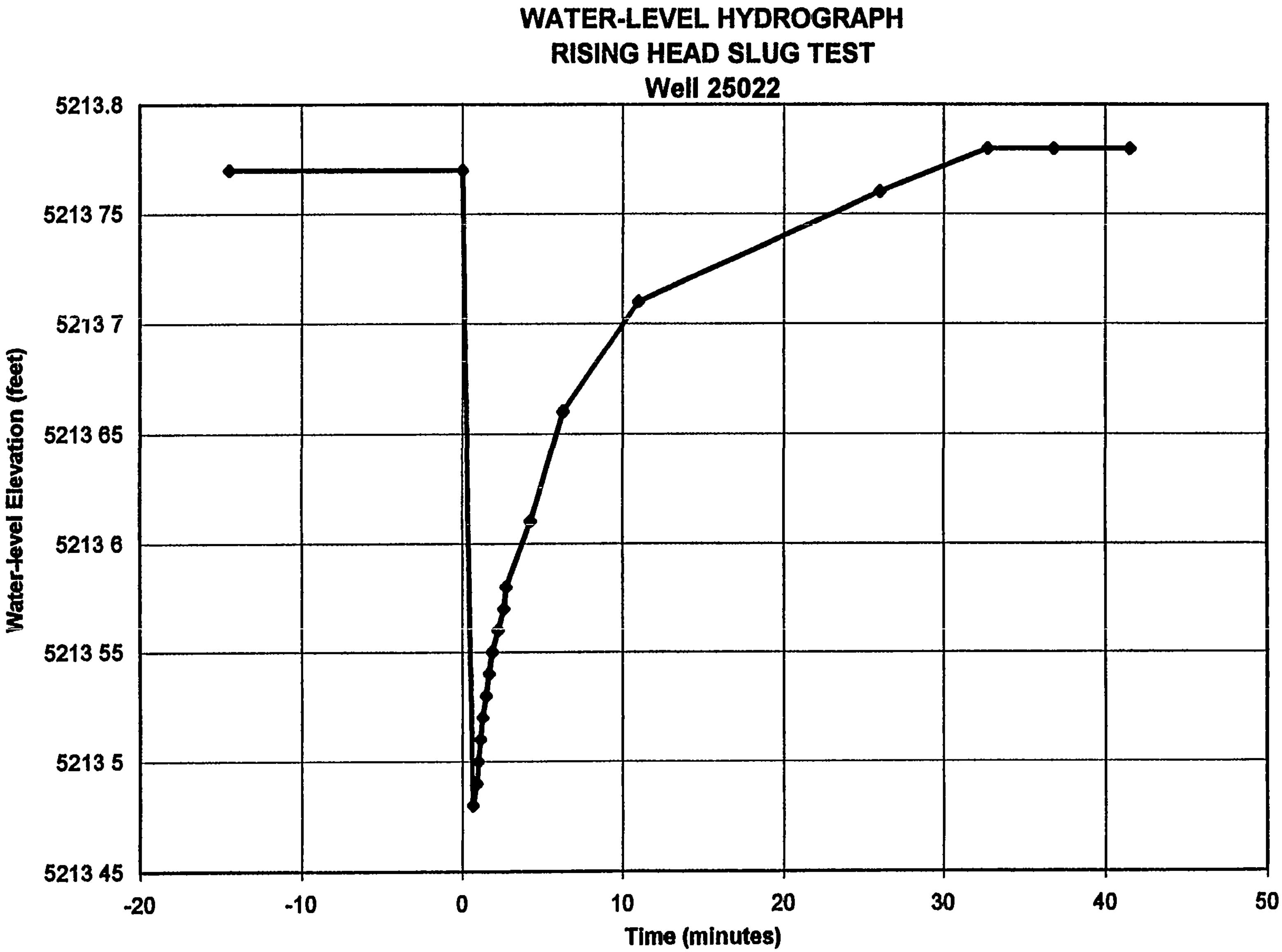

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25022
Water-level Elevation (feet)
5213.8
5213 75
5213 7
5213 65
5213 6
5213 55
5213 5
5213 45
-20
-10
0
10
20
30
40
50
Time (minutes)

Figure A3.3

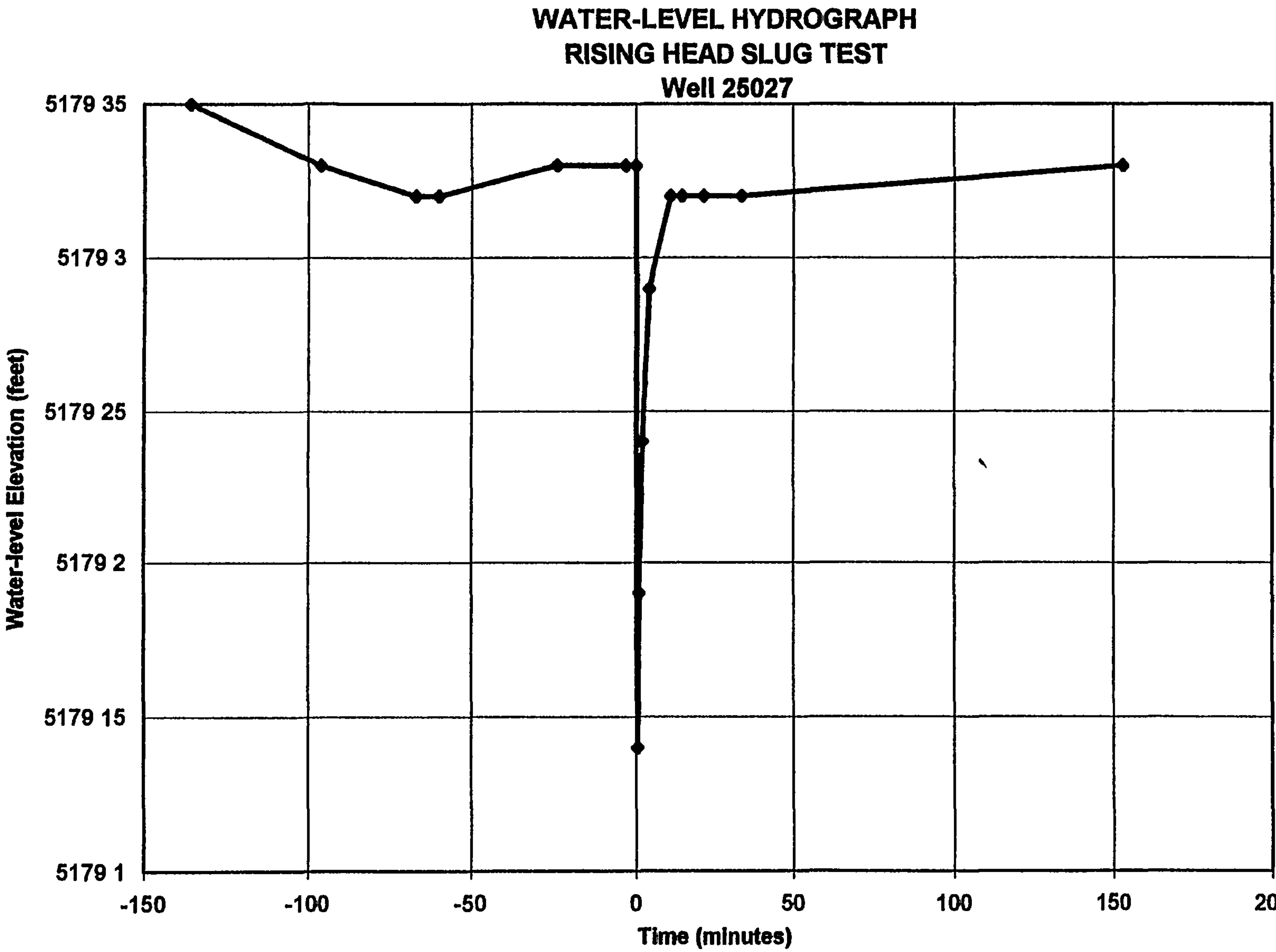

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25027
5179 35
5179 3
5179 25
5179 2
5179 15
5179 1
Water-level Elevation (feet)
-150
-100
-50
0
50
100
150
200
Time (minutes)

Figure A3.4

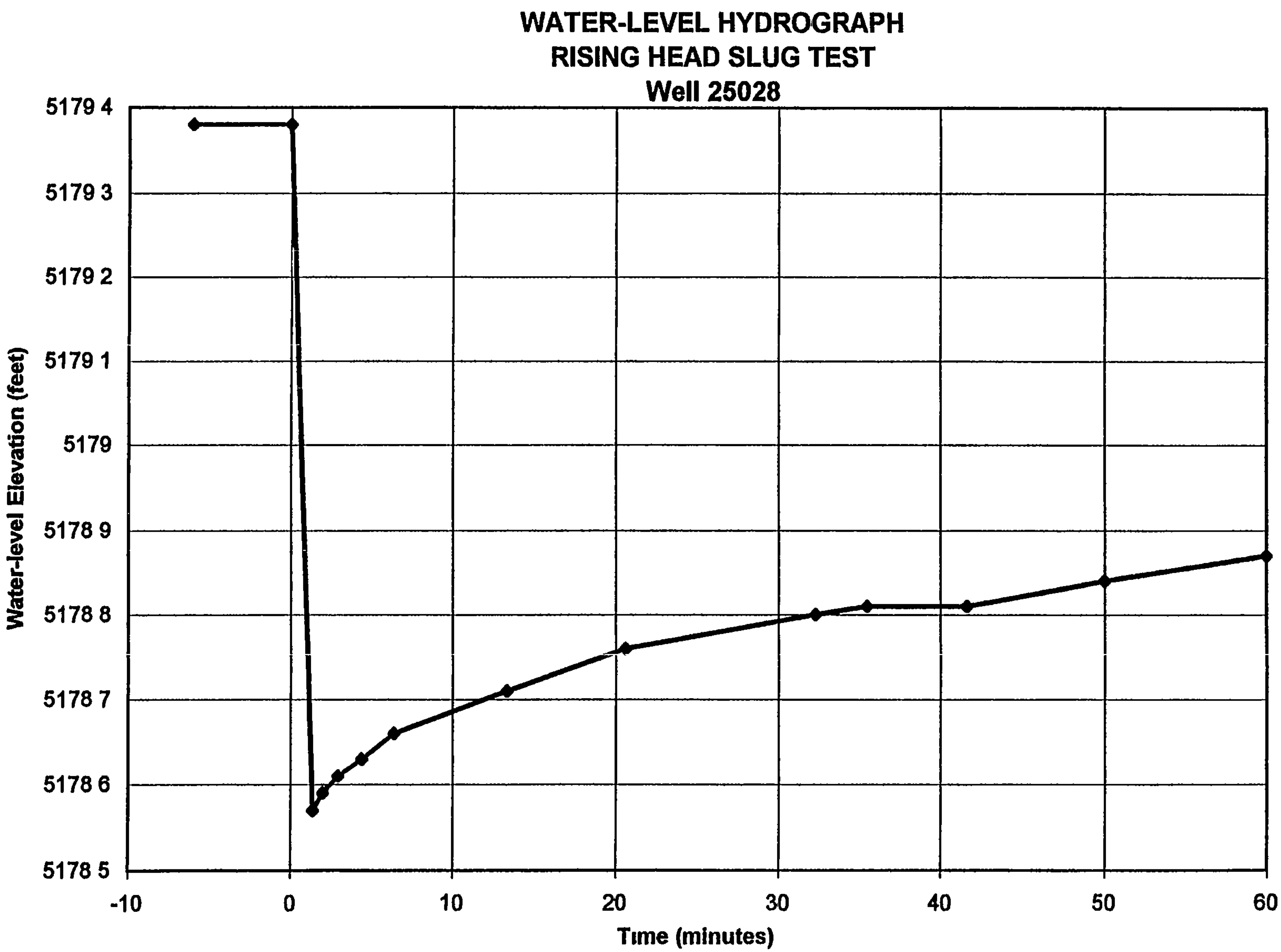

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25028
Water-level Elevation (feet)
5179 4
5179 3
5179 2
5179 1
5179
5178 9
5178 8
5178 7
5178 6
5178 5
-10
0
10
20
30
40
50
60
Time (minutes)

Figure A3.5

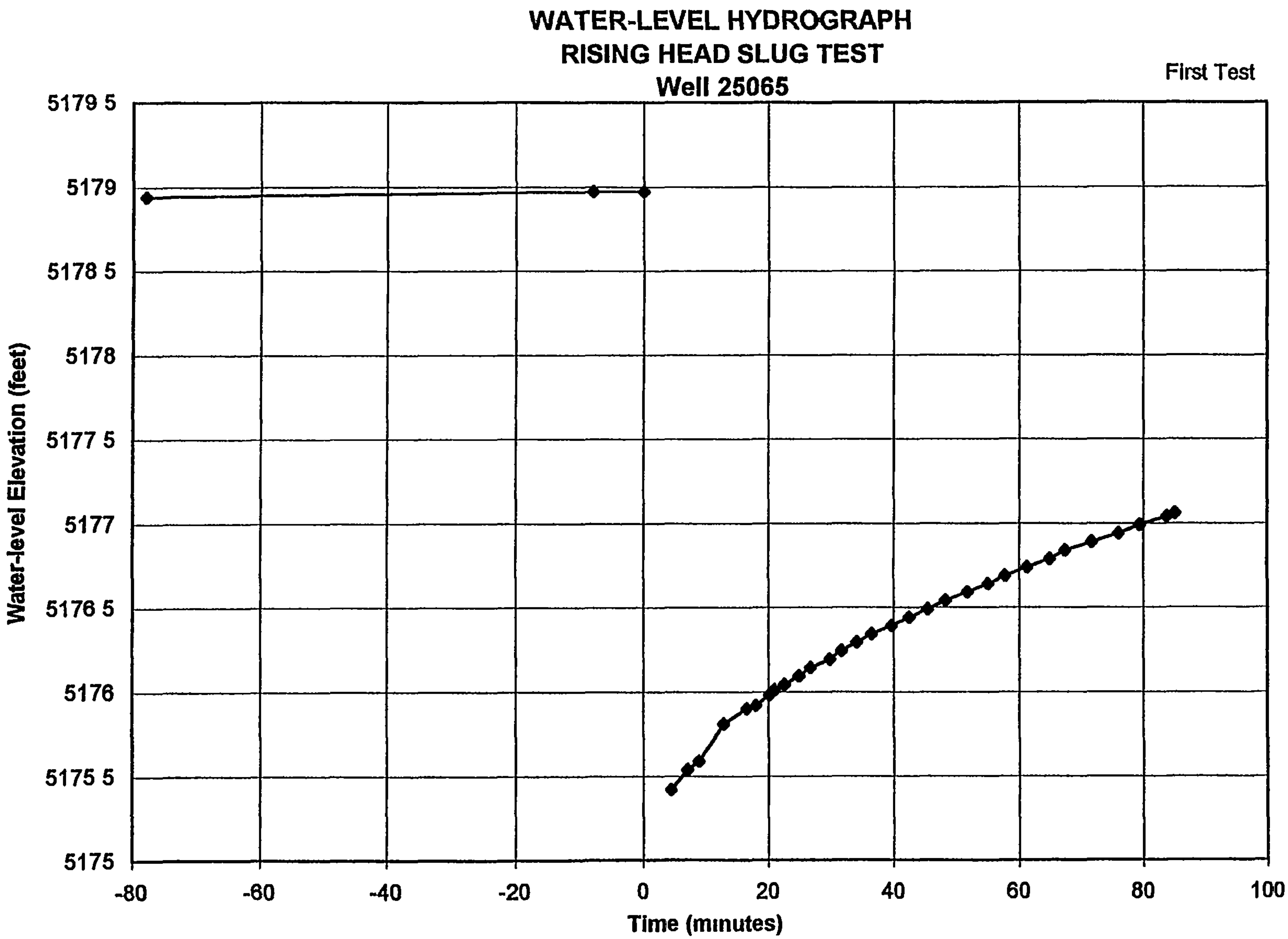

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25065
First Test
Water-level Elevation (feet)
5179 5
5179
5178 5
5178
5177 5
5177
5176 5
5176
5175 5
5175
-80
-60
-40
-20
0
20
40
60
80
100
Time (minutes)

Figure A3.6

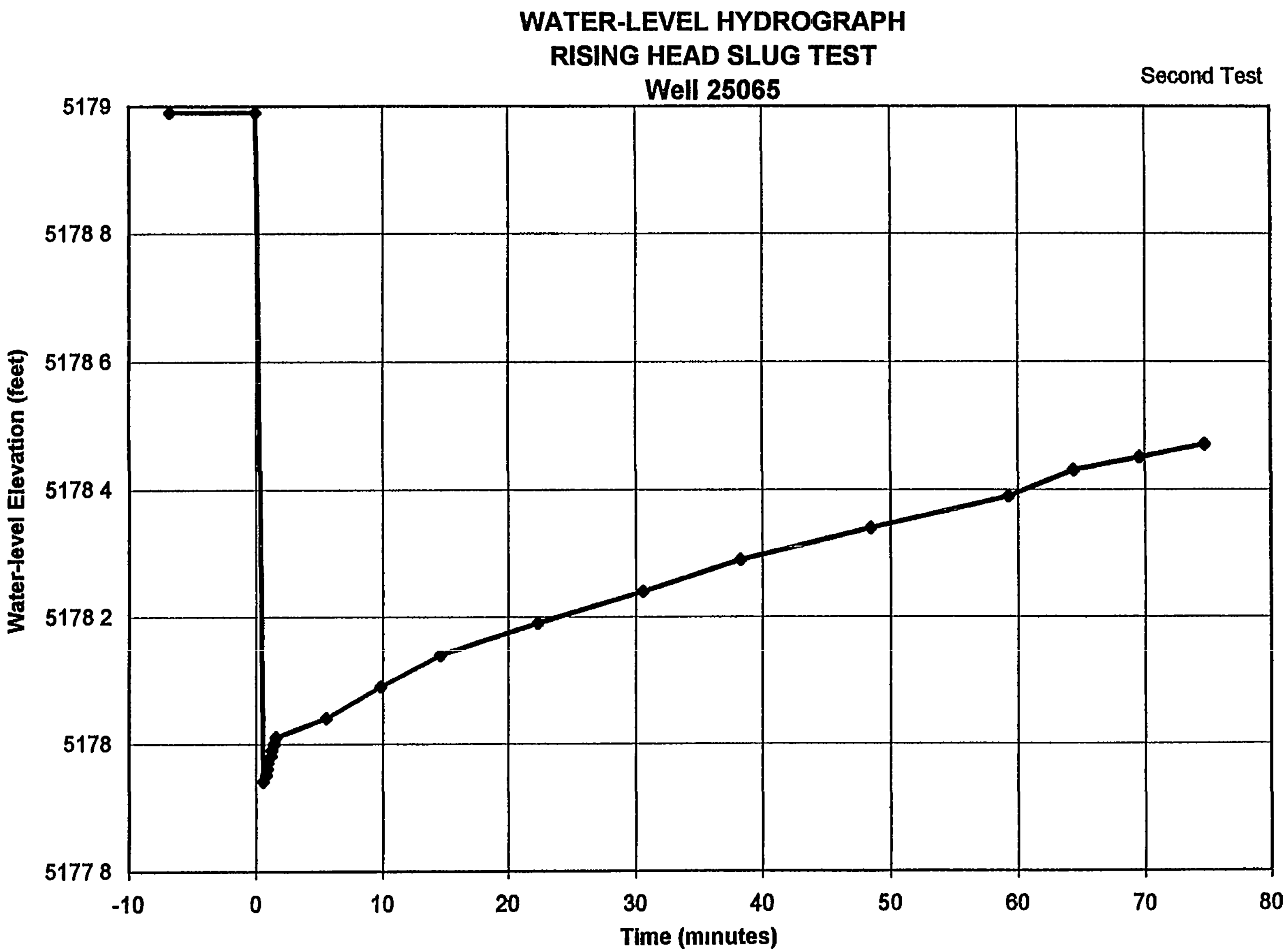

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25065
Second Test
5179
5178 8
5178 6
5178 4
5178 2
5178
5177 8
Water-level Elevation (feet)
-10
0
10
20
30
40
50
60
70
80
Time (minutes)

Figure A3.7

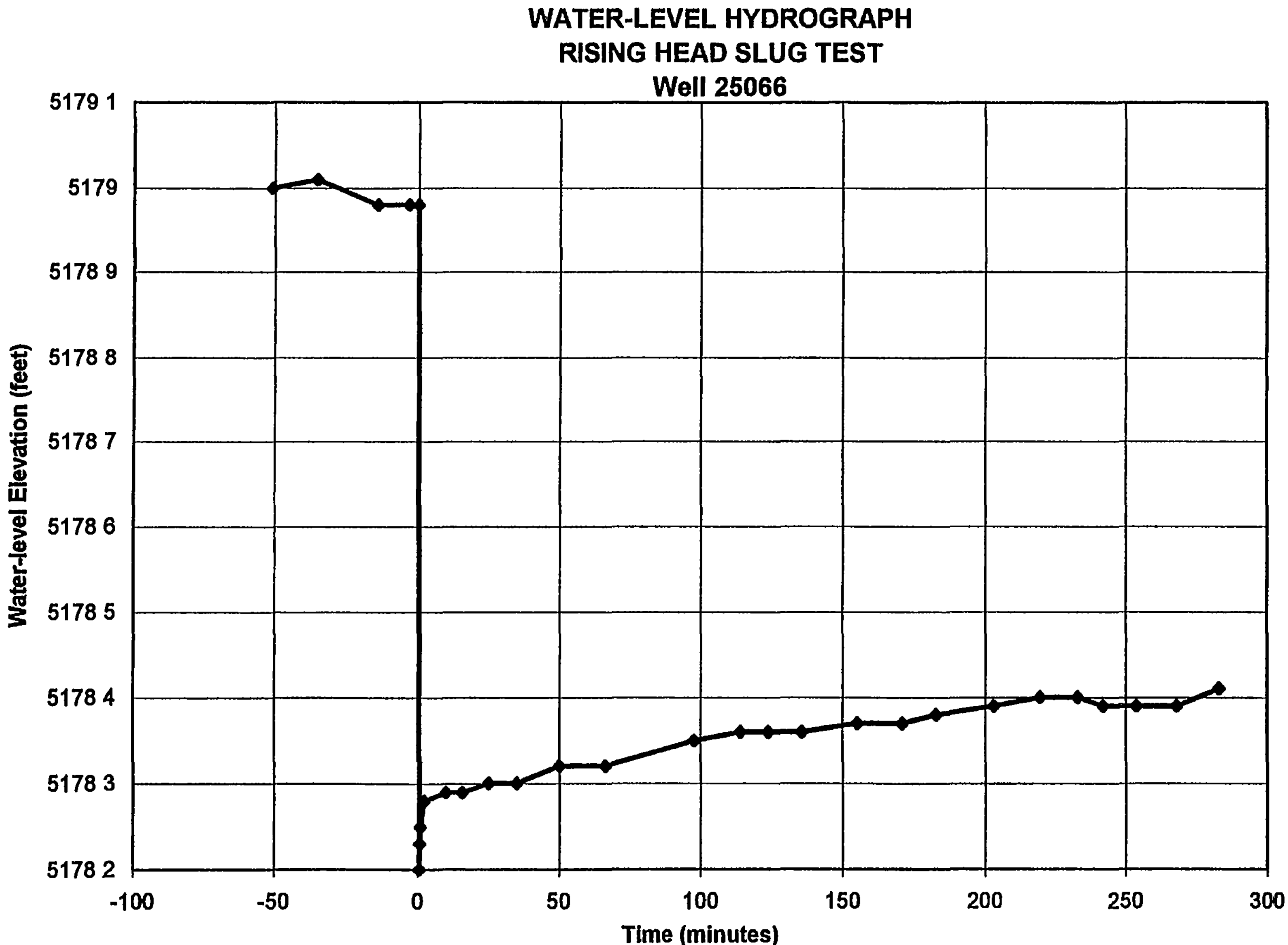
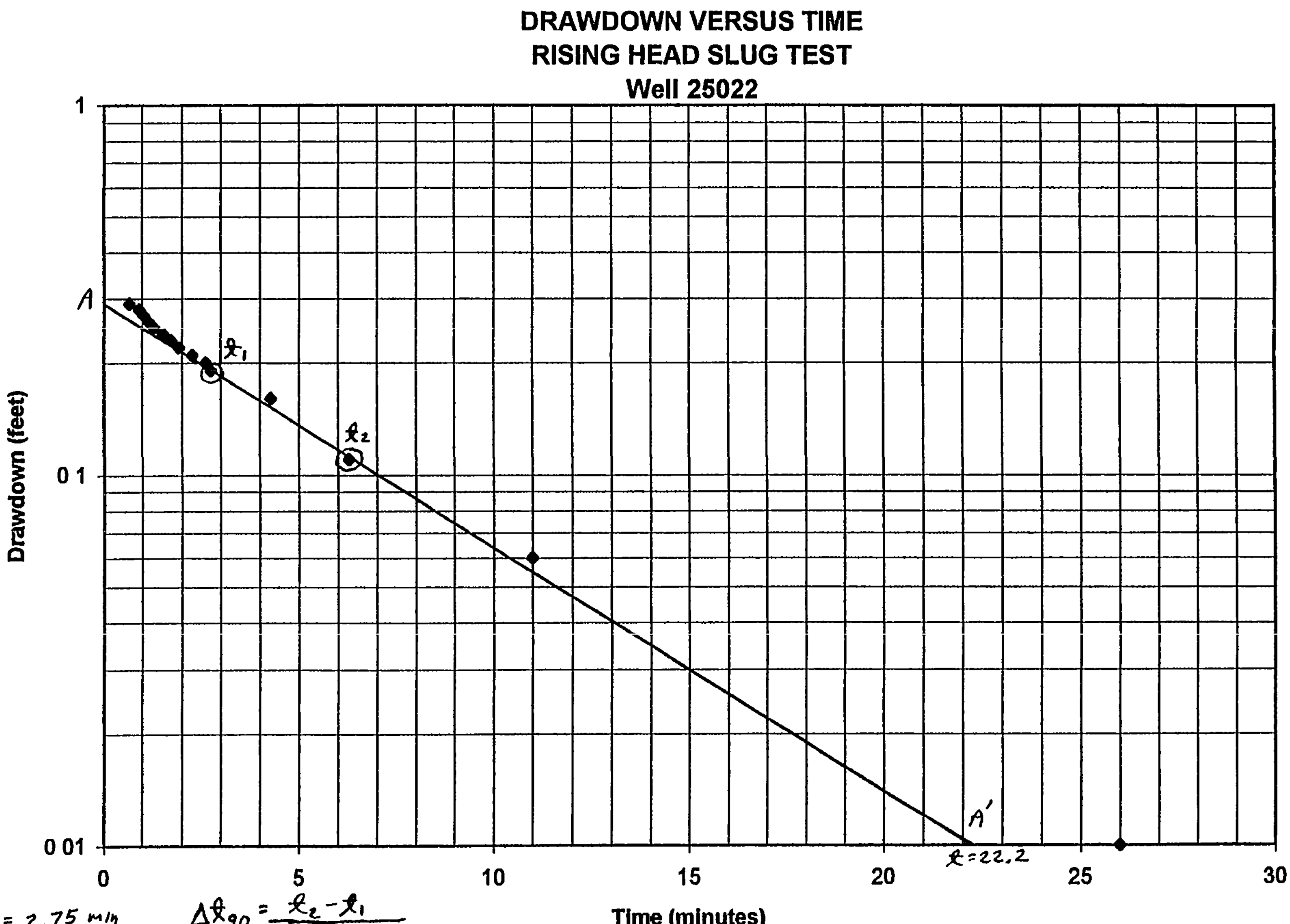

WATER-LEVEL HYDROGRAPH
RISING HEAD SLUG TEST
Well 25066
Water-level Elevation (feet)
5179 1
5179
5178 9
5178 8
5178 7
5178 6
5178 5
5178 4
5178 3
5178 2
-100
-50
0
50
100
150
200
250
300
Time (minutes)

Figure A3.8



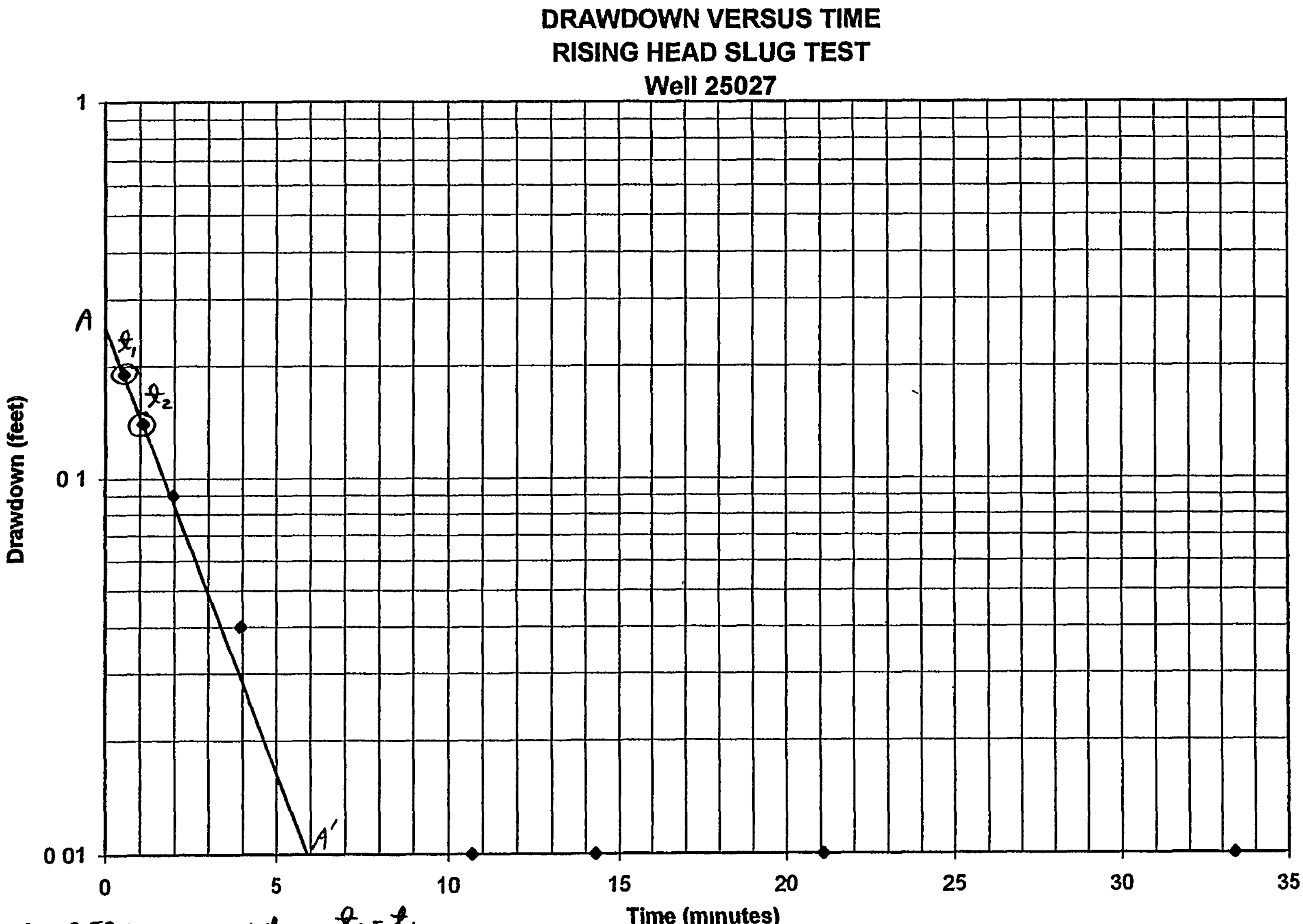
$t_1 = 2.75$ min
$t_2 = 6.28$ min
$s_1 = 0.19$ ft
$s_2 = 0.11$ ft

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{6.28 - 2.75}{\log 0.19 - \log 0.11}$$

$\Delta t_{90} = 14.87$ minutes

Figure A3.9



$t_1 = 0.53$ min

$t_2 = 1.08$ min

$s_1 = 0.19$ ft

$s_2 = 0.14$ ft

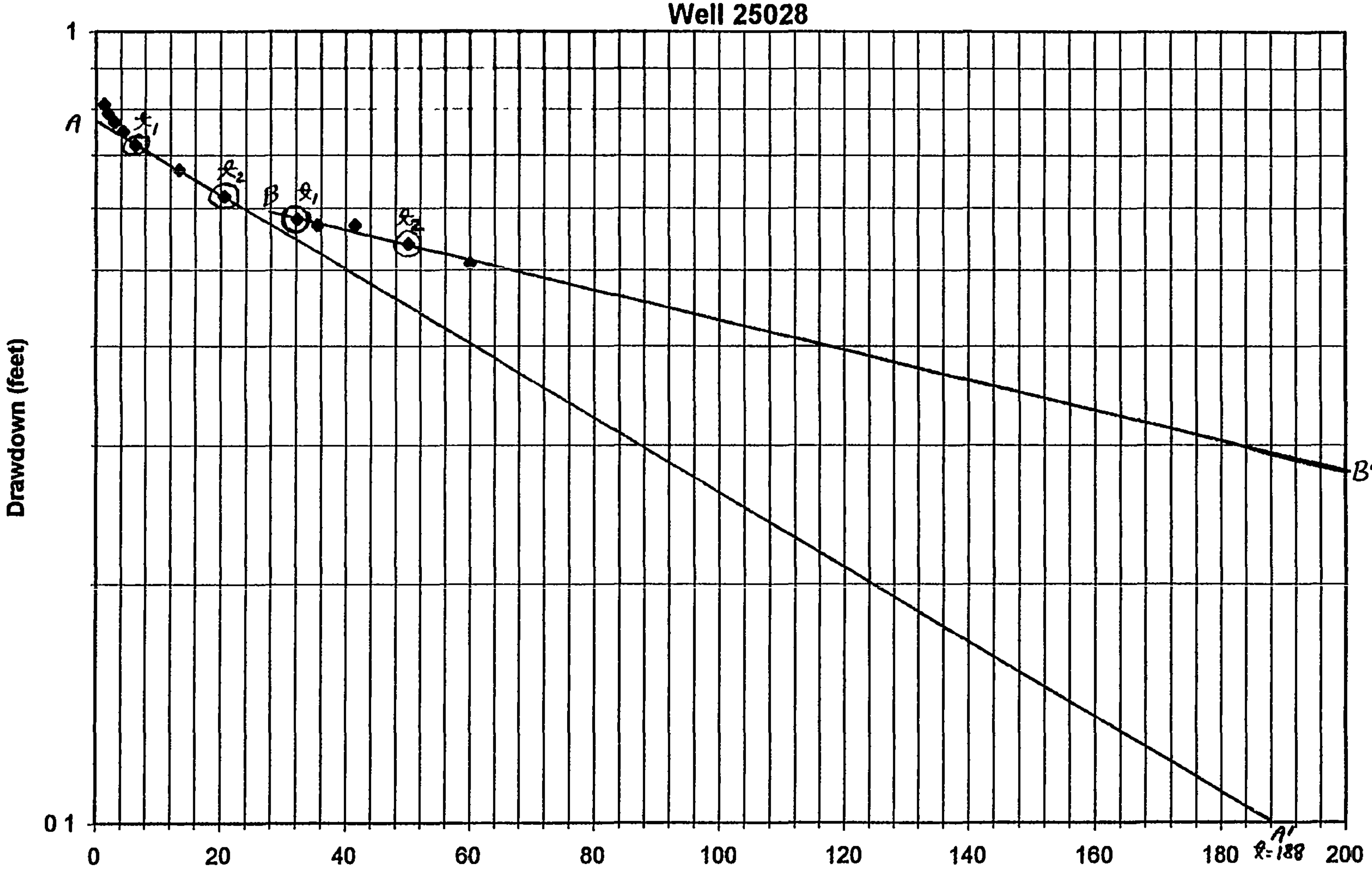
$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{1.08 - 0.53}{\log 0.19 - \log 0.14}$$

$\Delta t_{90} = 4.15$ minutes

Figure A3.10

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25028



A-A'
t_1 = 6.35 min
t_2 = 20.6 min
h_1 = 0.72 ft
h_2 = 0.62 ft

$$\Delta t_{90} = \frac{t_2 - t_1}{\log h_1 - \log h_2}$$

$$\Delta t_{90} = \frac{20.6 - 6.35}{\log 0.72 - \log 0.62}$$

Δt_{90} = 219 min

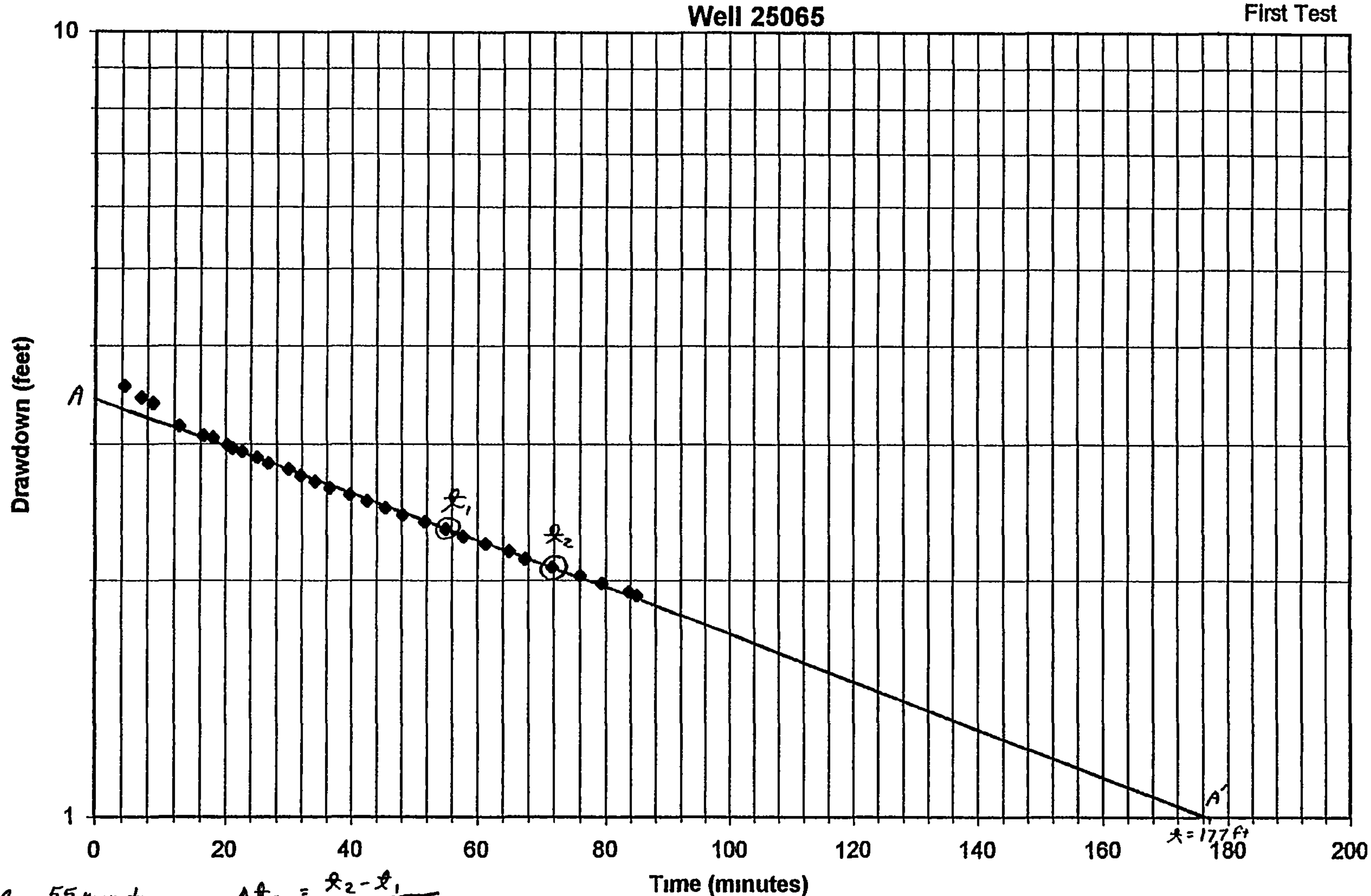
B-B'
t_1 = 32.30 min
t_2 = 50.0 min
h_1 = 0.58 ft
h_2 = 0.54 ft

$$\Delta t_{90} = \frac{50.0 - 32.30}{\log 0.58 - \log 0.54}$$

Δt_{90} = 570.34 min

Figure A3.11

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25065



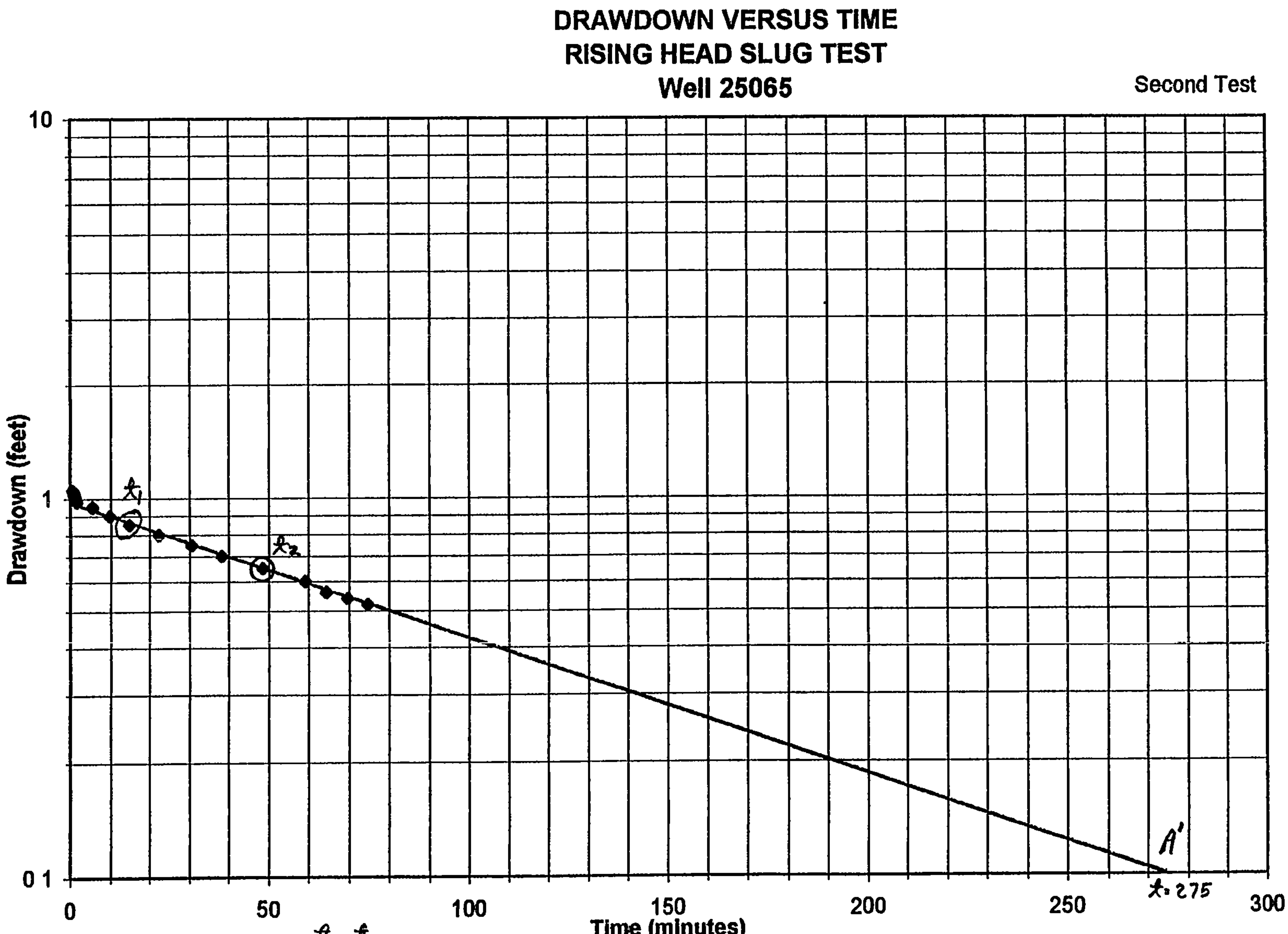
$t_1 = 55$ minute
$t_2 = 71.7$ minute
$s_1 = 2.33$ ft
$s_2 = 2.08$ ft

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2}$$

$$\Delta t_{90} = \frac{71.7 - 55}{\log 2.33 - \log 2.08}$$

$\Delta t_{90} = 338\ 79$ minutes

Figure A3.12



$t_1 = 14.6$ min

$t_2 = 48.5$ min

$h_1 = 0.85$ ft

$h_2 = 0.65$ ft

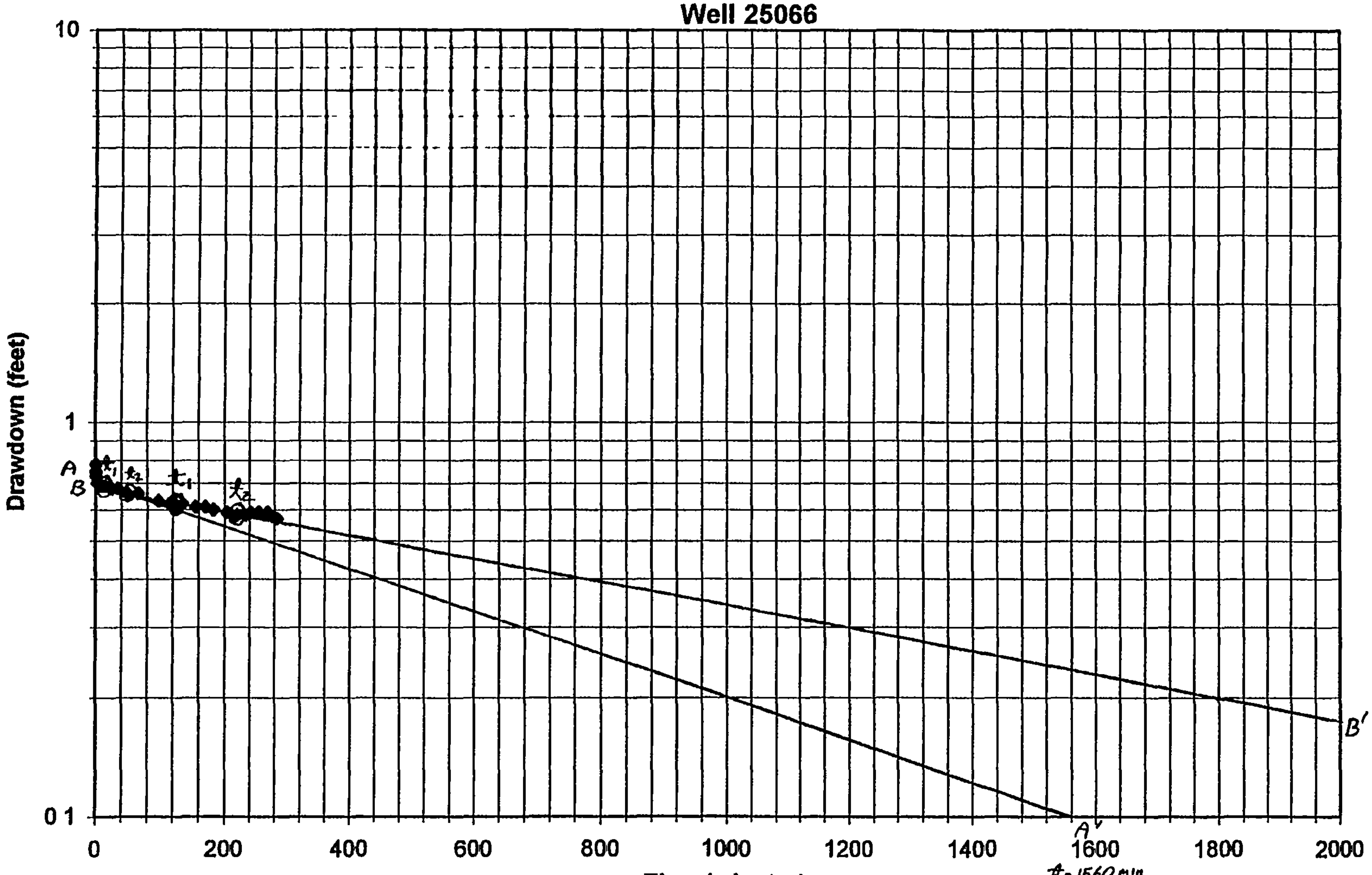
$$\Delta t_{90} = \frac{t_2 - t_1}{\log h_1 - \log h_2}$$

$$\Delta t_{90} = \frac{48.5 - 14.6}{\log 0.85 - \log 0.65}$$

$\Delta t_{90} = 290.97$ minutes

Figure A3.13

DRAWDOWN VERSUS TIME
RISING HEAD SLUG TEST
Well 25066



A-A'

$$\Delta t_{90} = \frac{t_2 - t_1}{\log s_1 - \log s_2} = \frac{50-25}{\log 0.68 - \log 0.66}$$

$\Delta t_{90} = 1928.27$ minutes

$t_1 = 25$ min
$t_2 = 50$ min
$s_1 = 0.68$ ft
$s_2 = 0.66$ ft

B-B'

$$\Delta t_{90} = \frac{219.5 - 123.9}{\log 0.62 - \log 0.58}$$

$\Delta t_{90} = 3300.68$ minutes

$t_1 = 123.9$ min
$t_2 = 219.5$ min
$s_1 = 0.62$ ft
$s_2 = 0.58$ ft

Figure A3.14

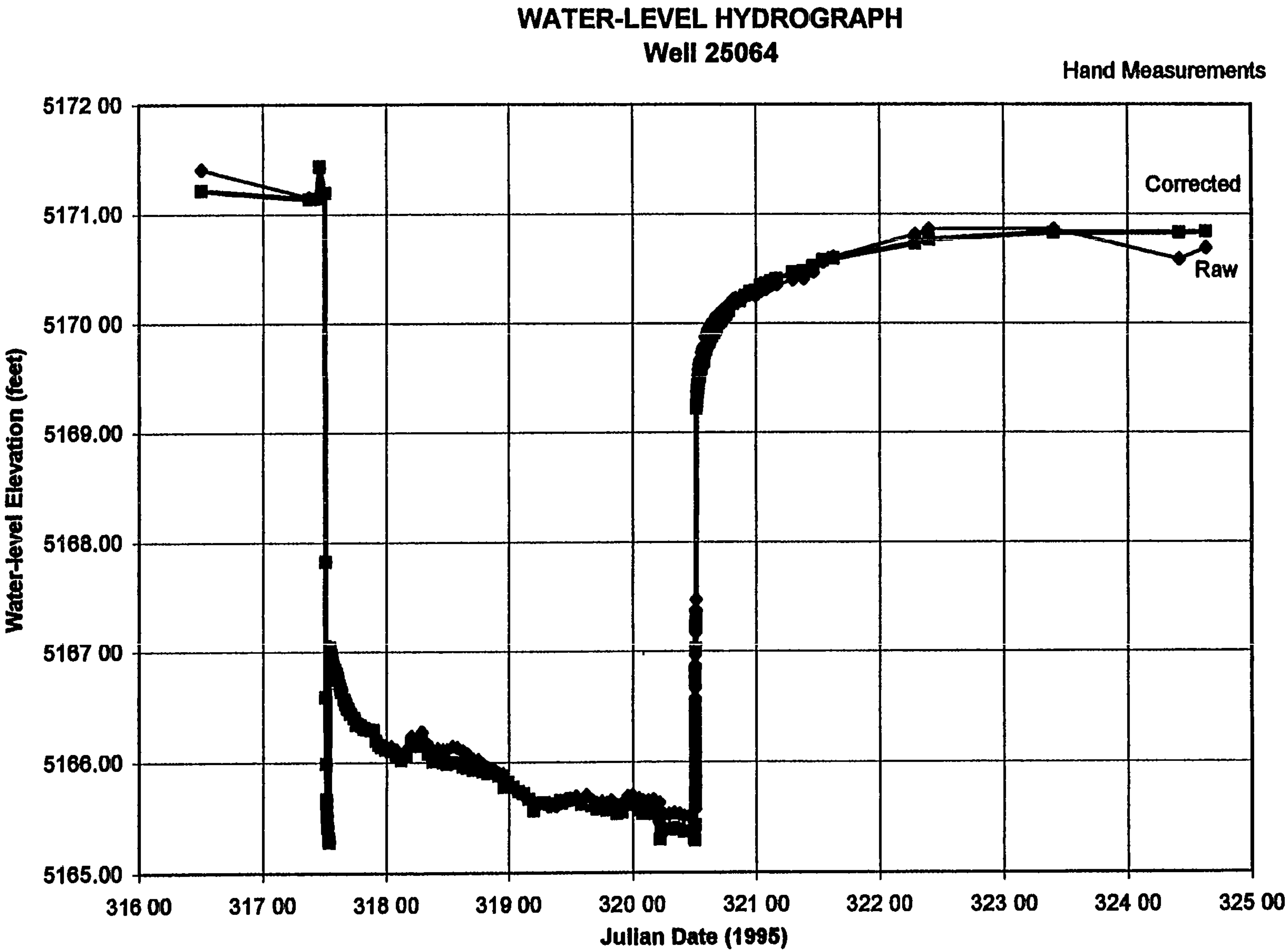
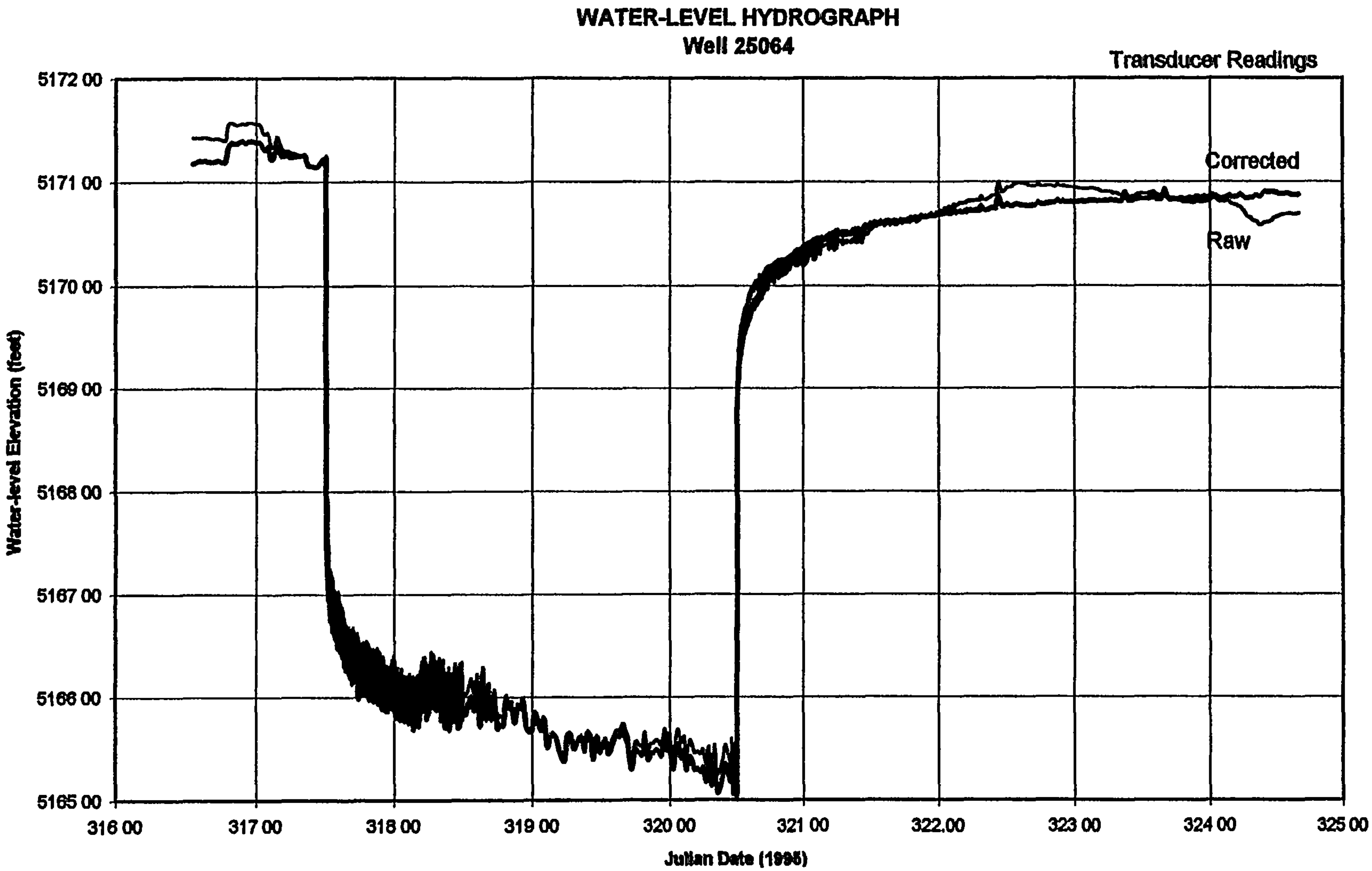

WATER-LEVEL HYDROGRAPH
Well 25064
Hand Measurements
Corrected
Raw
5172 00
5171.00
5170 00
5169.00
5168.00
5167 00
5166.00
5165.00
Water-level Elevation (feet)
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.15



WATER-LEVEL HYDROGRAPH
Well 25064
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 00
5170 00
5169 00
5168 00
5167 00
5166 00
5165 00
316 00
317 00
318 00
319 00
320 00
321 00
322.00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.16

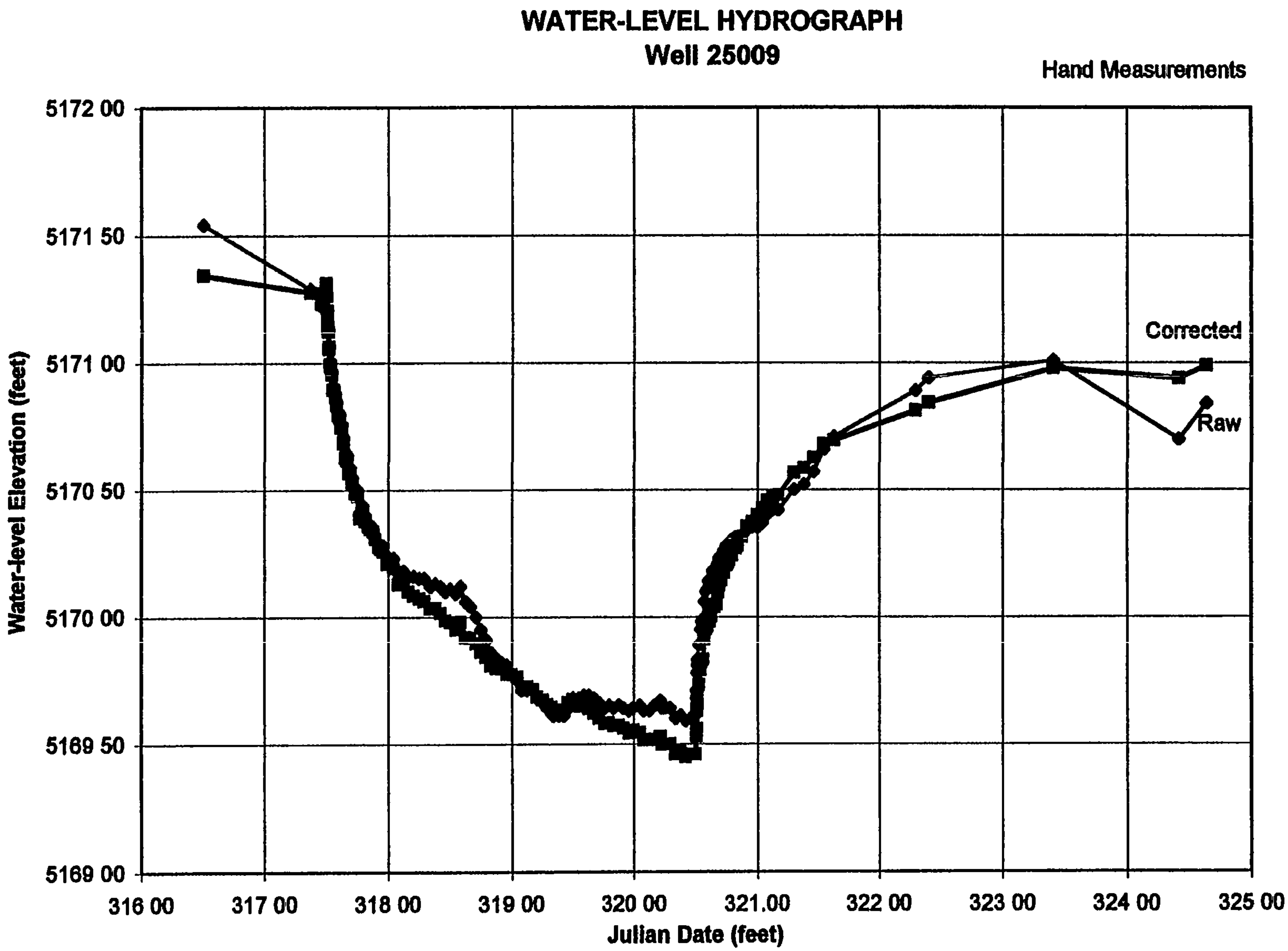
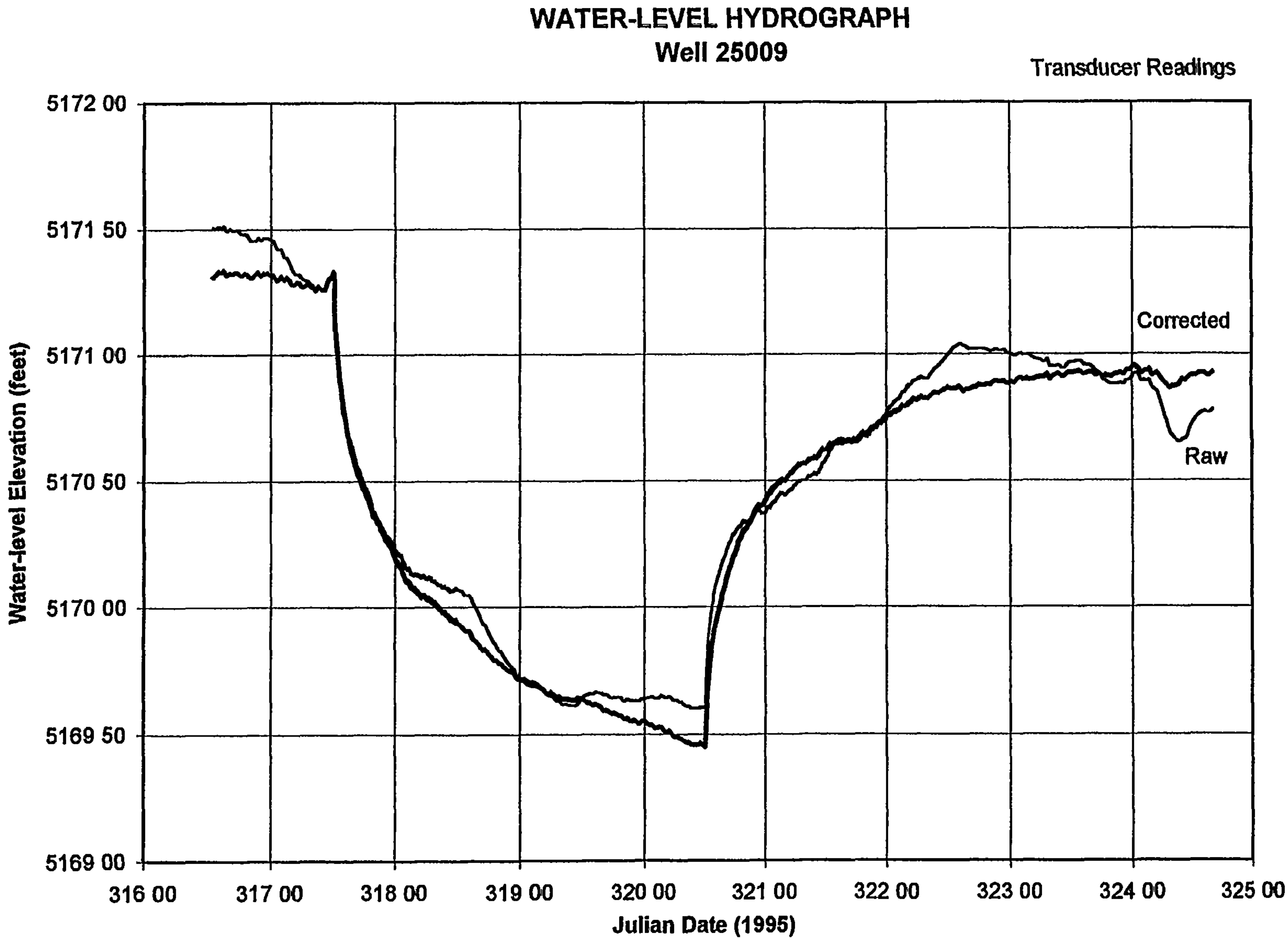

WATER-LEVEL HYDROGRAPH
Well 25009
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170 50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321.00
322 00
323 00
324 00
325 00
Julian Date (feet)

Figure A3.17



WATER-LEVEL HYDROGRAPH
Well 25009
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170 50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.18

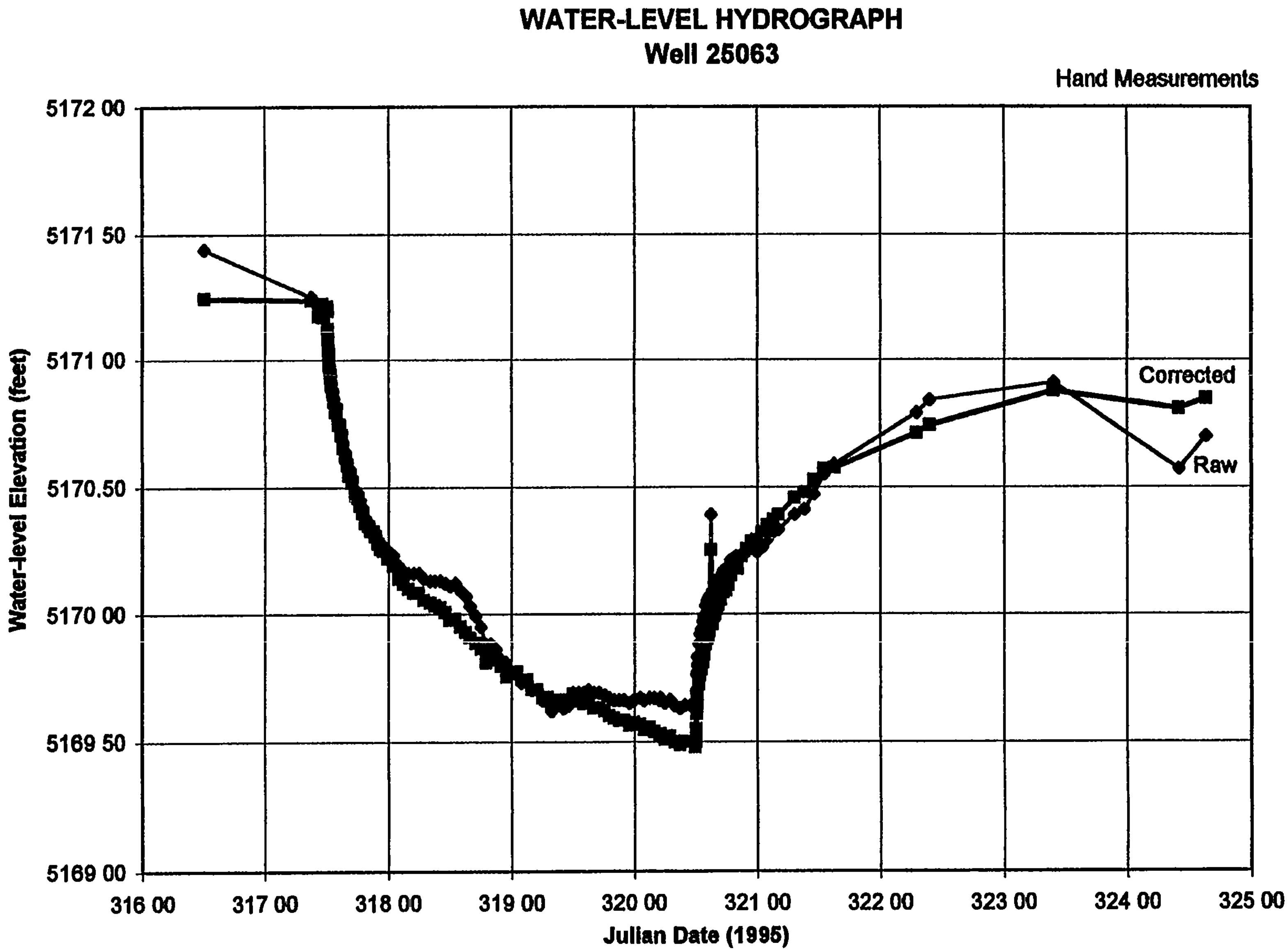

WATER-LEVEL HYDROGRAPH
Well 25063
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5172 00
5171 50
5171 00
5170.50
5170 00
5169 50
5169 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.19

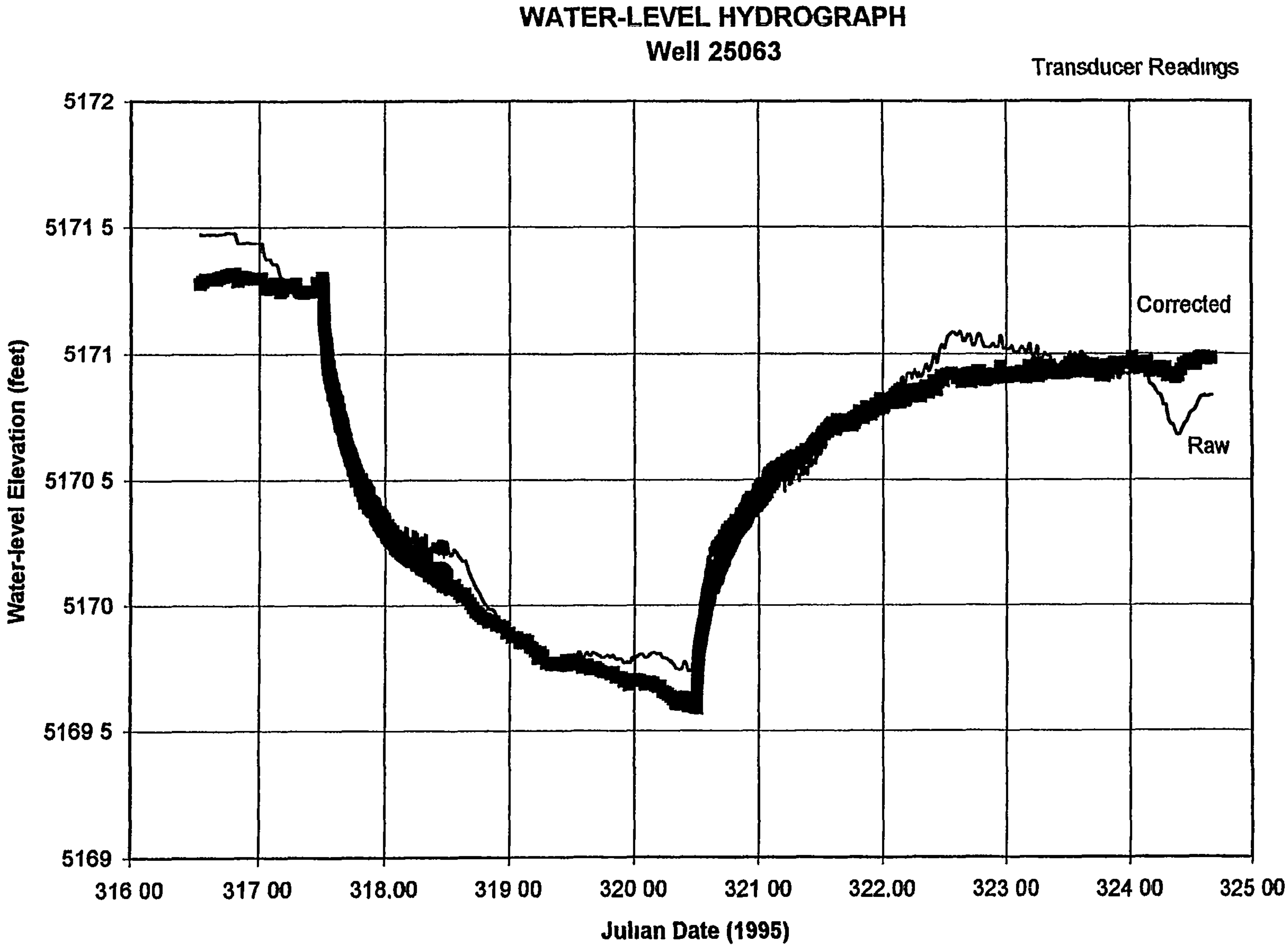

WATER-LEVEL HYDROGRAPH
Well 25063
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5172
5171 5
5171
5170 5
5170
5169 5
5169
316 00
317 00
318.00
319 00
320 00
321 00
322.00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.20

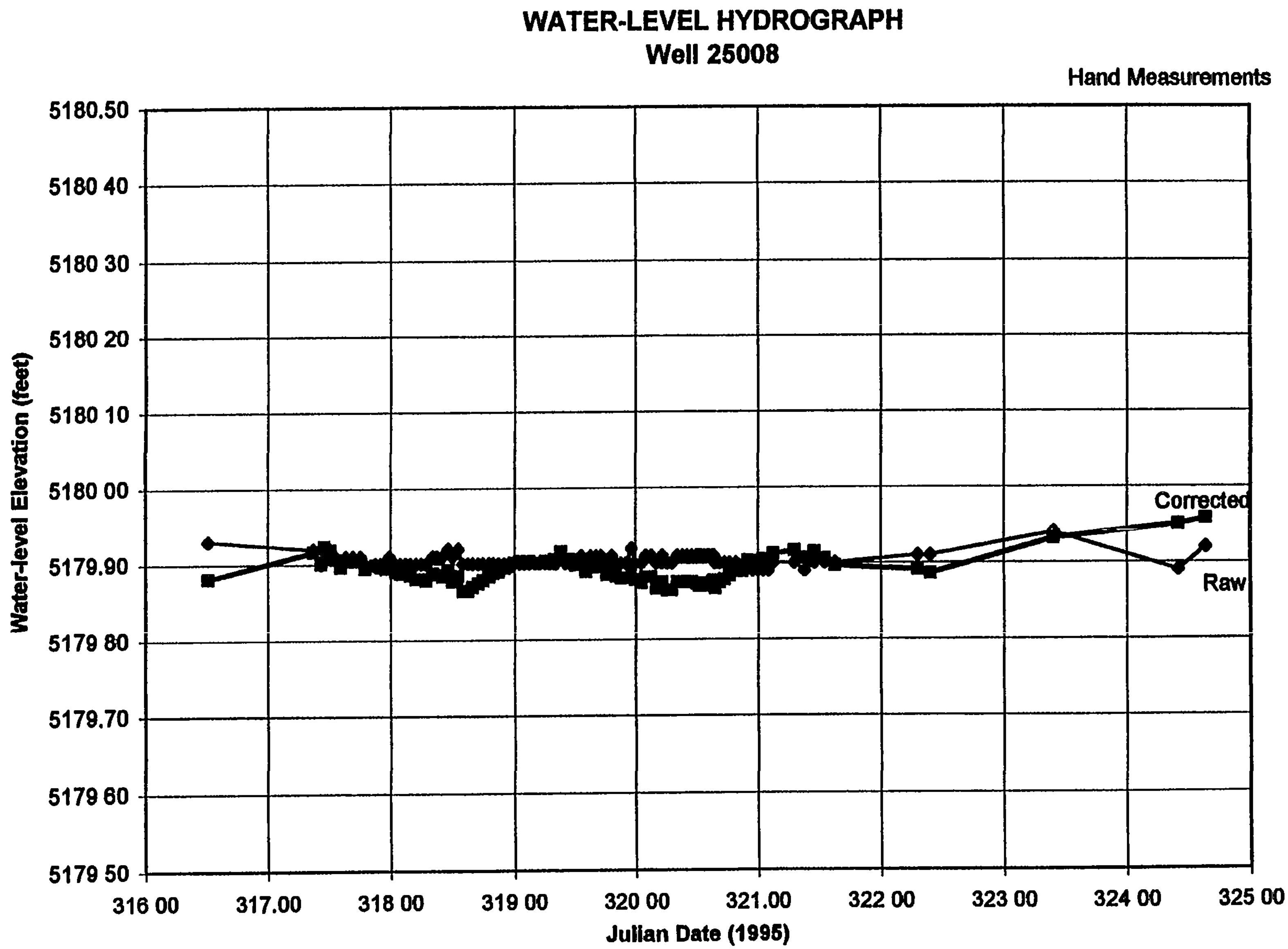

WATER-LEVEL HYDROGRAPH
Well 25008
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180.50
5180 40
5180 30
5180 20
5180 10
5180 00
5179.90
5179 80
5179.70
5179 60
5179 50
316 00
317.00
318 00
319 00
320 00
321.00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.21

WATER-LEVEL HYDROGRAPH
Well 25008

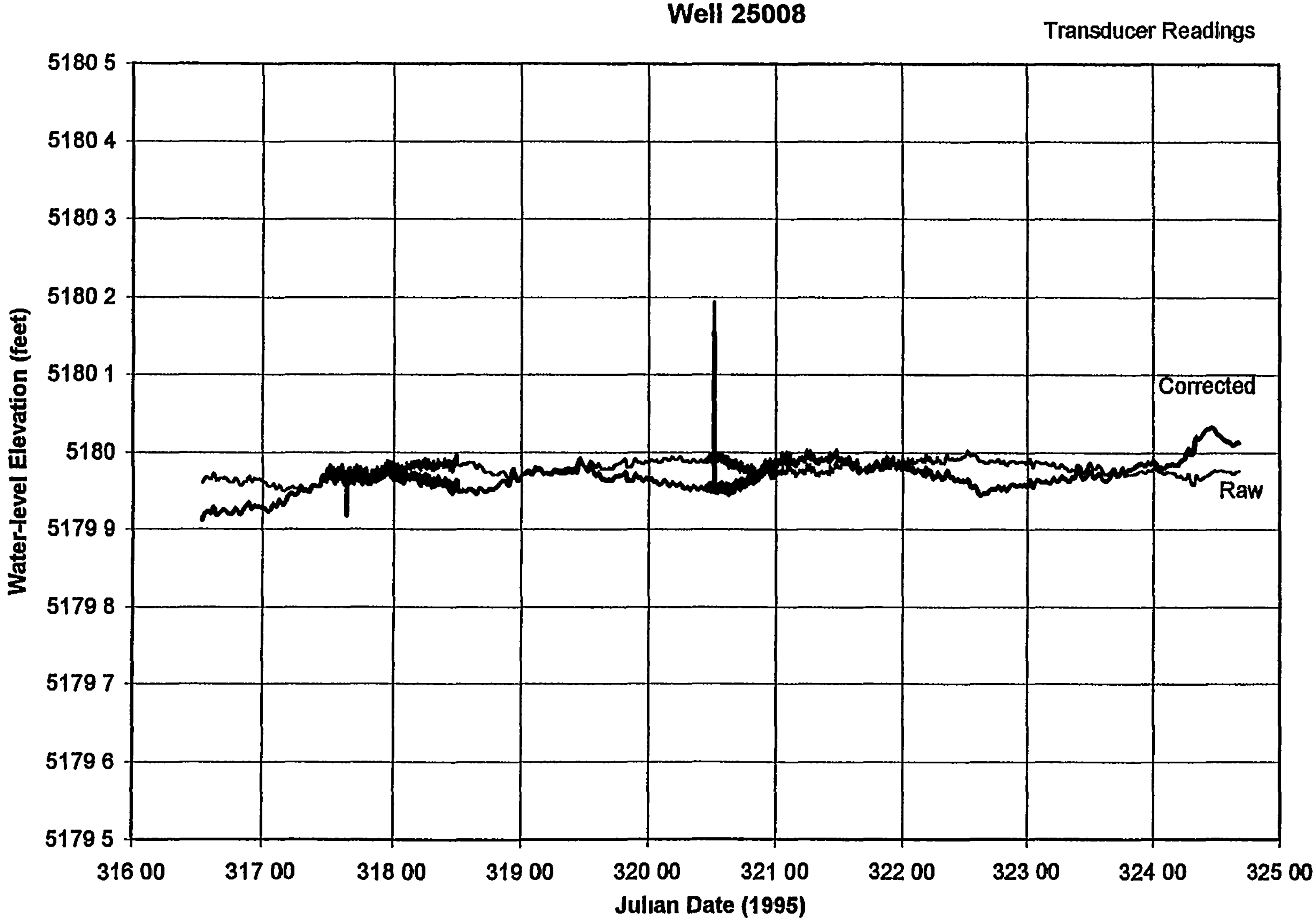


Figure A3.22

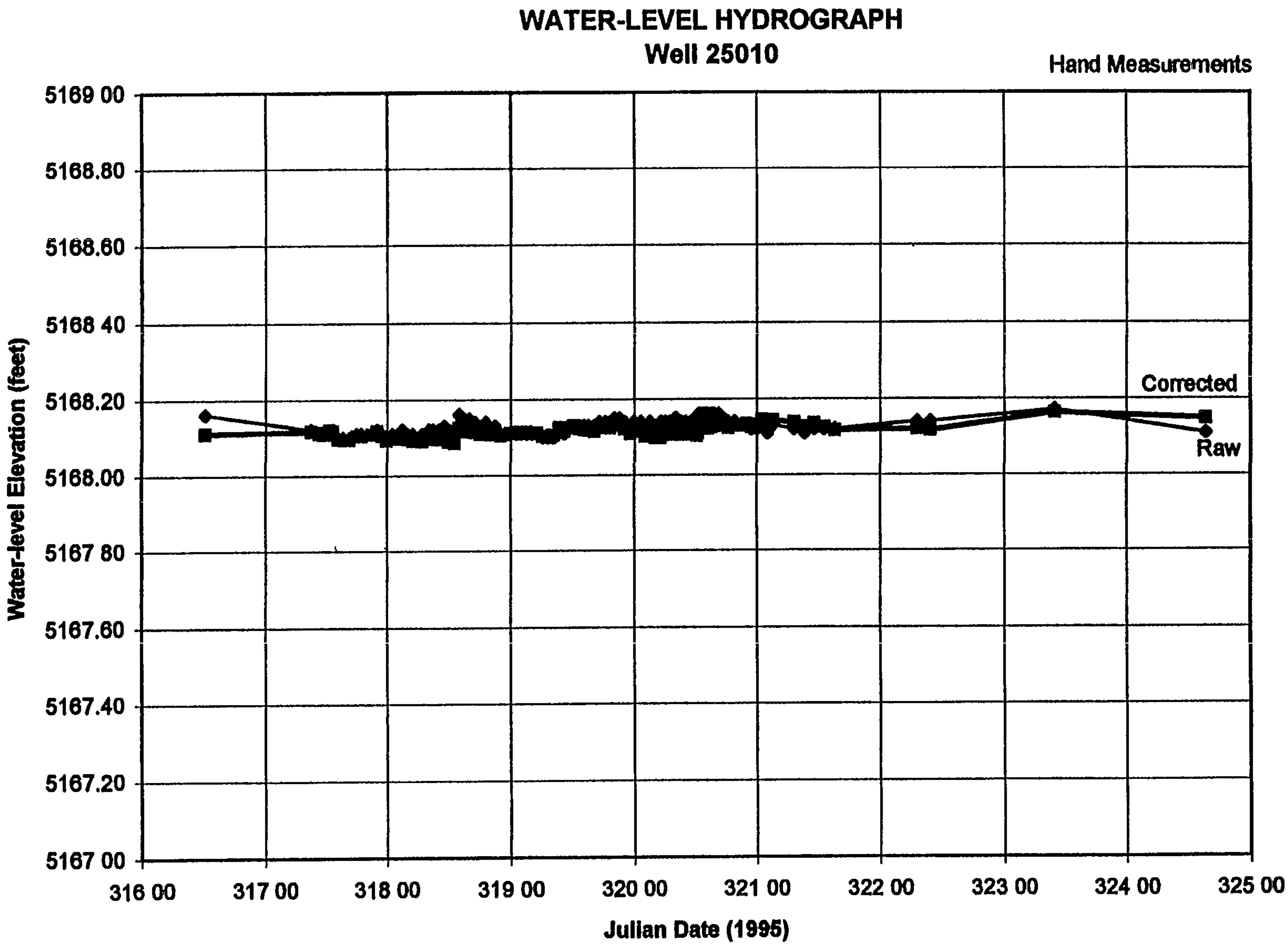

WATER-LEVEL HYDROGRAPH
Well 25010
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5169 00
5168.80
5168.60
5168 40
5168.20
5168.00
5167 80
5167.60
5167.40
5167.20
5167 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.23

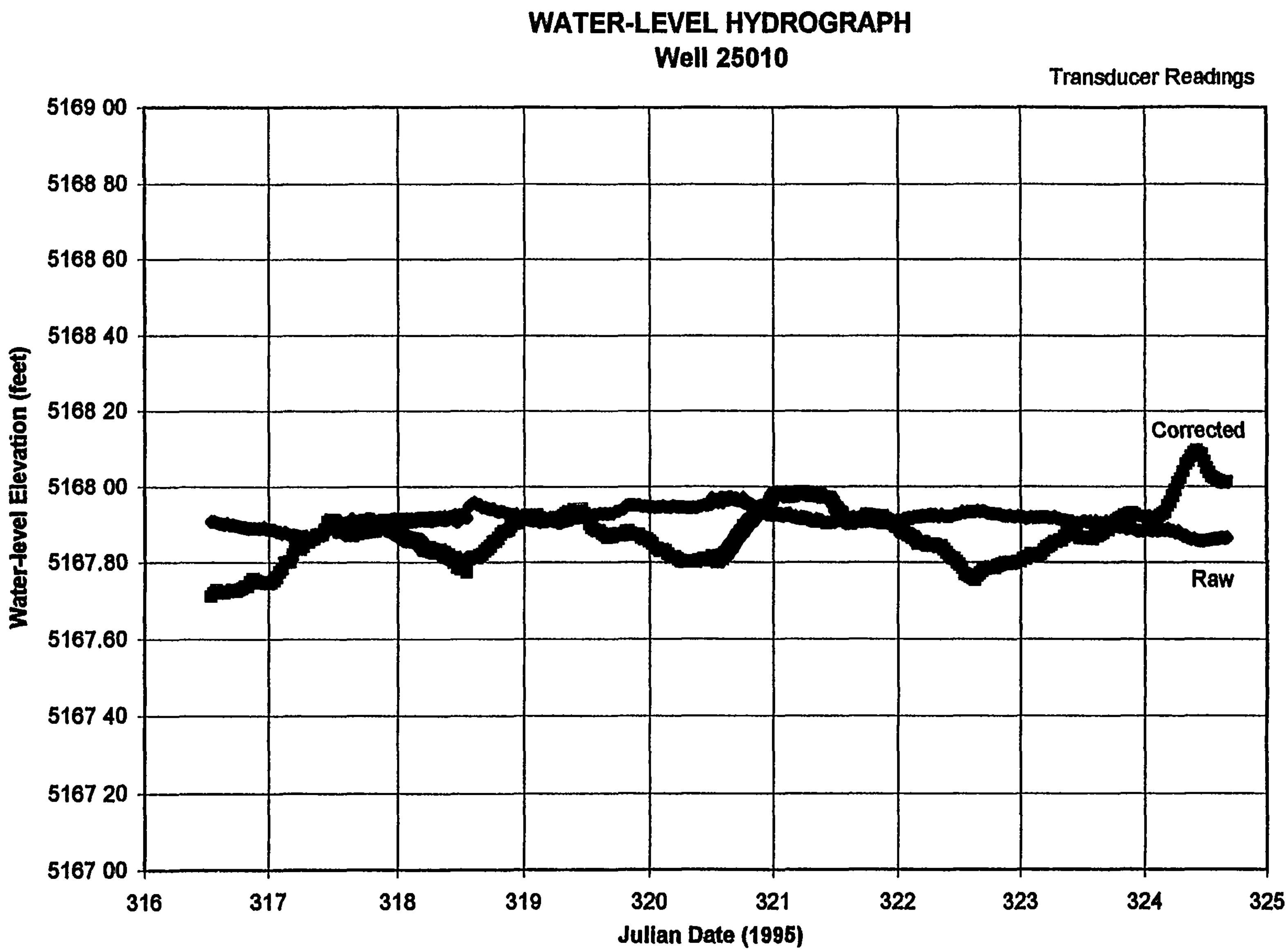

WATER-LEVEL HYDROGRAPH
Well 25010
Transducer Readings
Corrected
Raw
Water-level Elevation (feet)
5169 00
5168 80
5168 60
5168 40
5168 20
5168 00
5167.80
5167.60
5167 40
5167 20
5167 00
316
317
318
319
320
321
322
323
324
325
Julian Date (1995)

Figure A3.24

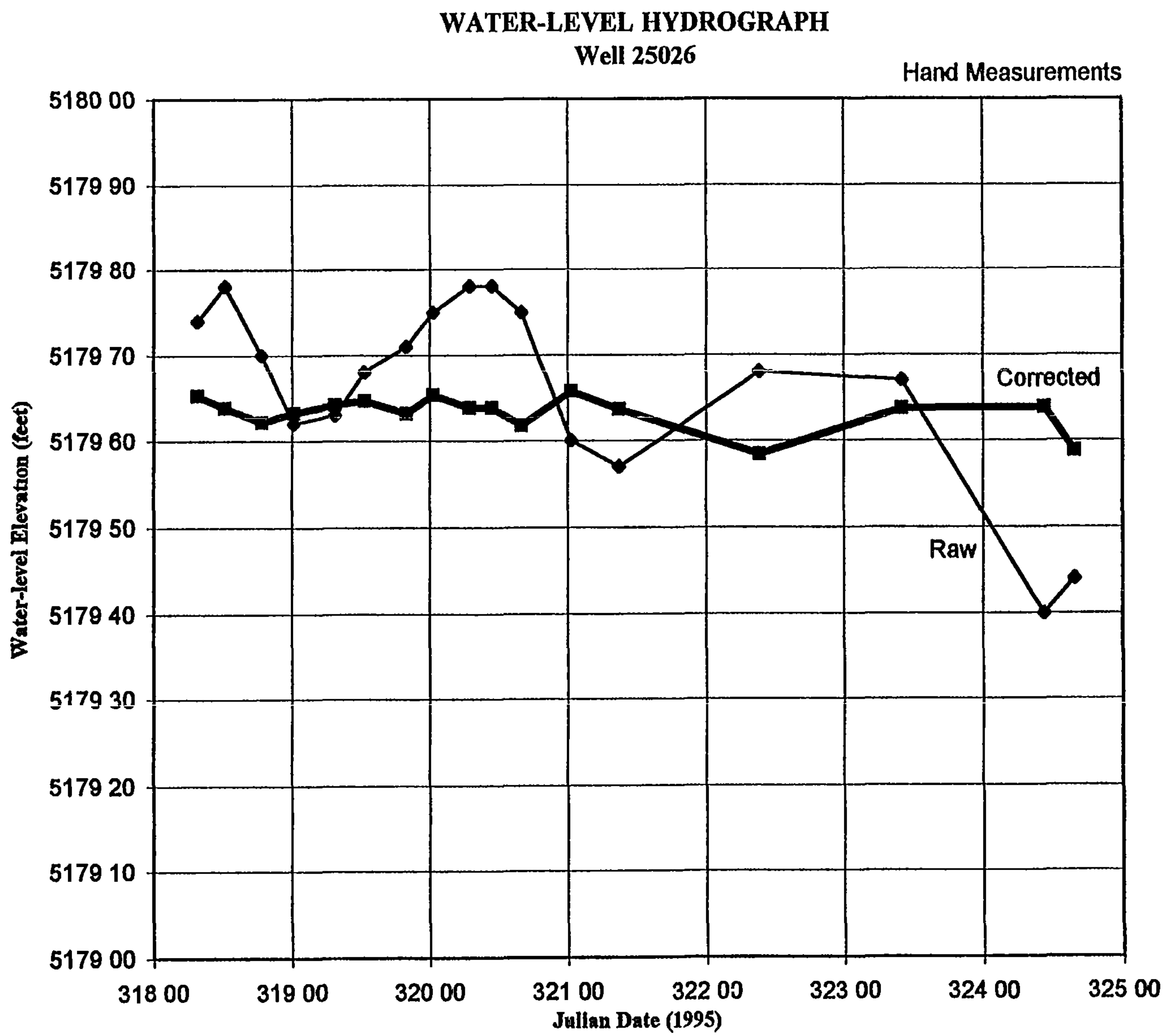

WATER-LEVEL HYDROGRAPH
Well 25026
Hand Measurements
5180 00
5179 90
5179 80
5179 70
5179 60
5179 50
5179 40
5179 30
5179 20
5179 10
5179 00
Water-level Elevation (feet)
Corrected
Raw
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.25

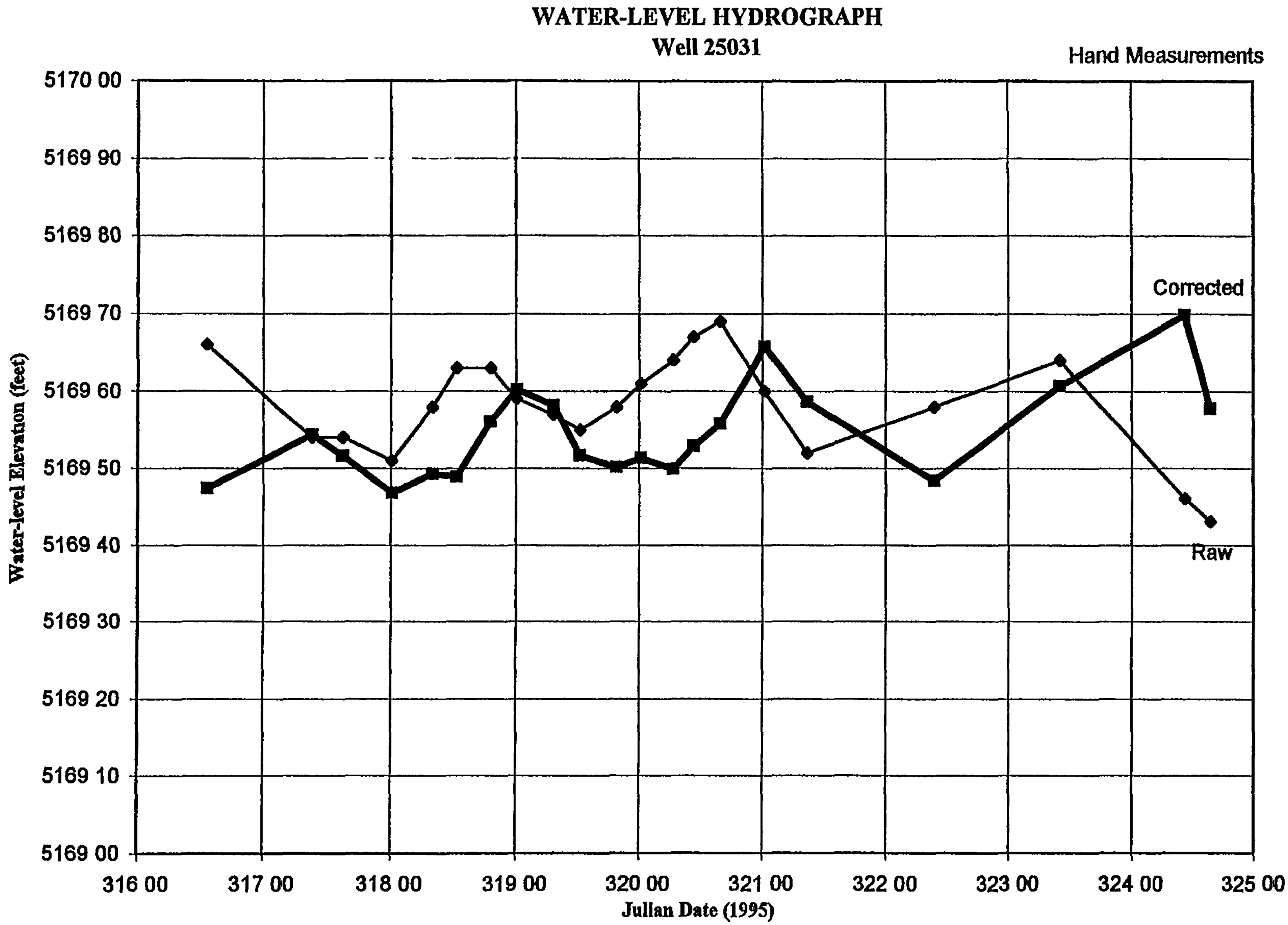
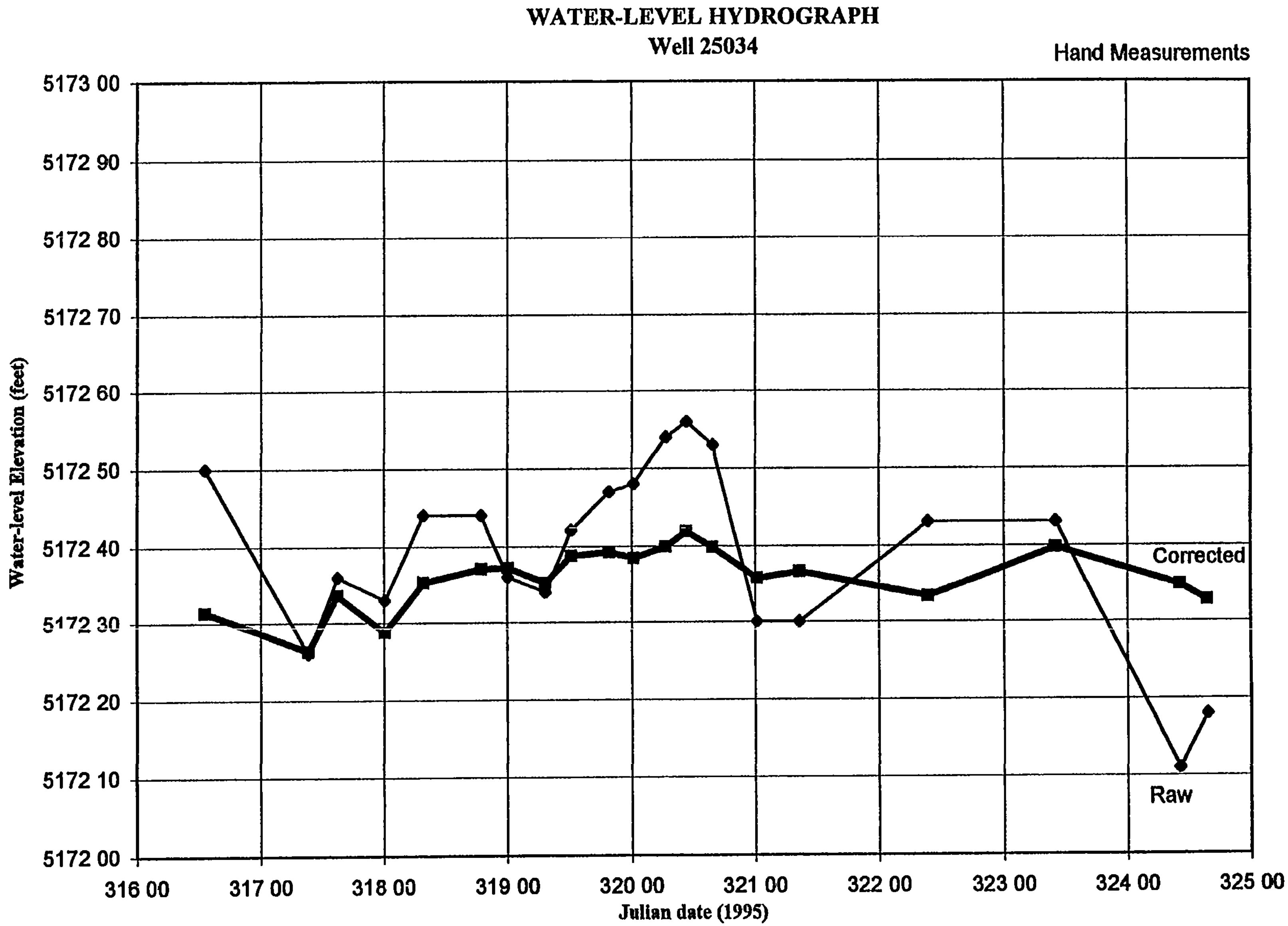

WATER-LEVEL HYDROGRAPH
Well 25031
Hand Measurements
Water-level Elevation (feet)
5170 00
5169 90
5169 80
5169 70
5169 60
5169 50
5169 40
5169 30
5169 20
5169 10
5169 00
Corrected
Raw
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.26



WATER-LEVEL HYDROGRAPH
Well 25034
Hand Measurements
5173 00
5172 90
5172 80
5172 70
5172 60
5172 50
5172 40
5172 30
5172 20
5172 10
5172 00
Water-level Elevation (feet)
Corrected
Raw
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian date (1995)

Figure A3.27

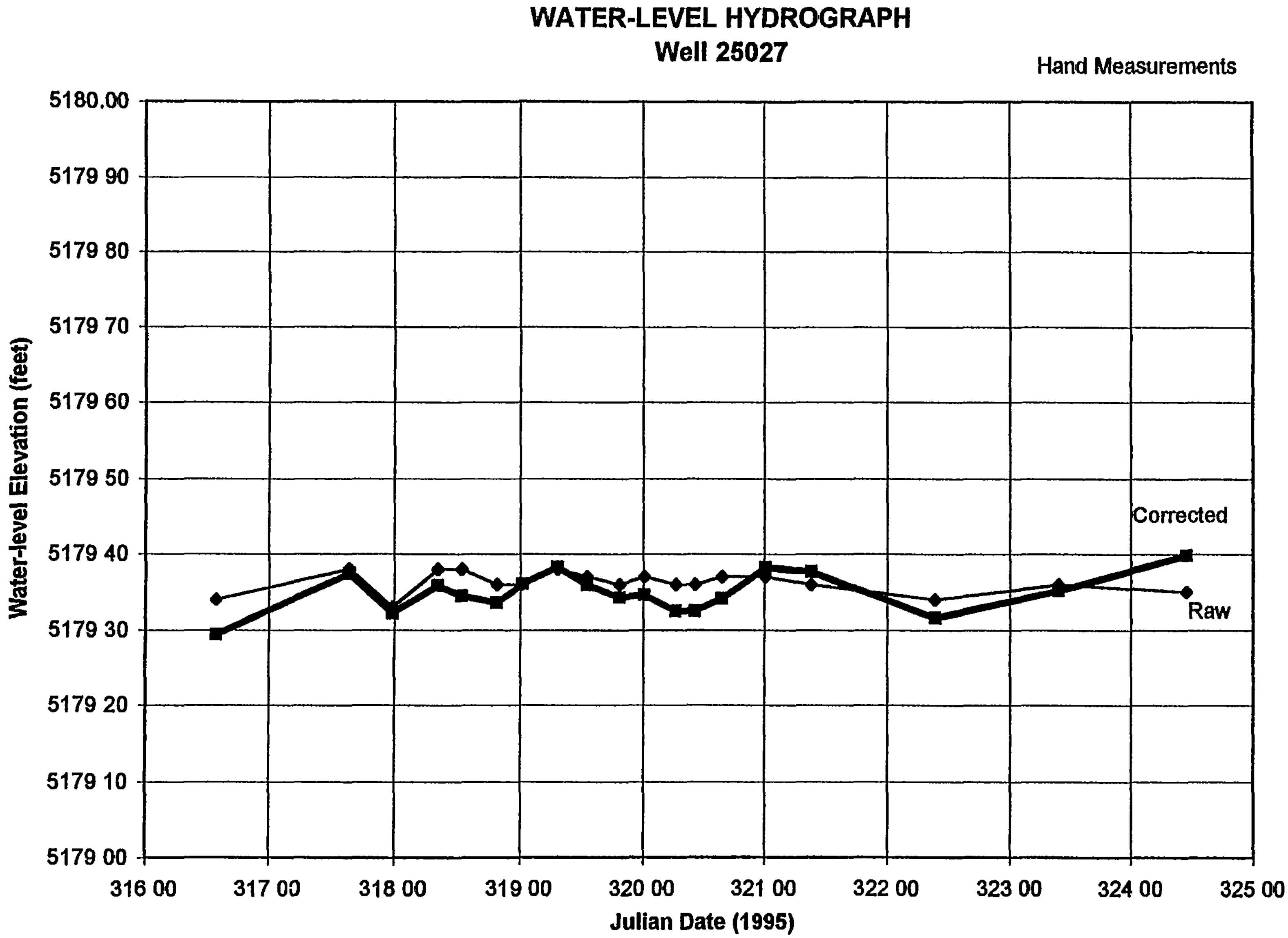

WATER-LEVEL HYDROGRAPH
Well 25027
Hand Measurements
Water-level Elevation (feet)
5180.00
5179 90
5179 80
5179 70
5179 60
5179 50
5179 40
5179 30
5179 20
5179 10
5179 00
Corrected
Raw
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.28

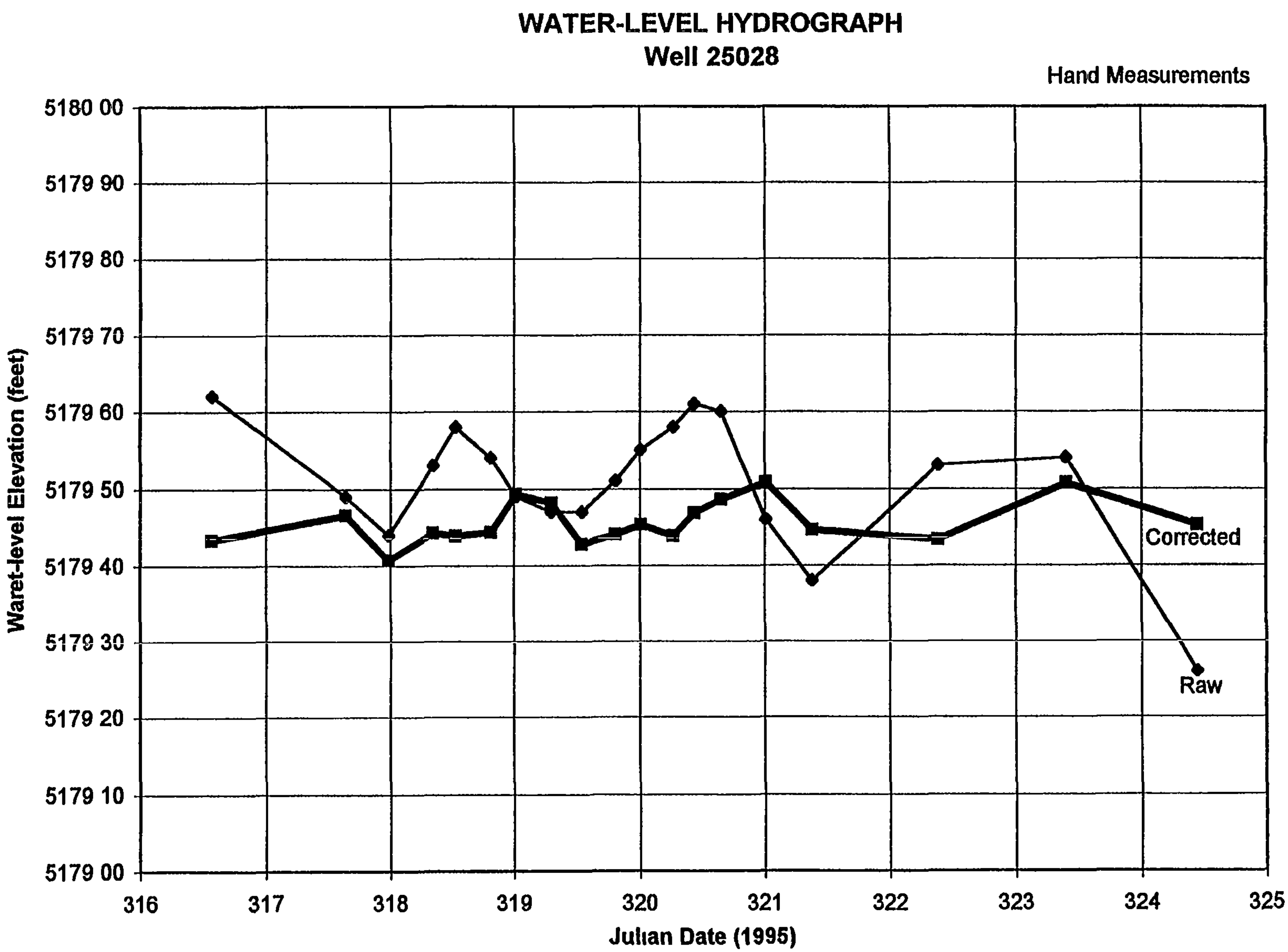

WATER-LEVEL HYDROGRAPH
Well 25028
Hand Measurements
5180 00
5179 90
5179 80
5179 70
5179 60
5179 50
5179 40
5179 30
5179 20
5179 10
5179 00
Waret-level Elevation (feet)
316
317
318
319
320
321
322
323
324
325
Julian Date (1995)
Corrected
Raw

Figure A3.29

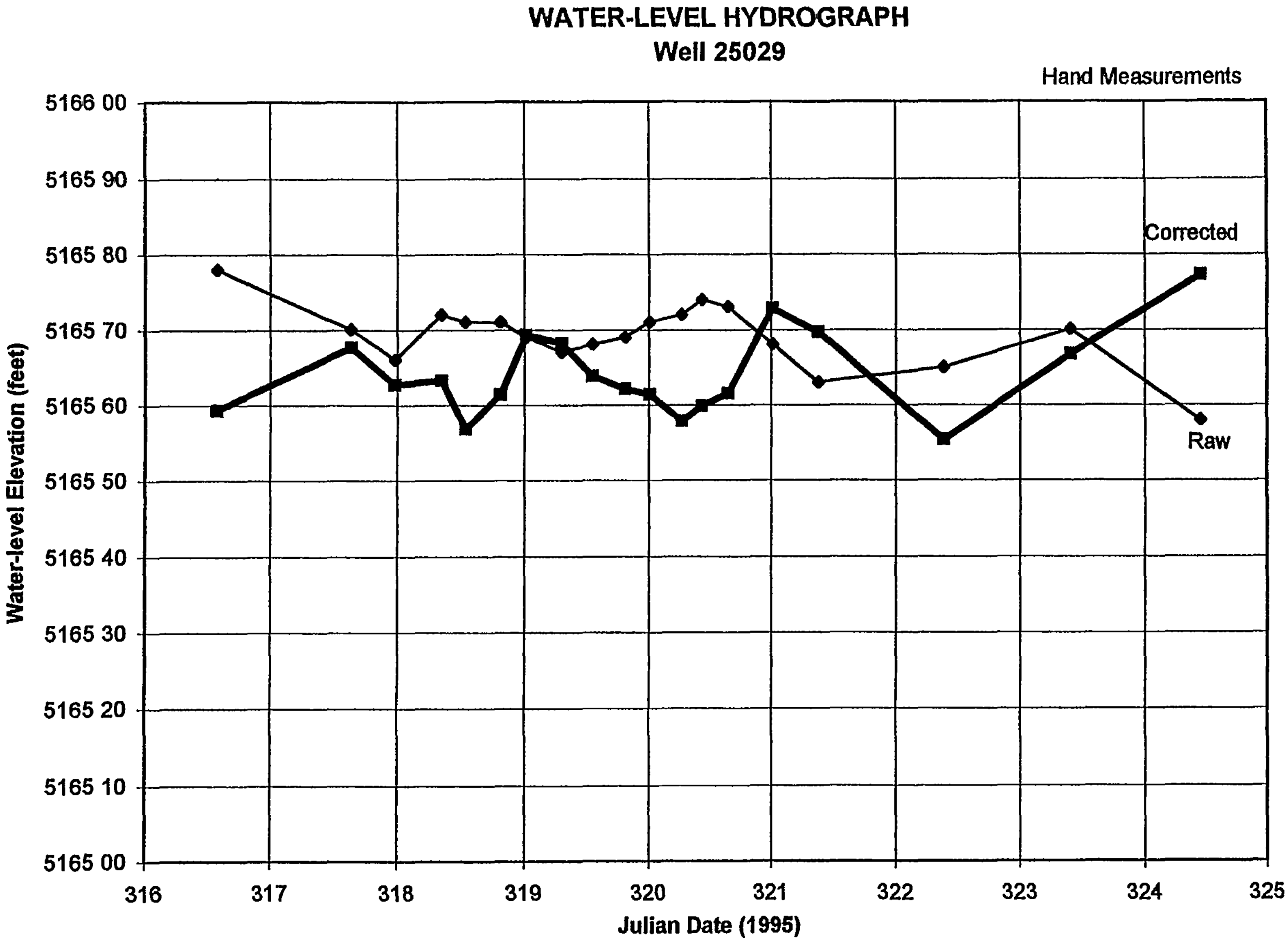

WATER-LEVEL HYDROGRAPH
Well 25029
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5166 00
5165 90
5165 80
5165 70
5165 60
5165 50
5165 40
5165 30
5165 20
5165 10
5165 00
316
317
318
319
320
321
322
323
324
325
Julian Date (1995)

Figure A3.30

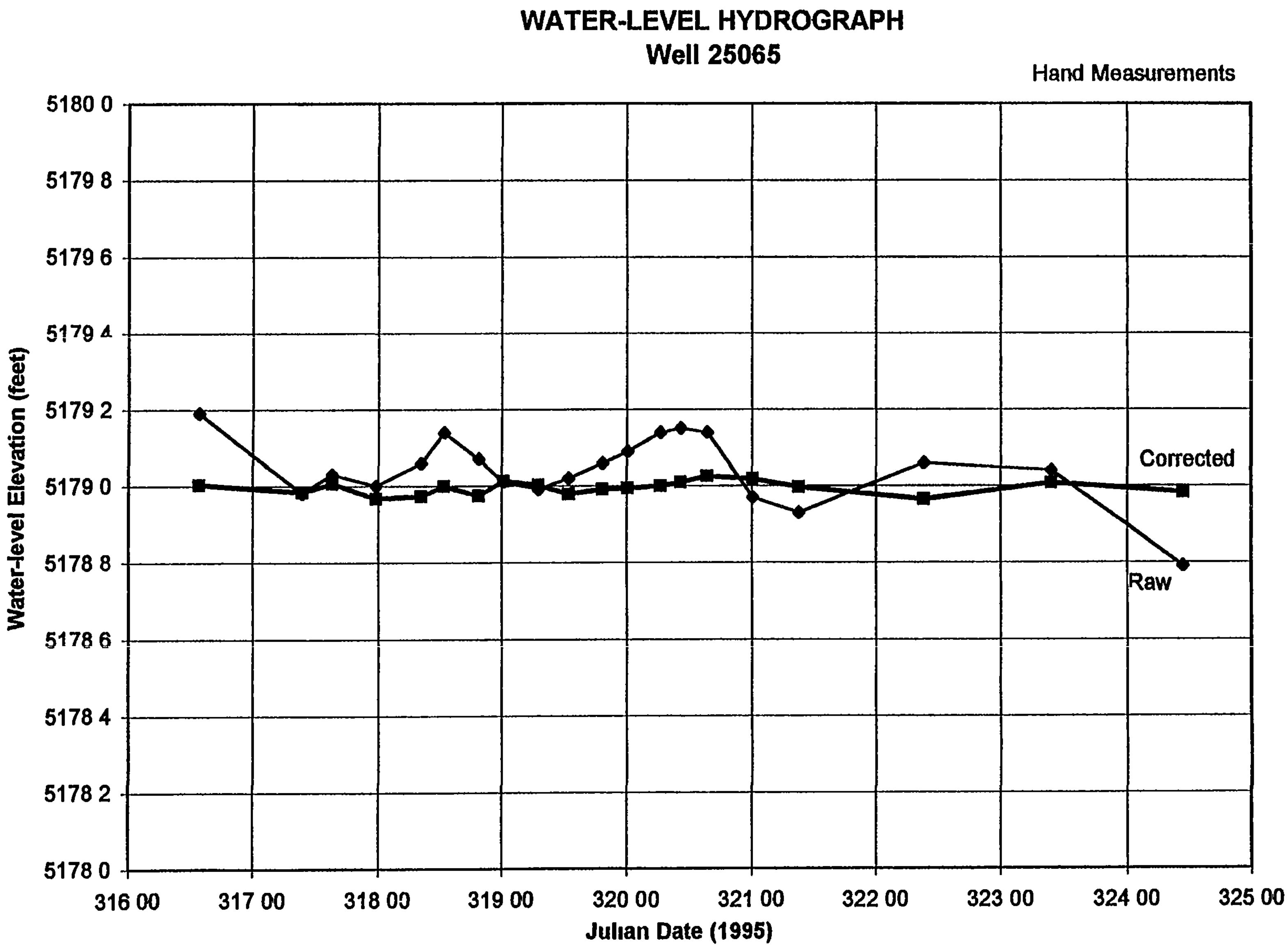

WATER-LEVEL HYDROGRAPH
Well 25065
Hand Measurements
Corrected
Raw
Water-level Elevation (feet)
5180 0
5179 8
5179 6
5179 4
5179 2
5179 0
5178 8
5178 6
5178 4
5178 2
5178 0
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian Date (1995)

Figure A3.31

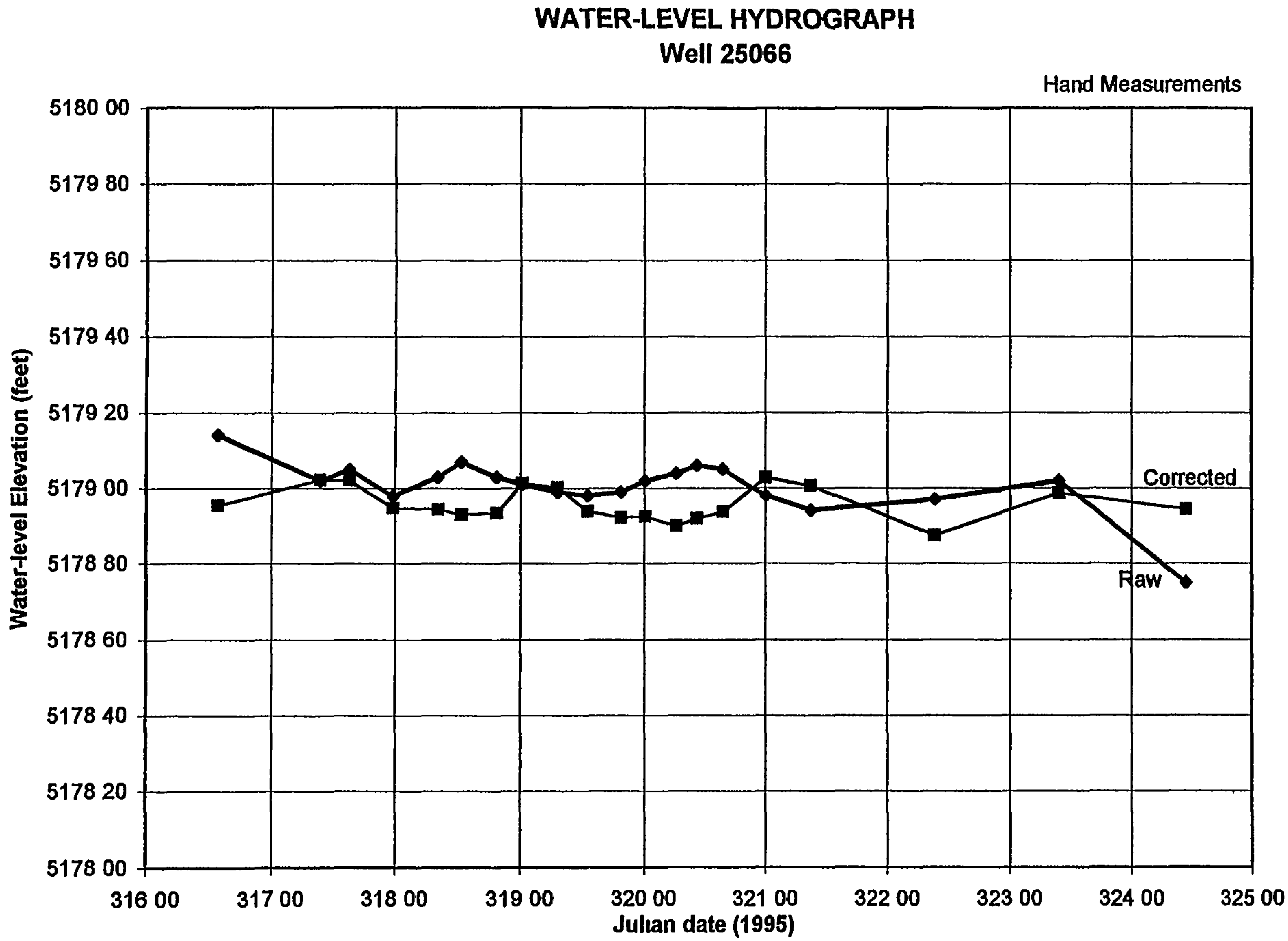

WATER-LEVEL HYDROGRAPH
Well 25066
Hand Measurements
Water-level Elevation (feet)
5180 00
5179 80
5179 60
5179 40
5179 20
5179 00
5178 80
5178 60
5178 40
5178 20
5178 00
316 00
317 00
318 00
319 00
320 00
321 00
322 00
323 00
324 00
325 00
Julian date (1995)
Corrected
Raw

Figure A3.32

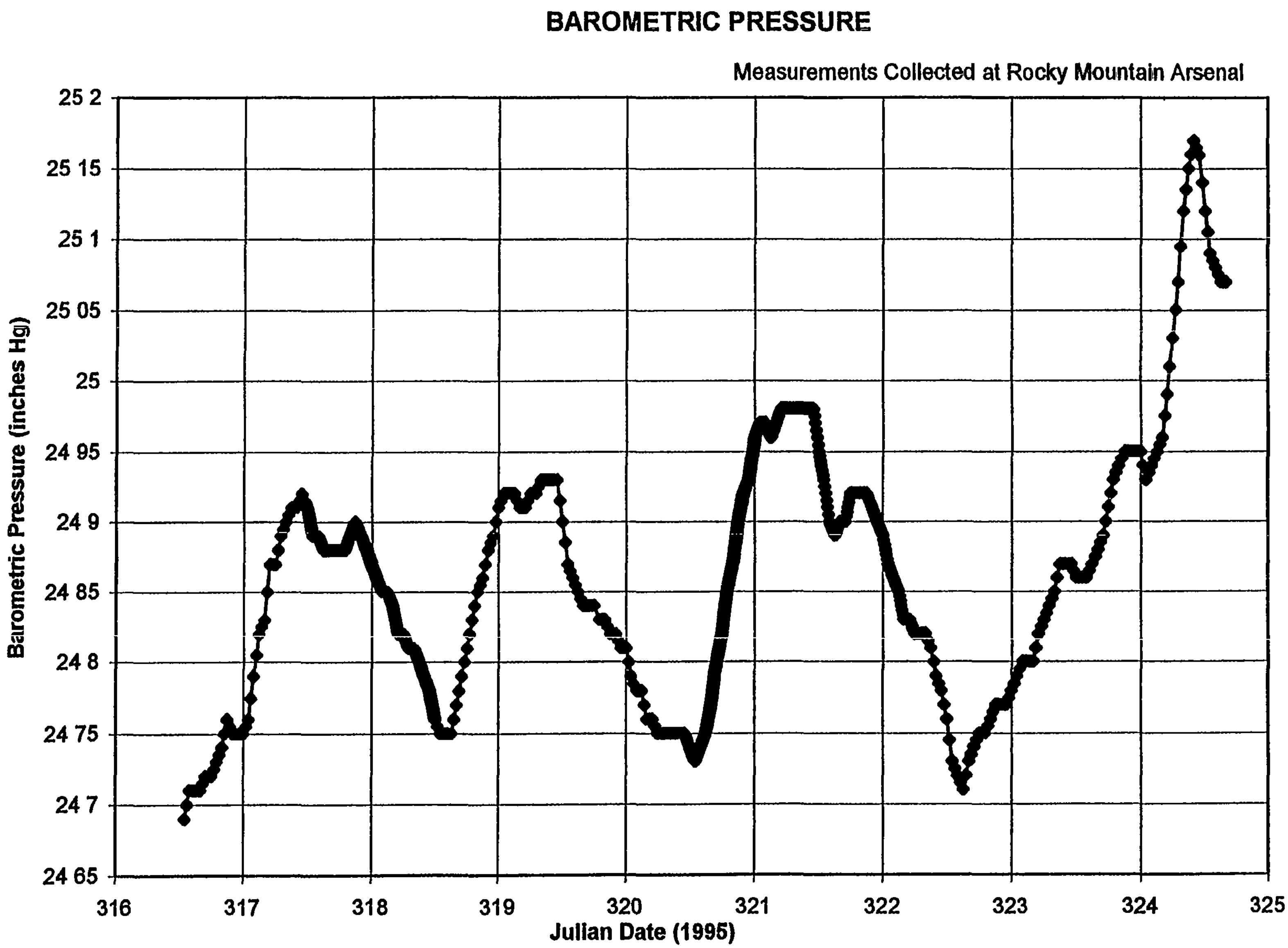


Figure J22

Figure A3.33

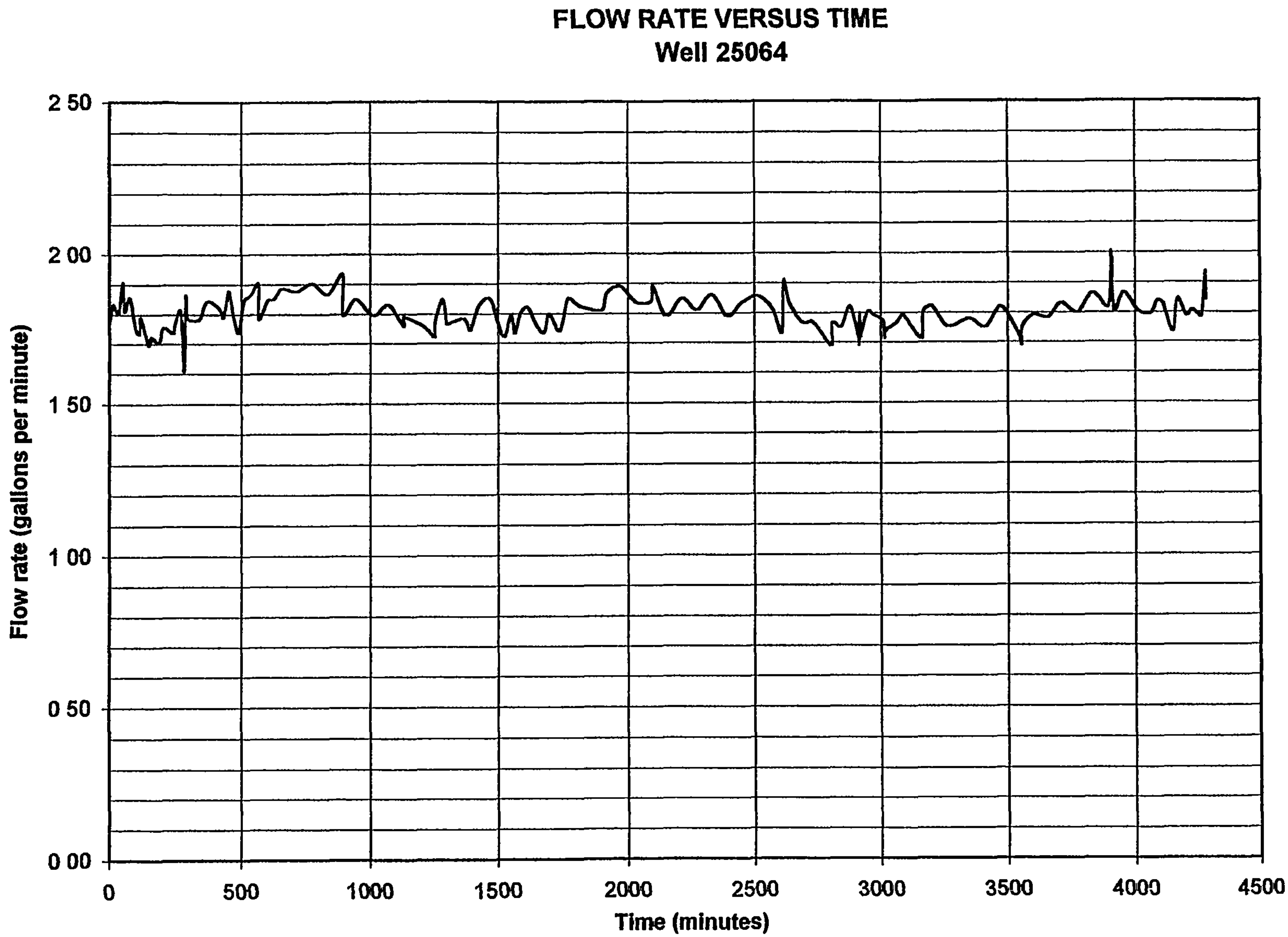
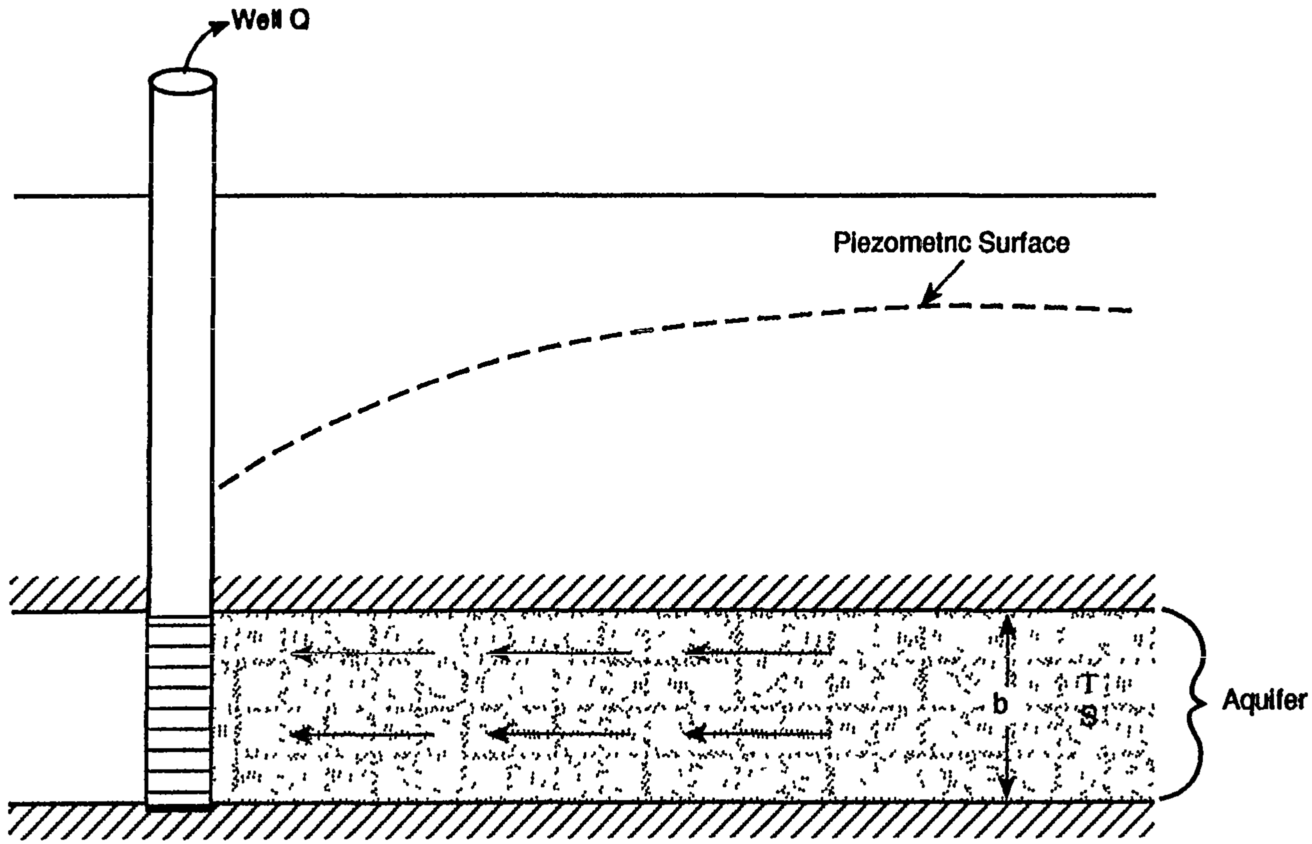

FLOW RATE VERSUS TIME
Well 25064
2 50
2 00
1 50
1 00
0 50
0 00
Flow rate (gallons per minute)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Time (minutes)

Figure A3.34

PHYSICAL MODEL FOR IDEAL AQUIFER



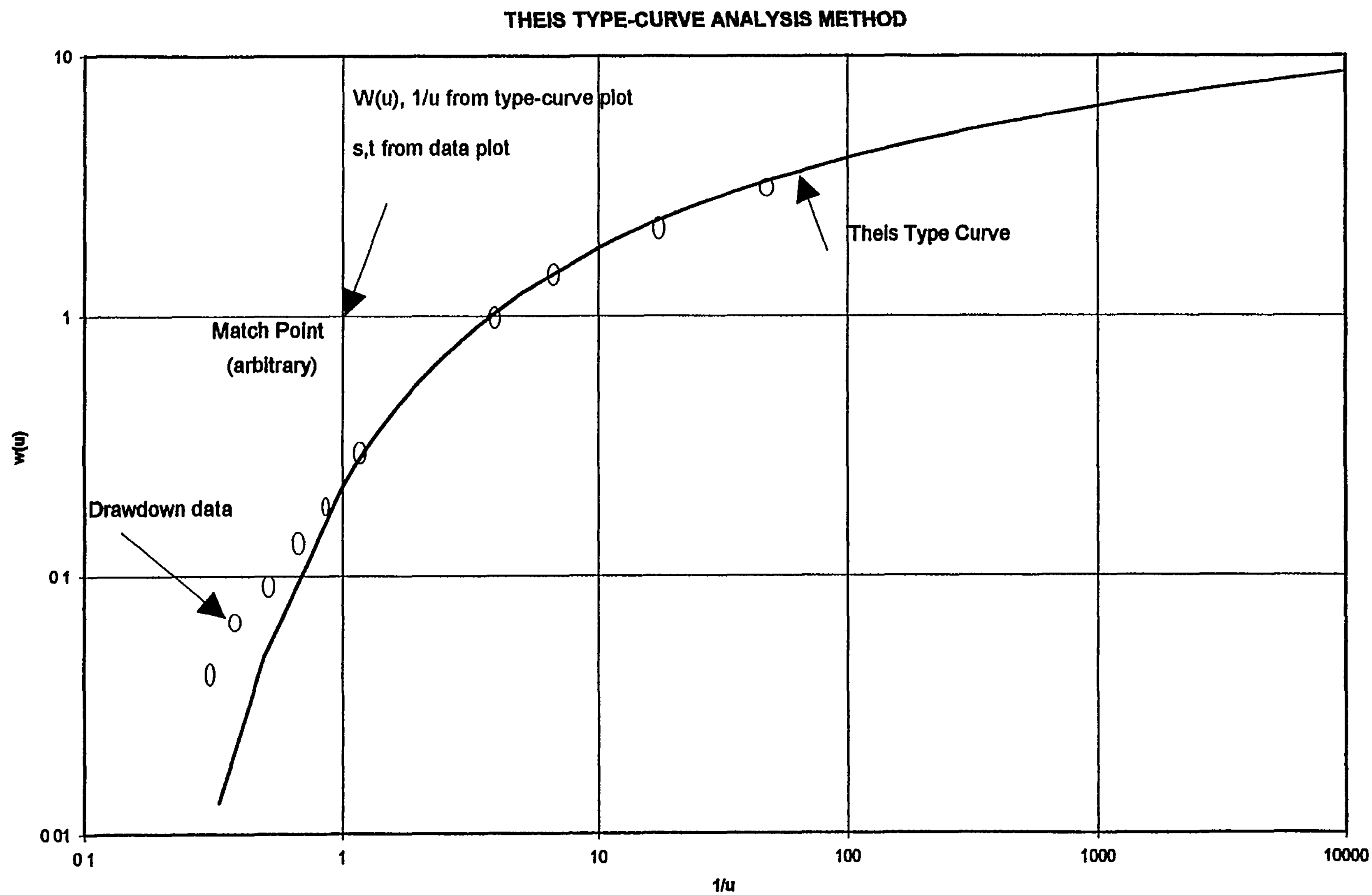
T = Transmissivity

S = Storativity

b = Saturated thickness

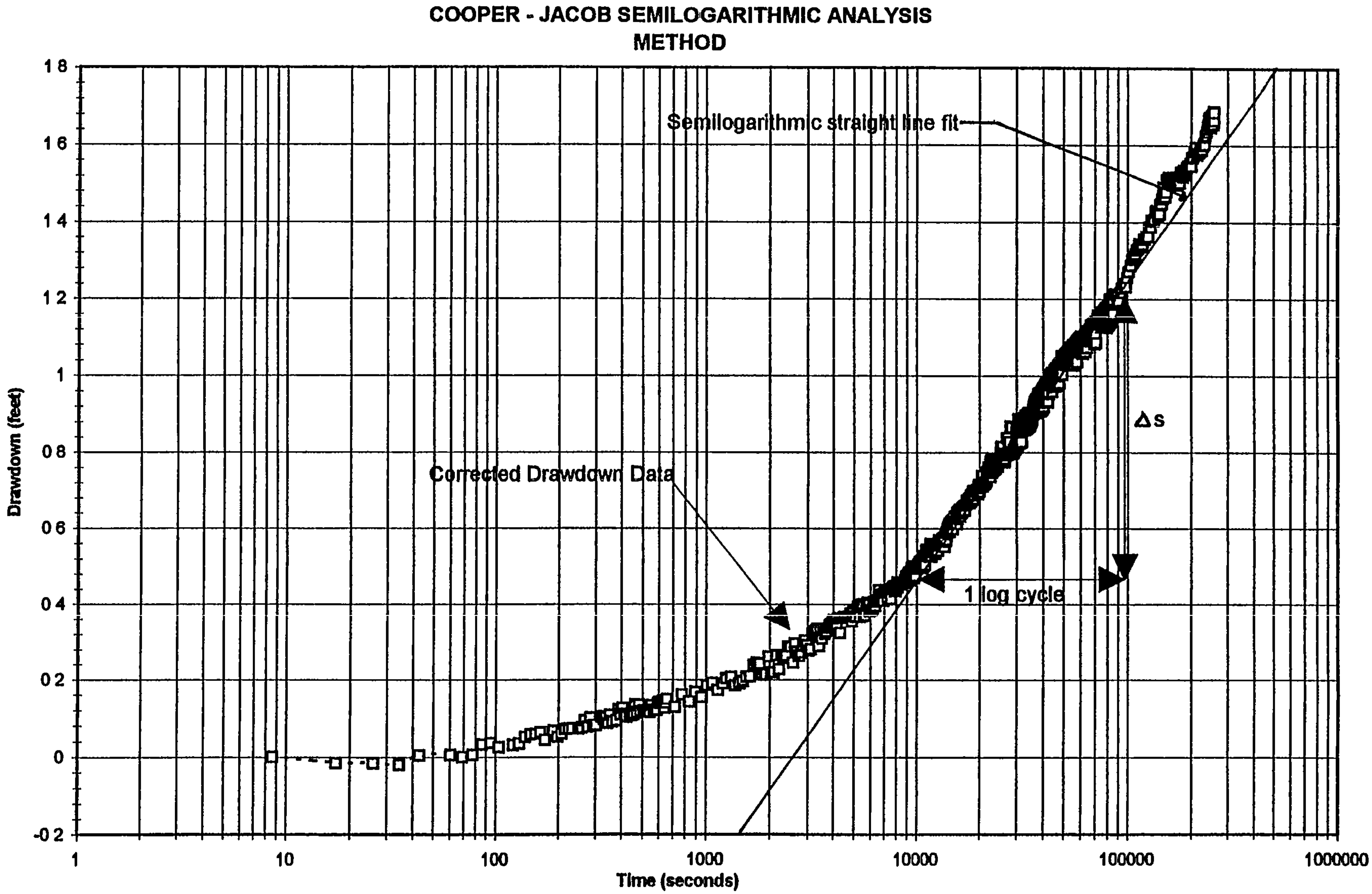
Q = Discharge

Figure A3.35



THEIS TYPE-CURVE ANALYSIS METHOD
10
1
0 1
0 01
0 1
1
10
100
1000
10000
1/u
w(u)
W(u), 1/u from type-curve plot
s,t from data plot
Theis Type Curve
Match Point
(arbitrary)
Drawdown data

Figure A3.36



COOPER - JACOB SEMILOGARITHMIC ANALYSIS
METHOD
Semilogarithmic straight line fit
Corrected Drawdown Data
1 log cycle
Δs
Drawdown (feet)
Time (seconds)
1 8
1 6
1 4
1 2
1
0 8
0 6
0 4
0 2
0
-0 2
1
10
100
1000
10000
100000
1000000

Figure A3.37

THEIS RECOVERY ANALYSIS METHOD

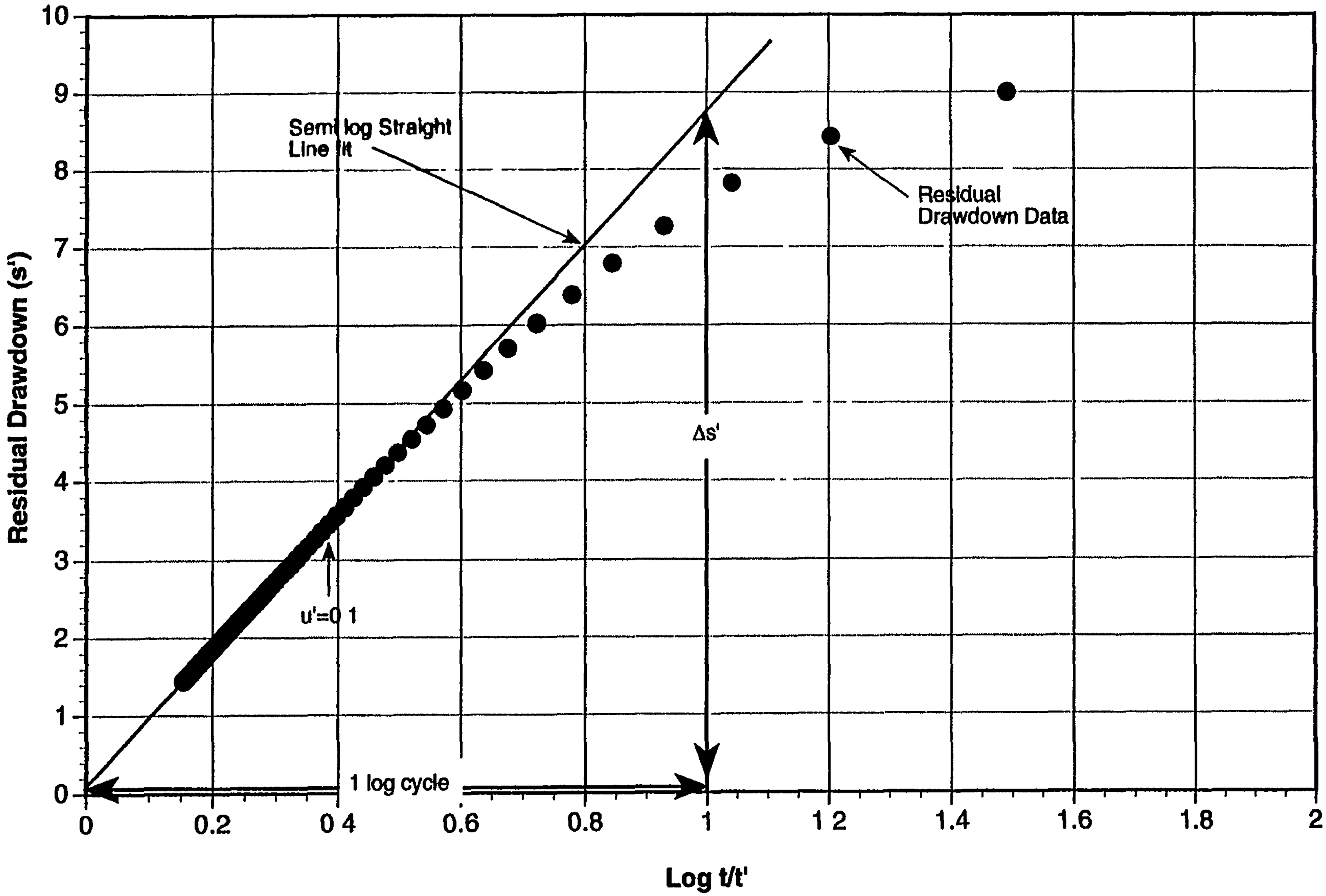
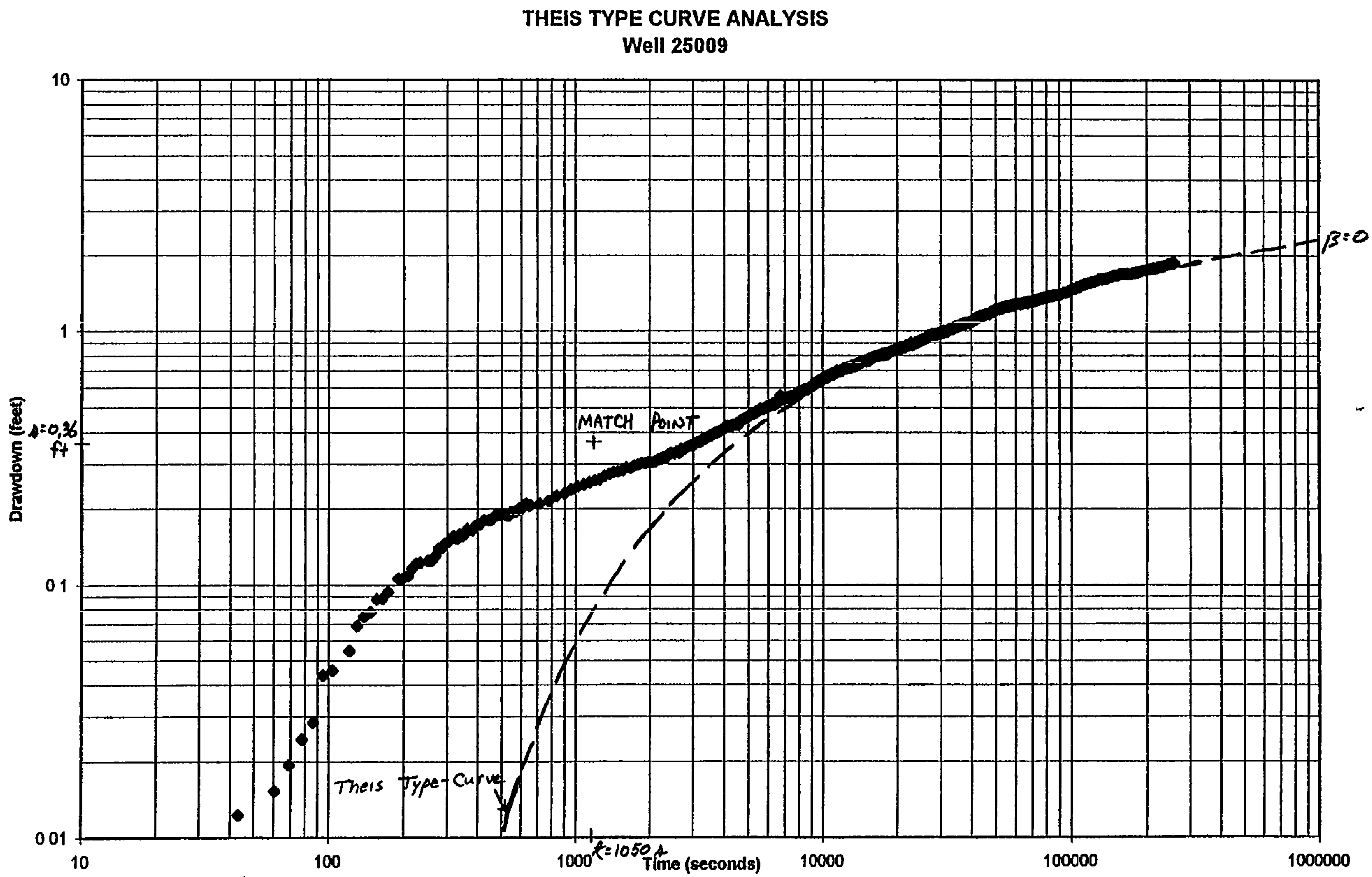


Figure A3.38



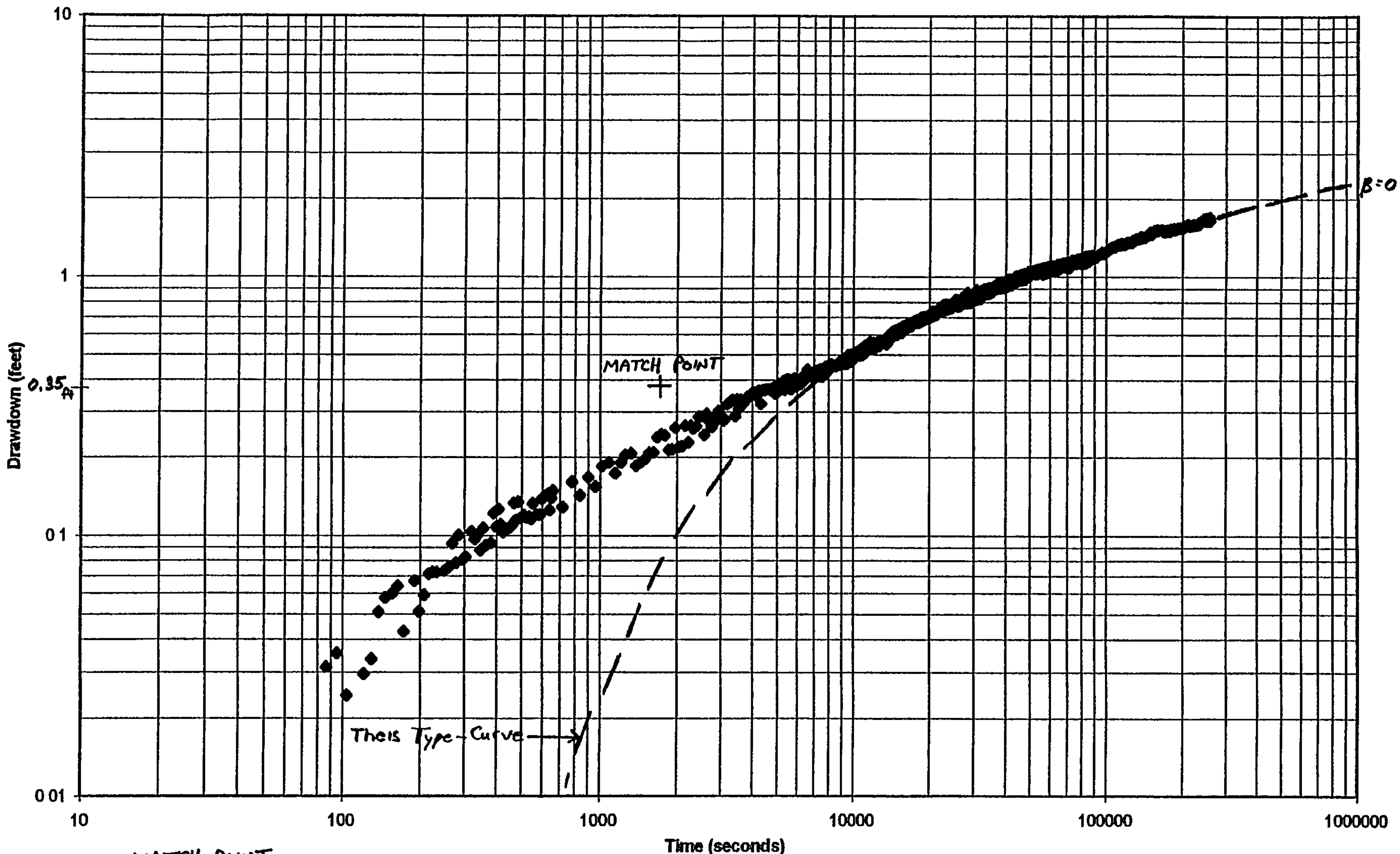
MATCH POINT

$\frac{1}{u}=1$ $t=1050\,s$

$W(u)=1$ $s=0.36$ ft

Figure A3.39

THEIS TYPE CURVE ANALYSIS
Well 25063



MATCH POINT

$\frac{1}{u} = 1$ $\quad$ $t = 1500$ s

$W(u) = 1$ $\quad$ $s = 0.35$ ft

Figure A3.40

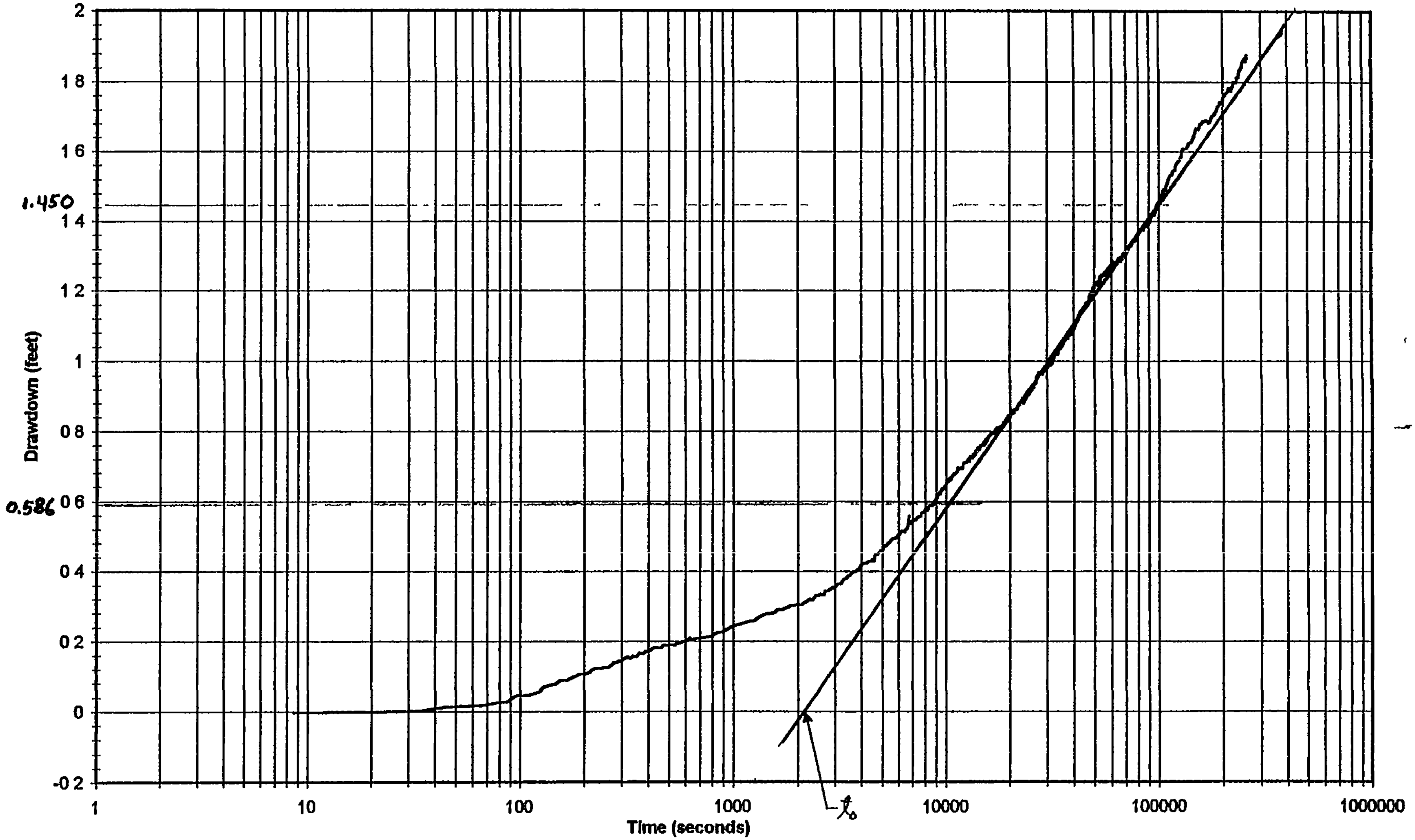

COOPER - JACOB SEMILOGARITHMIC ANALYSIS
Well 25009
Drawdown (feet)
Time (seconds)
2
1 8
1 6
1.450
1 4
1 2
1
0 8
0.586
0 6
0 4
0 2
0
-0 2
1
10
100
1000
10000
100000
1000000
t_0

Figure A3.41

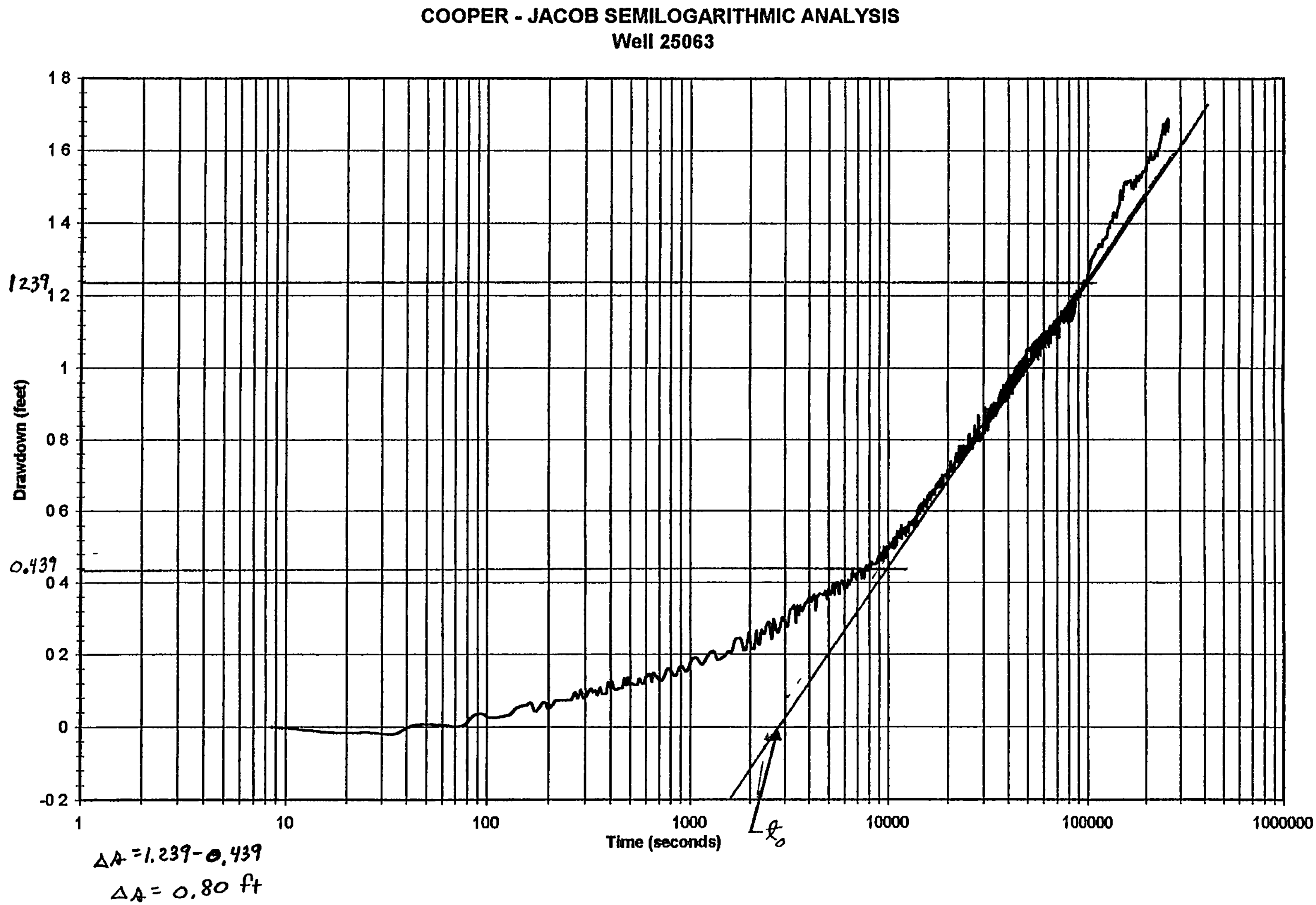
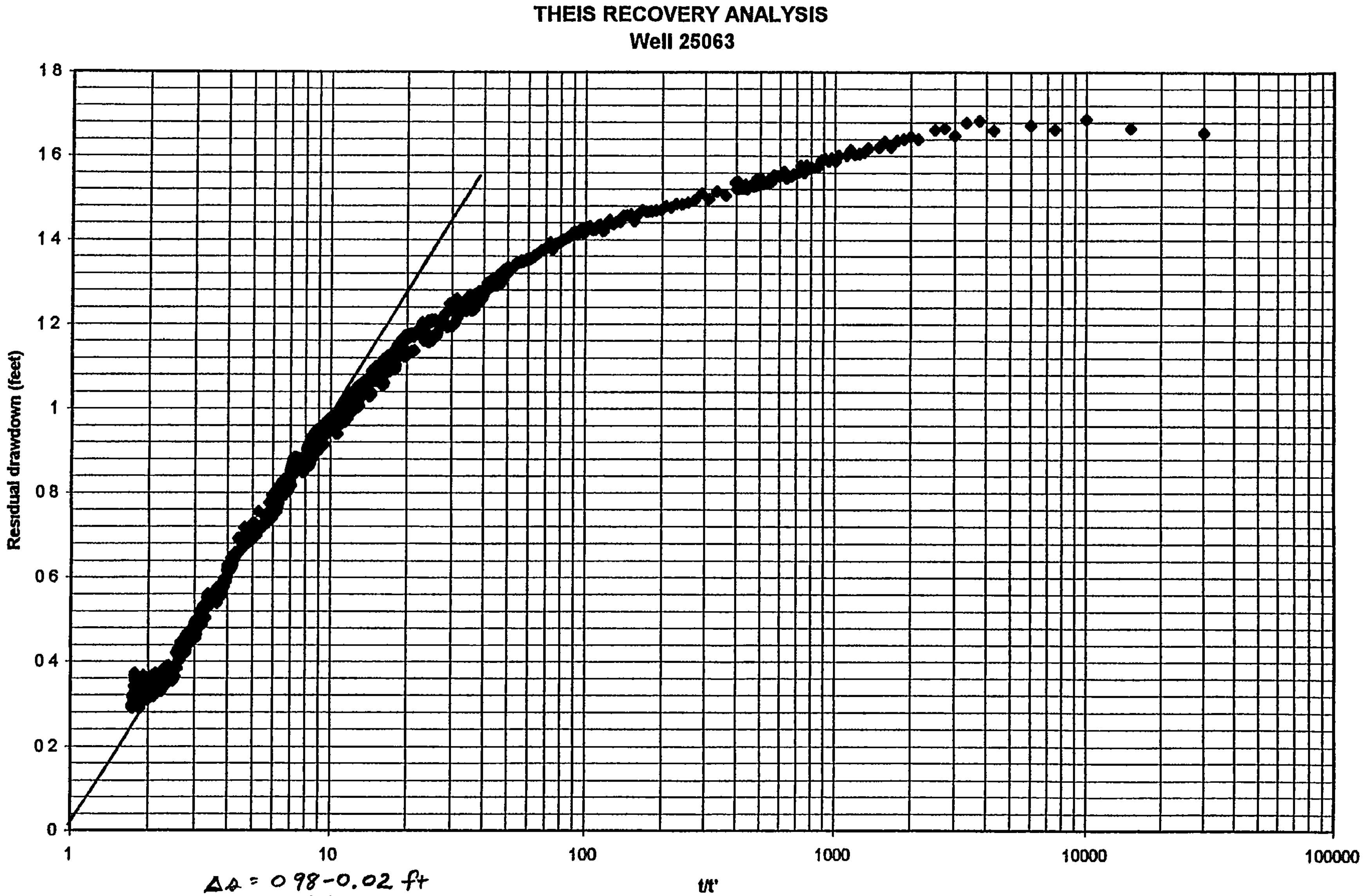

COOPER - JACOB SEMILOGARITHMIC ANALYSIS
Well 25063
Drawdown (feet)
Time (seconds)
1 8
1 6
1 4
1239
1 2
1
0 8
0 6
0.439
0 4
0 2
0
-0 2
1
10
100
1000
10000
100000
1000000
t_0
$\Delta s = 1.239 - 0.439$
$\Delta s = 0.80$ ft

Figure A3.42

$\Delta A = 1.02 - 0.24$ ft

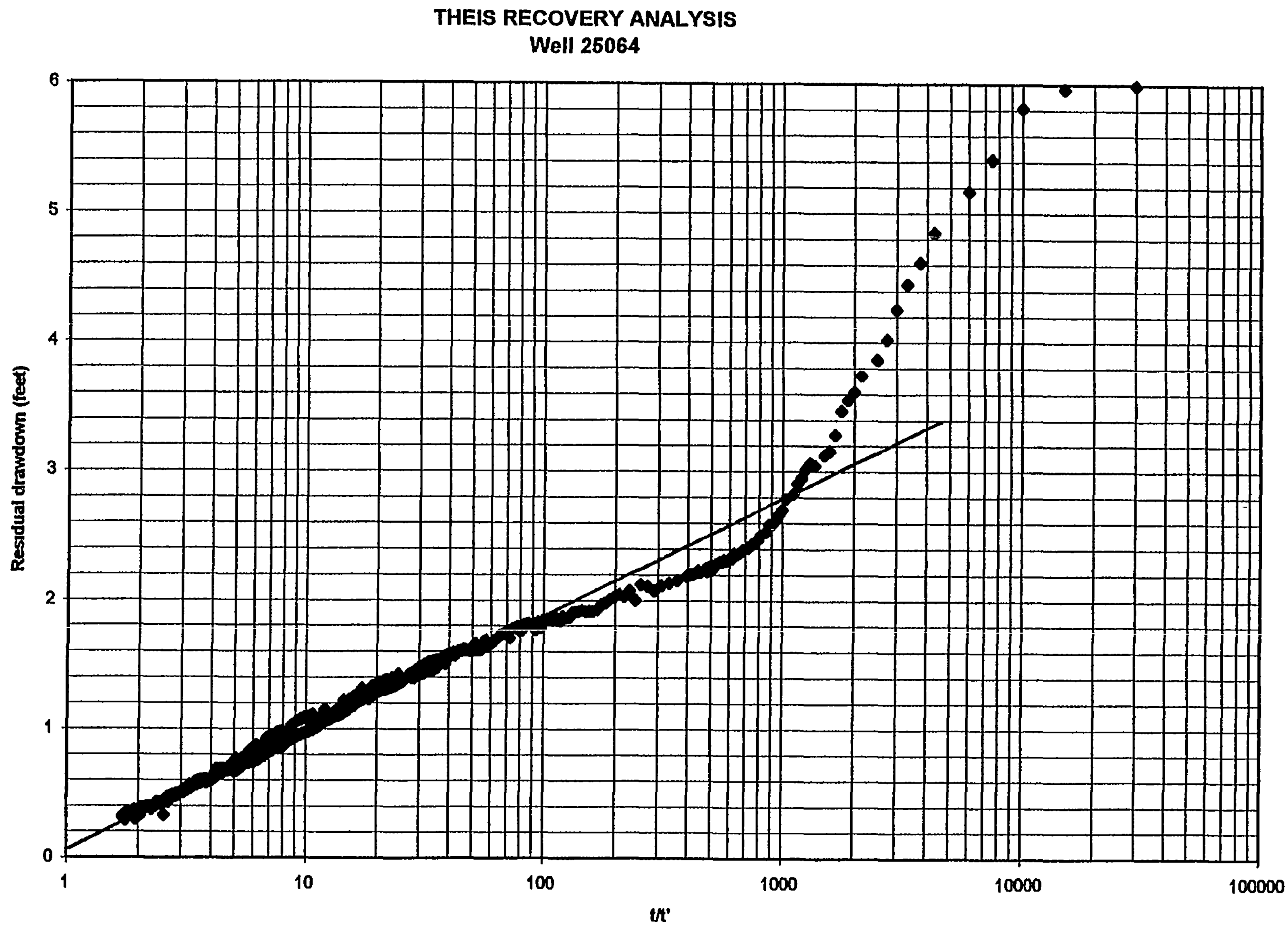
$\Delta A = 0.78$ ft

Figure A3.43



Δs = 0 98-0.02 ft
Δs = 0,96 ft

Figure A3.44



Δs = 0.98 − 0.08 ft

Δs = 0.90 ft

Appendix B

DESIGN NARRATIVE

CONTENTS

TABLE

FIGURE

ATTACHMENTS

1.0 INTRODUCTION

This Design Narrative has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3 The CDD has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Background

In June 1995, an Agreement for a Conceptual Remedy (the Conceptual Remedy) for the Cleanup of RMA among the State, U S Environmental Protection Agency (EPA), the Army, Shell, and the U.S Fish and Wildlife Service (FWS) was signed The Conceptual Remedy represents agreement by the parties relative to specific components of the remedy for the final cleanup of RMA These components of the remedy are included in the (1) Proposed Plan for the RMA Onpost Operable Unit and (2) Final Detailed Analysis of Alternatives Report (DAA) (Foster Wheeler, 1995) The Conceptual Remedy, the Proposed Plan for the Onpost Operable Unit, and the DAA are documents prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) The Conceptual Remedy calls for the construction and operation of a new onsite hazardous waste landfill for disposal of principal threat and human health exceedance soil and debris as those categories of contamination are defined in the DAA

In the On-Post Operable Unit Detailed Analysis of Alternatives Dispute Resolution Agreement dated October 16, 1995, it was agreed that the future hazardous waste landfill area, the Basin F Waste Pile drying Unit, and the appropriate waste staging and/or management area(s) will be included within a CAMU. The CAMU will be designated in accordance with the provisions of Section 264.552 of the 6 Code of Colorado Regulations (CCR) 1007-3.

The area of the CAMU intended for the state-of-the-art hazardous waste Landfill is located in portions of Section 25 and 26 between Former Basin F and North Plants (See Figure Bl). Double-lined cells within the landfill will receive principal threat and human health exceedance materials, as defined in the DAA, from 17 contaminated areas of RMA. In addition. drum wastes generated as a result of RI/FS activities may also be disposed in the landfill. **A triple-lined cell** will be constructed to receive principal threat **and human health exceedance** soils from the Basin F Waste Pile and **Former Basin F, human health exceedance soils from Sand Creek Lateral, and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.** The total volume of waste to be placed in the landfill is estimated to be 1,855,000 cubic yards, of which approximately 655,000 cubic yards are to be placed in the triple-lined cells. It is estimated that the total volume of the landfill including daily cover will exceed 2 million cubic yards

In addition to the landfill and the Basin F Waste Pile drying Unit, the CAMU will include waste staging/consolidation areas and decontamination facilities. The waste staging/consolidation areas may include areas within the CAMU that will be used for the temporary storage, consolidation, and processing of wastes after excavation from various source areas and prior to placement within the landfill. Processing waste may consist of the bulking and/or sizing of the waste as necessary to enhance landfill operations. The staging/consolidation areas may be located near the Basin F Waste Pile excavation, near the area of the Basin F drying Unit, or near the landfill. The drying Unit will be located on or near the Basin F Waste Pile. At least one decontamination facility will be located near the landfill, and another may be located near the Basin F Waste Pile The landfill area will be located within the western half of Section 25 and the eastern half of Section 26 A leachate storage/offloading area may be included in the vicinity of the landfill area.

Working sessions were conducted prior to and throughout the preparation of this document Working session participants included the Army, Shell, Colorado Department of Public Health and Environment (CDPHE), FWS, EPA, Adams County, Tri-County Health Department, and the U S Corps of Engineers (COE) During these working sessions, proposed design criteria and landfill liner system components, as well as the level of detail to be included in the CDD, were presented and discussed To the extent applicable, this document incorporates the results of the working sessions and the Army's technical position on the CAMU design-related issues

1.2 Purpose and Scope

This document has been prepared as an appendix to the CDD The CDD will be submitted to CDPHE to respond to the design components of 6CCR 1007-3 Section 264 552(e)(2)

Section 264 552 (a)(3) of 6 CCR 1007-3 specifies that when the remediation waste placed into a CAMU is classified as hazardous and is to remain in place after closure, the CAMU shall comply with the requirements for siting of hazardous waste disposal sites found in 6 CCR 1007-2, Part 2 (Part 2) Section 2 4 and 2 5 of Part 2 address design performance criteria and requirements for design of a hazardous waste landfill

The primary performance goal, stated within Sections 2 4 and 2.5 of Part 2, is that the landfill is designed and built to assure long-term protection of human health and the environment. Section 2 5 3 of Part 2 requires that the design performance of engineered barriers within a hazardous waste landfill, combined with the geological and hydrological conditions of the landfill area, shall be such that reasonable assurance is provided that the hazardous waste will be isolated for 1,000 years within the disposal area and away from natural environmental pathways that could expose the public

Section 264 552(e)(2) requires that the CAMU designation specify the design and operation requirements applicable to the remediation waste management that are to take place within the CAMU This design narrative has been developed so that, after review and approval by CDPHE, it can be incorporated into the CAMU designation as the requirements for design of the landfill and other CAMU components

This design narrative provides performance standards, design guidance, design parameter demonstration, and resultant design criteria for the components of the landfill systems These terms are defined as follows

- Performance Standard An objective for design that is based on a regulatory requirement, regulatory guidance, and/or standard practice.
- Design Guidance Standard engineering reference manuals and design elements that have been identified in regulatory guidance or have been demonstrated by past practice to meet the performance standards
- Design Parameter Demonstration Analysis required to demonstrate that the design criteria will provide for conformance with the design guidance and the performance standard
- Resultant Design Criteria Specific elements of the design that have been shown by supporting analytical demonstration to meet the related performance standard

Collectively, these terms are referred to as design parameters in the CDD Where applicable, the types of engineering analyses that may be performed during the design to document conformance with the performance standards are presented

1.3 Guidance Documents

EPA guidance and other published documents were used as references to prepare this document. Those references used are listed in Section 11 0, Bibliography The general format and guidance given in the EPA document entitled "Guide to Technical Resources for the Design of Land Disposal Facilities" (EPA, 1988) was incorporated into the landfill-related sections (Section 3 0 and 4 0) below Application of the approach presented in these sections during design will provide a "road map" to verify, through an EPA published reference, that the landfill design submitted for CDPHE approval contains the EPA-recommended level of detail using appropriate EPA-recommended references In some cases, it was necessary to update the information given in this seven-year-old EPA document to reflect technological advances and regulation changes that have occurred since its publication During the design of the landfill, current references, methodologies, and design approaches will be reviewed and used, as applicable, to provide a "state of the art" landfill design.

1.4 Organization

The remainder of this document is divided into 10 sections Section 2 0 describes the development of the overall CAMU layout The necessary components and considerations for the design of the CAMU components are discussed as follows

- Section 3.0 Landfill Foundation and Lining Systems
- Section 4 0 Landfill Cover Systems
- Section 5 0 Run-on/Runoff Control Systems
- Section 6 0 Waste Staging/Consolidation Areas
- Section 7.0 Leachate Management Systems
- Section 8 0 Decontamination Facilities
- Section 9 0 Basin F Waste Pile Drying Unit

Section 10 0 presents the acronyms used in this document and Section 11 0 provides the bibliography In addition to the main body of this appendix, conceptual drawings of the landfill area are included as Attachment B1 and conceptual foundation and slope stability analyses are included as Attachment B2

The conceptual drawings show a landfill concept that is considered to be a feasible design that could accomplish the goals for the landfill as outlined in the Conceptual Remedy under CERCLA This concept may undergo revision during design but the concept is accurate enough to define the CAMU footprint and make the appropriate siting demonstrations The drawings show the concept's plan views, cross sections, and selected details of the landfill cell geometry, landfill lining systems, cover systems, and run-on/runoff control systems

In the development of Table B1, certain geotechnical analyses were performed on the conceptual design shown in Attachment B1 and the results included as a component of this design narrative These analyses are included in Attachment B2

The following geotechnical analyses were performed

- Foundation settlement
- Foundation bearing capacity
- Potential for excess hydrostatic pressure on the foundation
- Excavated slope stability, including seismic considerations
- Cover slope stability, including seismic considerations

The results of these individual conceptual analyses indicate that the conceptual design will not be severely constrained by these design considerations The design of the landfill will include a more comprehensive evaluation of these and other design considerations

During the working sessions, design parameter tables were presented and discussed The results of these discussions have been consolidated into the CAMU Landfill Design Parameters table presented in Table B1 This table presents the design items for the CAMU landfill and characterizes each related design component as performance standards, design guidance, design parameter demonstration, and/or resultant design criteria. The design demonstrations referenced in Table B1 will be completed during the design process

2.0 CAMU DEVELOPMENT PLAN

During the initial working sessions, various conceptual CAMU development plans were presented In later working sessions, it was agreed that a CAMU development plan would not be included in the CDD Therefore, completion of a preliminary CAMU development plan is planned as the initial task in the CAMU design. The preparation of a preliminary CAMU development plan will enable the designer to proceed more efficiently with the detailed design tasks discussed in later sections of this document The preparation of the CAMU development plan can be divided into three subtasks

- Individual landfill cell layout alternative and final plan preparation
- Comprehensive CAMU layout plan preparation
- Phased construction document preparation

These subtasks are described in this section.

Figure B1 shows the landfill area boundary, the conceptual locations of the other CAMU facilities, and the overall CAMU boundary The individual landfill cells are to be located within the areal extent of the landfill portion of the CAMU The remaining CAMU facilities may or may not be located where shown in Figure B1, however, they will be located within the overall CAMU boundary These facilities may include, but are not be limited to the following

- Decontamination facilities
- Basin F Waste Pile drying unit
- Waste staging/consolidation areas
- Leachate storage/offloading area

The subsections below discuss the recommended methodology for development of a preliminary CAMU development plan.

2.1 Landfill Cell Layout Alternative and Final Plan

The initial step in preparing a CAMU development plan will be to develop a preliminary plan for the layout of the individual landfill cells. The individual cells are divided into two groups: double-lined cells and triple-lined cells. The triple-lined cells will contain waste from the Basin F Waste Pile and **Former Basin F, Sand Creek Lateral soil and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.** The double-lined cells will contain the remaining waste identified for landfilling in the Detailed Analysis of Alternatives (DAA) (Foster-Wheeler, 1995). The DAA is a CERCLA document.

2.1.1 Design Parameters

During the CAMU working sessions, the design parameters for the layout of the landfill cells were discussed. The layout design parameters arc presented in Table Bl with the exception for those related to the excavated surface geology. The surface of an excavated 1andfill cell will likely contain alluvial sandy soil or sand unit subcrops of the Denver Formation. The potential for piping and infiltration of surface water behind and below the liner as a result of sand outcrops at the surface and adjacent excavation perimeter will be evaluated during the design and addressed accordingly. As a design guidance, the base of the excavated surface located within soil classified as coarser than SM by the Unified Soil Classification System (USCS) will be over excavated a minimum of 3 feet and backfilled with structural fill that classifies finer than SM. The over excavation requirements for portions of excavated side slopes located within soil classified as coarser than SM will be determined during design.

2.2 Comprehensive CAMU Layout Plan Preparation

After completion of the individual cell layout, the next step in preparing the CAMU development plan will be to calculate the area required for each of the various remediation waste handling facilities to be constructed within the CAMU. The conceptual facility locations shown in Figure Bl are only for designating a potential use within the indicated CAMU boundary. The need for each facility along with its size and location will be determined during design. In all cases, the facilities must be located within the CAMU boundary shown in Figure B1 Once the required areal extent of the CAMU facilities has been calculated, phased construction requirements will be analyzed

2.3 Phased Construction Document Preparation

The individual CAMU cells and facilities will be constructed over a multi-year period and the individual construction-level design drawings will be prepared and submitted to CDPHE for approval over the same multi-year time period The design will typically include a series of drawings to show the phased development of the CAMU from initial construction through final closure The phased construction drawings will contain sufficient detail to determine the required areas and location of the various CAMU facilities (cells, roadways, treatment units, drainage channels, etc) These phased development drawings will typically show the facilities to be constructed or closed as part of a given phase and the pertinent run-on/runoff controls for that phase

3.0 LANDFILL FOUNDATION AND LINING SYSTEMS

This section outlines significant design considerations for the design of the landfill foundations and lining systems Design parameters for foundations and lining systems are presented in Table B1 This section does not include landfill cover system design, which is discussed in Section 4 0 This section follows the format of Section 2 0, 3 0, and 4 0 of the previously referenced "Guide to Technical Resources for the Design of Land Disposal Facilities (EPA, 1988) "

3.1 Foundations

The landfill foundation design will include (as appropriate) an assessment for, and calculated estimates of settlement, compression, consolidation, bearing capacity, shear failure, uplifts, liquefaction of the foundation soil, and the effect, if any, of hydraulic and gas pressures on the foundation This analysis will include pertinent geologic, geotechnical, hydrogeologic, and seismic information Foundation design will address the potential for soft-spots or unsuitable soil in foundation subgrade areas Subgrade evaluations will be performed, methodologies may include proof rolling, visual observation and soil mapping The subsections below provide additional detail on the type of information typically needed and the individual analyses typically performed

3.1.1 Design Parameters

The design of the individual landfill cells will include an analysis of the expected foundation conditions and the potential effect of foundation movement on the landfill components The design parameters for the foundation design are presented in Table B1

3.1.2 Site Investigation and Laboratory Testing

An adequate site investigation is necessary to ensure that the foundation design will accommodate the expected foundation conditions A comprehensive site investigation, including field and laboratory work, was performed by HLA and was described in the report entitled "Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program" (FS Report) (HLA, 1995a) The FS

Report is attached to the CDD as Appendix R Also, additional field data are included in Appendix A, Part 2, Siting Compliance Demonstration

The available geotechnical, geological, and hydrogeological data should be reviewed during design to evaluate whether additional field and laboratory data are required to complete the foundation design If a geotechnical investigation is necessary to complete design, a work plan will be prepared and submitted to CDPHE for approval

3.1.3 Design Considerations

Design considerations relative to the landfill foundation design are presented below These considerations are discussed according to waste and structure, settlement, seepage and hydrostatic pressures, and bearing capacity

3.1.3.1 Waste and Structure

The majority of the foundation analyses will be a function of the foundation soil/bedrock properties, but the results of the analyses can be significantly influenced by the loadings assumed in the analyses The expected maximum loading on a landfill foundation is a function of the density of the waste/daily cover and lining components and the maximum height of the waste/daily cover and lining components placed over the foundation The actual waste density may vary significantly from waste stream to waste stream Because some of the landfill cells may contain significantly different waste than other cells, it is conceivable that the loadings, and thus the analytical results, may vary significantly from one cell to another The foundation design analysis will include estimates of the loadings, the landfill configuration, and the estimated waste characteristics and volumes

3.1.3.2 Settlement

An analysis of the total and differential settlement due to the maximum loadings will be performed as part of the foundation design The results of this analysis will then be used to evaluate the ability of the landfill components to maintain their integrity due to the additional stresses induced as a result of the settlement/compression. In calculating the estimated settlements, evaluations of the settlements due to primary consolidation and secondary compression will be performed

Settlement analyses will be performed to assess the downward soil movement due to the stresses caused by the overlying landfill components (embankments, waste, liners, etc) Total settlements will typically be calculated for the toe, center, crest, and any other critical points of the load distributions for each distinct soil layer being loaded The settlements for each layer will then be summed to attain the total settlement at a particular point Differential settlements will then be calculated by subtracting the settlements between points

A conceptual settlement analysis of the foundation soil was performed to evaluate if the landfill can be designed to account for foundation settlement. This analysis was performed using available site data and assumptions using published data Conservative assumptions were used for the type of foundation soil, the height of the water table, and the premise that the water table may drop in the future The assumptions used in the analysis included

- Landfill cells will be excavated 30 feet below the natural ground surface
- Waste and cover components will be placed 30 feet above the natural ground surface
- Foundation soil will consist of 30 feet of clay overlying bedrock.
- Groundwater will be initially at the base of excavation and then drop 30 feet

The results of the analysis indicate that foundation settlement is expected to be less than 2 inches under the areas of maximum loading Thus, the estimated differential settlement within the foundation soil will be 2 inches or less The landfill components can be designed to account for this amount of differential settlement The complete calculation package, including assumptions and references, is included in Attachment B2

3.1.3.3 Seepage and Hydrostatic Pressures

Seepage into the landfill from groundwater is not anticipated due to the minimum groundwater separation of 20 feet. The results of the analysis conducted in Appendix A shows that the rate of advective movement of water from the landfill is negligible (<0 007 inches per year) The design will include an evaluation of whether the maximum leakage through the bottom liner (included in Appendix A) can provide pathways that may eventually result in failures from excessive differential settlement due to piping and soft spots Although not expected, if this evaluation results in an unacceptable conclusion, additional enhancements will be designed and incorporated into the construction requirements

The conceptual engineering analyses included in Attachment B2 include an analysis of the possible effect of excess hydrostatic pressure. The result of this analysis indicates that the groundwater will have to rise to a level approximately two times the liner thickness above the liner for the buoyancy effect of the hydrostatic pressure to be greater then the overburden pressure of the liner system As waste is placed over the liner system and the overburden pressure increased, the groundwater must rise even higher to have an effect. The potential impacts of hydrostatic pressures resulting from infiltration of surface water through piping channels will be evaluated and addressed, if applicable, during design

3.1.3.4 Bearing Capacity

For landfill cells, differential settlement is the major foundation concern. However, for specific components, primarily the sump areas and riser pipe pads, the bearing capacity of the underlying soil is also of concern An accurate estimate of the bearing capacity of the landfill foundation soil is necessary to properly estimate the amount of settlement to be expected under a given load distribution The foundation will be designed to ensure that the actual bearing stress is less than the bearing capacity of the foundation.

The analyses included in Attachment B2 includes a conceptual analysis of the calculated bearing capacity and the calculated loading using the assumptions developed as part of the conceptual foundation settlement analysis The results of this conceptual analysis indicate that the factor of safety against bearing capacity failure is 2 6

3.2 Embankment Integrity and Slope Stability

The individual CAMU landfill cells will likely be constructed above and below grade in the general configuration shown on Drawing C-7 in Attachment B1 Drawing C-7 does not currently reflect the construction of earthen embankments (dikes) as part of the landfill foundation. However, embankment construction may be incorporated into the design to some extent to meet the layout criteria described in Section 2 0 and to account for surface topography changes The landfill cell excavated slopes and embankments (if used) will be designed to ensure that they will be stable during the construction, operation, closure, and postclosure periods

The conceptual analyses included in Attachment B2 also include a slope stability analysis of the excavated cell slopes shown on the Drawings in Attachment B1 This analysis was performed using the computer program PCSTABLE5M developed by Purdue University and available site and published data The results of this analysis indicates factors of safety of 1 8 under static loads and 1 5 under pseudo-static (static and seismic) loads are obtainable Attachment B2 includes the data parameters, computer printouts, and assumptions of this analysis

Acceptable methodology for the analysis of the stability of the excavated slopes and embankments is discussed in the subsections below

3.2.1 Design Parameters

The design of the individual landfill cells will include an analysis of the stability of slopes and the integrity of earthen embankments constructed as part of a landfill cell foundation. The design parameters for the analysis are incorporated in the general and foundation design parameters in Table B1

3.2.2 Site Investigation and Laboratory Testing

As discussed in Section 3 1 2, a site investigation and laboratory testing program has been performed and additional field and laboratory work may be performed to complete the detailed design of the landfill cells within the CAMU areal configuration. Appendix I to the CDD describes a laboratory testing program to be implemented for the construction and testing of a clay liner test fill Also, a report identifying potential borrow materials and their engineering properties entitled, "Final Feasibility Study Soils Support Program Report" (Borrow Study Report) (HLA, 1995b) is available for review at RMA Interface shear testing between the various components of the landfill lining system and various index and shear strength tests of the soil expected to be part of the landfill construction may also be performed This collective data will provide the designer with the necessary site-specific information to perform the stability analyses

3.2.3 Design Considerations

The stability of a slope is a function of the properties of the soil and other materials, such as geosynthetics, that comprise the slope, the configuration of the slope, and the hydraulic conditions of the slope The slopes designed for the landfill will typically be analyzed for stability against circular and translational failure Circular failure is movement about a curved slip surface approximated by a circle Translational failure is movement along one or more planes of weakness in a slope Additionally, the embankments and slopes will be analyzed as appropriate for stability against failure due to differential settlement, seepage-induced piping failure, and soft spots

Translational failure analyses will include both planar and wedge-type failures Both planar and wedge-type failure analyses will be performed for the lining systems on the slopes As discussed in Section 3 2 2, critical geosynthetic interfaces, soil/geosynthetic interfaces, and soil internal strengths may be estimated in the laboratory using site-specific materials The results of these tests, along with published parameters, will be used in this analysis. The results of the analysis will be used in selecting the final type of geosynthetic (i.e., geocomposite or geotextile overlying geonet), grade of geosynthetic (i.e., textured or smooth geomembrane), and anchor trench/runout length design.

3.3 Lining Systems

The landfill lining systems will consist of the following from top to bottom:

- Protective soil layer
- A leachate collection system (LCS)
- An uppermost composite liner (FML overlying a CCL)
- A leak detection system (IDS)
- A lowermost composite liner
- A tertiary IDS (triple-lined cells only)
- A tertiary composite liner (triple-lined cells only)

The design parameters and methodology for theses components are discussed in the subsections below.

3.3.1 Design Parameters

As stated in Section 2.0, the Landfill CAMU boundary will contain one or more individual double-lined cells and **one triple-lined cell**. Conceptual cross sections of the double-and triple-lined cell lining components are shown on Drawing C-3 in Attachment Bl. The design parameters for lining systems are presented in Table Bl.

3.3.2 Design Considerations

The components of the double- and triple-lined cell lining systems can be divided into three groups, compacted clay liners (CCLs), flexible membrane liners (FMLs), and LCSs/LDSs. LCSs and LDSs are grouped together because the LCS and LDS performance standards and materials of construction are similar. The subsections below describes the purpose, design configuration and calculations, and material specification considerations for each of these groups.

3.3.2.1 Compacted Clay Liners

The design of CCLs can be divided into five groups site and material selection, thickness, hydraulic conductivity, strength and bearing capacity, and slope stability Site selection consists of selecting both the site on which the CCL will be constructed and the site from where the clay for the CCL will be obtained

The preliminary selection of the CCL material borrow sites and the required material properties have been completed and the results are summarized in the FS Report and the Borrow Study Report The Test Fill Construction Program presented in Appendix I, when completed, will finalize selection of the clay borrow site(s) and the CCL material property requirements The minimum overall thickness of the CCLs used in the cell lining systems will be 6 feet

The in situ hydraulic conductivity is the most important property of a CCL It is also the property that is the most dependent on construction procedures Appendix I presents a typical program for evaluating and establishing the required material properties and construction procedures Also, the hydraulic conductivity of CCLs using leachate of the quality expected in the landfill will be assessed as discussed in Section 3 3 3

The strength, bearing capacity, and slope stability of the CCLs and the foundations over which they are placed will be analyzed as part of the design to verify stability of the CCLs under the expected conditions Typical analyses for these parameters are discussed in Section 3 1 and 3.2

3.3.2.2 Flexible Membrane Liners

The results of the foundation analysis, slope stability analysis, CCL design, and the chemical compatibility testing will be used to select an appropriate FML and its required properties The chosen FML will demonstrate low permeability, chemical compatibility, and the required physical properties to meet the performance standards set forth in Table B1 The FML used will likely be a high density polyethylene (HDPE) liner due to its ability to meet the physical and chemical property requirements and its proven performance history in similar applications Polyethylene FMLs with lower densities may be considered due to their elongation properties and lower coefficients of thermal expansion. An additional criterion in selecting the FML is the its ability to be installed (deployed, seamed, tested, repaired, and covered) with a high confidence in the quality of installation.

Chemical compatibility testing and evaluation using leachate of the quality expected for the landfill will be performed on the selected FML prior to completion of design. The procedures to be used are discussed in Section 3 4

The required physical properties, including thickness, strength, and frictional characteristics, will be selected through analysis The maximum differential settlements will be used to evaluate the required elongation properties The slope stability requirements will be used to select the minimum frictional characteristics and tensile strengths The expected installation and covering procedures, type of cover materials, magnitude and distribution of loadings (during construction, operation, and closure), along with the results of the foundation and slope stability analyses will be used to select the minimum thickness and associated strength properties

3.3.2.3 LCSs/LDSs

The LCS and LDS for each landfill cell will include the following

- A base sloped at a minimum of one percent
- A high permeability drainage layer consisting of either a granular layer or a geonet layer overlain by a filter geotextile
- Separate collection sump or sumps for each LCS and LDS that provide access for removal of any collected liquids
- Consideration of system flushing capabilities

The initial step in designing the LCS and LDS is typically to layout the components within the landfill cell Drawings C-3, C-4, and C-5 of Attachment B1 show typical LCS and LDS design configurations Using the drawings and dimensions from the landfill layout plan, the dimensions, extent, and slopes for the system being designed, can be selected The expected settlement of the foundation and underlying CCLs will be analyzed to verify that the base slope will not be less than one percent at any time during the operational and postclosure period Adjustments will then be made to the base slope based on this analysis

The overall stability of side wall slopes using the expected system components will be analyzed and the stability of the individual system components will also be considered under the expected range of loading conditions Considerations for creep and collapse of geonets (if used) will be included in this analysis

As presented in Table B1, the performance standard for the LCS and LDS requires that these systems maintain less than 1 foot of leachate depth on top of each liner system throughout the active life and post-closure period The depth of liquid over the liner is a function of the impingement (percolation) rate into the liner, the base slope, the spacing of collection pipes (if used), and the LCS's and LDS's drainage capability (hydraulic conductivity or transmissivity) The ultimate design of the LDS to achieve this performance standard will allow calculation of the action leachate rate (ALR) for any given cell The ALR is the maximum design flow rate that the LDS can remove without fluid head on the bottom liner exceeding 1 foot The ALR will be included in a Response Action Plan (see Outline in Appendix N)

The impingement rate onto the LCS will be obtained from the Hydrologic Evaluation of Landfill Performance (HELP) computer model or similar computer program The other variables will be obtained from the layout of the LCS as discussed above These variables will then be used to analyze and modify the LCS design The HELP model may also be used to estimate head buildup above the uppermost composite liner for a variety of designs, time periods, and storm events The results will then be used to verify that the head limitation will not be exceeded for the expected range of conditions

The LDS will be designed to collect and remove consolidation water from the overlying CCL, any potential leakage from the overlying liner, and to meet the general performance standards of the LCS The design of the LDS will be nearly identical to the LCS design except that the impingement rate will be a function of the amount of consolidation water plus the potential leakage rate estimated from the HELP or similar computer model As previously discussed, laboratory geotechnical testing will be performed as necessary to obtain the appropriate parameters to estimate the amount of consolidation water to be collected in the LDS As a precaution, the maximum flow capacity of the LDS will be equal to or greater than the maximum flow capacity of the LCS

The required strength of the components of the systems (both LCS and LDS) will also be analyzed under the expected range of loading conditions (including equipment loadings with minimal cover and material loadings after closure) The effects of the compressive loads on the drainage capability of the drainage layers and piping will be estimated prior to the specification of materials and construction procedures Transmissivity tests will be performed under the expected field conditions (boundary materials, loads, gradient) to confirm the design transmissivity value for the drainage layer Piping will be sized and specified based on the required flow capacity and the necessary strength requirements for the range of loading conditions The piping system will be designed to account for clogging potential

Perforated piping may be included in the LCS for rapid collection and removal of leachate and to provide the capability to flush the LCS Piping may also be incorporated into the LDS design if granular material is used as the drainage layer If granular materials are used, pipe perforations and/or filters will be designed to mitigate clogging of the pipe Adequate flow velocities for the piping will be designed to promote self-cleaning The design and selection of filter geotextile properties will also be performed to minimize the potential for clogging from both physical and chemical processes

3.3.3 Chemical Compatibility

Chemical compatibility testing will be conducted for liner, leachate collection system, and sump materials The chemical compatibility of landfill components to leachate will be a consideration for the long-term integrity of the landfill Prior to development of the chemical compatibility testing program, the existing manufacturer's information and data from testing performed on the Pond A HDPE primary liner during closure of Pond A will be evaluated Initial assessment of material compatibility will be based on a review of existing leachate data and demonstrated properties of the landfill component being tested Standard testing protocols to assess the chemical effect on the hydraulic characteristics of geotextiles and geonets have not been developed Appropriate hydraulic chemical compatibility testing procedures for these materials will be developed and implemented during design General protocols provided below will be implemented for the mechanical chemical compatibility testing of geosynthetics and the hydraulic chemical compatibility testing of earthen materials prior to construction

Compatibility testing will typically consist of performing EPA Method 9090A testing on geosynthetic components (including pipes) and EPA Method 9100 testing on soil components EPA Method 9090A is performed by immersing an FML in a representative sample of leachate over a 120-day period and periodically measuring the physical properties of the test sample to analyze for deterioration due to the leachate immersion Although this test method was written for FMLs, the setup and immersion procedures can also be used for other geosynthetics In addition to measuring the physical properties, the testing program may be developed based on testing of the design function of the geosynthetic

Several of the EPA Method 9090A parameters have become outdated and even inappropriate for some FMLs, including HDPE FMLs Some laboratories recommend performing the test using modifications or replacements to EPA Method 9090A. An alternate procedure is ASTM D5747-95 "Standard Practice for Tests to Evaluate the Chemical Resistance of Geomembranes to Liquids "

EPA Method 9100 is performed by hydrating low permeability earthen materials (CCLs or geosynthetic clay liners [GCLs]) with representative leachate to access the effect of the leachate on hydraulic conductivity An alternate method is ASTM D5084-90 "Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter " GCLs and CCLs will typically be tested in accordance with the general guidelines of EPA Method 9100 and/or ASTM D5084 to ascertain the effect of leachate on the hydraulic conductivity of these materials Typically, the test will consist of hydrating the test sample with water, obtaining a hydraulic conductivity value for water only, and then passing a minimum of two pore volumes of leachate through the test sample and obtaining a hydraulic conductivity value for leachate This method will typically allow the designer to evaluate the effect of leachate on the hydraulic conductivity of the test sample Testing may also be performed using leachate as the only permeate to assess the leachate's effect on the swelling ability of the test sample

3.4 Construction Specifications

The design will set forth the material and procedural requirements for each component of the landfill construction These data will be incorporated into detailed construction specifications Typical earthwork and geosynthetic specifications are presented in Appendix P These typical specifications are provided to demonstrate that materials and methods are available for potential use that meet the design performance requirements outlined in this appendix. The specifications in Appendix P present the general content and format that will be included in the construction specifications During design, detailed construction specifications will be prepared based on engineering evaluations, additional data collection, and relevant technical considerations

The construction specifications will typically include material requirements, including quality control requirements for borrow soil, subgrade, geosynthetics, and other landfill components, performance requirements during construction (such as compacted soil moisture/density requirements and seam strength requirements), and the procedural requirements during construction (e g , all seams will be nondestructively tested) Construction specifications will be submitted to CDPHE for approval prior to implementation

3.5 Construction Quality Assurance

An effective Construction Quality Assurance (CQA) program will be implemented to verify that the landfill is constructed as designed The CQA program will be described in a CQA Plan that will be completed prior to construction. The CQA plan will be submitted to CDPHE for approval prior to implementation

The CQA Plan will describe the CQA inspection and monitoring requirements, the CQA testing frequencies, the documentation requirements during construction, and the certification report requirements for each component of the landfill Appendix H presents an outline of a typical CQA Plan for the construction of the landfill portion of the CAMU This typical CQA Plan outline is intended to provide the reviewer with an example of the level of detail to be included in the CQA Plan developed prior to construction.

4.0 LANDFILL COVER SYSTEMS

This section presents the design parameters and general design considerations to be used for the design of the landfill cover systems Design parameters for the landfill cover systems are presented in Table B1 The landfill cover system will be a multi-layered system comprised of earthen and synthetic materials The design will incorporate erosion control, water balance, and biotic and infiltration barriers as the primary components The components and methodology described below may be modified during design Any modifications to the components and methodology described below will be subject to review and approval by CDPHE prior to implementation

Drawing C-8 shows the conceptual cover section that was agreed upon during the CAMU working sessions Each component of the cover system will perform a unique function and in some cases one component may serve multiple functions The components of the cover system are listed below from top to bottom

- Upper Soil Layer consisting of a
  - Vegetative/erosion protection layer overlying a
  - Water storage layer
- Biota Barrier/Capillary Break Layer
- Drainage Layer and/or Cushion Layer
- Composite Hydraulic Barrier
- Gas Venting System (if necessary)
- Prepared Subgrade

4.1 Design Parameters

The design parameters for the cover system are presented in Table B1

4.2 Design Considerations

Design considerations related to the cover system are presented in the following sections

4.2.1 Settlement

EPA guidance states that cover settlement is caused by primary consolidation and secondary compression Considerations for the settlement analysis will include the magnitude and distributions of the loadings, the expected percent of void space within the cell configuration of waste, the waste placement and compaction procedures, and the waste composition and structure (soil, containers, etc) The minimum slope of the cover system will be designed to account for settlement to maintain positive outward drainage The results of the settlement analysis will be used to select cover slopes, and configurations and to prepare the construction specifications

4.2.2 Slope Stability

The stability of the slope will be evaluated using the same procedure previously described for the cell lining systems The results of the stability analysis will also be used to select materials and slopes and to prepare the construction specifications

A conceptual analysis of the cover system slope stability under static and pseudo-static (static and seismic) loads using the computer program PCSTABLE5M was performed The results of this analysis indicated factors of safety of 2 8 for static loads and 2 2 for pseudo-static loads are obtainable Attachment B2 includes the data parameters, computer printouts, and assumptions of this analysis

4.2.3 Vegetation

The Conceptual Remedy states that the entire surface of the cover systems will be vegetated In some cases it may be necessary to use erosion control materials in conjunction with vegetation prior to vegetation of the entire surface The vegetated surface will be designed to provide surface stabilization/erosion control, enhanced transpiration and impact wildlife in a manner consistent with guidance from the FWS

The selection of vegetation species for the cover systems will be based on a mixture of desired characteristics based on input from the FWS and Soil Conservation Service (SCS) The selected vegetation species will provide an adequate root mass with a variation of root depths to remove moisture at differing levels of infiltration and will include some species that are drought resistant and some that resist damage from wind and water erosion Consideration will be given to species that establish rapidly in the spring to provide early protection and transpiration while other species are developing

4.2.4 Erosion Control Materials

Erosion control materials may be necessary prior to or during vegetation establishment and/or on steepened side slopes where the erosion analysis (discussed below) indicates that the soil/gravel admixture and vegetation together will not provide adequate long-term protection Erosion control materials may consist of gravel armoring, mats, or meshes using a combination of synthetic, earthen, or vegetative materials The erosion control materials are of significant benefit during the vegetation establishment period to protect bare slopes and prevent seed washout The erosion control materials will reduce erosion damage to barren slopes before vegetation establishes, but some may hinder the growth and consistency of the vegetation. This reduction in consistency of vegetation coverage may reduce the transpiration rate and the loss of root mass may reduce the long-term soil stability achieved from the root binding mechanism Therefore, after adequate initial vegetation is established, the erosion control materials may be eliminated and efforts concentrated toward the establishment of adequate long-term vegetation

4.2.5 Vegetative/Erosion Protection Layer

A preliminary analysis of the uppermost soil layer of the cover system was performed to assess its ability to resist damage from the erosive effects of wind and water This analysis assumed topsoil similar to that present in the landfill area would be used on the cover systems This preliminary analysis indicated that once consistent vegetation is established, the native soil and vegetation will provide adequate performance Because erosion control is an important consideration in the Part 2, 1,000-year demonstration (see Appendix A), natural erosion control measures for unvegetated areas should be incorporated into the design Vegetative monitoring using reference areas and statistical analysis will be performed to evaluate areas vegetated during implementation of the CAMU.

Gravel mixed with topsoil improves erosion resistance A soil/gravel admixture will gradually lose fines, thus leaving the gravel exposed The exposed gravel forms a "desert pavement" increasing the erosion resistance of unvegetated areas of the cover systems Desert pavement formation has be attributed to three processes concentration of stones by wind deflation, concentration of stones by runoff erosion, and concentration of stones by upward migration (Waugh et al , 1988)

4.2.5.1 Erosion Resistance

The design of the cover system will include an analysis of the effects of erosion (both wind and water) on the cover surface The erosion analysis will include calculations for the estimated soil loss due to wind and water erosion over the 1,000-year design life Precipitation event data used in the analyses will be consistent with the data given in the Urban Stormwater Drainage Criteria Manual (USDCM) and/or other appropriate references (Denver Regional Council of Governments, 1969 [updated]) The cover system will be designed such that the estimated soil loss does not exceed the EPA-recommended 2-tons/acre/year and that the vegetative/erosion control layer is of sufficient thickness that a portion of this layer will remain after 1,000 years

Calculation methods that are currently available that may be used are listed below

- The total depth of soil loss due to wind erosion over 1,000 years may be calculated using the wind erosion equation and parameters given in the National Agronomy Manual, or other appropriate reference

- To calculate the total depth of soil loss due to water erosion over 1,000 years, the Revised Universal Soil Loss Equation (RUSLE), Version 1.04 or later, or other suitable method may be used RUSLE is a revision and update of the universal soil loss equation (USLE). RUSLE retains the equation structure of the USLE, but each of its factor relationships has been either updated with recent data, or new relationships have been derived based on modern erosion theory and data

- The design should also consider the vegetative layer's resistance to gully erosion for both the top and side slopes.

4.2.6 Water Storage Layer

Directly below the vegetative/erosion protection layer is the water storage layer. This layer consists of fine-grained soil with a primary function of providing water storage to nourish the vegetation root mass and to provide adequate soil depth for the establishment of the root system. The Ascalon soil series native to RMA have an available water capacity of 0.13 to 0.15 inch per inch and the Platner soil series, also native to RMA, have an available water capacity of 0.14 to 0.18 inch per inch. Both of these soil types should provide adequate water retention capabilities.

The design of the water storage layer will define the optimum thickness of the water storage layer to contain extreme precipitation events for which maximum infiltration may occur. The HELP model or similar program will be used to calculate the percent of the infiltrated moisture that would be retained in the top 48-inches of the cover system. The results of this modeling will be used to estimate whether the retained moisture is adequate to sustain vegetation and minimize the amount of infiltration that reaches the underlying composite hydraulic barrier.

For frost protection, the cover system design will provide a minimum thickness of 42 inches of cover over any CCL in the cover system. For example, the minimum thickness of the upper components in the cover system shown in the conceptual cover system (Drawing C-8) is 60 inches (48-inch minimum soil layer for root growth and 12-inch minimum biota layer).

4.2.7 Geotextile

The conceptual cover (Drawing C-8) proposes a geotextile between the fine-grained soil and the underlying biota layer. This geotextile serves the primary functions of filtration and separation. Segregation must be maintained between the overlying fine-grained soil of the water storage layer and the underlying large rock layer in order for a capillary break to function properly.

The geotextile will be selected during design based on its filtration characteristics, frictional characteristics, puncture resistance, and tensile strength The geotextile design considerations include resistance to puncture and tear because it will be placed directly over rock and subjected to equipment loadings during the construction of the remainder of the cover system

4.2.8 Biota Barrier/Capillary Break Layer

The primary functions of this layer are to deter animal intrusion into the underlying drainage layer and composite hydraulic barrier and to provide for a capillary break. A capillary break is essential in minimizing the amount of infiltration that reaches the composite hydraulic barrier A capillary break is formed when there is a large differential in air void size between two materials When soils are unsaturated, atmospheric pressures exceed the soil capillary pressures Moisture is retained in the fine-grained soil due to surface tension between the fine particles and the increased atmospheric pressure of the large voids in the rock layer The fine-grained soil must become saturated before moisture will break through the capillary barrier The composition, size, and angularity of the aggregate used in the biota barrier will be chosen based on the durability of the rock, the potential for damage to surrounding geosynthetics, and the size and burrowing habits of the local animal species The size (weight) of the rocks will be chosen based on the weight of an average animal of the species the FWS anticipates may pose a burrowing problem Angularity of the aggregate will be selected to form an interlocking-bridging action that will make it difficult for animals to burrow, yet minimize the potential for damage to adjacent geosynthetics The overall thickness of the biota barrier will be selected to allow adequate interlock

A secondary function of the biota barrier/capillary break layer will be to deter plant intrusion Research conducted at the Los Alamos National Laboratory indicates that plant roots are discouraged by the large air void spaces and lack of moisture present in this layer Roots penetrate downward in search of moisture Therefore, after reaching certain depths with no moisture reserve, the roots will be discouraged and stop growing deeper This protects the underlying drainage layer from becoming clogged from root growth.

4.2.9 Drainage Layer and/or Cushion Layer

As a redundant system, a drainage layer may be provided The biota/capillary break layer discussed in Section 4 2 8 may also serve as the drainage layer If a separate drainage layer is utilized, it will typically consist of a sloped lateral drainage layer placed above the cover system's composite hydraulic barrier (FML and overlying a CCL or GCL) and will be designed to remove infiltration from above the composite hydraulic barrier

The drainage layer will typically consist of one of the components listed in Section 3 3 2 3 The design considerations that will determine the drainage material selection include

- The frictional characteristics based on slope stability requirements
- Transmissivity/permeability based on the expected amount of infiltration and the slope of the drainage layer
- Strain characteristics based on the expected amount of differential settlement.
- The compressive, tensile, and puncture strength characteristics based on the expected construction and post-construction conditions
- The cushioning characteristics based on the expected loadings and the angularity of the biota barrier rocks

As indicated above, the biota barrier/capillary break layer may also be designed to function as a drainage layer If this option is selected by the designer, the layer discussed in this section will serve only as a cushion between the biota barrier and the FML

4.2.9.1 Cover Toe Drain

The toe drain will be designed to collect the lateral flow from the cover drainage layer and transport the flow to a point of discharge in a controlled manner The drain will be sized to carry the maximum flows anticipated over the design life

4.2.10 Flexible Membrane Liner

The FML component of the composite hydraulic barrier will provide the primary hydraulic barrier to prevent moisture migration downward The FML will be chosen to provide suitable properties over the long-term design life of this cover system The selection of the FML will be dependent on the results of the slope stability, settlement, and other design considerations given in Section 3 3 Chemical compatibility may be a design consideration if the FML is in contact with waste material

4.2.11 Compacted Clay Liner/Geosynthetic Clay Liner

A CCL or a GCL will be the lower component of the composite hydraulic barrier The design considerations for this layer are typically the same as for CCLs or GCLs used in the cell lining systems (see Section 3 3) excluding considerations for chemical compatibility Chemical compatibility may also be a design consideration if the CCL or GCL is in contact with waste material

4.2.12 Gas Venting System

The amount of expected gas generation, if any, will be estimated during design Depending on the expected gas generation rate of the material being covered, a gas venting system may be incorporated into the cover system This system would collect and remove gases that may migrate upward through the waste The gas venting system will consist of a collection layer attached to vents that will penetrate the cover system The collection layer will typically consist of synthetic and/or earthen materials capable of capturing and directing gas flows out of the landfill Chemical compatibility of gas venting system components may be a design consideration The lateral extent of the collection layer may or may not cover the entire cell surface The lateral extent of the collection layer will be determined during design based on the expected gas generation rates

4.3 Construction Specifications

The design will set forth the material and procedural requirements for each component of the cover system construction These data will be incorporated into detailed construction specifications The cover system construction specifications may or may not be combined with the landfill construction specifications Typical earthwork and geosynthetic specifications are presented in Appendix P. These typical specifications are provided to demonstrate that materials and methods are available for potential use that meet the design performance standards outlined in this appendix The specifications in Appendix P typify the level of detail to be included in the construction specifications

The construction specifications will typically consist of material requirements, including quality control requirements for borrow soil, geosynthetics, and other cover components, performance requirements during construction (i e , compacted soil moisture/density requirements, seam strength requirements), and the procedural requirements during construction (e g , all seams will be nondestructively tested) Construction specifications will be submitted to CDPHE for approval prior to implementation

4.4 Construction Quality Assurance (CQA)

An effective CQA program will be implemented to verify that the cover system is constructed as designed The CQA program will be described in a CQA Plan that will be completed prior to construction The cover system CQA Plan may or may not be combined with the landfill construction CQA Plan. The CQA Plan will describe the CQA inspection and monitoring requirements, the CQA testing frequencies, the documentation requirements during construction, and the certification report requirements for each component of the cover system Appendix H presents an outline of a typical CQA Plan for the construction of the cover systems within the CAMU This typical CQA Plan outline is intended to provide the reviewer with an example of the level of detail to be included in the final CQA Plan The CQA Plan will be submitted to CDPHE for approval prior to implementation

5.0 RUN-ON/RUNOFF CONTROL SYSTEMS

Surface-water management within the CAMU is necessary to prevent the flow of water onto contaminated areas (run-on), the flow of water off contaminated areas (runoff), and to minimize the effect of erosion on the design performance of the CAMU Surface-water management will be provided through the use of channels, culverts, and other drainage structures This section provides the design parameters and considerations for the CAMU run-on/runoff control system Design parameters for the run-on/runoff control systems are presented in Table B1

5.1 Design Parameters

The design parameters for run-on/runoff control systems are as follows

- Performance Standards
  - Design, construct, operate and maintain
    - o A run-on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 100-year storm
    - o A runoff management system to collect and control at least the water volume resulting from a 24-hour, 100-year storm
- Design Guidance/Alternatives
  - Control systems should typically be sized to contain both the peak discharge of a 100-year storm (which typically results from a storm duration of less than 24 hours) and the volume of water resulting from a 100-year, 24-hour storm
  - The general methodology, parameters, and criteria given in the USDCM should be complied with in the systems design.

5.2 Design Considerations

The basis for the design of the run-on control system is to prevent drainage of surface water onto active waste management areas The active waste management areas will consist of open landfill cells, waste staging/consolidation areas, and possibly the decontamination area(s) The control system will include channels, berms, and other diversions as necessary The run-on will be directed out of the CAMU into the existing drainage near the northern boundary of the CAMU The run-on control system will be sized to carry the peak discharge from the appropriate duration 100-year storm

The runoff control systems will be typically sized to carry the peak flows and at least the volume of water resulting from a 100-year, 24-hour storm The basis for the design of the runoff control systems is also to segregate runoff of surface water that could potentially come into contact with waste from surface runoff from uncontaminated areas The runoff control system will include channels, berms, and other diversions as necessary The potentially contaminated runoff will be directed to retention pond(s) located within the CAMU Contaminated runoff will be treated onsite or sent offsite for disposal in accordance with applicable regulations

As agreed in the CAMU working sessions, the primary design reference for the design of the run-on/ runoff control system will be USDCM (Denver Regional Council of Governments, 1969 [updated]) This comprehensive three-volume document provides methodology, criteria, and parameters specific to the Denver area for the design of surface-water management systems, including channels, culverts, retention ponds, erosion control, and other surface-water control structures

6.0 WASTE STAGING/CONSOLIDATION AREAS

Construction staging areas will be used for temporary staging, material sizing and/or storage of soil/debris between processing steps or to temporarily stockpile soil for transport The waste staging/consolidation area at the landfill may include size reduction equipment to improve handling, placement, and compaction characteristics of the waste Preliminary staging areas may be used at the Basin F Waste Pile and the landfill The locations are preliminary and may be revised during the design.

The waste staging/consolidation areas will be designed to prevent release of potentially contaminated solids, liquids and vapors to the environment through the use of liners, covers, containment systems, run-on and runoff controls, and vapor containment/treatment systems (e g , covers or temporary structures with ventilation and vapor treatment equipment) as necessary The components of the waste staging/consolidation areas will be designed to meet the regulatory requirements that are applicable to that component

7.0 LEACHATE MANAGEMENT SYSTEMS

Leachate generated from the landfill will be temporarily stored and either sent offsite for disposal or treated in an onsite treatment system in accordance with all applicable regulations The onsite storage and/or treatment system will be designed in accordance with applicable regulatory requirements

8.0 DECONTAMINATION FACILITIES

Decontamination facilities will be constructed to decontaminate construction and operation equipment Decontamination facilities will potentially be located in the vicinity of the Basin F Waste Pile and the landfill The landfill decontamination facilities will be designed to decontaminate, as necessary, equipment leaving areas of contamination and will be used over a multi-year period extending from landfill construction to closure Decontamination facilities that may be associated with the Basin F Waste Pile closure will be designed to decontaminate, as necessary, equipment leaving the excavation to transport waste to the landfill These facilities will have shorter operating lives than the landfill facility and will use materials and construction methods commensurate with their operating lifespan.

Decontamination facilities will typically be equipped with a pressure washer, mechanical scrubbing equipment (e g , brushes), concrete or geomembrane liner decontamination pad, wash water collection sump, wash water transfer equipment, and wash water storage and treatment equipment Pressure washers and brushes may be used to remove contaminated material from equipment and personnel leaving areas containing potentially contaminated material Wash water will be appropriately managed onsite or offsite Solids collected during decontamination will be dried to pass the paint filter test and placed in the landfill

Decontamination facilities will be designed to prevent release of potentially contaminated wash water to the environment through the use of containment curbs, collection sumps and splash containment Tank systems that will be designed to meet applicable regulatory requirements may include a waste water storage tank, settling tank and detergent/chemical storage tanks

9.0 BASIN F WASTE PILE DRYING UNIT

A drying unit will be constructed to dry Basin F Waste Pile solids that do not pass the paint filter test before placement into the triple-lined cell(s) of the landfill There are approximately 600,000 cubic yards (cy) of Basin F materials that will be placed into the landfill An estimated 100,000 cy of waste pile materials are assumed to require drying prior to placement in the landfill (Foster Wheeler, 1995) As described in the DAA, the drying system may consist of a direct or indirect-fired heating unit used to increase the soil temperature and drive off moisture The off-gases from the dryer will be collected and treated

The drying unit will be designed to prevent release of potentially contaminated solids, liquids, and vapors to the environment through the use of containment systems, run-on and runoff controls, and vapor treatment systems, as necessary Components of the drying unit will meet the regulatory requirements that are applicable to that particular component.

10.0 ACRONYMS

Army	U.S Department of the Army
Borrow Study Report	Final Feasibility Study Soils Support Program Report
CAMU	Corrective Action Management Unit
CCL	Compacted clay liner
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
cm/s	centimeters per second
COE	U S Army Corps of Engineers
Conceptual Remedy	Agreement for the Cleanup of Rocky Mountain Arsenal
CQA	Construction Quality Assurance
cy	Cubic yards
DAA	Final Detailed Analysis of Alternatives
EPA	U.S Environmental Protection Agency
EPA Design Resource Guide	Guide to Technical Resources for the Design of Land Disposal Facilities
FFA	Federal Facilities Agreement
FML	Flexible membrane liner
FS Report	Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program
FWS	U S Fish and Wildlife Service
GCL	Geosynthetic clay liner
HELP	Hydrologic Evaluation of Landfill Performance
HLA	Harding Lawson Associates
LCS	Leachate Collection System
LDS	Leak Detection System
RMA	Rocky Mountain Arsenal
RUSLE	Revised Universal Soil Loss Equation

Shell	Shell Chemical Company
SCS	Soil Conservation Service
State	State of Colorado
USCS	Unified Soils Classification System
USDCM	Urban Stormwater Drainage Criteria Manual
USLE	Universal Soil Loss Equation

11.0 BIBLIOGRAPHY

Denver Regional Council of Governments 1969 (updated) *Urban stormwater Drainage criteria manual*

Foster Wheeler 1995 *Final detailed analysis of alternatives, version 4 1* October

Harding Lawson Associates 1995a *Final landfill site feasibility report for the feasibility study soils support program* 1995

——— 1995b *Final feasibility study soils support program report* January

U S Department of Agriculture 1988 *National Agronomy Manual, Second Edition,* Soil Conservation Service Washington D C March

U S Environmental Protection Agency 1988 *Guide to technical resources for the design of land disposal facilities* December EPA/625/6-88/018

——— 1989(a) *Technical guidance document Final covers on hazardous waste landfills and surface impoundments* July EPA/530-SW-89-047

——— 1989(b) *Seminar publication, requirements for hazardous waste landfill design, construction, and closure* August. EPA/625/1-89/022

——— 1994 *Hydrologic evaluation of landfill performance model, engineering documentation for version 3 September EPA/600/R-94/168b*

——— 1988 *Lining of waste containment and other impoundment facilities* September EPA/600/2-88/052

Waugh, W J , S O Link. 1988 *Barrier erosion control test plan gravel mulch, vegetation, and soil water interactions* WHC-EP-067 Westinghouse Hanford Company, Richland, Washington

Table B1: CAMU Landfill Design Parameters

	Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
1	Layout of CAMU Landfill Development Area	Individual cell layout and size	Balance minimizing land area on which waste will remain after closure and maintaining minimum 20-foot depth to groundwater Provide compatible scheduling of landfill capacity versus waste generation Provide for flexible expansion of landfill cell volume within the defined CAMU footprint	Applicable portions of the Conceptual Remedy and CAMU regulations	Technical feasibility and review of layout concepts by the parties, followed by detailed design analysis of the selected layout configuration	To be determined following design analysis
2	Foundations	Site geology/ engineering characterization			Geotechnical index parameters, geological profiles, representative construction drawings (plans and specifications)	
		Settlement (total and differential)/ consolidation	Prevent failure of the liner and other landfill components due to settlement and subsidence	Address the potential for a falling groundwater table	Engineering analysis	Allowable settlement to be selected following analysis
		Bearing capacity	Prevent failure of the liner and other landfill components from failure due to loading		Engineering analysis	Allowable settlement to be selected following analysis
		Potential for excess hydrostatic pressure	Prevent failures due to hydrostatic pressure	Evaluate hydrostatic pressure caused by groundwater or infiltration of surface water as applicable	Engineering analysis	To be selected following analysis
		Seismic considerations	Building and earthen structures will withstand seismic stresses		Engineering analysis	To be selected following analysis
3	Slope Stability	Cover slopes	Prevent failure of the landfill cover components.		Engineering analysis	To be selected following analysis
		Excavated and constructed slopes	Prevent slope failure during excavation cell construction and waste placement		Engineering analysis	To be selected following analysis.

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
4 Landfill Liner Systems (also see requirements for (2) foundations and (3) slope stability)	Composite liners general	Reduce potential for contaminant transport from the landfill and design leachate removal components to maintain a leachate depth less than 1 foot over the liner Provide natural and synthetic materials that are compatible with expected waste generated leachate	Double or triple lined cells as outlined in the applicable portions of the Conceptual Remedy	Standard practice and engineering analysis Compatibility testing.	The total cumulative thickness of CCL within the multiple liner system will be a minimum of 6 feet thick Two composite liners, each of which consists of a minimum 3 feet thick CCL and 60-mil minimum FML on top will be provided An alternative design thickness for the top CCL may be allowed with supporting equivalence demonstration if the total minimum CCL thickness remains 6 feet and if the minimum thickness of the bottom CCL remains 3 feet
	Lowermost composite liner				Composite liner will consist of a minimum 3 foot thick CCL with a minimum 60-mil FMI on top
	Uppermost composite liner				Composite liner will consist of a minimum 3 foot thick CCL with a minimum 60 mil FML on top An alternative design thickness for the top CCL may be allowed with supporting equivalence demonstration if the total minimum CCL thickness remains 6-feet and if the minimum thickness of the bottom CCL remains 3 feet
	Tertiary composite liner				Composite liner shall consist of a minimum 3 feet thick CCL with a minimum 60-mil FML on top An alternative material and thickness in lieu of CCL, may be considered based on a supporting demonstration of engineering performance
	Borrow/clay liner material	Provide sufficient quantity of satisfactory material at a rate that is sufficient to meet the construction schedule. Provide material that is compatible with leachate	$K \leq 1 \times 10^{-7}$ cm/s Geotechnical index parameters for the clay liner materials will fall within a range considered by the test fill analysis	Index testing. Testfill analysis for conductivity constructability water content alterations, scarification requirements, and methods of amending soil if required Engineering analysis of bearing capacity, settlement, and slope stability, compatibility testing, and evaluation.	To be selected following analysis

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Subgrade (excavated sideslopes)	Provide stable foundation capable of providing support to the lining system and resistance to pressure above and below the liner to prevent liner system failure due to settlement, compression, or uplift	Evaluate the potential for and develop, if necessary, methods to prevent hydrostatic failure during construction and waste placement Provide a suitable subgrade free of soft spots, organics, or unsuitable materials Subgrade evaluations will be performed Methods such as proof rolling, visual observation or soil mapping may be employed to evaluate subgrade condition	Engineering analysis of slope stability, bearing capacity, constructability, hydrostatic failure, and suitability of subgrade materials. Subgrade and borrow source suitability will be verified using methods identified during design that may include soil mapping, soil classification, and grain size analysis	To be selected following analysis
	Subgrade (bottom)	Provide stable foundation capable of providing support to the lining system and resistance to pressure above and below the liner to prevent liner system failure due to settlement, compression, or uplift	Evaluate the potential for hydrostatic failure Develop if necessary, methods to prevent foundation failure due to excess hydrostatic pressure during construction and waste placement Provide a suitable subgrade free of soft spots, organics, or unsuitable materials Subgrade evaluations will be performed Methods such as proof rolling, visual observation, or soil mapping may be employed to evaluate subgrade condition Provide materials for backfill that are finer than SM Abandoned wells and borings should be addressed to remove a potential migration pathway Recompacted backfill in the subgrade should be placed to provide a surface with adequate settlement and bearing capacity properties	Engineering analysis of settlement, bearing capacity, buildup of hydrostatic pressure and suitability of subgrade materials	Remove a minimum of 3 feet of soil coarser than SM and replace with structural fill that classifies as finer than SM
	Leachate collection system, general	Maintain less than 1 foot of leachate on the underlying liners throughout the active life and postclosure period Prevent failure of the LCS due to settlement, loading, waste incompatibility and clogging throughout the active life and post closure period	Design system to maintain minimum 1 percent slope and control clogging. Approaches to mitigate clogging will be evaluated during design and may include filtration, flushing, etc	Engineering analysis Chemical compatibility evaluation and testing of leachate collection system components to demonstrate long-term performance	To be selected following analysis.
	Leachate collection system, granular material	Maintain less than 1 foot of leachate on the immediate underlying FML.	Provide granular material which has a hydraulic conductivity ≥0.01 cm/s.	Engineering analysis Demonstrate selected granular material will provide adequate drainage under surcharge	To be selected following analysis.

Table B1 (continued)

Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Leachate collection system synthetic material	Maintain less than 1 foot of leachate on the immediate underlying FML	Use of a geotextile to prevent silting Use of a geonet with a transmissivity $\geq 3\times10^{-4}$ sq m/s	Engineering analysis Performance of synthetics as the only drainage material will require a demonstration that synthetic drainage material provides equivalent performance to granular material Demonstrate adequate performance under surcharge	To be selected following analysis
	Leachate collection system, piping system	To the extent necessary to drain the LCS to maintain less than 1 foot of leachate on the immediate underlying FML, provide for drainage of the granular or synthetic drainage media	Prevent clogging through design and maintenance of self flushing flow velocities	Engineering analysis of leachate flow velocities	To be selected following analysis
	Leachate collection system sump	Allow for removal and measurement of leachate		Engineering analysis of leachate flow velocities, accessibility and constructability	To be selected following analysis
	Leak detection system	Meet the above performance standards for the leachate collection system	Applicable guidance presented above for the leachate collection system	Applicable engineering analysis presented above for the leachate collection system.	To be selected following analysis
	FML	Reduce the area on which the leachate head pressure is imposed on the underlying CCL. Provide material that is compatible with the leachate	60-mil minimum thickness	Engineering analysis of material properties to match the design stresses Compatibility evaluation and testing.	To be selected following analysis Minimum 60-mil thickness
	Protective soil layer	Protect the liner from frost and construction damage	Thickness $\geq$42 inches for frost protection in Colorado, may consist of contaminated soil that is free of deleterious substances		To be selected following analysis.
5 Covers	General	Accommodate settlement to maintain cover integrity and promote gravity drainage to the perimeter Maintain final slopes and vegetative covers	EPA Cover Guidance	Engineering analysis of slope stability settlement, bearing capacity, seismic pressures, gas migration, erosional effects (wind and water), to evaluate long-term performance	Configuration to be finalized following analysis
	Vegetation	Final cover slopes will be revegetated	Appropriate portions of the conceptual remedy Select species to provide for adaptive, even distribution of vegetation with long term resistance to disease and plant succession.	Identification of vegetation that meets requirements	To be selected following analysis

Table B1 (continued)

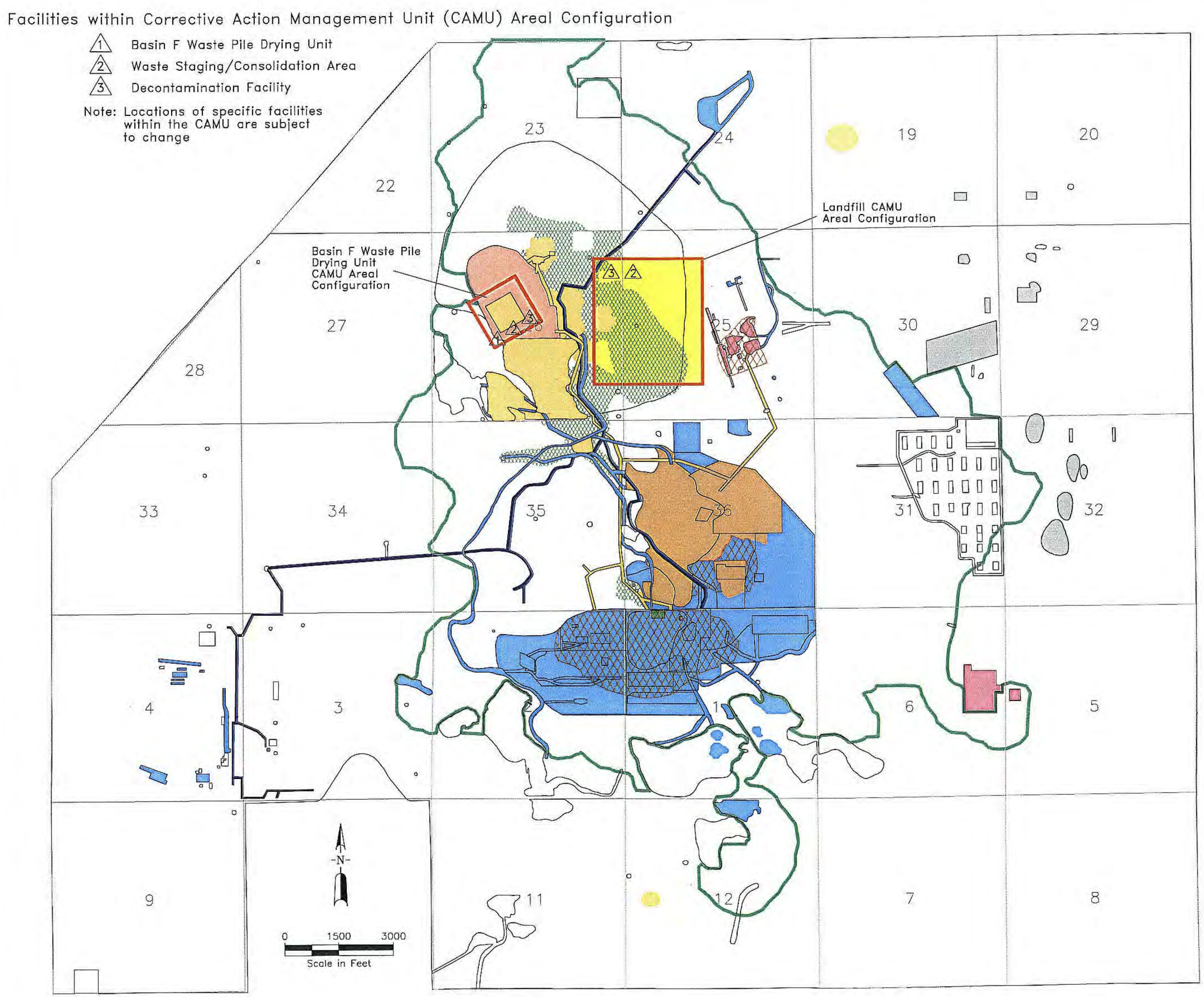
Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
	Upper vegetative soil layer	Provide an evapotranspiration layer protect lower cover components from erosion effects and freeze/thaw cycles and provide for retention of infiltration	Appropriate portions of the Conceptual Remedy and DAA (minimum thickness of 48 inches)	Engineering analysis of vegetation evapotranspiration, erosion, and water storage	To be selected following analysis
	Biota barrier/ capillary break	Minimize burrowing animal and plant root intrusion into underlying layers of the cover Provide a capillary break to reduce the amount of infiltration reaching the drainage layer and increase moisture retention in the water storage layer		Material composition to be selected through engineering analysis of cover material	To be selected following analysis
	Drainage layer	Maximize gravity drainage of infiltration from the cover Protect cover FML from biota barrier during construction	$K \geq 1x10^{-2} cm/s$	Engineering analysis of drainage through cover Engineering analysis to demonstrate flow velocities in piping will promote self cleaning and reduce clogging Combine with biota barrier if engineering analysis indicates that biota layer will function adequately as a drainage layer	To be selected following analysis
	FML	See standards for liner system Compatibility evaluations may be required			
	Clay liner	Minimize infiltration into the underlying waste	Minimum 2 feet of clay with $K \leq 1x10^{-7}$ cm/s	Engineering analysis to determine suitability of clay material	To be selected following analysis An alternative for the clay in the low permeability layer may be considered based on a demonstration acceptable to the CDPHE that engineering performance of alternative materials is equivalent to cover designs using a CCL/FML composite design
	Gas venting system	Prevent the development of landfill gas pressure that would impact the integrity of the landfill cover		Engineering analysis of gas production rates and required gas permeability of the venting system	To be selected following analysis
	Cover subgrade	Provide a stable surface for installation of the cover		Engineering analysis to select required thickness and material	To be selected following analysis

Table B1 (continued)

	Design Item	Component	Performance Standards[a]	Design Guidance[b]	Design Parameter Demonstration[c]	Resultant Design Criteria[d]
6	Run On/Runoff	General	Provide run on control system capable of preventing flow onto the active portion of the landfill during peak discharge from at least a 100-year storm Provide a runoff management system to collect and control at least the water volume resulting from a 24 hour 100 year storm		Engineering drawings profiles and calculations to size system including estimates of peak flow rates erosion potential management of water systems separation of run-on and runoff provisions for retention of runoff	To be selected following analysis

CAMU Corrective Action Management Unit
CCL Compacted clay liner
CDPHE Colorado Department of Public Health and Environment
cm/s Centimeters per second
DAA Detailed Analysis of Alternatives Version 4 1 Foster Wheeler, October 1995
FML Flexible membrane liner
ft Feet
K Hydraulic conductivity
LCS Leachate collection system
SM Silty sand (Unified Soil Classification System)
sq m/s Square meters per second

a Performance standard an objective for design that is based on a regulatory requirement regulatory guidance and/or standard practice
b Design guidance standard engineering practice reference manuals and design elements that have been identified in regulatory guidance or have been demonstrated by past practice to meet the performance standards
c Design parameter demonstration analysis required to demonstrate that the design criteria will provide for conformance with the design guidance and the performance standard
d. Resultant design criteria specific elements of design that have been shown by supporting analytical demonstration to meet the related performance standard



Explanation

- Arsenal Boundary
- Study Area Report Boundary
- Area of Contamination Boundary
- CAMU Areal Configuration
- Landfill Principal Threat Volume; RCRA-Equivalent Cap
- Caps/Covers
- Direct Solidification/Stabilization
- Hex Pit Excavation
- Landfill Human Health Soil,[1] Consolidation of Biota Soil
- Landfill Human Health Soil[2]
- Landfill Site
- Soil Covers
- Agent Screening Area (Caustic wash/landfill)
- Unexploded Ordnance Screening Area (Detonation/landfill)
- Surficial Soil Consolidation
- Access Restrictions
- 5 Section Number

[1] Refuse from the Sanitary Landfills Medium Group will be consolidated

[2] Wastepile material will be dried prior to landfilling if paint filter test is failed

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by: Tetra Tech EC Inc.

Figure B1

Proposed Corrrective Action Management Unit Areal Configuration
Rocky Mountain Arsenal

Attachment B1

CONCEPTUAL DESIGN DRAWINGS

ROCKY MOUNTAIN ARSENAL
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS
TASK 93-03

ADAMS COUNTY, COLORADO

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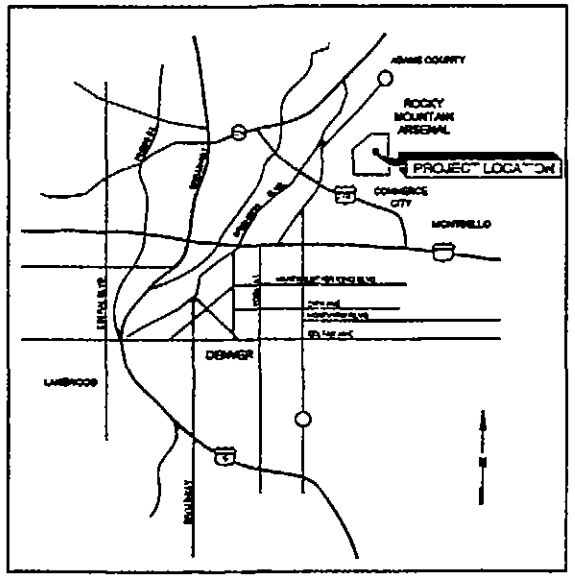
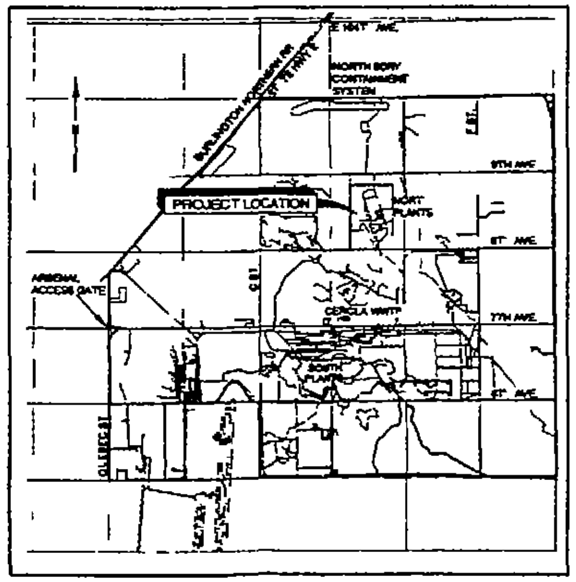


VICINITY MAP
NTS



LOCATION MAP
NTS

DRAWING INDEX

DRAWING NO.	TITLE	SHEET NO
GENERAL		
G-1	COVER SHEET (TITLE, MAPS, DRAWING INDEX, CONTACTS)	1 OF 11
CIVIL		
C-1	1995 EXISTING SITE CONDITIONS AND CAMU BOUNDARY	2 OF 11
C-2	TYPICAL CELL PLAN	3 OF 11
C-3	TYPICAL CELL LINER SYSTEM SECTIONS AND DETAILS	4 OF 11
C-4	TYPICAL LEACHATE COLLECTION SYSTEM SECTIONS AND DETAILS	5 OF 11
C-5	TYPICAL LEACHATE COLLECTION SYSTEM SECTIONS AND DETAILS	6 OF 11
C-6	TYPICAL FINAL COVER PLAN	7 OF 11
C-7	TYPICAL CELL AND COVER CROSS-SECTIONS	8 OF 11
C-8	TYPICAL COVER SECTION	9 OF 11
C-9	TYPICAL SITE DRAINAGE PLAN	10 OF 11
C-10	TYPICAL SITE DRAINAGE PLANS, SECTIONS AND DETAILS	11 OF 11

PREPARED FOR

PROGRAM MANAGER FOR
ROCKY MOUNTAIN ARSENAL
BUILDING 111
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PREPARED BY

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PRIMARY CONTACT RICK L KINSHELLA, P E
SECONDARY CONTACT ROBERT A FARRIS

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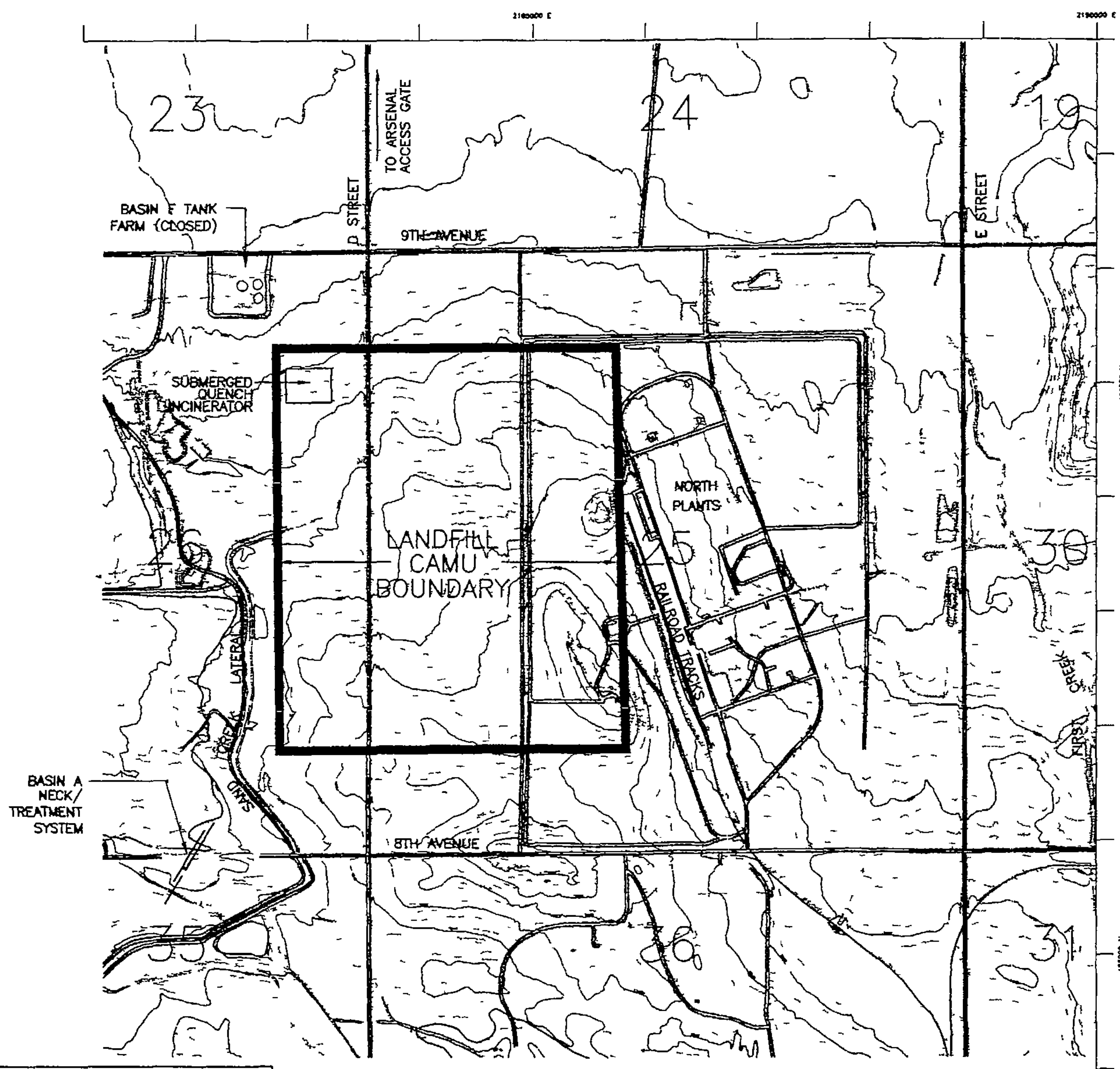
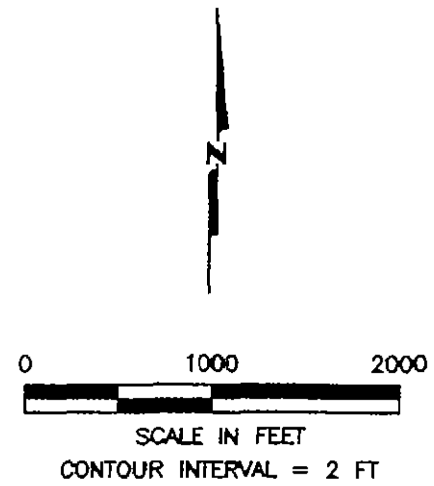
DRAWING NO. G-1

1 / 11





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NOTES.

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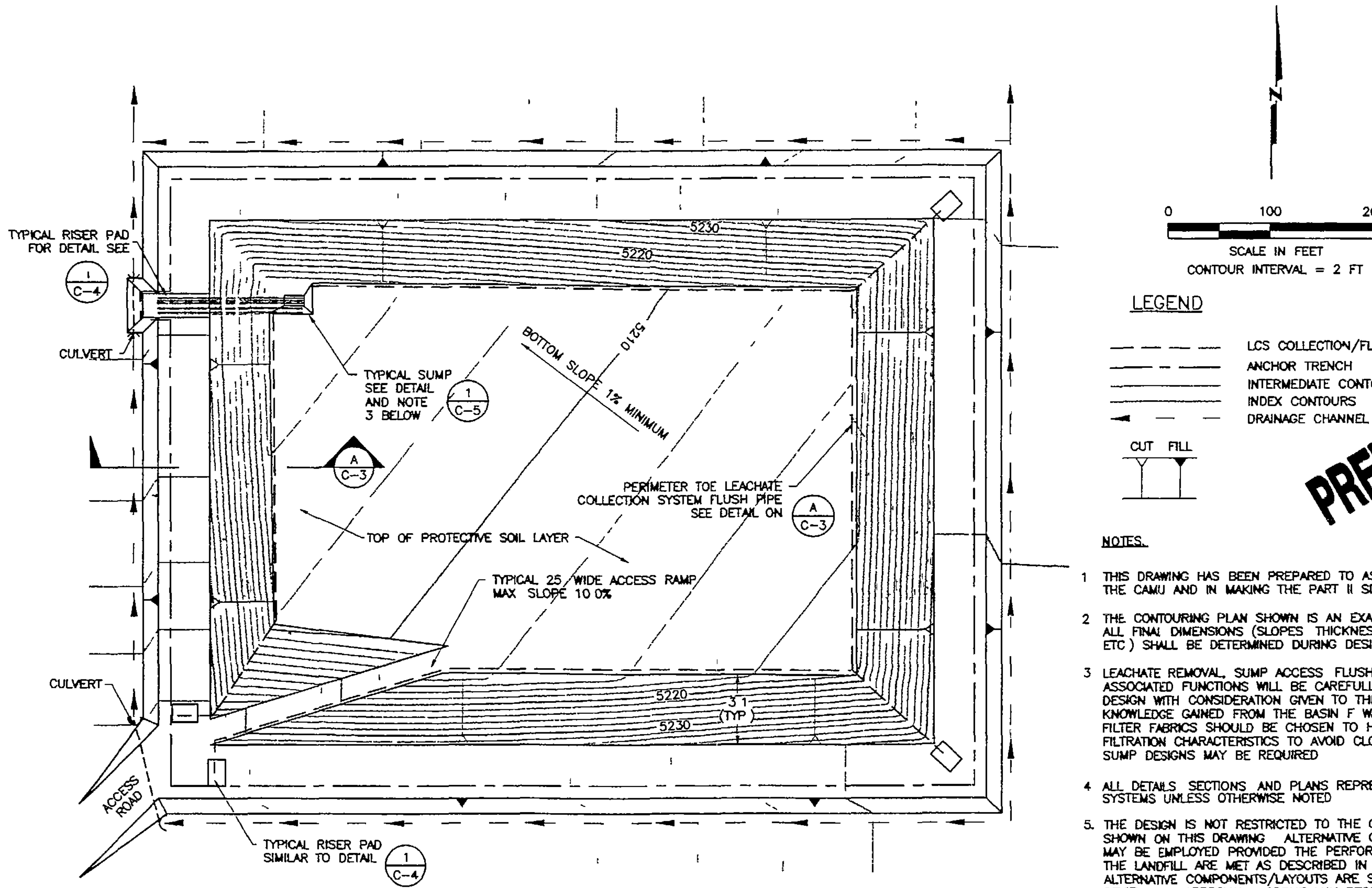
ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

1995 EXISTING SITE CONDITIONS AND CAMU BOUNDARY

DRAWING NO: C-1

2 / 11



LEGEND

- LCS COLLECTION/FLUSH PIPING
- ANCHOR TRENCH
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- DRAINAGE CHANNEL

CUT FILL

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NOTES.

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3 LEACHATE REMOVAL, SUMP ACCESS FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE. GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED

4 ALL DETAILS SECTIONS AND PLANS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED

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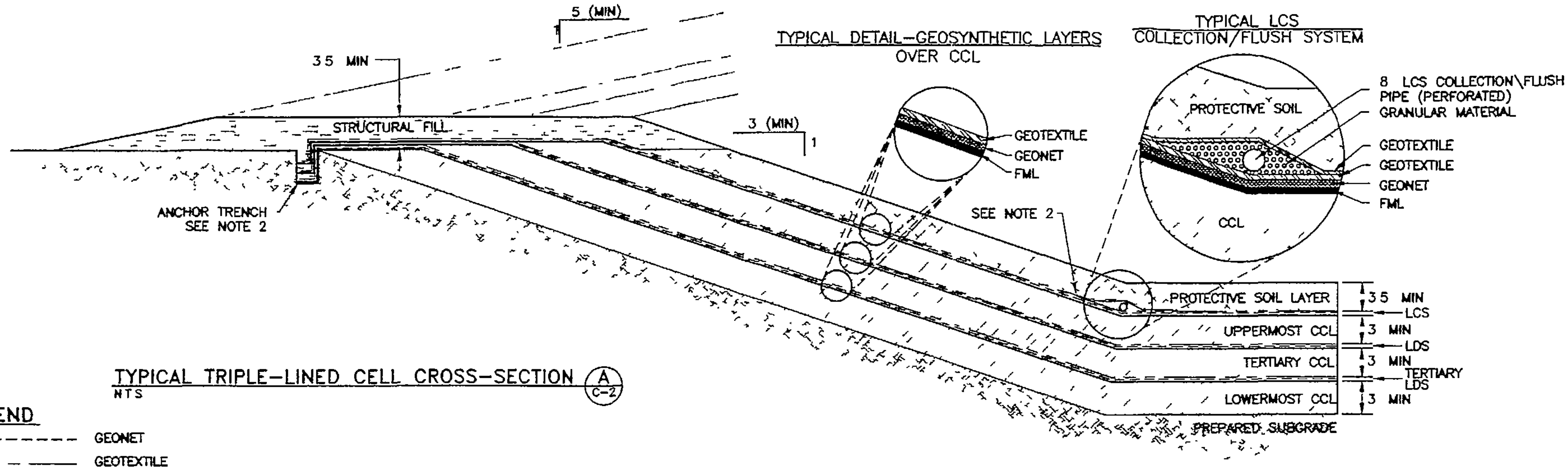
ENGINEER: SES	SCALE: AS NOTED		CAMU DESIGNATION DOCUMENT DESIGNATION LEVEL DRAWINGS
CHECKED:	APPROVED:		TYPICAL CELL PLAN
DATE:	DATE:		DRAWING NO: C-2 3 / 11

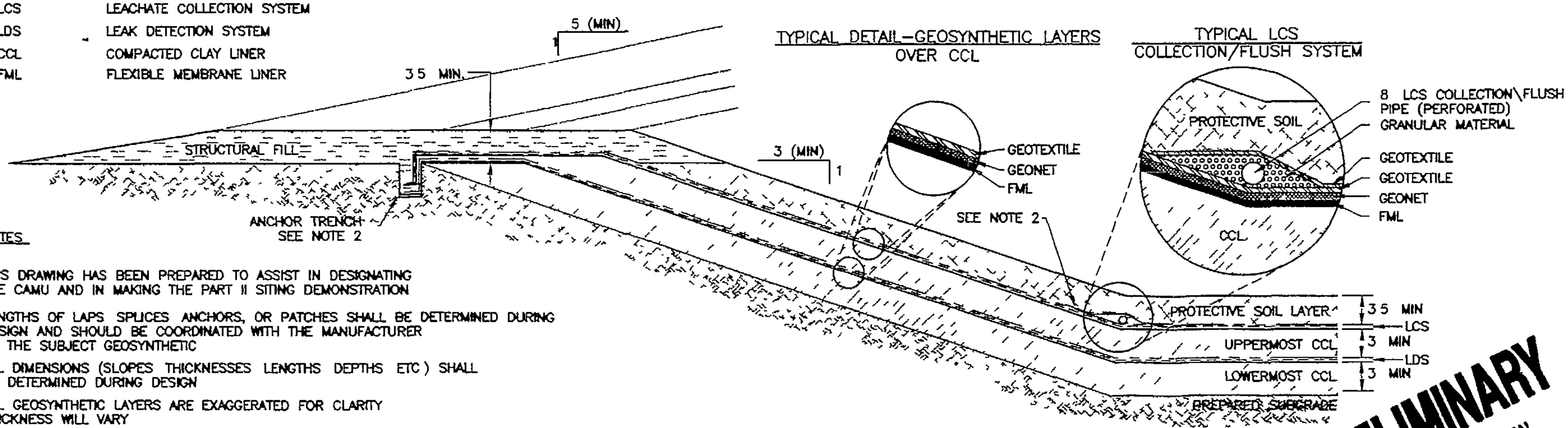


TYPICAL TRIPLE-LINED CELL CROSS-SECTION (A / C-2)

NTS

LEGEND

– – – – – –	GEONET
——— – – ———	GEOTEXTILE
————————	FLEXIBLE MEMBRANE LINER
LCS	LEACHATE COLLECTION SYSTEM
LDS	LEAK DETECTION SYSTEM
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER



NOTES

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3 ALL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN

4 ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY

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TYPICAL DOUBLE-LINED CELL CROSS-SECTION (B / TYP)

N.T.S.

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COMMERCE CITY COLORADO

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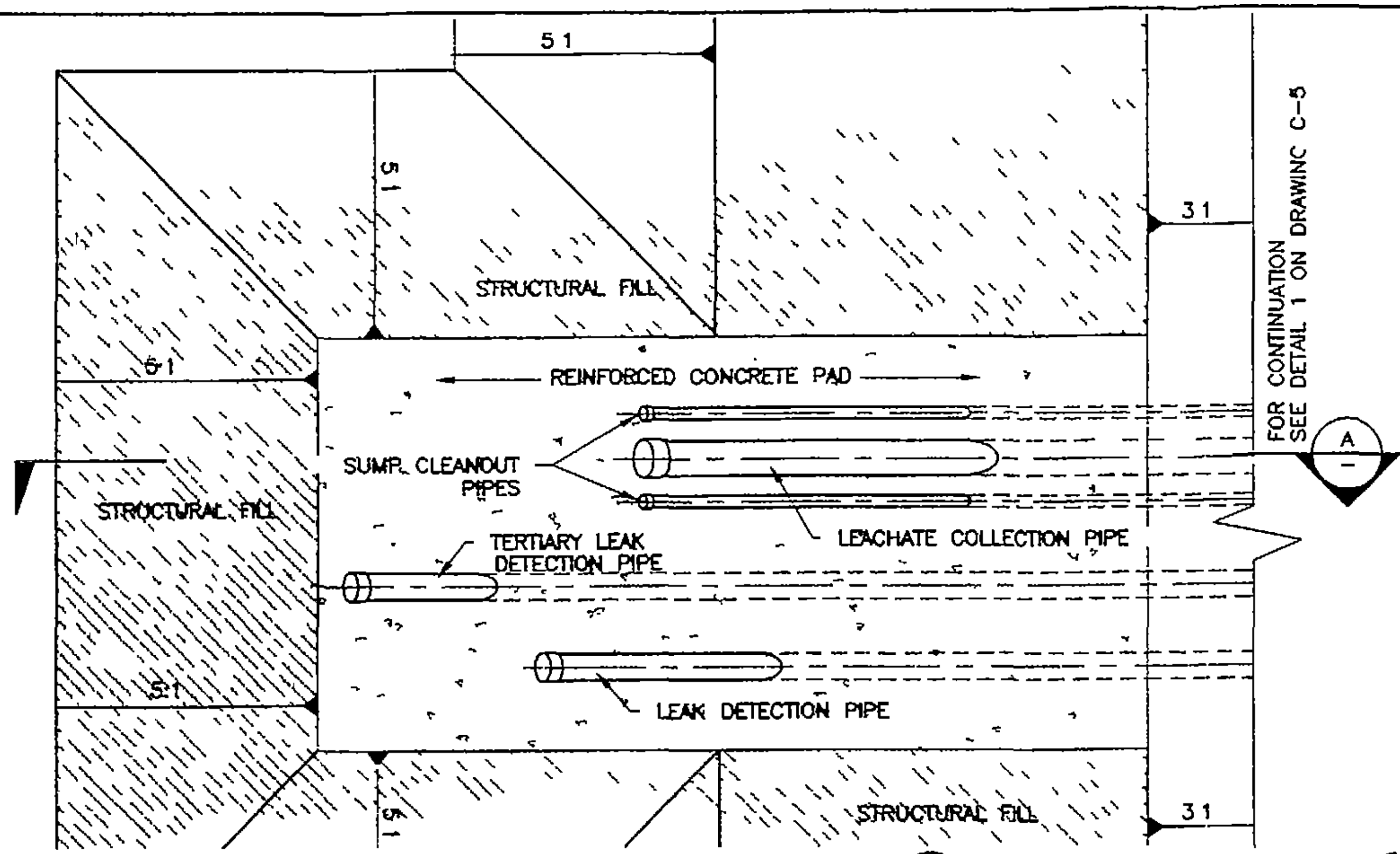
DESIGNATION LEVEL DRAWINGS

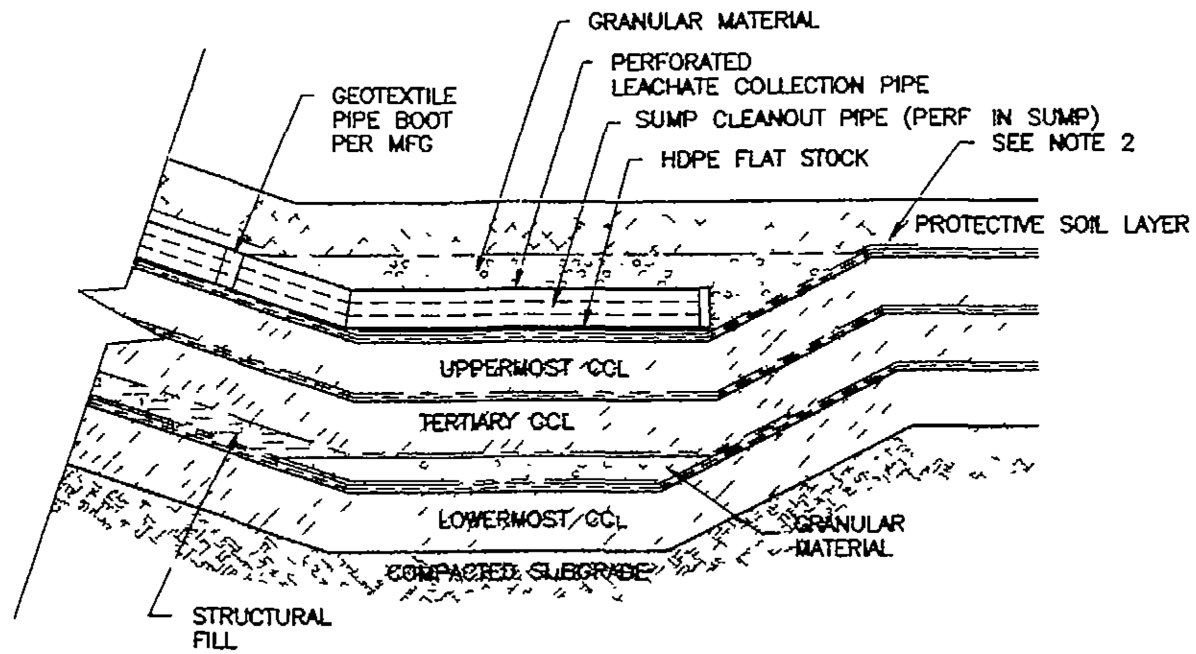
TYPICAL CELL LINER SYSTEM
SECTIONS AND DETAILS

DRAWING NO: C-3

4 / 11



TYPICAL RISER PAD 1/C-2
N.T.S.



TYPICAL SUMP CROSS-SECTION B/C-5
N.T.S.

LEGEND

- - - - - - -	GEONET
——— — — ———	GEOTEXTILE
———————	FLEXIBLE MEMBRANE LINER
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER

CUT FILL

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NOTES.

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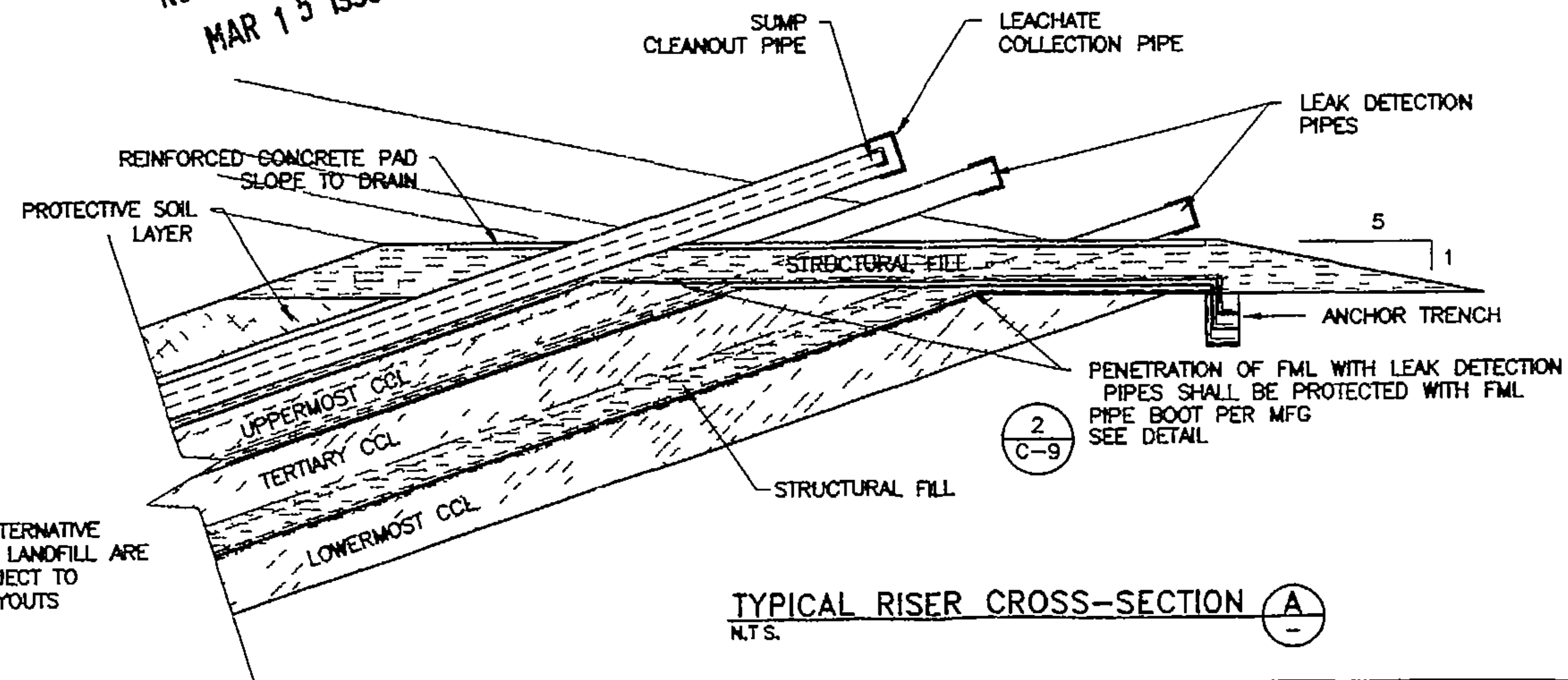

TYPICAL RISER CROSS-SECTION A/–
N.T.S.

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TASK 93-03
COMMERCE CITY COLORADO

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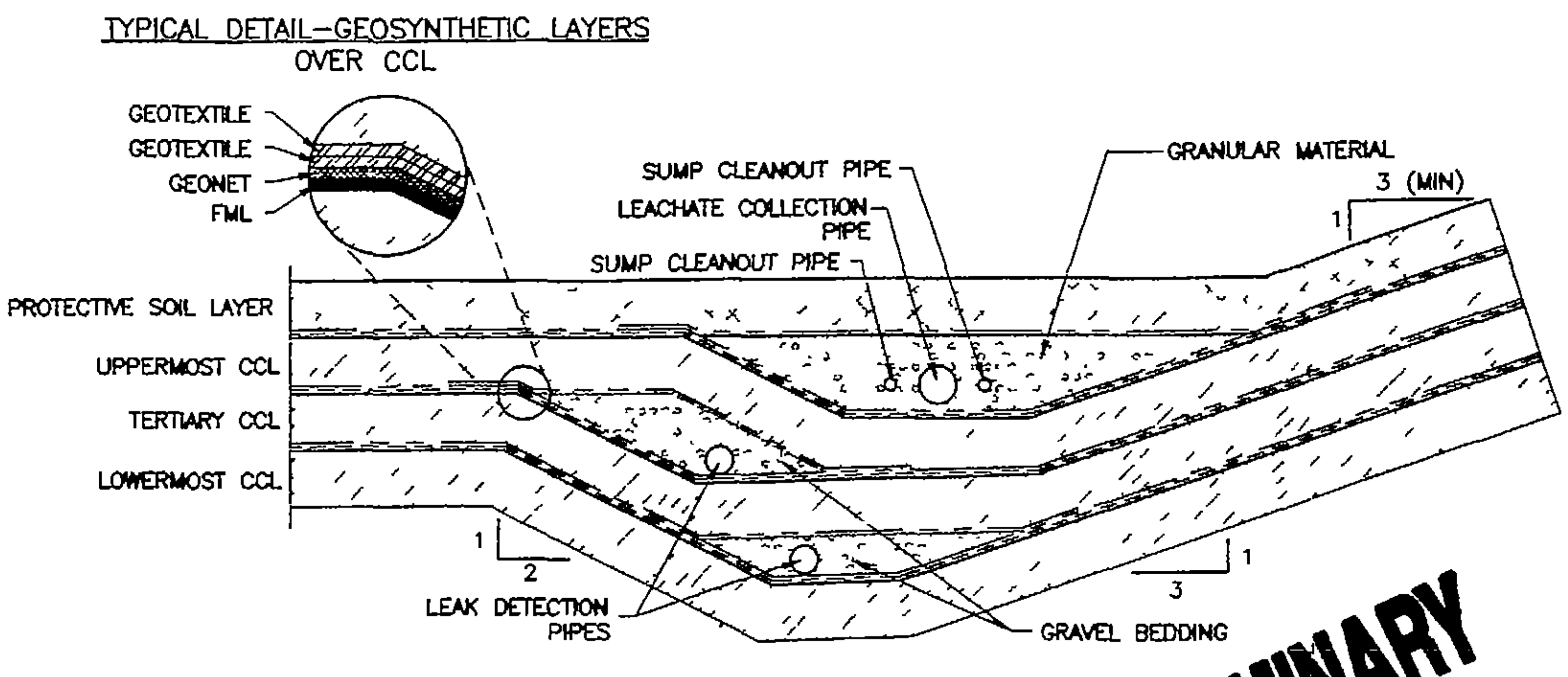
DESIGNATION LEVEL DRAWINGS

TYPICAL LEACHATE COLLECTION SYSTEM – SECTIONS AND DETAILS

DRAWING NO: C-4

5 / 11



TYPICAL SUMP CROSS-SECTION (A/–)
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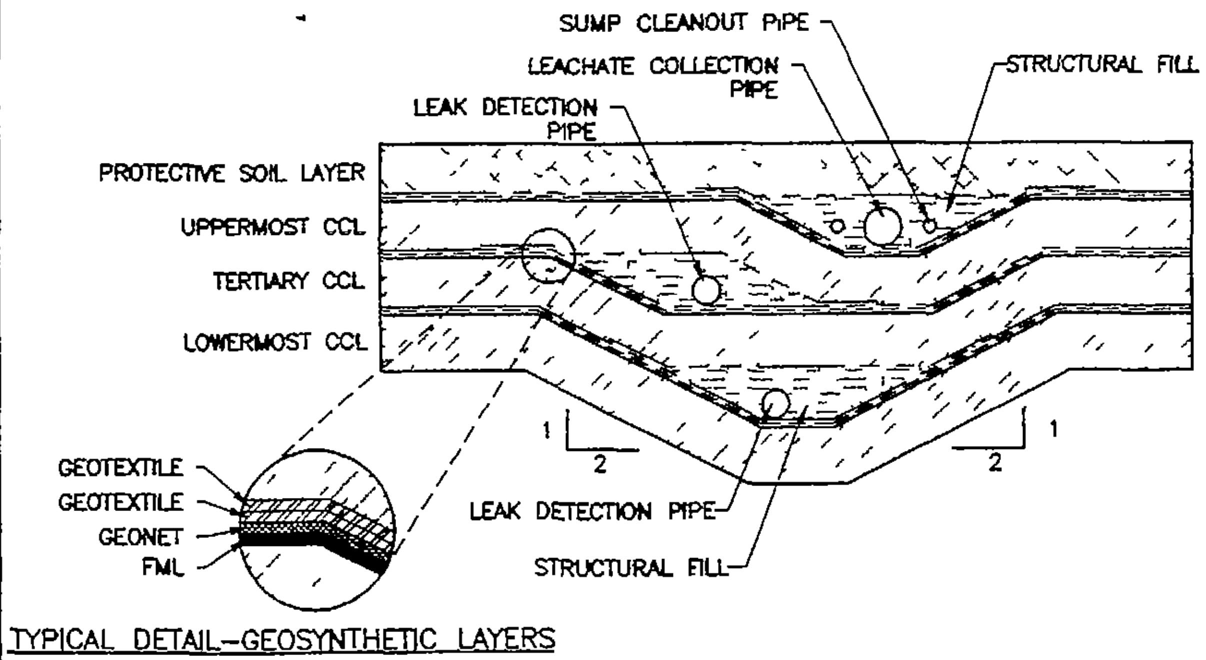

TYPICAL RISER TRENCH CROSS-SECTION (B/–)
N.T.S

LEGEND

- - - - - - - -	GEONET
—— — — ——	GEOTEXTILE
————————	FLEXIBLE MEMBRANE LINER
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER

CUT FILL

NOTES

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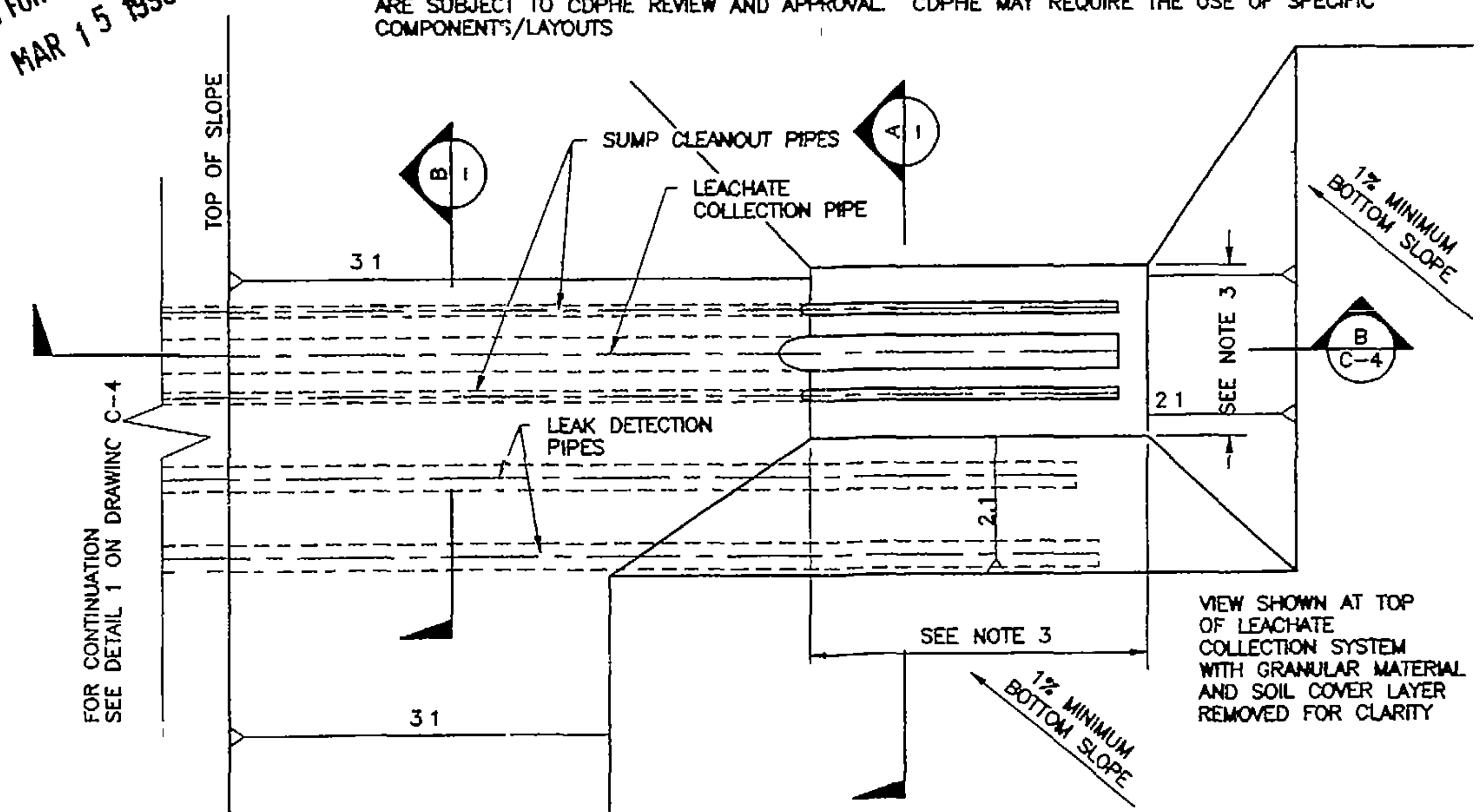

TYPICAL SUMP PLAN (1/C-2)
N.T.S.

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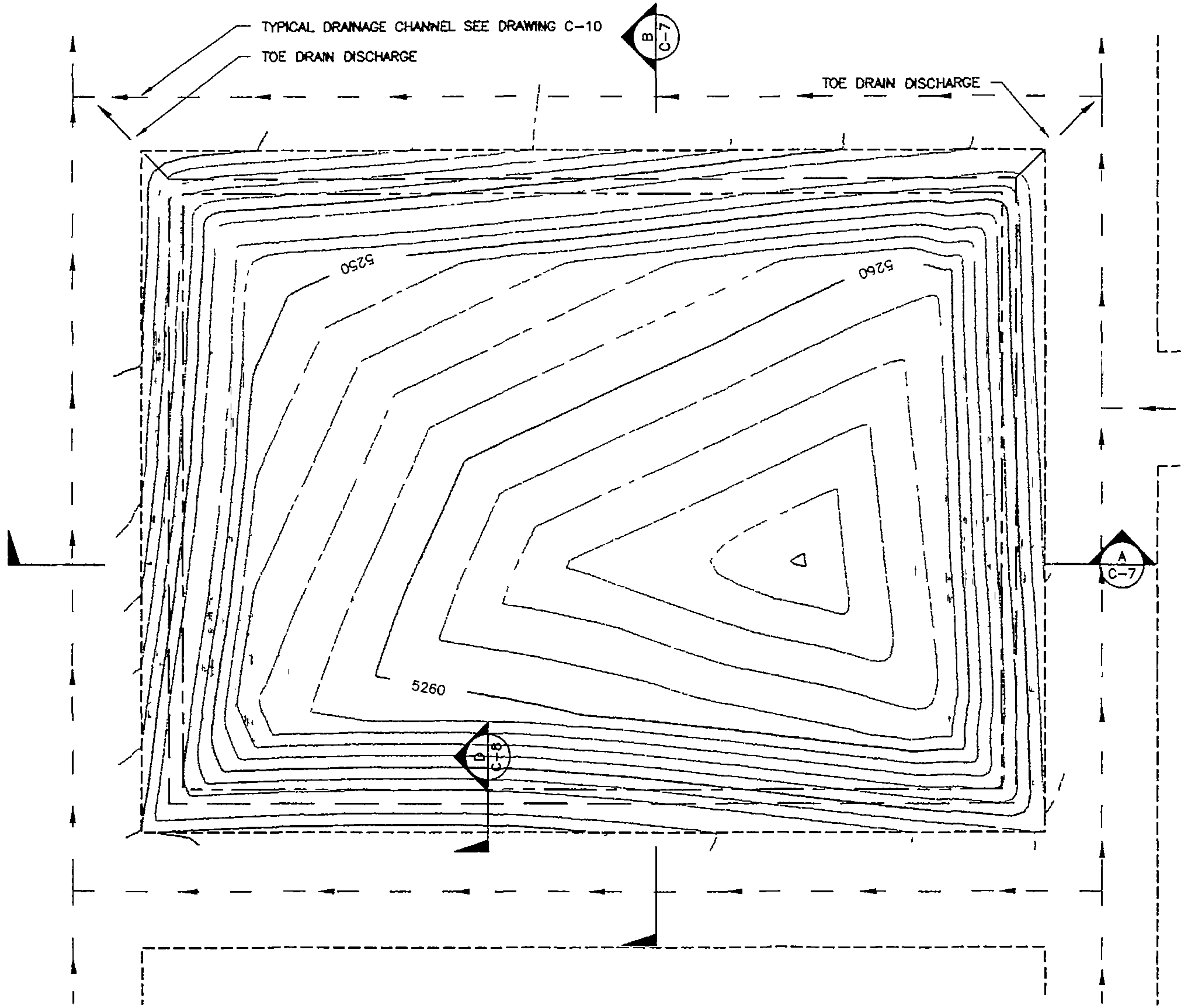
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY COLORADO

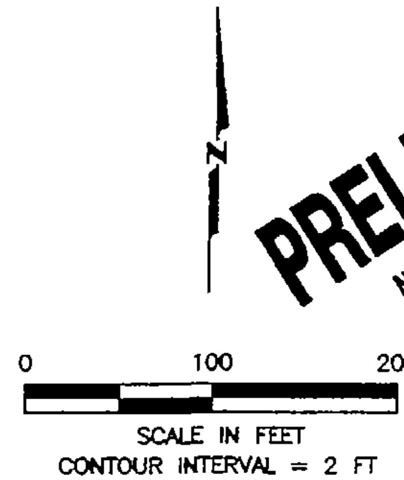
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL LEACHATE COLLECTION SYSTEM - SECTIONS AND DETAILS

DRAWING NO: C-5

6/11





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LEGEND

- APPROXIMATE LIMITS OF WASTE
- FINAL COVER TOE DRAIN
- DRAINAGE CHANNEL
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- APPROX LIMITS OF FINAL COVER

NOTES.

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CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL FINAL COVER PLAN

DRAWING NO: C-6

7 / 11

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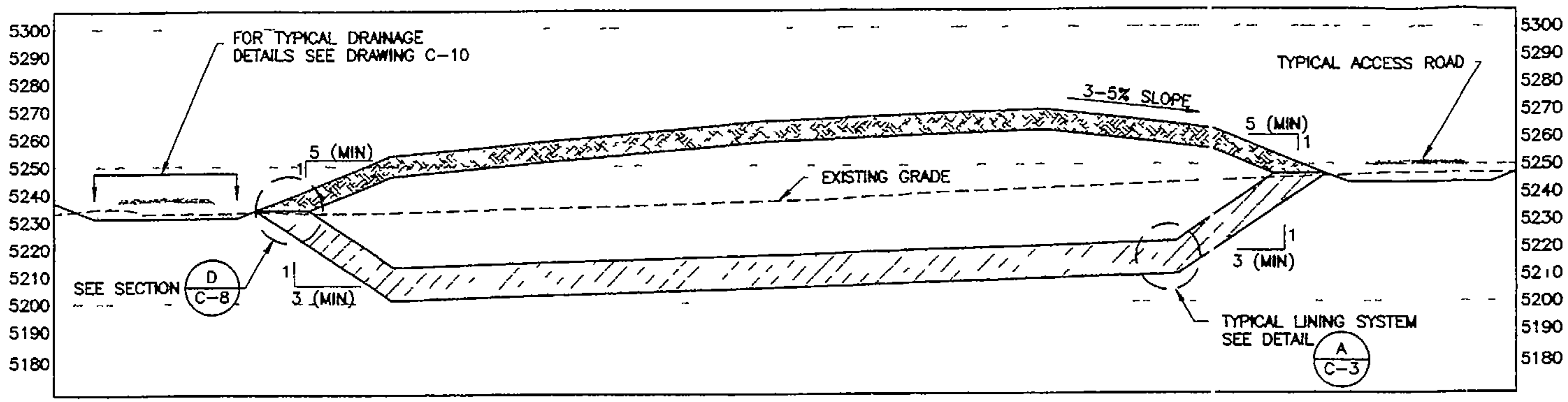
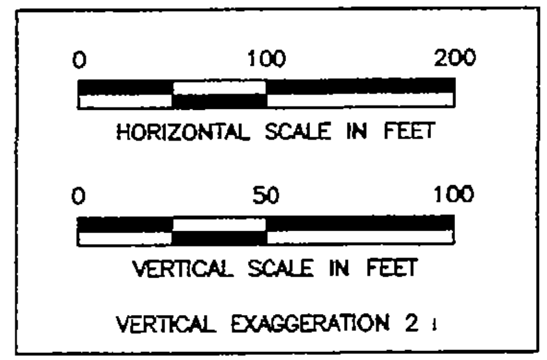
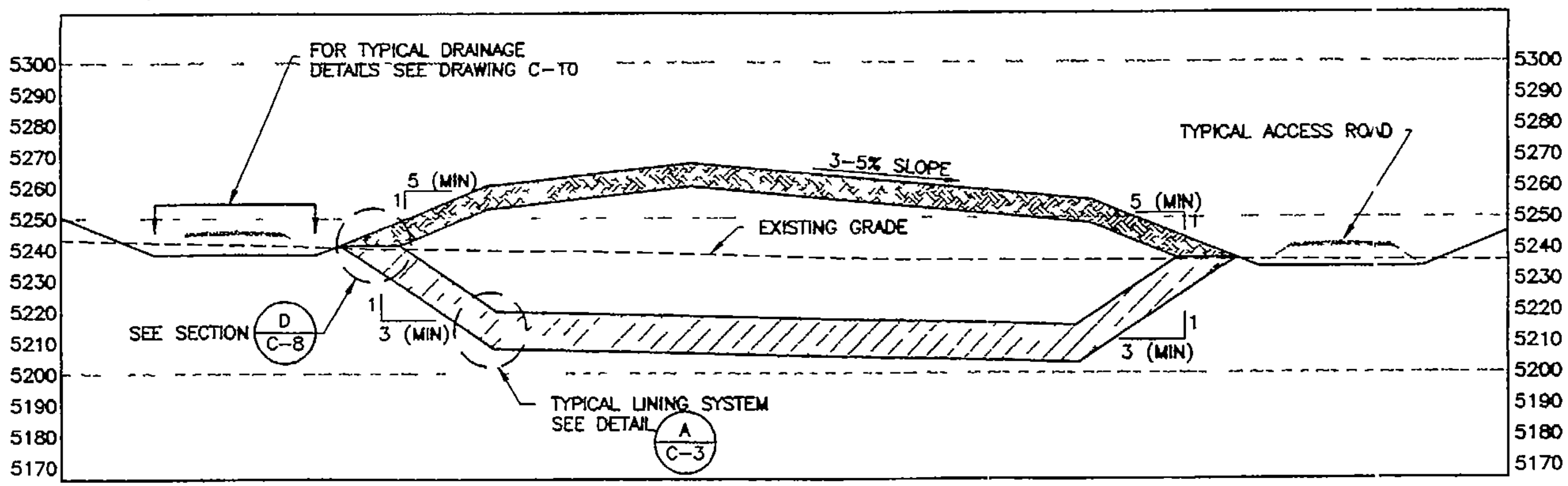
NOT FOR CONSTRUCTION
MAR 15 1996



TYPICAL TRIPLE-LINED CELL AND COVER CROSS-SECTION (A / C-)
NTS





TYPICAL TRIPLE-LINED CELL AND COVER CROSS-SECTION (B / C-6)
N.T.S.

NOTES

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. ALL FINAL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ELEVATIONS ETC) SHALL BE DETERMINED DURING DESIGN
3. ACCESS ROAD AREAS MAY BE REGRADED DURING DESIGN TO DEVELOP DRAINAGE CHANNELS. SEE SHEET C-10
4. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING. ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

NO.	DATE	REVISIONS	BY	CHK

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ENGINEER:	SES	SCALE:	AS NOTED
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DATE:		DATE:	

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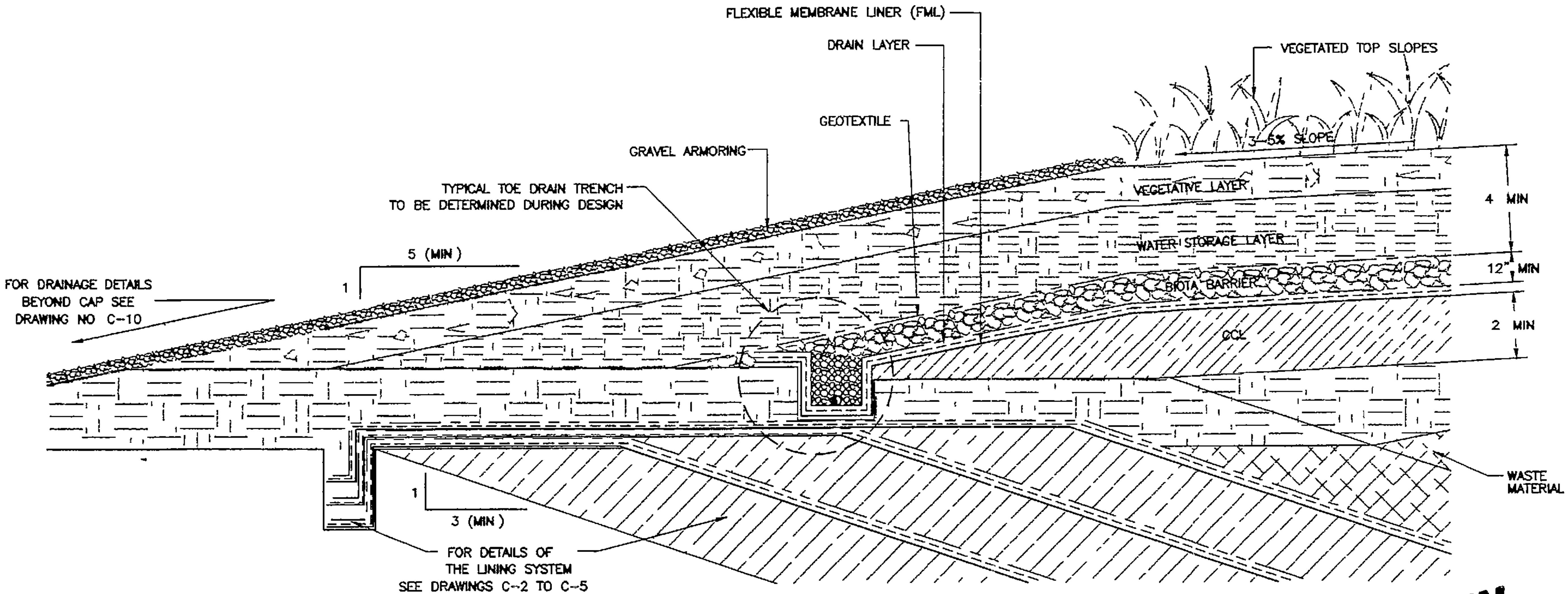
TASK 93-03
COMMERCE CITY COLORADO

CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL AND COVER CROSS-SECTIONS

DRAWING NO: C-7

8 / 11



TYPICAL COVER SECTION (D / C-6)
NTS.

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LEGEND

- - - - - - - - - -	GEONET
—— — — ——	GEOTEXTILE
————————	FLEXIBLE MEMBRANE LINER (FML)
CCL	COMPACTED CLAY LINER

NOTES

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 TOE DRAIN TRENCH SHALL BE DESIGNED TO POSITIVE DRAIN AND CONSTRUCTED TO AVOID DAMAGE TO THE UNDERLYING GEOSYNTHETIC MATERIALS DIMENSIONS ARE TO BE DETERMINED DURING DESIGN

3. LENGTHS OF LAPS, SPLICES OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC.

4 ALL FINAL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN

5 ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY

6 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

NO.	DATE	REVISIONS	BY	CHK	DRAWN: SES	PROJECT NO: 21907
					ENGINEER: SES	SCALE: NONE
					CHECKED:	APPROVED:
					DATE:	DATE:

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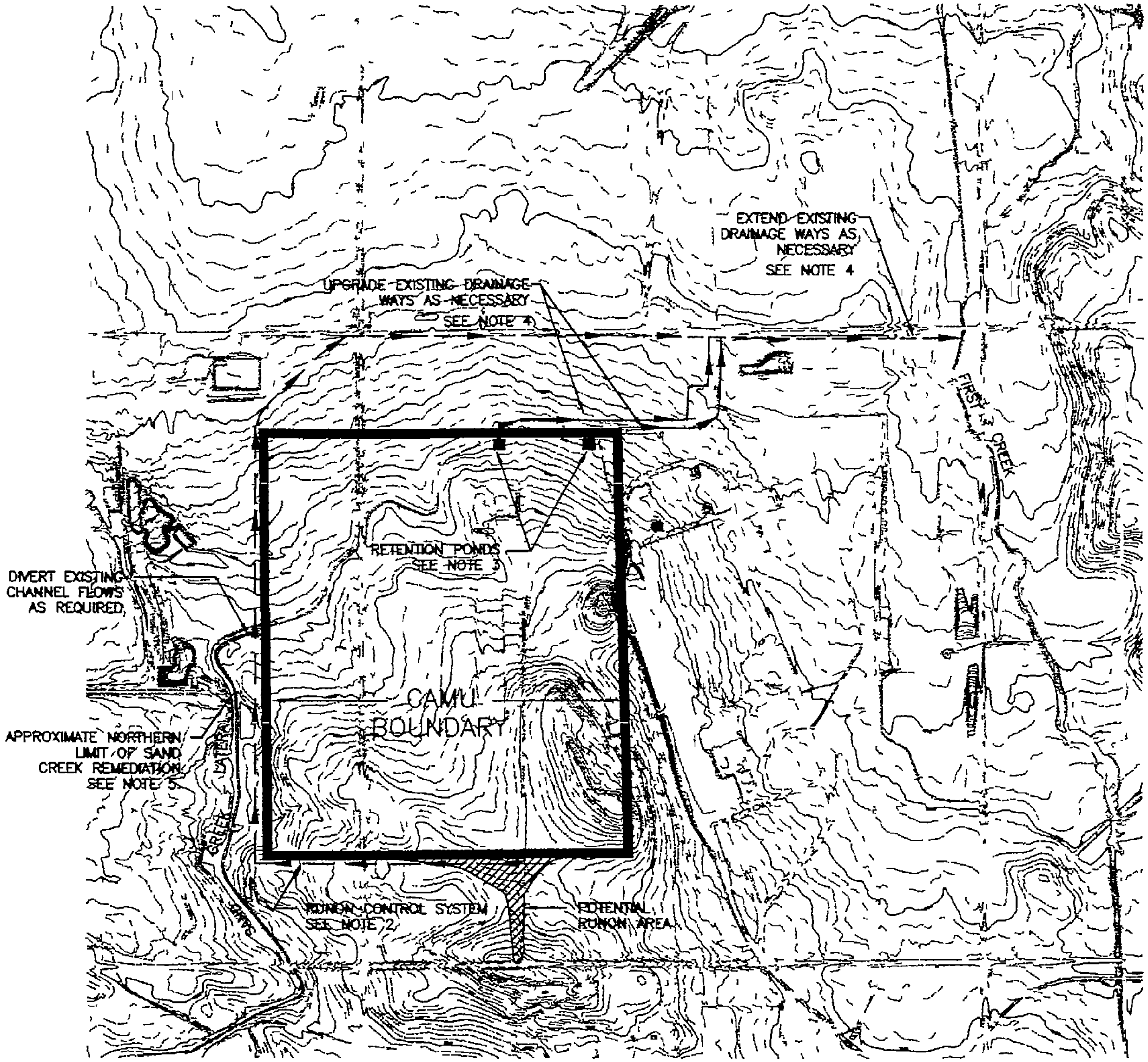
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL COVER SECTION

DRAWING NO: C-8

9 / 11



N

0	1000	2000

SCALE IN FEET

CONTOUR INTERVAL = 2 FT

LEGEND

- CAMU BOUNDARY
- RUNON CONTROLS
- EXISTING DRAINAGE WAYS
- EXISTING DRAINAGE WAYS PROPOSED FOR USAGE
- NEW/EXTENDED DRAINAGE WAYS
- INDEX CONTOURS (10)
- INTERMEDIATE CONTOURS (2)

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NOTES

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 RUN-ON CONTROLS SUCH AS DITCHES BERMS SWALES ETC SHALL BE IMPLEMENTED PRIOR TO CONSTRUCTION OPERATIONS TO DIVERT RUNON AWAY FROM ACTIVE WASTE MANAGEMENT AREAS WASTE MANAGEMENT AREAS MAY INCLUDE LANDFILL CELLS WASTE TREATMENT AREAS AND DECONTAMINATION FACILITIES THESE DIVERTED FLOWS SHALL BE DIRECTED IN A CONTROLLED MANNER TO EXISTING DRAINAGE WAYS

3 DURING OPEN CELL OPERATIONS RUNOFF CONTROLS SHALL BE INSTALLED AND MAINTAINED TO COLLECT FLOWS FROM THE LANDFILL CELL AREA, AND OTHER WASTE TREATMENT/HANDLING AREAS. THIS COLLECTED RUNOFF SHALL BE CHANNELED TO RETENTION PONDS AND HANDLED AS DISCUSSED IN THE DESIGN NARRATIVE. ONCE THE CELLS ARE COVERED COLLECTED FLOWS FROM WITHIN THESE AREAS MAY BYPASS THE RETENTION PONDS AND BE DIRECTLY DISCHARGED TO EXISTING DRAINAGE WAYS

4 EXISTING DRAINAGE WAYS DESIGNATED TO RECEIVE FLOWS FROM THE CAMU OR ASSOCIATED DIVERSIONS SHALL BE ANALYZED FOR ADEQUATE CAPACITY SOME ENHANCEMENTS MAY BE REQUIRED EXTENSIONS TO EXISTING DRAINAGE WAYS MAY ALSO BE NECESSARY

5 FOR ADDITIONAL INFORMATION ON THE SAND CREEK LATERAL REMEDIATION SEE THE DETAILED ANALYSIS OF ALTERNATIVES VOLUME III CHAPTER 18

6 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS

NO.	DATE	REVISIONS	BY	CHK

DRAWN: SES	PROJECT NO: 21907
ENGINEER: SES	SCALE: AS NOTED
CHECKED:	APPROVED:
DATE:	DATE:

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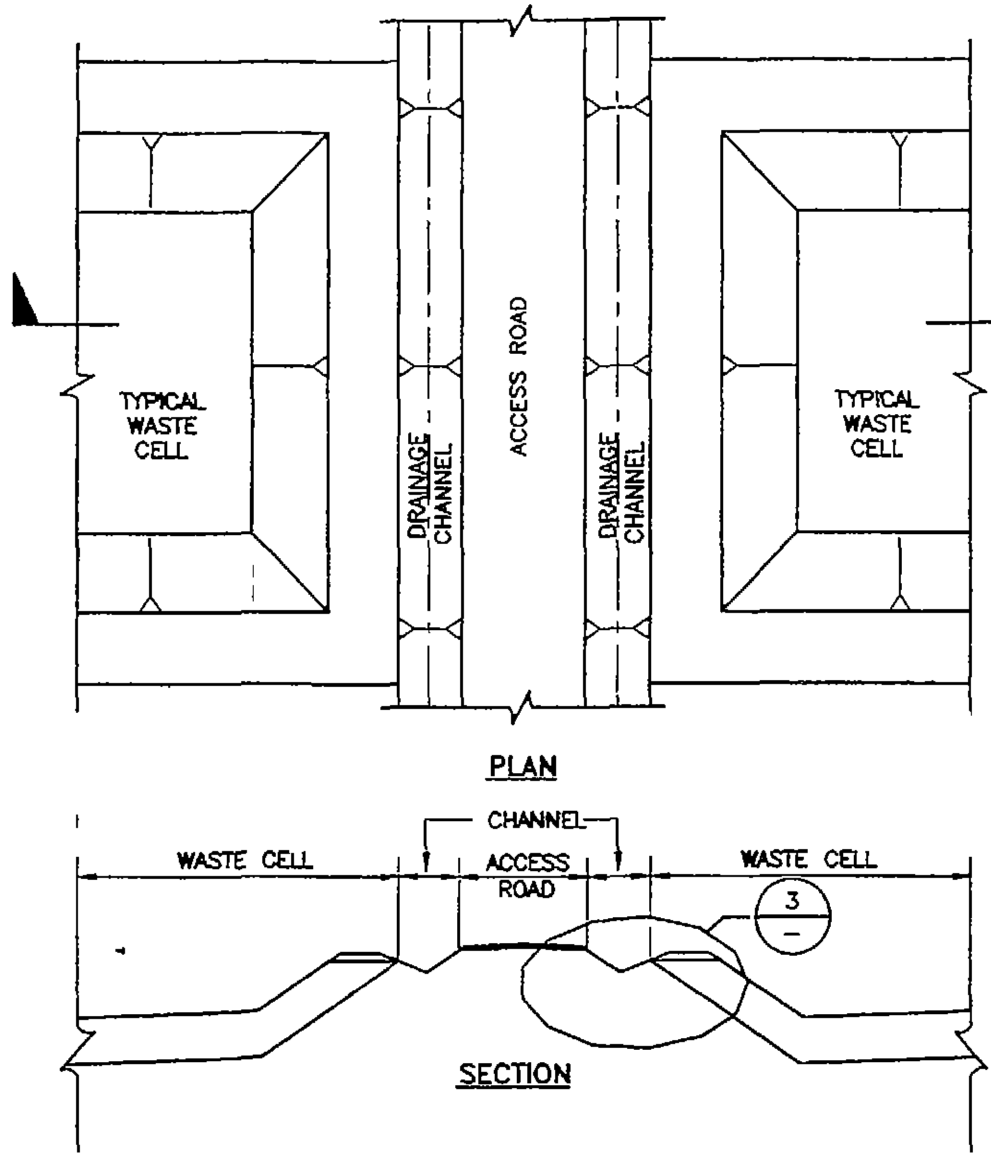
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

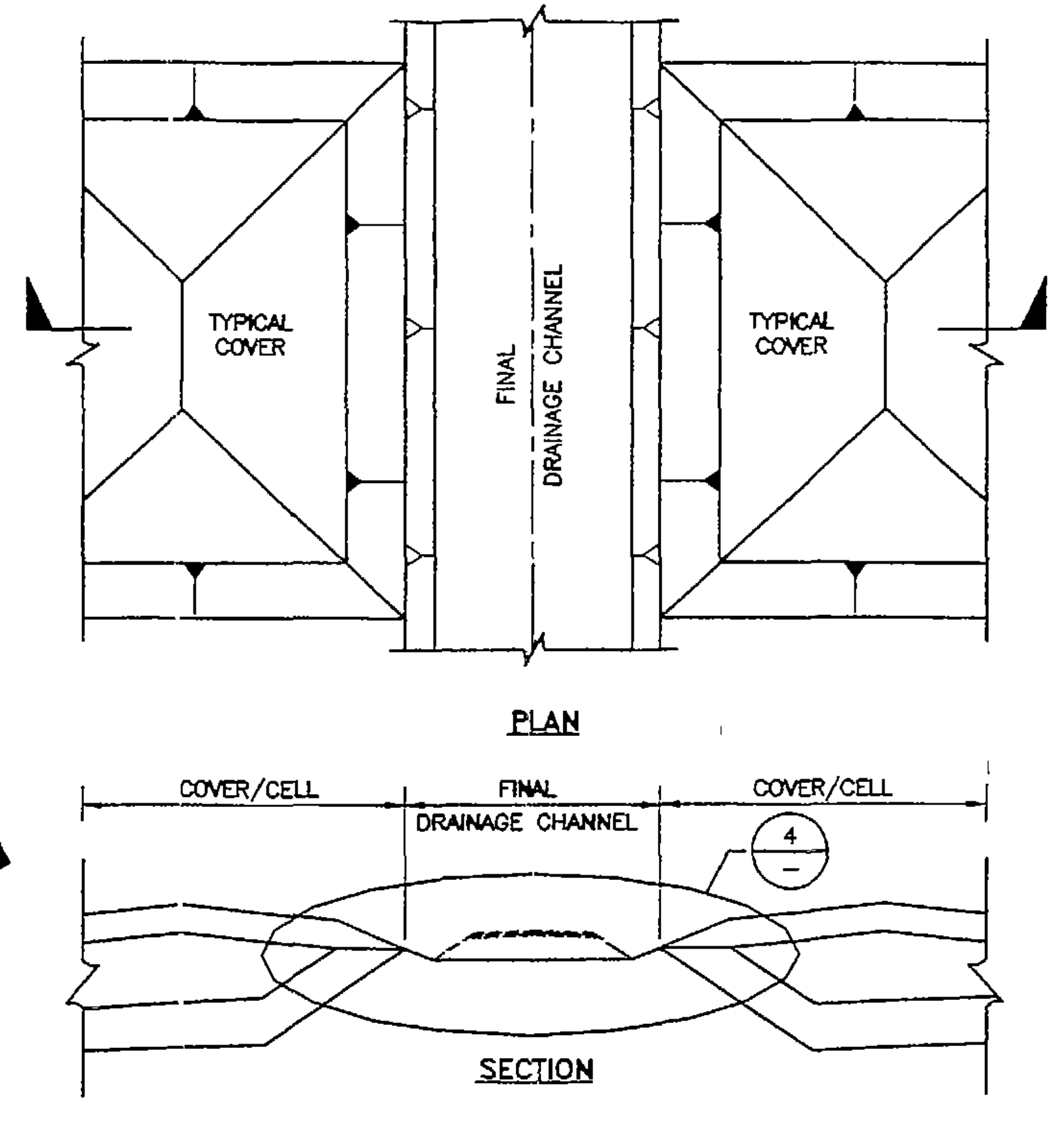
TYPICAL SITE DRAINAGE PLAN

DRAWING NO: C-9

10 / 11



TYPICAL CELLS DURING OPERATION (1)
N.T.S.



TYPICAL COVER/CELLS AFTER CLOSURE (2)
N.T.S.

PRELIMINARY
NOT FOR CONSTRUCTION
MAR 15 1996

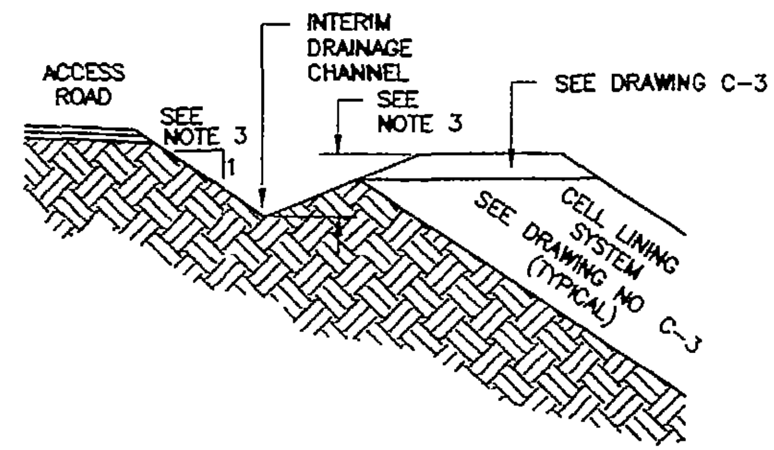
NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

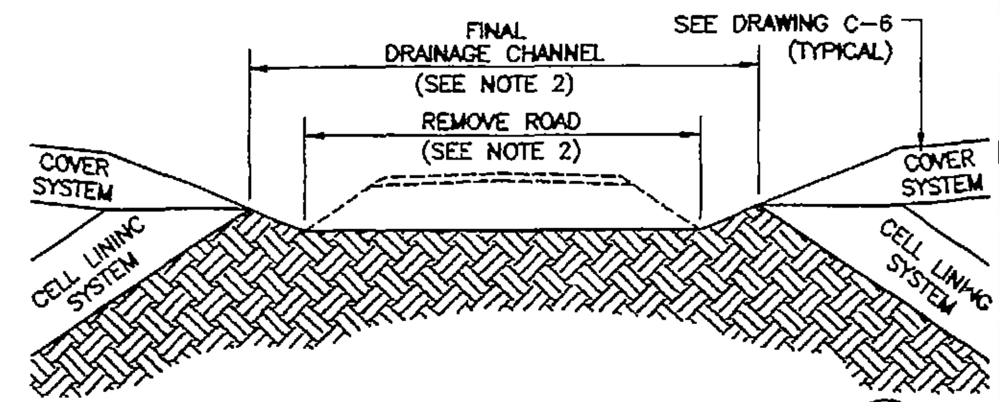
2 REGRADE ACCESS THE ROAD/INTERIM SWALE AREA TO DEVELOP ADEQUATE FLOW AREA FOR THE FINAL DRAINAGE DITCH SYSTEM

3 ALL DIMENSIONS (SLOPES THICKNESSES LENGTHS DEPTHS ETC) AND PROVISIONS FOR EROSION CONTROL SHALL BE DETERMINED DURING DESIGN

4 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE. ALTERNATIVE COMPONENTS/LAYOUTS ARE SUBJECT TO CDPHE REVIEW AND APPROVAL. CDPHE MAY REQUIRE THE USE OF SPECIFIC COMPONENTS/LAYOUTS.



TYPICAL CHANNEL DETAIL BETWEEN CELLS (3)
N.T.S.
DURING OPEN CELL OPERATIONS



TYPICAL CHANNEL DETAIL BETWEEN CELLS (4)
N.T.S.
AFTER CLOSURE

NO.	DATE	REVISIONS	BY	CHK

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CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL SITE DRAINAGE PLANS
SECTIONS AND DETAILS

DRAWING NO: C-10
11 / 11

Attachment B2

CONCEPTUAL ENGINEERING ANALYSES

In the development of Table B1, CDPHE requested that certain conceptual engineering analyses be performed on the conceptual design shown in Attachment B1 and included a component of this design narrative These analyses are included in Attachment B2

The following conceptual engineering analyses were performed

- Foundation settlement
- Foundation bearing capacity
- Potential for excess hydrostatic pressure on the foundation
- Excavated slope stability, including seismic considerations
- Cover slope stability including seismic considerations

The results of these individual conceptual analyses indicate that the conceptual design will not be severely constrained by these design considerations The design of the landfill will include a more comprehensive evaluation of these and other design considerations

CONCEPTUAL FOUNDATION SETTLEMENT ANALYSIS

Harding Lawson Associates
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SHEET 1 OF 67
JOB NO 21907-705011.1
DATE 2/13/96
COMPUTED BY A. Hernandez
CHECKED BY D Bay

PROJECT RMA 93-03/CDD
SUBJECT Geotechnical Calculations

SETTLEMENT EVALUATION

Purpose: Evaluate settlement of foundation soils to assess impact to composite liner system. Settlement will result from loads associated with the new liner, waste fill, and cover soil.

Idealized Soil Profile:

Appendix R* indicates, that the soil profile consists of 5' to 58' of Alluvium over Rock. The Alluvium consists of 65% clay (CL/CH), 35% Clayey Sand (SC), and 5% other soil types. Appendix B indicates that approximately the upper 30' of soil will be excavated to construct the disposal cells. Review of 33 boring logs in Appendix R indicate that 24 logs encountered rock at a depth less than 30'. Therefore, from a settlement standpoint, the worst case would consist of approximately 30' of clay underlying the new cells.

Appendix K, states that the groundwater level is 20' to 70' below existing grades. The shallow groundwater level may be due to a leaking watermain. The design assumption is that groundwater will be at least 20' below the liner bottom. From a settlement standpoint, assume the initial watertable is at a depth of the proposed liner bottom and that it is lowered below the depth of soil after liner construction; this is a conservative assumption.

I agree

* HLA, 1996. Proposed Corrective Management Unit Design Document, Rocky Mountain Arsenal, Commerce City, Co. Vol I and II. January 12.

Clay Properties:

The following data was taken from information in Appendix R:

- Liquid Limit 25-88, Avg ≈ 45 (LL)
- Plasticity Index 5-75, Avg ≈ 30 (PI)
- Water Content Avg ≈ 18% for clays (W_n) below 30' (92 samples)
- Blow Counts Avg 20 to 30 blows/FT (BPF)

From this data & published correlations settlement parameters were derived as follows:

- Compression Index, C_{EC}

  A chart of C_{EC} vs W_n indicates $C_{EC} \approx 0.05$ for a $W_n \approx 18\%$.

- Recompression Index, C_{ER}

  experience on [illegible]

  The C_{ER} is known to be equal to approximately $\frac{1}{10}$ to $\frac{1}{20}$ of C_{EC}.

  Assume $C_{ER} = \frac{1}{10} C_{EC} = 0.005$

- Unit Weight, γ_T

  No data - may be high

  For clays and clayey sands assume a total unit weight of 130 pcf

- Preconsolidation Pressure, P_c'

  $P_c' = P_o'(OCR)$
  where P_o' = insitu effective stress
  OCR = Overconsolidation Ratio

(Ladd et al. 1977)
(& Schmertmann 1977)

$$(OCR)^{0.8} = \frac{(S_u/P_o')_{\text{overconsolidated}}}{(S_u/P_o')_{\text{Normally Consolidated}}}$$

Lambe & Whitman (1969)
Soil Mechanics

pg 3 of 67

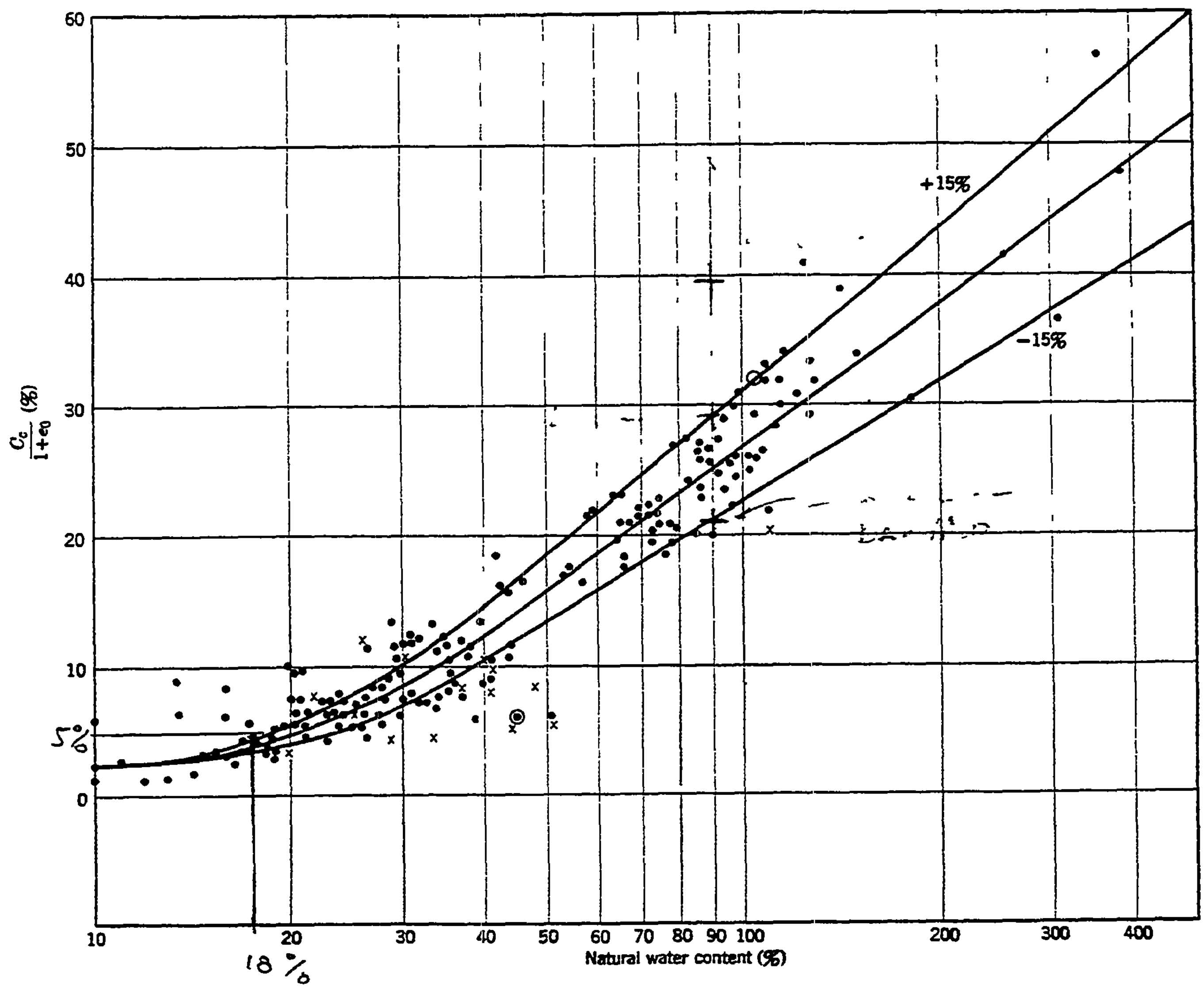

Fig 22 1(c)

Unloading

Upon unloading a soil sample in confined compression the sample expands, as illustrated in Fig 20.5. The parameter most commonly used to measure the expansion is

$$C_s = \text{swell index} = \frac{-\Delta e}{\Delta \log \bar{\sigma}_v} \qquad (22\ 1)$$

C_s is always much smaller than C_c for virgin compression. This is illustrated by the data in Table 22 1 By consolidating a series of specimens to different maximum vertical stresses $\bar{\sigma}_{vm}$ before unloading, a series of expansion curves are obtained Such expansion curves tend to be parallel. Note, for example, in Fig. 20.5 that the unload portion from the first cycle and that from the second cycle are approximately parallel. Thus C_s is more or less the same for all $\bar{\sigma}_{vm}$

In Fig 22.2 values of swell index have been plotted against the corresponding liquid limit. C_s increases with increasing liquid limit, but any relation between C_s and w_l will be only approximate.

Reloading

If a clay is subjected to many cycles of load and unload, the compression and recompression curves tend toward each other, i.e , C_c for recompression approximately equals C_s.

The compressibility of a soil depends very much on the stress level in relation to the stress history For example, we can see from Fig 20 5 that the compressibility of the Cambridge clay is much greater in the virgin compression range than it is in the recompression range; this means the compression index above $\bar{\sigma}_{vm}$ is much greater than below $\bar{\sigma}_{vm}$. This important fact presents the engineer

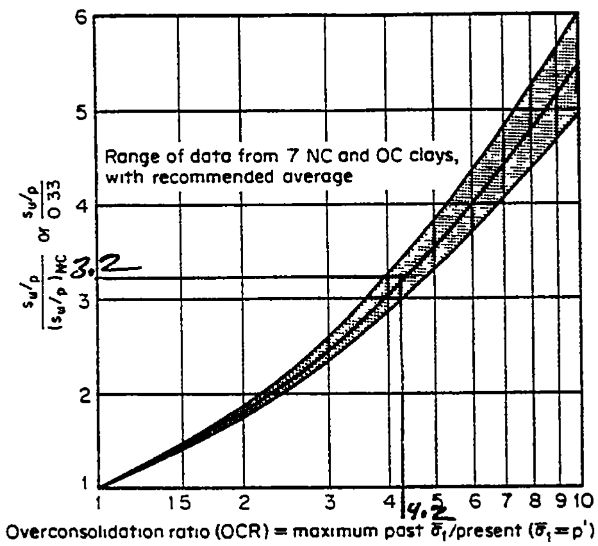

FIG 3.71 Normalized s_u/p' ratio vs OCR for use in estimating OCR from q_c in clays. [*From Schmertmann (1977)*[78] *Reprinted with permission of the Federal Highway Administration.*]

Compression in Sands

Sands and other cohesionless granular materials undergo a decrease in void volume under applied stress, caused primarily by rearrangement of grains (Art 3.5.4) Small elastic compression of quartz grains may occur In most cases the greater portion of compression is essentially immediate upon application of load

Expansion

An increase in volume occurs as a result of reduction in applied stress, increase in moisture content or mineralogical changes in certain soil and rock materials (*see Arts 3.5.4 and 10.6*)

3.5.3 ROCK DEFORMATION MEASUREMENTS

Methods Summarized

Laboratory Testing

Intact specimens are statically tested in the laboratory in the triaxial and unconfined compression apparatus, dynamic properties are measured with the resonant column device or by ultrasonic testing (ASTM 2845) A summary of parameters measured, apparatus description, and test performance is given on Table 3.36

The data are normally used for correlations with in situ test data

In Situ Testing

IMPORTANCE In situ testing provides the most reliable data on the deformation characteristics of rock masses because of the usual necessity to account for the effects of mass defects from discontinuities and decomposition

REQUIREMENTS Determination of moduli in situ requires that the deformation and the stress producing it are measurable and that an analytical method of describing the geometry of the stress deformation relationship is available

Analytical methods are governed by the testing method Modulus is the ratio of stress to strain, and since strain is the change in length per total length, the deflection that is measured during in situ testing must be related to the depth of the stressed zone to determine strain The depth of the stressed zone may be determined by instrumentation (*see Chap 4*), or the Boussinesq equations may be used to determine stress distributions The values for the modulus E are given in terms of the test geometry, the applied pressure, the deflection, and Poisson's ratio

STATIC MODULI Determined from plate-jack tests, radial jacking and pressure tunnel tests, flat-jack tests, borehole tests (dilatometer and Goodman jack), and triaxial compression tests

DYNAMIC MODULI Determined from seismic direct velocity tests (*see Art 2.3.2*) and the 3-D velocity probe (sonic logger) (*see Art. 2.3.6*) Relationships between seismic velocities and dynamic moduli are given on Table 3.35 In moduli computations the shear-wave velocity V_s is used rather than the compression-wave velocity V_p because water in rock fractures does not affect V_s, whereas it couples the seismic energy across joint openings, allowing much shorter travel times for P waves than if an air gap existed Dynamic moduli are always higher than static moduli because the seismic pulse is of short duration and very low stress level, Where $\left(\frac{S_u}{P_o'}\right)_{overconsol}$ is the ratio of the undrained shear strength of the clay divided by its insitu effective stress and $\left(\frac{S_u}{P_o'}\right)_{normally\ Consol.}$ is the ratio if the clay were normally consolidated (OCR = 1.0).

$$S_{u\,over\,consol} \approx 120 \times BPF = 120 \times 25 = 3000\,psf$$

$$P'_{o\,insitu\,@D=45'} = 130 \times 20' + (130-62.4)25' = 4290\ psf \approx 4300\,psf$$

$$\therefore \left(\frac{S_u}{P_o'}\right)_{over\,consol} = \frac{3000}{4300} = 0.70$$

Skempton 1954 $\longrightarrow$ $\left(\frac{S_u}{P_o'}\right)_{Normally\,Consol} = 0.11 + 0.0037\ PI$

$$= 0.11 + 0.0037(30)$$
$$= 0.22$$

$$(OCR)^{0.8} = \frac{0.70}{0.22} = 3.2 \quad \therefore OCR = 4.2$$

$$P'_{c\,@D=45'} = P'_o(OCR) = 4300 \times 4.2 \approx 18{,}000\ psf$$

Load Changes:

Load changes during construction will occur as follows:

1. Remove 30' of overburden
2. Construct $9\frac{1}{2}'$ to $12\frac{1}{2}'$ thick liner. γ_T liner from Appendix R $\approx$ 125 pcf.
3. Place waste fill to height up to 30' above original grades

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SHEET 6 OF 67
JOB NO 21907-705011 1
DATE 2/13/96
PROJECT RMA 93-03 / CDD
COMPUTED BY L. Herlache
SUBJECT Geotech. Calcs
CHECKED BY D [illegible]

(Appendix B, Dwg C-7). Assume $\gamma_T = 125$ pcf.

4. Lower watertable to below clay layer.

Assumed Profile:

ELEVATION, FT

5280

5270 — Maximum Final Grades

5260

Cover/Waste Fill
$\gamma_T \approx 125$ pcf

5240 — Original Grades

5220 — Original watertable

Liner $\gamma_T \approx 125$ pcf

Bottom of Liner

5200

Clay
$\gamma_T = 130$ pcf
$C_{\epsilon c} = 0.05$
$C_{\epsilon r} = 0.005$
$P_c' \approx 18{,}000$ psf

5180 — Final Watertable

Rock (Assume incompressible)

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SHEET 7 OF 67
JOB NO 21907-705011 1
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COMPUTED BY A. Herlache
SUBJECT Geot. Calcs
CHECKED BY D Bef

Settlement Calculations:

The data indicates that settlement will only be associated with recompression of the clay and that the loads will not be large enough to exceed the preconsolidation pressure. Therefore:

$$S = HC_{er} \log\left(\frac{P_f'}{P_i'}\right)$$

where P_f' = the final effective stress after adding the new waste fill, liner, and cover, and after lowering the water-table.

P_i' = the initial effective stress taken as that occurring after excavation to conservatively account for rebound during unloading; assume that the watertable is at the bottom of the excavation.

See the attached spreadsheet printout for the results of the settlement calculations.

Summary of Result:

Thickness of New Fill (FT)	Settlement (inches) Ignoring Water-Table Change	Settlement (inches) With Watertable Change
30	1.4	1.5
60	1.9	1.9

CONSOLIDATION SETTLEMENT CALCULATIONS
RMA 93-03/CDD
HLA Project No 21907-705011 1
February 13, 1996
By A. Herlache Reviewed By

I Neglecting Watertable Change
New Fill Thickness (Feet) 60
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change in Thickness (inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Cec	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	7500	0	7669	0 005	0 050	0 008	0 000	0 5
2	5 0	10 0	7 5	5 0	507	18000	7500	0	8007	0 005	0 050	0 006	0 000	0 4
3	10 0	15 0	12 5	5 0	845	18000	7500	0	8345	0 005	0 050	0 005	0 000	0 3
4	15 0	20 0	17 5	5 0	1183	18000	7500	0	8683	0 005	0 050	0 004	0 000	0 3
5	20 0	25 0	22 5	5 0	1521	18000	7500	0	9021	0 005	0 050	0 004	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	7500	0	9359	0 005	0 050	0 004	0 000	0 2
Total				30 0										1.9

II Accounting for Watertable Change
New Fill Thickness (Feet) 60
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change in Thickness (inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Cec	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	7500	156	7825	0 005	0 050	0 008	0 000	0 5
2	5 0	10 0	7.5	5 0	507	18000	7500	468	8475	0 005	0 050	0 006	0 000	0 4
3	10 0	15 0	12.5	5 0	845	18000	7500	780	9125	0 005	0 050	0 005	0 000	0.3
4	15 0	20 0	17.5	5 0	1183	18000	7500	1092	9775	0 005	0 050	0 005	0 000	0.3
5	20 0	25 0	22.5	5 0	1521	18000	7500	1404	10425	0 005	0 050	0 004	0 000	0 3
6	25 0	30 0	27.5	5 0	1859	18000	7500	1716	11075	0 005	0 050	0 004	0 000	0 2
Total				30 0										1.9

Pg 8 of 67

CONSOLIDATION SETTLEMENT CALCULATIONS
RMA 93-03/CDD
HLA Project No 21907-705011 1
February 13, 1996
By A Herlache Reviewed By

I Neglecting Watertable Change

New Fill Thickness (Feet) 30
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change in Thickness (Inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Ceo	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	3750	0	3919	0 005	0 050	0 007	0 000	0 4
2	5 0	10 0	7 5	5 0	507	18000	3750	0	4257	0 005	0 050	0 005	0 000	0 3
3	10 0	15 0	12 5	5 0	845	18000	3750	0	4595	0 005	0 050	0 004	0 000	0 2
4	15 0	20 0	17 5	5 0	1183	18000	3750	0	4933	0 005	0 050	0 003	0 000	0 2
5	20 0	25 0	22 5	5 0	1521	18000	3750	0	5271	0 005	0 050	0 003	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	3750	0	5609	0 005	0 050	0 002	0 000	0 1
Total				30 0										1 4

II Accounting for Watertable Change

New Fill Thickness (Feet) 30
New Fill Unit Weight (Pcf) 125

Layer No	Layer Depth (Feet)			Layer Thickness (Feet)	Initial Effective Stress (Psf)	Preconsol Pressure (Psf)	Stress Change (Psf)		Final Effective Stress (Psf)	Compression Ratio		Vertical Strain		Change in Thickness (Inches)
	Top	Bottom	Average				New Fill	Water-Table Change		Rebound Cer	Virgin Ceo	Recompress	Virgin	
1	0 0	5 0	2 5	5 0	169	18000	3750	156	4075	0 005	0 050	0 007	0 000	0 4
2	5 0	10 0	7 5	5 0	507	18000	3750	468	4725	0 005	0 050	0 005	0 000	0 3
3	10 0	15 0	12 5	5 0	845	18000	3750	780	5375	0 005	0 050	0 004	0 000	0 2
4	15 0	20 0	17 5	5 0	1183	18000	3750	1092	6025	0 005	0 050	0 004	0 000	0 2
5	20 0	25 0	22 5	5 0	1521	18000	3750	1404	6675	0 005	0 050	0 003	0 000	0 2
6	25 0	30 0	27 5	5 0	1859	18000	3750	1716	7325	0 005	0 050	0 003	0 000	0 2
Total				30 0										1 5

pg 9 of 67

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SHEET 10 OF 67
JOB NO 21907-705011 /
DATE 2/13/96
PROJECT RMA 93-03/CDD
COMPUTED BY A. Harlacke
SUBJECT Geot. Calcs
CHECKED BY DBG

Conclusions:

The results indicate that the worst case settlement will be less than 2 inches. I most cases the liner system will be placed directly on rock; for this situation the settlement will be much smaller (likely less than ½ inch).

We judge that the liner system can be designed to accommodate these relatively low values of settlement.

Harding Lawson Associates
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SHEET 1 OF 2
JOB NO 21907 705011.1
DATE 3/12/96
COMPUTED BY BAC
CHECKED BY WGK

PROJECT BMA 93-03
SUBJECT Settlement Evaluation II

SUPPLEMENT TO CONCEPTUAL SETTLEMENT EVALUATION

THE SETTLEMENT EVALUATION (P.2 of 67 through p. 10 of 67, dated 2/13/96) CALCULATED VERY LITTLE SETTLEMENT FOR THE PARAMETERS USED. (≈1.9 in). Although the parameters used in the evaluation are considered highly conservative, an additional level of conservatism can be introduced by lowering the average number of blows/foot (penetration resista...) used in the original evaluation from 25 bpf to 17 bpf (a 1/3 reduction in assumed penetration resistance).

From p 2 of 67

$P_c' = P_o'(OCR)$ where P_c' is the preconsolidation pressure /
P_o' is the insitu effective stress
OCR is the overconsolidation ratio

and

$OCR^{(.8)} = \dfrac{(S_u/P_o')_{overconsolidated}}{(S_u/P_o')_{normally\ consolidated}}$ where S_u is the undrained shear strength
$P_o' = 4300$ psf (from p 5 of 67)

$S_u \approx 120 \times BPF$ (from p 5 of 67)

$\therefore S_u = 120 \times 17 = \underline{2{,}040\ psf}$

$\left(\dfrac{S_u}{P_o'}\right)_{OVER\ CONSOL} = \dfrac{2{,}040}{4300} = 0.4744$ and $\left(\dfrac{S_u}{P_o'}\right)_{normal\ consol} = 0.22$ (from p 5 of 67)

$OCR^{0.8} = \dfrac{0.47}{0.22} = 2.16 \qquad OCR = 2.6 \therefore$

P_c' @ D=45' $= P_o'(OCR) = 4300(2.6) = \underline{\underline{11{,}180\ psf}}$

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SHEET 2 OF 2
JOB NO 21907 705011.1
DATE 3/12/96
COMPUTED BY BAC
CHECKED BY [illegible]

PROJECT RMA 93-03
SUBJECT Settlement Evaluation II

The preconsolidation pressure used for the original evaluation (dated 2/13/96) was recalculated by reducing the estimated number of blows per foot by approx. 1/3 (25 bpf to 17 bpf). The reduction in BPF resulted in the following parameter changes

	Original Eval.	This Eval.
BPF	25	17
S_u	3000 psf	2040 psf
OCR	4.2	2.6
P_c'	18,000 psf	11,180 psf

Conclusion

The preconsolidation pressure recalculated based on a 1/3 reduction in penetration resistance is still higher than the maximum final effective stresses shown p. 8 & 9 of 67. This means that settlement of the foundation will follow the recompression portion of the consolidation curve and will still be approx. 2 inches for the parameters used.
A review of the blow counts given on the logs in App. R shows the 17 BPF value to be conservative (ave BPF is higher) for clays in the landfill area from 10' to 30' deep.

CONCEPTUAL FOUNDATION BEARING CAPACITY ANALYSIS

BEARING CAPACITY

Purpose: Check bearing capacity of landfill foundation to assess impact to Liner or other landfill Components

Idealized Soil Profile:

As indicated under the settlement calcs, the landfill will typically be underlain by rock; however, localized areas may be underlain by up to 30 feet of clays and clayey sands.

Groundwater will be at least 20 feet below the bottom of the liner system.

Material Properties:

Based on data in Appendix R.

- Undrained Shear Strength, Su

$S_u = 3000$ psf (See Pg 4)

- Unit Weight, γ_{TN}

$\gamma_T = 130$ pcf

- New Fill (Liner, Waste, Cover)

$\gamma_{TF} = 125$ pcf

Calculations:

Ult. Bearing Capacity =

$5.14\ S_u + \gamma_{TN} H$

Depth of assumed footing = height of native soil adjacent to the disposal cell

$= 5.14(3000) + (130 \times 30') = 19{,}320$ psf

$$\text{Load} = (\text{Height of Liner} + \text{waste} + \text{Cover})\, \gamma_{TF}$$
$$= 60' \times 125$$
$$= 7{,}500 \text{ ps}$$

$$FS = \frac{19320}{7{,}500} = 2.6$$

OK

Conclusions:

The calculations show that the factor of Safety against bearing failure is at least 2.6. These calcs include several very conservative assumptions including ignoring the presents of the rock below the clay soils, neglecting the shear strength of the soil above the bottom of the liner, and neglecting the fact that the landfill edges are sloped. Therefore, bearing capacity of the foundation soils is not a concern.

CONCEPTUAL ANALYSIS FOR EXCESS HYDROSTATIC PRESSURE ON THE LANDFILL FOUNDATION

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SHEET 13 OF 67
JOB NO 21907-705011.1
DATE 2/13/96
PROJECT RMA 93-03/CDD
COMPUTED BY A. Herlache
SUBJECT Geot. Calcs
CHECKED BY [signature]

POTENTIAL FOR EXCESS HYDROSTATIC PRESSURE

Purpose: To evaluate the potential for hydrostatic uplift on the bottom of the liner.

Groundwater Conditions:

Groundwater has been reported at a depth of 20 to 70 feet below existing grades. The shallower groundwater depth is believed do to a leaking watermain which will be repaired. The design assumptions state that the groundwater level will maintained at a depth of at least 20 feet below the bottom of the liner.

Conclusions:

The groundwater level is anticipated to be below the bottom of the liner at all times. Therefore, uplift associated with excess hydrostatic pressure is not a concern.

If the groundwater rises above the bottom of the liner, it would have to rise to a height approximately equal to twice the liner thickness above the bottom of the liner before the bouyancy effect would equal the liner weight. Once the waste is placed on the liner, it could resist higher uplift forces.

CONCEPTUAL EXCAVATED SLOPE STABILITY ANALYSIS

SLOPE STABILITY - LINER SYSTEM / EXCAVATED SLOPES

Purpose: To evaluate the stability of the excavated slopes and the liner system prior to filling the disposal cells with waste. This is a temporary condition. Based on the strength of the native soils, the critical surface will be above the native soils.

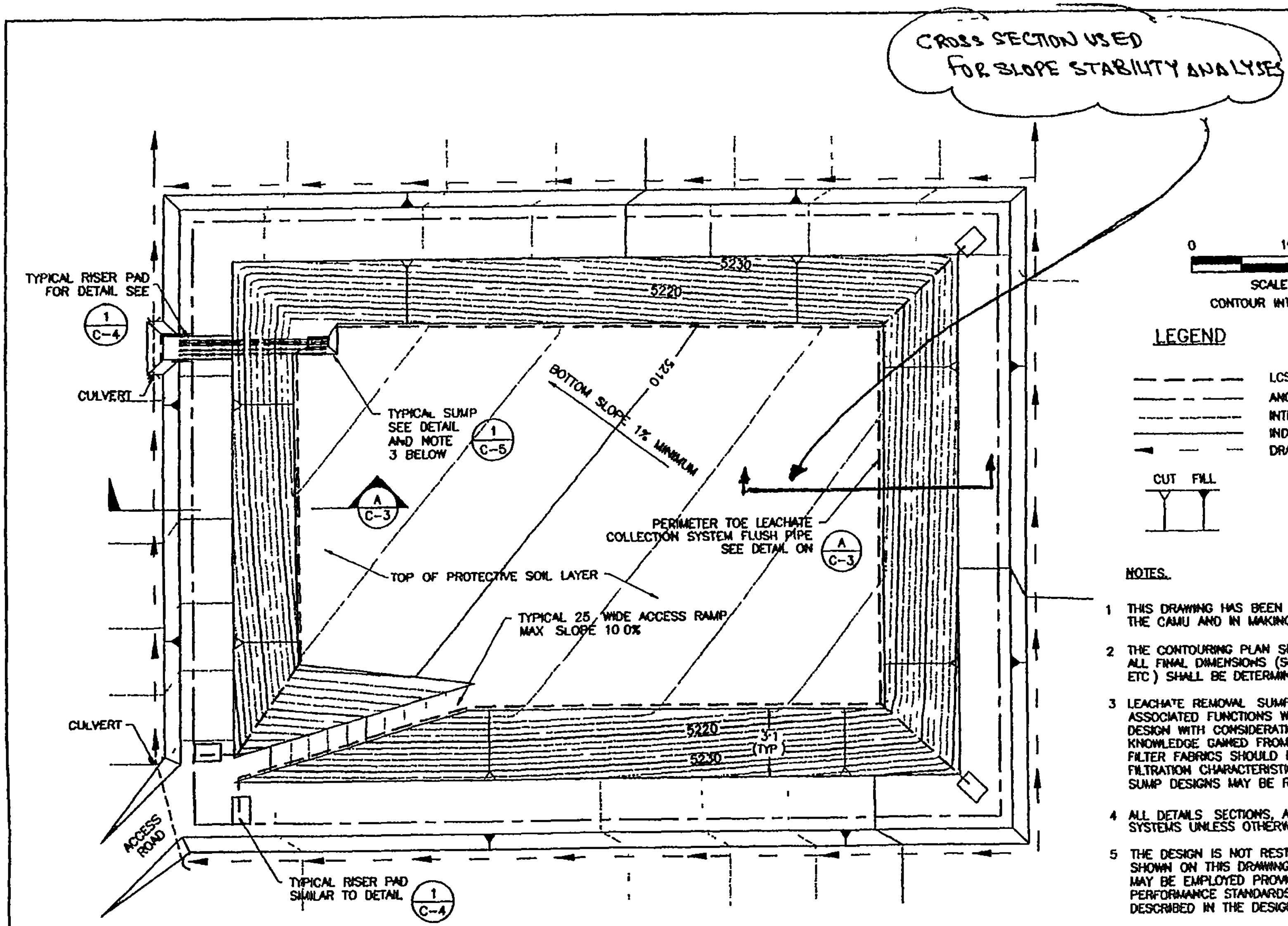
Slope Geometry:

A cross-section of the eastern slope was analyzed as shown on the attached Drawing No. C-2. The detailed geometry of the liner system is shown on Drawing No. C-3. We analyzed the double-lined cell configuration which can also be used to infer information regarding the stability of the Triple-Lined cell configuration.

Material Properties:

The following material properties were selected based on published literature:

- Protective Soil Layer / Structural Fill
  - Assume compacted sand
  - $\phi = 35°$
  - $c = 0$
  - $\gamma_T = 115$ pcf
- Geosynthetic Layers Interface
  - Assume textured HDPE for FML
  - $\phi = 12°$
  - $c = 0$
- CCL
  - $\phi = 0$
  - $c = 700$ psf
  - $\gamma_T = 125$ pcf



PRELIMINARY
NOT FOR CONSTRUCTION
JAN 1 2 1996

0 100 200

SCALE IN FEET

CONTOUR INTERVAL = 2 FT

LEGEND

- LCS COLLECTION/FLUSH PIPING
- ANCHOR TRENCH
- INTERMEDIATE CONTOURS
- INDEX CONTOURS
- DRAINAGE CHANNEL

CUT FILL

NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 THE CONTOURING PLAN SHOWN IS AN EXAMPLE LAYOUT ALL FINAL DIMENSIONS (SLOPES THICKNESS LENGTHS, DEPTHS, ETC) SHALL BE DETERMINED DURING DESIGN

3 LEACHATE REMOVAL SUMP ACCESS FLUSHING OPERATIONS AND ASSOCIATED FUNCTIONS WILL BE CAREFULLY ANALYZED DURING DESIGN WITH CONSIDERATION GIVEN TO THE OPERATING KNOWLEDGE GAINED FROM THE BASIN F WASTE PILE. GEOTEXTILE FILTER FABRICS SHOULD BE CHOSEN TO HAVE ADEQUATE FILTRATION CHARACTERISTICS TO AVOID CLOGGING ALTERNATIVE SUMP DESIGNS MAY BE REQUIRED.

4 ALL DETAILS SECTIONS, AND PLANS REPRESENT TRIPLE-LINED SYSTEMS UNLESS OTHERWISE NOTED

5 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING. ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE

NO.	DATE	REVISIONS	BY	CHK

DRAWN: MLK | PROJECT NO: 21907
ENGINEER: SCS | SCALE: AS NOTED
CHECKED: BAC | APPROVED: RZK
DATE: | DATE:

Harding Lawson Associates
Engineering and Environmental Services
Suite 2400
707 Seventeenth Street
Denver Colorado 80202
(303) 292-5365

ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

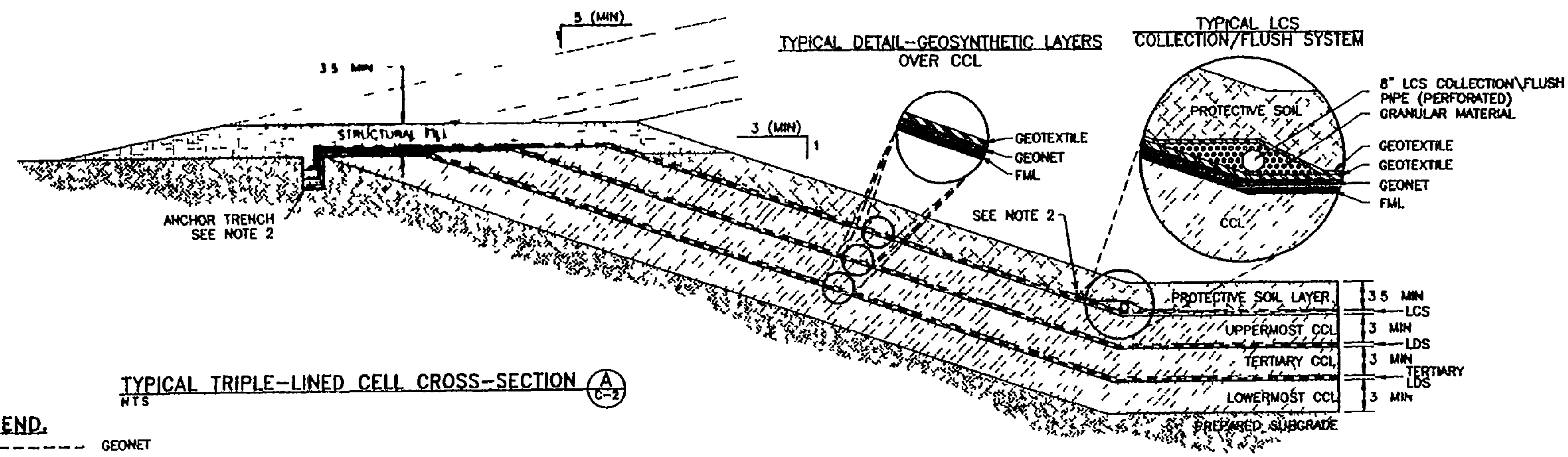
CAMU DESIGNATION DOCUMENT
DESIGNATION LEVEL DRAWINGS

TYPICAL CELL PI

DRAWING NO. C-2

3 / 11

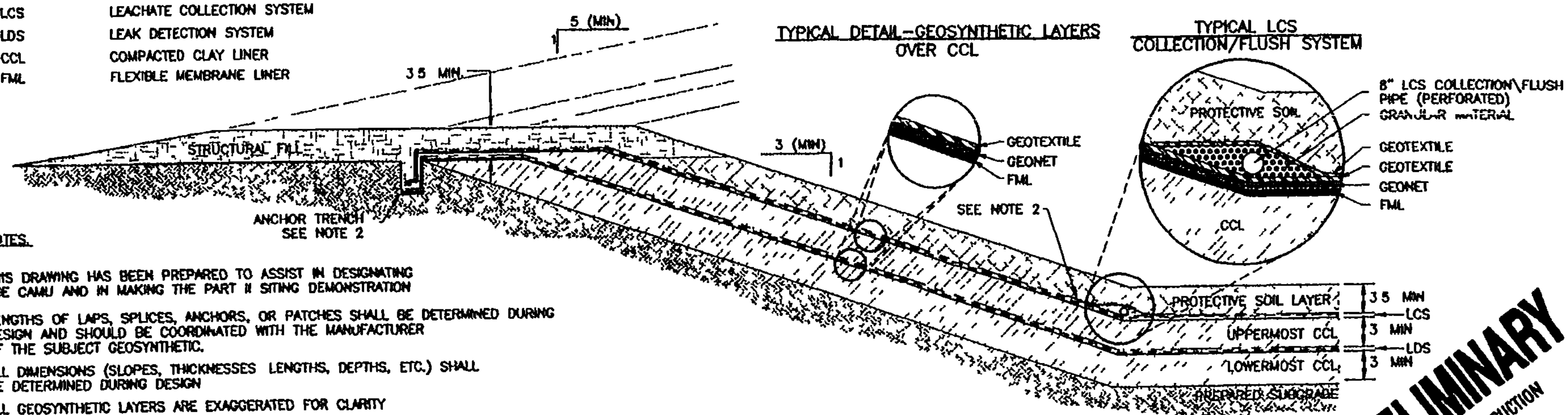
pg 40 of 67



TYPICAL TRIPLE-LINED CELL CROSS-SECTION (A / C-2)
NTS

LEGEND.

- - - - - - - -	GEONET
—— — — ——	GEOTEXTILE
————————	FLEXIBLE MEMBRANE LINER
LCS	LEACHATE COLLECTION SYSTEM
LDS	LEAK DETECTION SYSTEM
CCL	COMPACTED CLAY LINER
FML	FLEXIBLE MEMBRANE LINER



NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION
2. LENGTHS OF LAPS, SPLICES, ANCHORS, OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC.
3. ALL DIMENSIONS (SLOPES, THICKNESSES LENGTHS, DEPTHS, ETC.) SHALL BE DETERMINED DURING DESIGN
4. ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY
5. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE.

TYPICAL DOUBLE-LINED CELL CROSS-SECTION (B / TYP)
N.T.S.

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JAN 12 1996

DRAWN: MLK	PROJECT NO: 21997	Harding Lawson Associates Engineering and Environmental Services	ROCKY MOUNTAIN ARSENAL SOIL SUPPORT PROGRAM TASK 93-03 COMMERCE CITY, COLORADO
ENGINEER: SCS	SCALE: AS NOTED		CAMU DESIGNATION DOCUMENT DESIGNATION LEVEL DRAWINGS
CHECKER: BAC	APPROVER: RRK		TYPICAL CELL LINER SYSTEM SECTIONS AND DETAILS
DATE:	DATE:		DRAWING NO. C-3 — 4/11

NO.	DATE	REVISIONS	BY	CHK

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Harding Lawson Associates
Engineering and Enviromental Services

JOB NO 21907-705011.1
DATE 2/13/96
PROJECT RMA 93-03/CDD
COMPUTED BY A. Herlache
SUBJECT Geot. Calcs.
CHECKED BY D

- Alluvial (Native) Soil

$\phi = 0$
$C = 3000\ psf$
$\gamma_T = 130\ pcf$

Calculations:

The slope stability calculations were performed using the same methodology as was used to evaluate the cover system.

We first analyzed the stability under static loads. A search for the critical surface yielded a factor of safety = 1.8. The critical failure surface was along the shallowest geosynthetic layer. We performed another analysis forcing the failure surface through the deeper geosynthetic layer and the factor of safety rose to 2.5.

We then performed a psuedo-static analysis using the same seismic coefficient as was used to analyze the cover system. The analysis yielded a minimum factor of safety of 1.5.

The attached output presents the results of the stability analyses.

Conclusions:

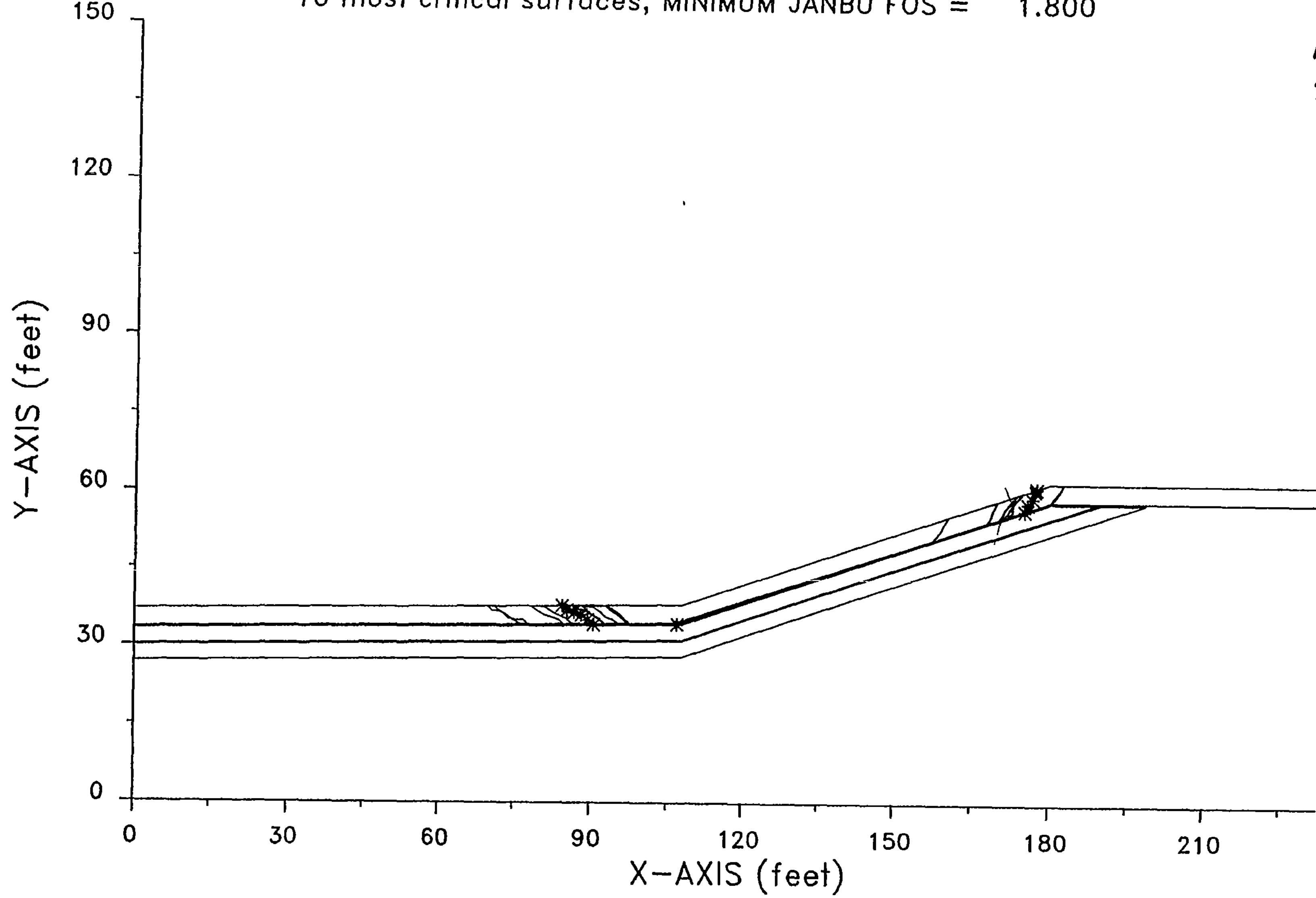
The calculated factors of safety for both static and seismic loading are at or above the commonly accepted factor of safety of 1.5. Therefore, the stability of the liner system on excavated slopes is acceptable.

Prepared by: [illegible]
Checked by LO

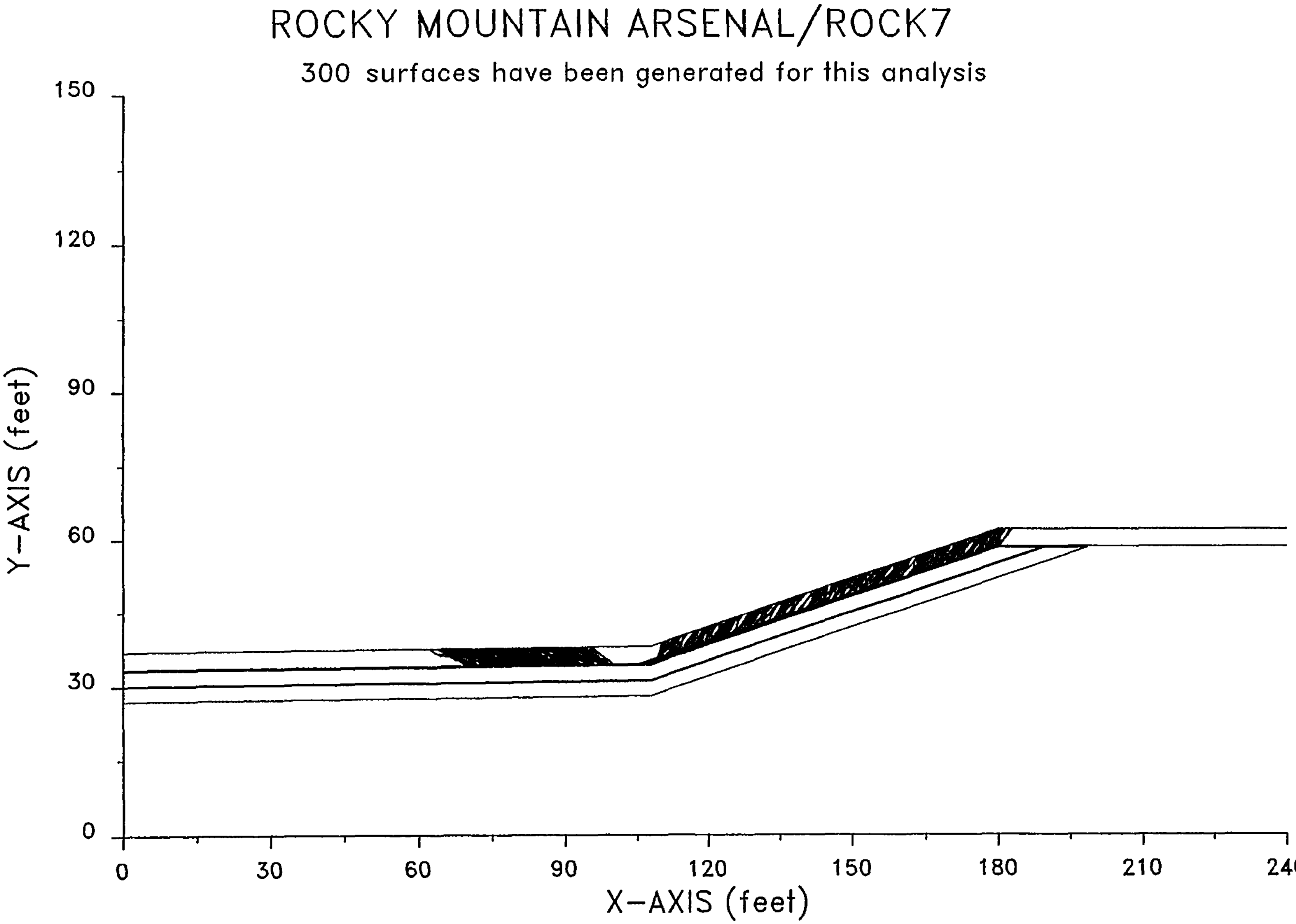
ROCKY MOUNTAIN ARSENAL/ROCK7

10 most critical surfaces, MINIMUM JANBU FOS = 1.800

Liner
Static
Shallow Layer



pg 45 of 67


ROCKY MOUNTAIN ARSENAL/ROCK7
300 surfaces have been generated for this analysis
Y-AXIS (feet)
X-AXIS (feet)
150
120
90
60
30
0
0
30
60
90
120
150
180
210
240

```
*****************************************
*                XSTABL                 *
*                                       *
*     Slope Stability Analysis using    *
*   Simplified BISHOP or JANBU methods  *
*                                       *
*          Copyright (C) 1990           *
*   Interactive Software Designs, Inc.  *
*          All Rights Reserved          *
*                                       *
*          Jean Lou Chameau             *
*          Purdue University            *
*       W. Lafayette,  IN 47907         *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

16 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft) 34.1 33.85	y-left (ft) 34.07 33.82	x-right (ft) 34.4 33.25	y-right (ft) 34.38 34.10	Width (ft)
1	70.00	33.97	100.00	34.28	0.20
2	105.00	34.33	107.00	34.35	0.20
3	108.00	34.30	180.00	58.40	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.49	37.76
2	85.44	37.03
3	86.84	36.49

Top

4	88.26	35.99
5	89.45	35.08
6	90.67	34.20
7	106.95	34.26
8	175.09	56.75
9	175.72	58.12
10	176.72	59.24
11	177.17	60.67
12	177.44	61.15

5686

** Corrected JANBU FOS = 1.800 ** (Fo factor =1.025)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	71.11	37.62
2	71.54	37.26
3	72.80	36.46
4	73.86	35.40
5	75.33	35.06
6	76.82	35.00
7	77.91	33.96
8	~~106.85~~	34.29
9	174.87	56.58
10	175.92	57.65
11	176.77	58.89
12	177.16	60.34
13	177.96	61.32

5683

5621

66 82

345

** Corrected JANBU FOS = 1.892 ** (Fo factor =1.027)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.30	37.85
2	94.09	37.24
3	95.33	36.40
4	96.44	35.39
5	97.50	34.33
6	106.99	34.42
7	169.77	54.92
8	170.70	56.09
9	171.38	57.43
10	172.38	58.55
11	173.42	59.63
12	173.69	59.90

** Corrected JANBU FOS = 1.910 ** (Fo factor =1.023)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	80.00	37.71
2	81.18	37.53
3	82.41	36.66
4	83.72	35.94
5	85.13	35.43
6	86.21	34.39
7	87.71	34.22
8	89.20	34.19
9	106.91	34.40
10	171.65	55.53
11	172.63	56.66
12	172.83	58.15
13	173.24	59.59
14	173.27	59.76

** Corrected JANBU FOS = 2.023 ** (Fo factor =1.026)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.39	37.80
2	89.15	37.16
3	90.21	36.10
4	91.54	35.41
5	92.67	34.42
6	94.14	34.17
7	106.39	34.30
8	170.70	55.23
9	171.68	56.37
10	172.49	57.63
11	173.42	58.81
12	174.47	59.88
13	174.56	60.19

** Corrected JANBU FOS = 2.037 ** (Fo factor =1.024)

Failure surface No. 6 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.02	37.85
2	93.84	37.07
3	95.05	36.18
4	96.25	35.28
5	97.31	34.22
6	105.96	34.32
7	179.90	58.27
8	180.74	59.51
9	181.79	60.58
10	182.38	61.96
11	182.40	62.00

** Corrected JANBU FOS = 2.054 ** (Fo factor =1.020)

Failure surface No. 7 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	69.80	37.61
2	70.72	36.78
3	72.22	36.73
4	73.54	36.03
5	74.75	35.14
6	76.03	34.35
7	77.50	34.04
8	106.96	34.42
9	179.95	58.31
10	181.01	59.37
11	181.63	60.74
12	182.50	61.96
13	182.53	62.00

** Corrected JANBU FOS = 2.085 ** (Fo factor =1.026)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	78.46	37.70
2	78.47	37.69
3	79.67	36.79
4	80.98	36.07
5	82.38	35.54
6	83.79	35.01
7	84.97	34.08
8	106.65	34.31
9	167.42	54.14
10	168.38	55.29
11	168.91	56.70
12	169.49	58.08
13	169.89	58.63

** Corrected JANBU FOS = 2.088 ** (Fo factor =1.027)

Failure surface No. 9 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.95	37.81
2	89.09	37.66
3	90.59	37.53
4	91.83	36.69
5	92.89	35.63
6	94.31	35.12
7	95.54	34.27
8	106.18	34.39
9	176.05	56.98
10	176.70	58.33

11	176.93	59.81
12	177.98	60.88
13	178.50	61.50

** Corrected JANBU FOS = 2.089 ** (Fo factor =1.023)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.03	37.79
2	87.58	37.27
3	89.02	36.88
4	90.29	36.07
5	91.59	35.33
6	92.66	34.27
7	94.16	34.21
8	95.66	34.19
9	106.86	34.26
10	157.07	50.77
11	158.09	51.87
12	159.07	53.01
13	159.68	54.38
14	160.52	55.51

** Corrected JANBU FOS = 2.094 ** (Fo factor =1.028)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	1.800	1.025	84.49	177.44	9193.
2.	1.892	1.027	71.11	177.96	9277.
3.	1.910	1.023	93.30	173.69	8414.
4.	2.023	1.026	80.00	173.27	8622.
5.	2.037	1.024	88.39	174.56	8509.
6.	2.054	1.020	93.02	182.40	9249.
7.	2.085	1.026	69.80	182.53	9595.
8.	2.088	1.027	78.46	169.89	8106.
9.	2.089	1.023	88.95	178.50	8898.
10.	2.094	1.028	87.03	160.52	6846.

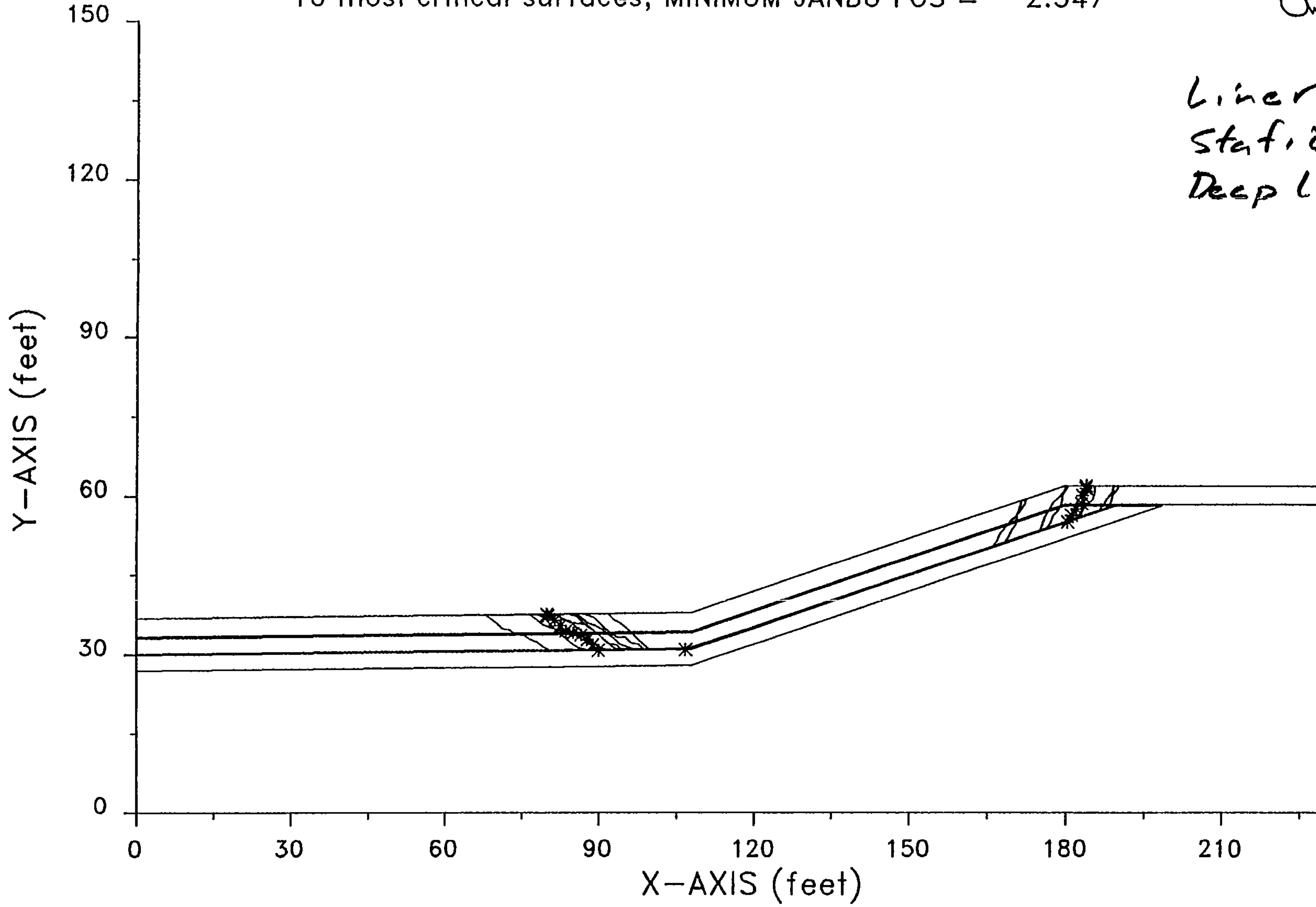
* * * END OF FILE * * *

ROCKY MOUNTAIN ARSENAL/ROCK10A

10 most critical surfaces, MINIMUM JANBU FOS = 2.547

Prepared by Maria Flessas
Checked by L.O.

Liner
Static
Deep layer



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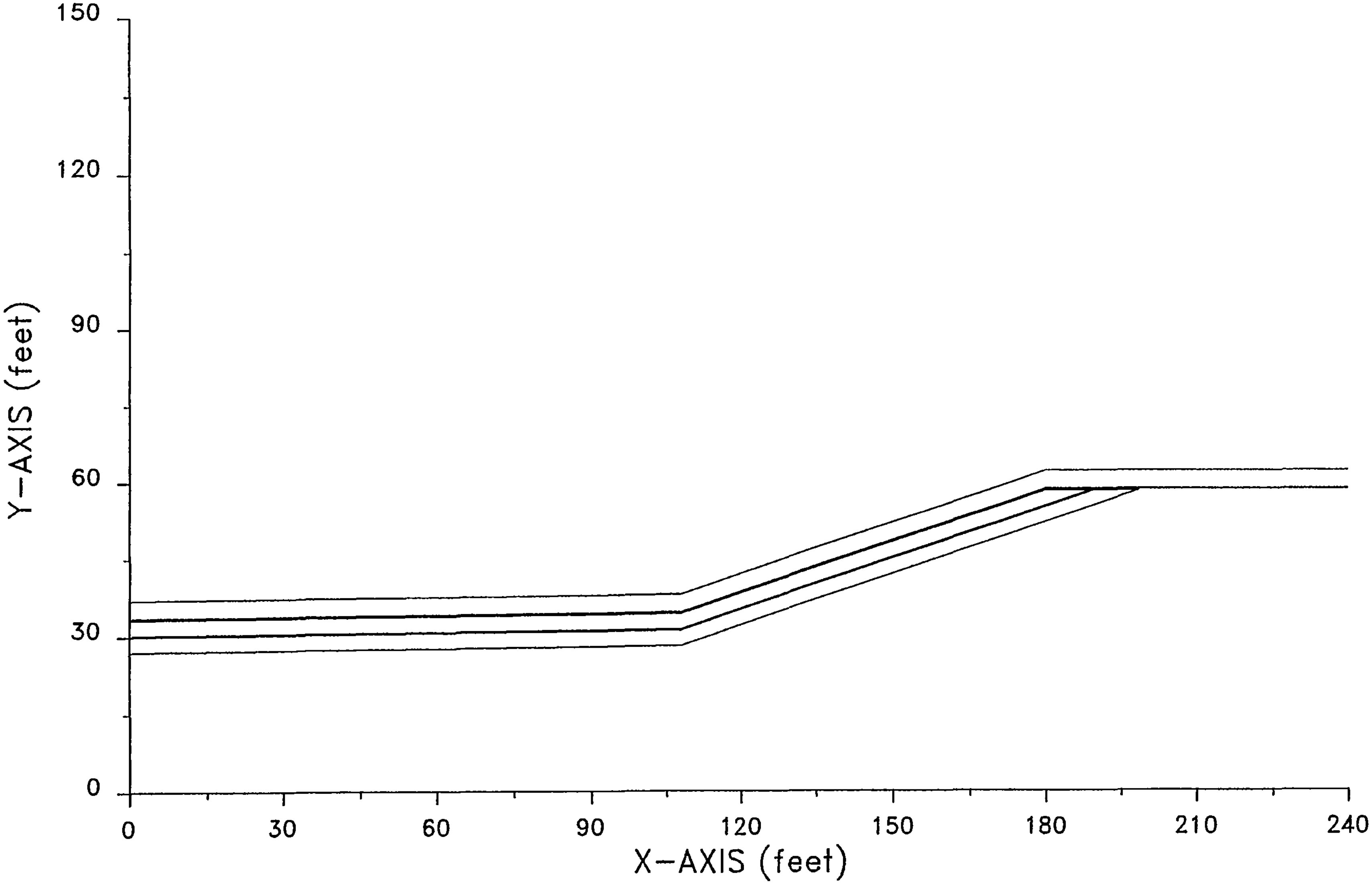
ROCKY MOUNTAIN ARSENAL/ROCK7



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*         Jean Lou Chameau             *
*         Purdue University            *
*      W. Lafayette,  IN 47907         *
*                                      *
*  Ver. 3.00                     1002  *
****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK10A

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

16 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	80.00	30.83	100.00	31.02	0.20
2	105.00	31.08	107.00	31.09	0.20
3	108.00	31.12	189.00	58.12	0.20

Factors of safety have been calculated by the :

* * * * *   MODIFIED JANBU METHOD   * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 18 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	79.96	37.71
2	80.26	37.45
3	81.52	36.64

4	82.62	35.62	
5	83.69	34.57	
6	85.15	34.22	
7	86.60	33.84	
8	87.74	32.86	
9	88.93	31.96	
10	90.00	30.90	
11	106.78	31.01	
12	180.40	55.16	55.38 top
13	181.12	56.48	
14	182.08	57.63	
15	183.08	58.74	
16	183.32	60.22	
17	183.94	61.59	
18	184.04	62.00	

** Corrected JANBU FOS = 2.547 ** (Fo factor =1.049)

Failure surface No. 2 specified by 20 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.50	37.79
2	87.63	37.66
3	89.07	37.25
4	90.16	36.22
5	91.24	35.17
6	92.40	34.23
7	93.66	33.41
8	95.16	33.40
9	96.23	32.35
10	97.69	32.03
11	98.81	31.02
12	106.82	30.99
13	175.11	53.40
14	175.60	54.82
15	176.11	56.23
16	176.88	57.52
17	177.61	58.83
18	178.67	59.89
19	179.72	60.96
20	180.34	62.00

** Corrected JANBU FOS = 2.586 ** (Fo factor =1.050)

Failure surface No. 3 specified by 18 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	76.53	37.68
2	76.70	37.62
3	77.96	36.80
4	79.13	35.86
5	80.52	35.30
6	81.97	34.94
7	83.42	34.54

8	84.72	33.80
9	86.21	33.60
10	87.39	32.68
11	88.62	31.81
12	89.79	30.88
13	106.97	31.06
14	187.81	57.67
15	188.70	58.88
16	189.04	60.34
17	190.10	61.40
18	190.20	62.00

** Corrected JANBU FOS = 2.648 ** (Fo factor =1.047)

Failure surface No. 4 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	91.85	37.84
2	92.85	36.84
3	94.15	36.08
4	95.38	35.23
5	96.48	34.21
6	97.55	33.15
7	98.61	32.10
8	99.72	31.09
9	106.88	31.05
10	176.14	53.79
11	177.07	54.97
12	177.61	56.37
13	178.64	57.46
14	179.26	58.82
15	179.48	60.31
16	180.35	61.53
17	180.54	62.00

** Corrected JANBU FOS = 2.712 ** (Fo factor =1.048)

Failure surface No. 5 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.45	37.76
2	85.73	37.40
3	86.80	36.35
4	87.97	35.42
5	89.24	34.61
6	90.37	33.63
7	91.52	32.66
8	92.58	31.60
9	93.91	30.92
10	106.74	31.03
11	179.76	54.99
12	180.72	56.14
13	181.60	57.36
14	182.15	58.76

15	182.93	60.04
16	183.96	61.12
17	184.38	62.00

** Corrected JANBU FOS = 2.785 ** (Fo factor =1.048)

Failure surface No. 6 specified by 21 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	81.62	37.73
2	81.75	37.60
3	83.11	36.97
4	84.39	36.19
5	85.88	36.06
6	87.38	35.96
7	88.63	35.13
8	89.80	34.18
9	90.87	33.13
10	91.97	32.12
11	93.46	31.94
12	94.60	30.96
13	106.91	31.02
14	168.05	51.10
15	169.06	52.21
16	169.72	53.56
17	170.52	54.83
18	170.67	56.32
19	171.13	57.74
20	171.59	59.17
21	171.61	59.20

** Corrected JANBU FOS = 2.876 ** (Fo factor =1.054)

Failure surface No. 7 specified by 17 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	77.95	37.69
2	79.35	37.21
3	80.41	36.15
4	81.47	35.09
5	82.54	34.03
6	83.76	33.16
7	84.89	32.17
8	86.14	31.35
9	87.61	31.06
10	89.11	30.96
11	106.64	31.02
12	182.05	55.75
13	182.87	57.00
14	183.64	58.29
15	183.72	59.78
16	184.39	61.13
17	185.14	62.00

** Corrected JANBU FOS = 2.910 ** (Fo factor =1.049)

Failure surface No. 8 specified by 19 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	82.19	37.74
2	83.18	36.76
3	84.63	36.40
4	85.72	35.37
5	86.98	34.55
6	88.05	33.50
7	89.12	32.45
8	90.28	31.50
9	91.65	30.88
10	106.96	31.01
11	165.85	50.44
12	166.85	51.55
13	167.46	52.92
14	168.40	54.10
15	169.41	55.21
16	170.47	56.27
17	171.43	57.42
18	172.26	58.67
19	172.51	59.50

** Corrected JANBU FOS = 2.930 ** (Fo factor =1.054)

Failure surface No. 9 specified by 16 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	85.85	37.77
2	86.79	37.08
3	87.99	36.17
4	89.38	35.62
5	90.72	34.95
6	91.84	33.94
7	93.07	33.10
8	94.14	32.05
9	95.54	31.50
10	96.96	31.01
11	106.70	31.02
12	186.31	57.22
13	187.26	58.38
14	188.00	59.69
15	188.94	60.86
16	189.35	62.00

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.045)

Failure surface No.10 specified by 19 coordinate points

Point No.	x-surf (ft)	y-surf (ft)

1	67.92	37.59
2	68.96	37.07
3	70.11	36.11
4	71.23	35.11
5	72.71	34.84
6	73.90	33.93
7	75.40	33.87
8	76.65	33.04
9	78.06	32.54
10	79.20	31.56
11	80.54	30.89
12	82.04	30.84
13	106.85	31.03
14	182.53	55.95
15	183.27	57.25
16	184.18	58.44
17	185.22	59.52
18	185.67	60.95
19	185.69	62.00

** Corrected JANBU FOS = 2.955 ** (Fo factor =1.050)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK10A

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.547	1.049	79.96	184.04	188.15E+02
2.	2.586	1.050	87.50	180.34	180.66E+02
3.	2.648	1.047	76.53	190.20	187.58E+02
4.	2.712	1.048	91.85	180.54	183.39E+02
5.	2.785	1.048	84.45	184.38	187.24E+02
6.	2.876	1.054	81.62	171.61	162.97E+02
7.	2.910	1.049	77.95	185.14	187.44E+02
8.	2.930	1.054	82.19	172.51	160.51E+02
9.	2.943	1.045	85.85	189.35	186.33E+02
10.	2.955	1.050	67.92	185.69	188.50E+02

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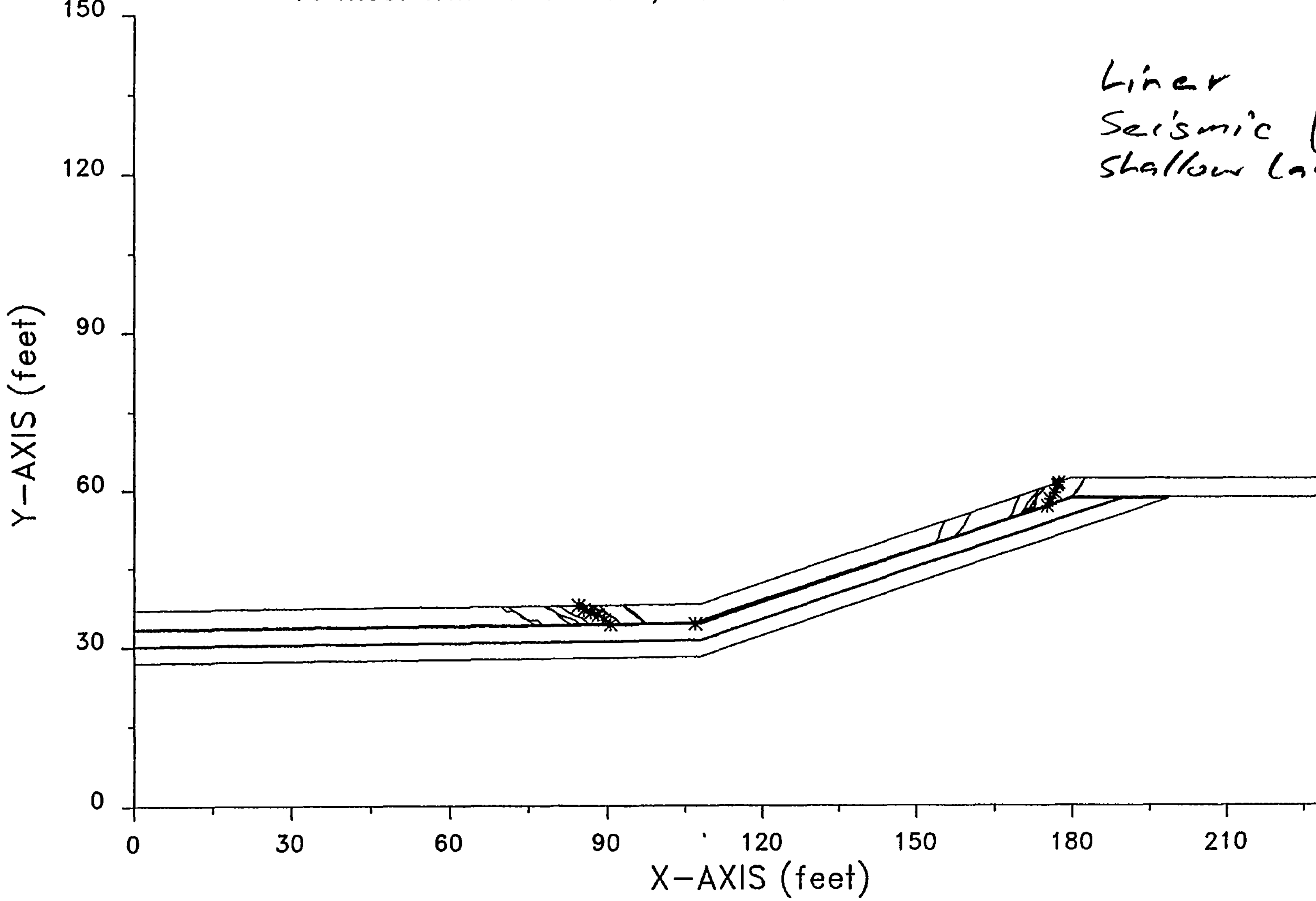
ROCKY MOUNTAIN ARSENAL/ROCK7EQ

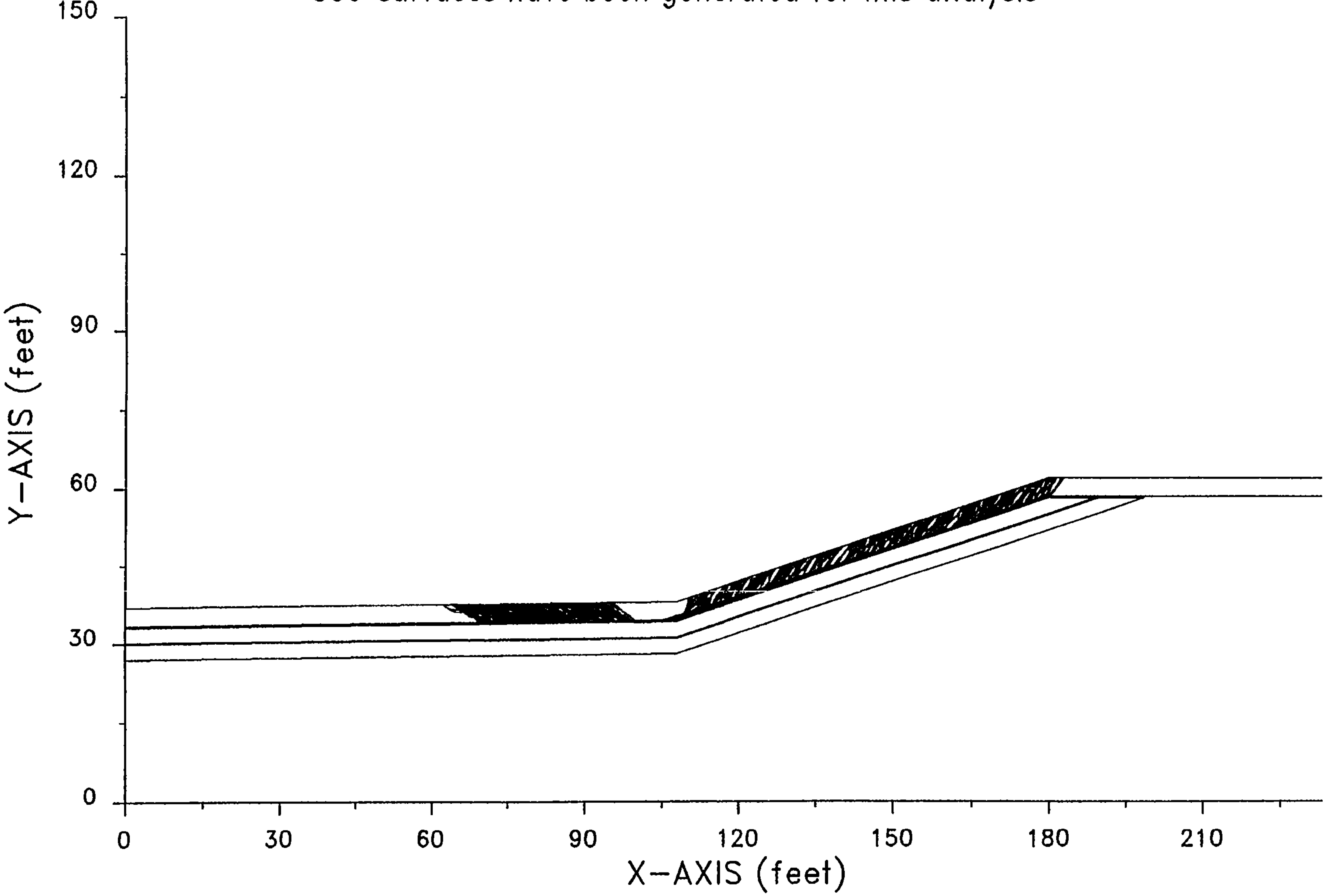
10 most critical surfaces, MINIMUM JANBU FOS = 1.491



Liner
Seismic ($K_H = 0.05g$)
shallow layer

ROCKY MOUNTAIN ARSENAL/ROCK7EQ

300 surfaces have been generated for this analysis



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*           Jean Lou Chameau            *
*           Purdue University           *
*        W. Lafayette,  IN 47907        *
*                                       *
*  Ver. 3.00                       1002 *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7EQ

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	36.90	108.00	38.00	1
2	108.00	38.00	180.00	62.00	1
3	180.00	62.00	240.00	62.00	1

16 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	33.40	108.00	34.50	2
2	108.00	34.50	180.00	58.50	2
3	180.00	58.50	198.70	58.50	2
4	198.70	58.50	240.00	58.50	4
5	0.00	33.15	108.00	34.25	3
6	108.00	34.25	180.00	58.25	3
7	180.00	58.25	189.00	58.25	3
8	189.00	58.25	189.70	58.25	2
9	189.70	58.25	198.50	58.25	3
10	198.50	58.25	198.70	58.50	4
11	0.00	30.15	108.00	31.25	2
12	108.00	31.25	189.00	58.25	2
13	0.00	29.90	108.00	31.00	3
14	108.00	31.00	189.70	58.25	3
15	0.00	26.90	108.00	28.00	4
16	108.00	28.00	198.50	58.25	4

ISOTROPIC Soil Parameters

4 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	35.0	0.000	0.0	1
2	10.0	10.0	0.0	12.0	0.000	0.0	1
3	125.0	125.0	700.0	0.0	0.000	0.0	1
4	130.0	130.0	3000.0	0.0	0.000	0.0	1

A horizontal earthquake loading coefficient
of 0.050 has been assigned

A vertical earthquake loading coefficient
of 0.000 has been assigned

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

3 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	70.00	33.97	100.00	34.28	0.20
2	105.00	34.33	107.00	34.35	0.20
3	108.00	34.30	180.00	58.40	0.20

Factors of safety have been calculated by the :

* * * * *   MODIFIED JANBU METHOD   * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	84.49	37.76
2	85.44	37.03
3	86.84	36.49
4	88.26	35.99
5	89.45	35.08
6	90.67	34.20
7	106.95	34.26
8	175.09	56.75
9	175.72	58.12
10	176.72	59.24
11	177.17	60.67
12	177.44	61.15

** Corrected JANBU FOS = 1.491 ** (Fo factor =1.025)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	71.11	37.62
2	71.54	37.26
3	72.80	36.46
4	73.86	35.40
5	75.33	35.06
6	76.82	35.00
7	77.91	33.96
8	106.85	34.29
9	174.87	56.58
10	175.92	57.65
11	176.77	58.89
12	177.16	60.34
13	177.96	61.32

** Corrected JANBU FOS = 1.538 ** (Fo factor =1.027)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.30	37.85
2	94.09	37.24
3	95.33	36.40
4	96.44	35.39
5	97.50	34.33
6	106.99	34.42
7	169.77	54.92
8	170.70	56.09
9	171.38	57.43
10	172.38	58.55
11	173.42	59.63
12	173.69	59.90

** Corrected JANBU FOS = 1.609 ** (Fo factor =1.023)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	80.00	37.71
2	81.18	37.53
3	82.41	36.66
4	83.72	35.94
5	85.13	35.43
6	86.21	34.39
7	87.71	34.22
8	89.20	34.19
9	106.91	34.40
10	171.65	55.53
11	172.63	56.66
12	172.83	58.15
13	173.24	59.59
14	173.27	59.76

** Corrected JANBU FOS = 1.657 ** (Fo factor =1.026)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	69.80	37.61
2	70.72	36.78
3	72.22	36.73
4	73.54	36.03
5	74.75	35.14
6	76.03	34.35
7	77.50	34.04
8	106.96	34.42
9	179.95	58.31
10	181.01	59.37
11	181.63	60.74
12	182.50	61.96
13	182.53	62.00

** Corrected JANBU FOS = 1.681 ** (Fo factor =1.026)

Failure surface No. 6 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	77.88	37.69
2	78.41	37.35
3	79.81	36.80
4	80.87	35.74
5	82.08	34.85
6	83.40	34.15

7	106.74	34.28
8	153.26	49.39
9	154.24	50.52
10	154.57	51.99
11	155.13	53.38
12	155.53	53.84

** Corrected JANBU FOS = 1.688 ** (Fo factor =1.030)

Failure surface No. 7 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	88.39	37.80
2	89.15	37.16
3	90.21	36.10
4	91.54	35.41
5	92.67	34.42
6	94.14	34.17
7	106.39	34.30
8	170.70	55.23
9	171.68	56.37
10	172.49	57.63
11	173.42	58.81
12	174.47	59.88
13	174.56	60.19

** Corrected JANBU FOS = 1.694 ** (Fo factor =1.024)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	78.46	37.70
2	78.47	37.69
3	79.67	36.79
4	80.98	36.07
5	82.38	35.54
6	83.79	35.01
7	84.97	34.08
8	106.65	34.31
9	167.42	54.14
10	168.38	55.29
11	168.91	56.70
12	169.49	58.08
13	169.89	58.63

** Corrected JANBU FOS = 1.696 ** (Fo factor =1.027)

Failure surface No. 9 specified by 11 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	93.02	37.85

2	93.84	37.07
3	95.05	36.18
4	96.25	35.28
5	97.31	34.22
6	105.96	34.32
7	179.90	58.27
8	180.74	59.51
9	181.79	60.58
10	182.38	61.96
11	182.40	62.00

** Corrected JANBU FOS = 1.724 ** (Fo factor =1.020)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	87.03	37.79
2	87.58	37.27
3	89.02	36.88
4	90.29	36.07
5	91.59	35.33
6	92.66	34.27
7	94.16	34.21
8	95.66	34.19
9	106.86	34.26
10	157.07	50.77
11	158.09	51.87
12	159.07	53.01
13	159.68	54.38
14	160.52	55.51

** Corrected JANBU FOS = 1.728 ** (Fo factor =1.028)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/ROCK7EQ

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	1.491	1.025	84.49	177.44	109.70E+02
2.	1.538	1.027	71.11	177.96	113.36E+02
3.	1.609	1.023	93.30	173.69	9919.
4.	1.657	1.026	80.00	173.27	103.90E+02
5.	1.681	1.026	69.80	182.53	117.40E+02
6.	1.688	1.030	77.88	155.53	7765.
7.	1.694	1.024	88.39	174.56	101.26E+02
8.	1.696	1.027	78.46	169.89	9841.
9.	1.724	1.020	93.02	182.40	109.14E+02
10.	1.728	1.028	87.03	160.52	8223.

* * * END OF FILE * * *

CONCEPTUAL COVER SLOPE STABILITY ANALYSIS

Harding Lawson Associates
Engineering
and
Enviromental Services

SHEET 14 OF 67
JOB NO 21907-705011.1
DATE 2/13/96
PROJECT RMA 93-03 / CAD
COMPUTED BY A. Herlache
SUBJECT Geot. Calcs
CHECKED BY D[illegible]

SLOPE STABILITY - COVER SLOPES

Purpose: To evaluate the stability of the cover system on perimeter slopes with respect to static and seismic loading.

Slope Geometry:

A cross-section of the eastern slope was analyzed as shown on the attached Drawing No. C-6. The detailed geometry of the cover system is shown on Drawing No. C-8.

Material Properties:

The following material properties were selected based on published literature

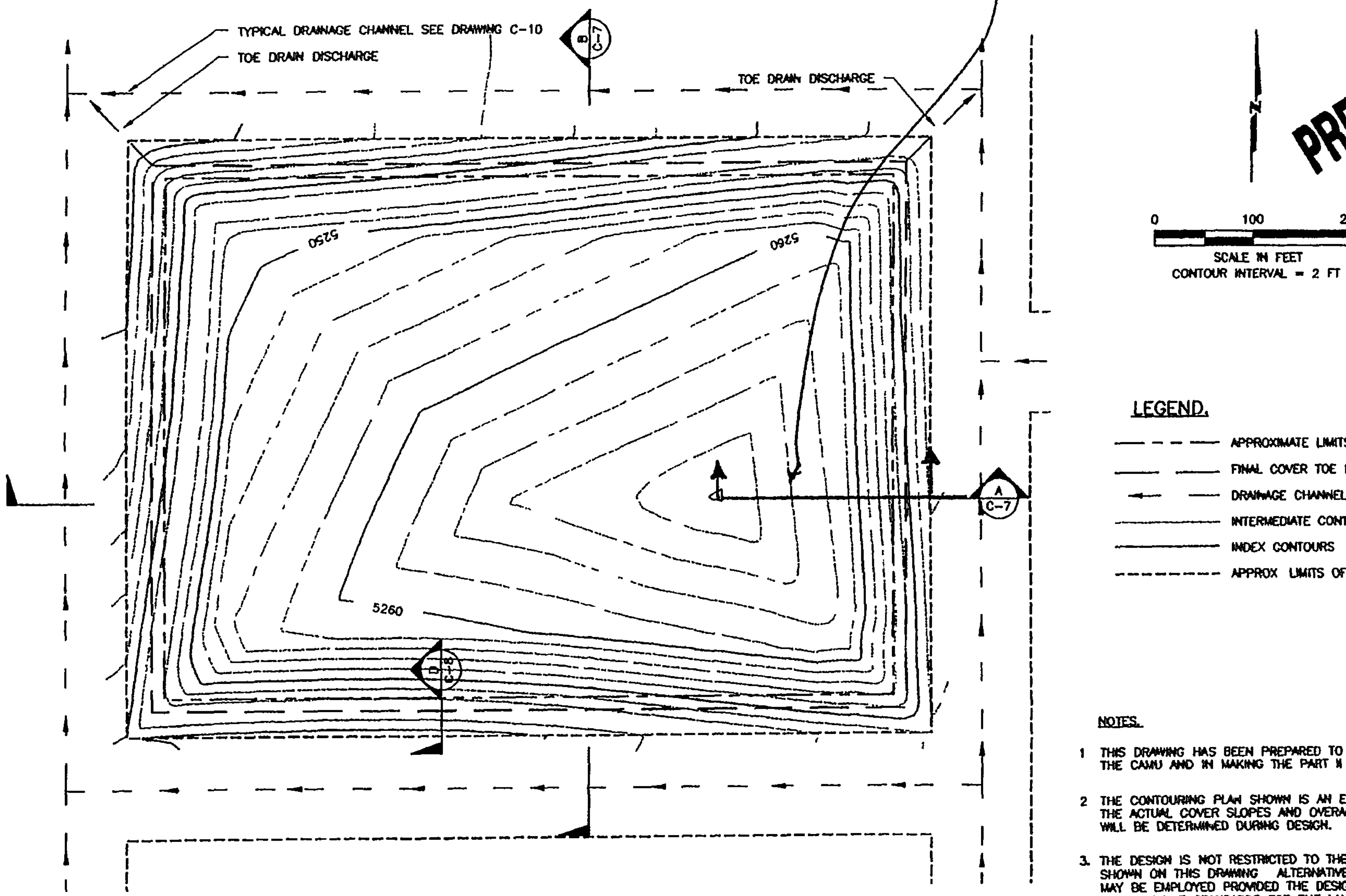
- Vegitative Layer
  Assume sandy material
  $\phi = 30°$
  $C = 0$
  $\gamma_T = 115$ pcf

- Water Storage Layer
  Assume cohesive soil COMPACTED
  $\phi = 0$
  $C = 1000$ psf
  $\gamma_T = 125$ pcf

- Water Storage Layer - Geotextile - Biota Barrier Interface
  $\phi = 20°$
  $C = 0$

- Biota Barrier GRAVEL
  $\phi = 37°$
  $C = 0$
  $\phi = 120$ pcf

CROSS SECTION USED FOR SLOPE STABILITY ANALYSES



PRELIMINARY
NOT FOR CONSTRUCTION
JAN 12 1996

LEGEND.

— — — —	APPROXIMATE LIMITS OF WASTE
——— ———	FINAL COVER TOE DRAIN
—◄— —	DRAINAGE CHANNEL
————	INTERMEDIATE CONTOURS
————	INDEX CONTOURS
-------	APPROX LIMITS OF FINAL COVER

NOTES.

1. THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART B SITING DEMONSTRATION.
2. THE CONTOURING PLAN SHOWN IS AN EXAMPLE LAYOUT THE ACTUAL COVER SLOPES AND OVERALL CONFIGURATIONS WILL BE DETERMINED DURING DESIGN.
3. THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE.

NO.	DATE	REVISIONS	BY	CHK

DRAWN: SCS	PROJECT NO: 21907
ENGINEER:	SCALE: AS NOTED
CHECKED: BAC	APPROVED: RBK
DATE:	DATE:

Harding Lawson Associates
Engineering and Environmental Services

ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

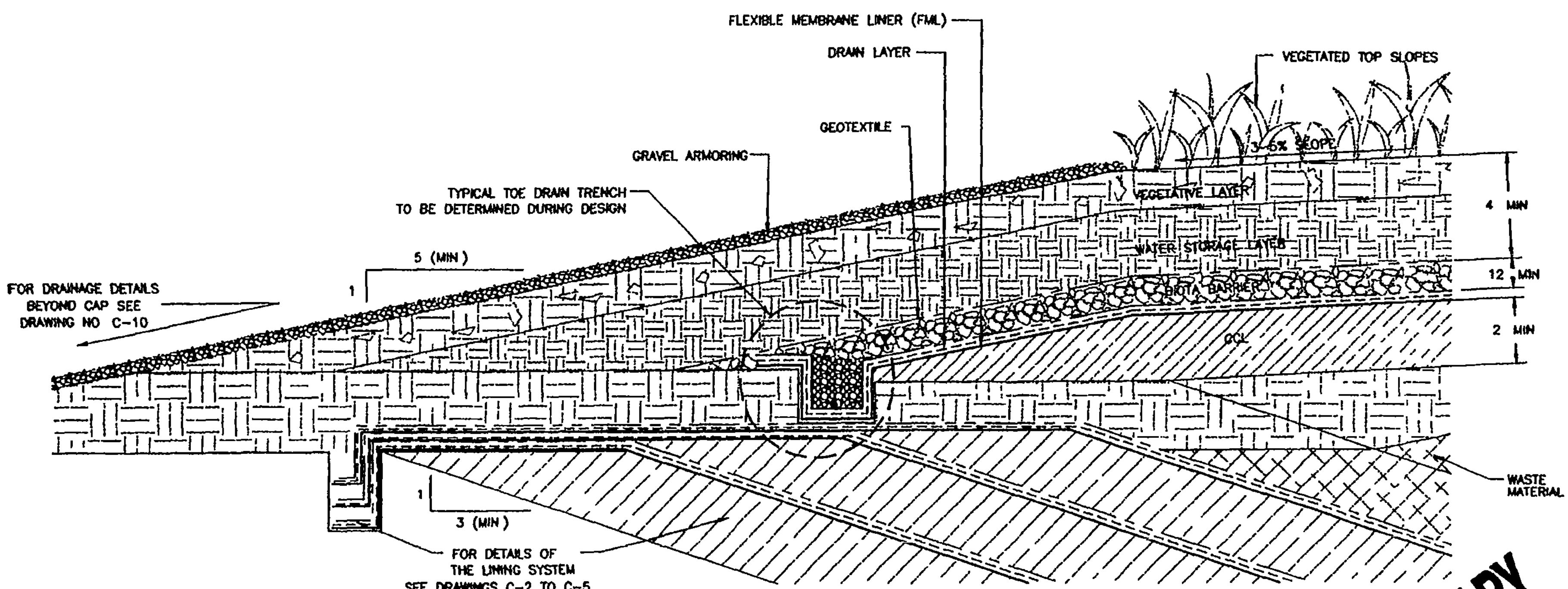
CAMU DESIGNATION DOCUMENT DESIGNATION LEVEL DRAWINGS

TYPICAL FINAL COVER PLAN

DRAWING NO. C-6

7/11

Pg 15 of 67



TYPICAL COVER SECTION (D / C-6)
NTS

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JAN 12 1996

Pg 16 of 67

LEGEND:

----------	GEONET
— — —	GEOTEXTILE
———	FLEXIBLE MEMBRANE LINER (FML)
CCL	COMPACTED CLAY LINER

NOTES.

1 THIS DRAWING HAS BEEN PREPARED TO ASSIST IN DESIGNATING THE CAMU AND IN MAKING THE PART II SITING DEMONSTRATION

2 TOE DRAIN TRENCH SHALL BE DESIGNED TO POSITIVE DRAIN AND CONSTRUCTED TO AVOID DAMAGE TO THE UNDERLYING GEOSYNTHETIC MATERIALS. DIMENSIONS ARE TO BE DETERMINED DURING DESIGN

3. LENGTHS OF LAPS, SPLICES OR PATCHES SHALL BE DETERMINED DURING DESIGN AND SHOULD BE COORDINATED WITH THE MANUFACTURER OF THE SUBJECT GEOSYNTHETIC

4 ALL FINAL DIMENSIONS (SLOPES, THICKNESSES LENGTHS, DEPTHS ETC) SHALL BE DETERMINED DURING DESIGN

5 ALL GEOSYNTHETIC LAYERS ARE EXAGGERATED FOR CLARITY THICKNESS WILL VARY

6 THE DESIGN IS NOT RESTRICTED TO THE COMPONENTS/LAYOUT SHOWN ON THIS DRAWING ALTERNATIVE COMPONENTS/LAYOUTS MAY BE EMPLOYED PROVIDED THE DESIGN CRITERIA OR PERFORMANCE STANDARDS FOR THE LANDFILL ARE MET AS DESCRIBED IN THE DESIGN NARRATIVE

NO.	DATE	REVISIONS	BY	CHK		
					DRAWN: SES	PROJECT NO. 21997
					ENGINEER: SES	SCALE: NONE
					CHECKED: BAC	APPROVED: RZK
					DATE:	DATE:

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ROCKY MOUNTAIN ARSENAL
SOIL SUPPORT PROGRAM
TASK 93-03
COMMERCE CITY, COLORADO

TYPICAL COVER SECTION

DRAWING NO. C-8
9 / 11

Harding Lawson Associates
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SHEET 17 OF 67
JOB NO 21907-705011.1
DATE 2/13/96
COMPUTED BY A. Herlache
CHECKED BY

PROJECT EMA 93-03/CDD
SUBJECT Geot. Calcs

- Biota Barrier - Geotextile - Geonet - FML - CCL Interface (Assume Textured HDPE)
  $\phi = 12°$ (see attached)
  $C = 0$

- CCL
  $\phi = 0$
  $C = 700$ psf
  $\gamma_T = 125$ pcf

- Waste Material
  Assume cohesive soil
  $\phi = 0$
  $C = 2000$ psf HIGH
  $\gamma_T = 125$ pcf

Calculations:

Slope stability calculations were performed using the computer program PC STABL 5M developed at Purdue University. The program uses Janbu's simplified method for noncircular slip surfaces.

The analyses was performed using the attached cross-section. We assumed that the drain layer would remove any infiltrating water so that hydrostatic pressure would not build up within the system.

We first analyzed the stability of the slope under static loading. A search for the critical surface yielded a factor of safety = 2.8. The critical surface was predominantly along the FML layer, which represen a low strength zone.

We then performed a pseudo-static analysis to simulate seismic loading conditions. We used a pseudo-static

- Sli.. .g along a surface that occurs between geosynthetics This may occur when multiple geosynthetic layers are used

3.6.1 Soil Geotextile Interface Friction

The interface friction between soils and geotextiles generally has a high efficiency under both low and high normal loads The efficiency is generally higher for wovens and needle-punched nonwovens than for heat-bonded nonwovens This is probably due to the rougher surface and larger amount of soil-to-fabric interaction with the wovens and needle-punched nonwovens Other factors or trends observed in performing direct shear tests between soils and geotextiles include

- There is some indication that wetting the geotextiles decreases the shear strength (El-Fermaoui and Nowatzi, 1982, Miyamori et al , 1986)
- For woven geotextiles, the machine and cross directions produce different interface friction values, with the cross direction typically being lower (Eigenbrod and Locker, 1987)
- The density of sand may not have a significant effect on the interface friction between sands and geotextiles, especialy for woven geotextiles (Eigenbrod and Locker, 1987, Koutsourais et al , 1990)
- Adhesion between soils and geotextiles may exist due to the interlocking of the materials The adhesion is most apparent in nonwoven geotextiles (Eigenbrod and Locker, 1987)
- For clay soils and nonwoven geotextiles at intermediate and high confining stresses, the interface friction angle may increase and the adhesion decrease due to consolidation of the soil adjacent to the geotextile (Williams and Houlihan, 1987)

Since the shear strength results are highly dependent on the soil and type of geotextile, it is highly recommended that direct shear tests using the actual materials be used However, for general guidance purposes or preliminary designs, Table 3 13 presents the results of soil geotextile friction tests reported in the literature (Myles, 1982, Martin et al , 1984, Miyamori et al , 1986, Eigenbrod and Locker, 1987, Williams and Houlihan, 1987, Eigenbrod et al , 1990, Koutsourais et al , 1990) The wide variations in the results presented in Table 3 13 are due to variations in testing procedures, normal stresses, soils, and geotextiles The range also covers both peak and residual friction angles

3.6.2 Soil Geomembrane Interface Strength

Since, unlike geotextiles, geomembranes do not contain openings or pores, the interface strength between soils and geomembranes is largely dependent on whether the surface of the geomembrane is flexible or rough enough to push the failure plane into the adjacent soils If the failure plane is pushed into the adjacent soils, the

TABLE 3.13 Typical Range of Reported Soil Geotextile Fric... Angles

Geotextile	Sand Friction Angle (deg) (Efficiency)	Clay Friction Angle (deg) (Efficiency)
Woven	23–42 (0 68–1 0)	16–26 (0 61–0 93)
Nonwoven, Needle-punched	25–44 (0 67–1 0)	15–28 (0 62–0 99)
Nonwoven, resin or heat bonded	22–40 (0 56–0 91)	17–33 (0 60–0 85)

interface friction strength is generally similar to the soil strength Factors that affect the soil strength include items such as the soil type, density, moisture content, and confining stress For clays, the loading and shearing conditions, such as consolidated drained (CD), consolidated undrained (CU), or unconsolidated undrained (UU), also have significant influence

If the failure plane is not pushed into the adjacent soils, low interface friction values may result For example, the interface strength between smooth HDPE geomembranes and clay can be less than 10° This low interface friction strength can lead to significant stability problems Also, if the interface between the clay and geomembrane is wetted (i e , due to condensation of water under the geomembrane, clay swelling, or excess moisture during construction), the interface strength can be further reduced (VonPein and Prasad, 1990, Mitchell et al , 1990) It is therefore critical that interface friction tests accurately model potential field conditions

Table 3 14 summarizes soil geomembrane interface strengths based on the results reported by several researchers (Martin et al , 1984, Williams and Houlihan

TABLE 3.14 Typical Range of Reported and Recommended Soil Geomembrane Friction Angles

Geomembrane	Reported Sand Friction Angles (deg) (Efficiency)	Recommended Sand Friction Angles, δ (deg)	Reported Clay Friction Angles (deg) (Efficiency)	Recommended Clay Friction Angles, δ (deg
PVC	21–33 (0 62–0 93)	20–30	6–39 (0 53–1 0)	6–15
HDPE	17–28 (0 45–0 81)	17–25	5–29 (0 47–0 88)	5–10
Textured HDPE	30–45 (0 86–1 0)	30–40	7–35 (0 70–1 0)	9–15
VLDPE[a]	21–28 (0 62–0 67)	—	—	—

[a] Since VLDPE is a relatively new product, limited results were reported in the literature It is anticipate that the range of efficiencies for VLDPE to sand interfaces is broader than shown Blank (—) mean insufficient data at this time

From: Waste Containment Systems, Waste Stabilization, and Landfills by Sharma and Lewis 1994

58
78

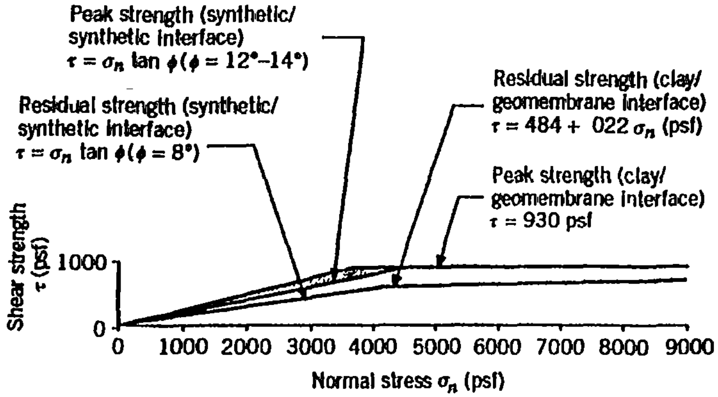

Figure 3.61 Liner strength relations (From Byrne et al , 1992 Reproduced by permission of ASCE)

1987, Soil and Material Engineers, 1987, Leach et al , 1987, Koutsourais et al , 1990, Swan et al , 1990, O'Rourke et al , 1990, Mitchell et al , 1990, Ojeshina, 1990, Druschel and O'Rourke, 1991, Somasundaram and Khilnani, 1991, Sharma and Hullings, 1993) The results are highly variable due to the large range of soil types and testing conditions Both peak and residual values are included within the reported range Table 3 14 also includes recommended soil geomembrane interface strengths

As shown in Figure 3 61, the interface strength of clay–geomembrane exhibits a linear shear strength (τ) and normal stress (σ_n) relationship at lower normal stresses The interface friction angles (δ) reported in Table 3 14 represent this behavior At higher normal loads, the interface friction angle becomes very low and for all practical purposes τ tends to become independent of σ_n The authors' experience on various low-plasticity (CL) and high-plasticity (CH) clays tested against both smooth and textured HDPE geomembrane confirms this τ–σ_n behavior Recommended values presented in Table 3 14 should be used only as a guide in feasibility studies Tests on site-specific materials and selected geomembranes should be conducted for final design purposes

3.6.3 Geosynthetic-to-Geosynthetic Shear Strength

Several researchers have tested various geosynthetic-to-geosynthetic interfaces (Martin et al , 1984, Williams and Houlihan, 1986, Koutsourais et al , 1990, Mitchell et al , 1990, Lydick and Zagorski, 1990, Ojeshina, 1990; Somasundaram and Khilnani, 1991) The results of these studies are summarized in Table 3 15 The primary components of interface friction between multiple layers of geosynthetics are sliding between layers and dilation at the geosynthetic surface (Williams and Houlihan, 1986)

TABLE 3 15 Typical Range of Reported Geosynthetic to Geosynthetic Friction Angles (Degrees)

	PVC	HDPE Smooth	HDPE Textured	Geonet
Woven Geotextile	10–28	7–11	9–17	9–18
Nonwoven, needle-punched Geotextile	16–26	8–12	15–33	10–27
Nonwoven, resin/heat-bonded Geotextile	18–21	9–11	15–16	17–21
Geonet	11–24	5–19	7–25	—

The testing conditions may also have a significant effect on results Mitchell e al (1990) noted that polishing of geomembrane surfaces by geotextiles reduce interface friction Also, the orientation of geonet strands can affect the interfac strength between geonets and geomembranes (Geotek, 1987, Mitchell et al , 1990) Site-specific tests should therefore be performed using the actual materials and anticipated shear conditions

3.6 4 Geosynthetic Clay Liner Shear Strength

Limited information is currently available on the internal shear strength of GCLs due primarily to their relatively short history The tests that have been performe are also difficult to compare, due to the numerous variations in test conditions Many of these variations, such as strain rate, normal load, sample size, and consolidation conditions, are similar to the variations experienced when comparing shea strength testing of other geosynthetics An additional variation of GCLs, howeve is the hydrating conditions, including the hydrating liquid Hydration can occu under free swell, constrained swell, or partially constrained swell, or the sampl may be tested unhydrated Even if ' ydrated under free-swell conditions, it may b difficult to assess whether full hydration has occurred since the bentonite may b restricted from free swell by the bonded geotextiles Also, due to the large wat absorption of bentonite, most shear strength test results will incorporate some immeasurable pore pressure effects unless the test is performed at extremely low displacement rates

Table 3 16 presents the results of direct shear testing performed under variou hydration conditions The tests were performed at a strain rate of 9 mm/min and normal stresses up to 60 kPa Although these test results provide some informatio on the internal shear strength of GCLs, it is highly recommended that project specific testing be performed

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PROJECT RMA 93-03 / CDD
SUBJECT Geot Calcs.

SHEET 20 OF 67
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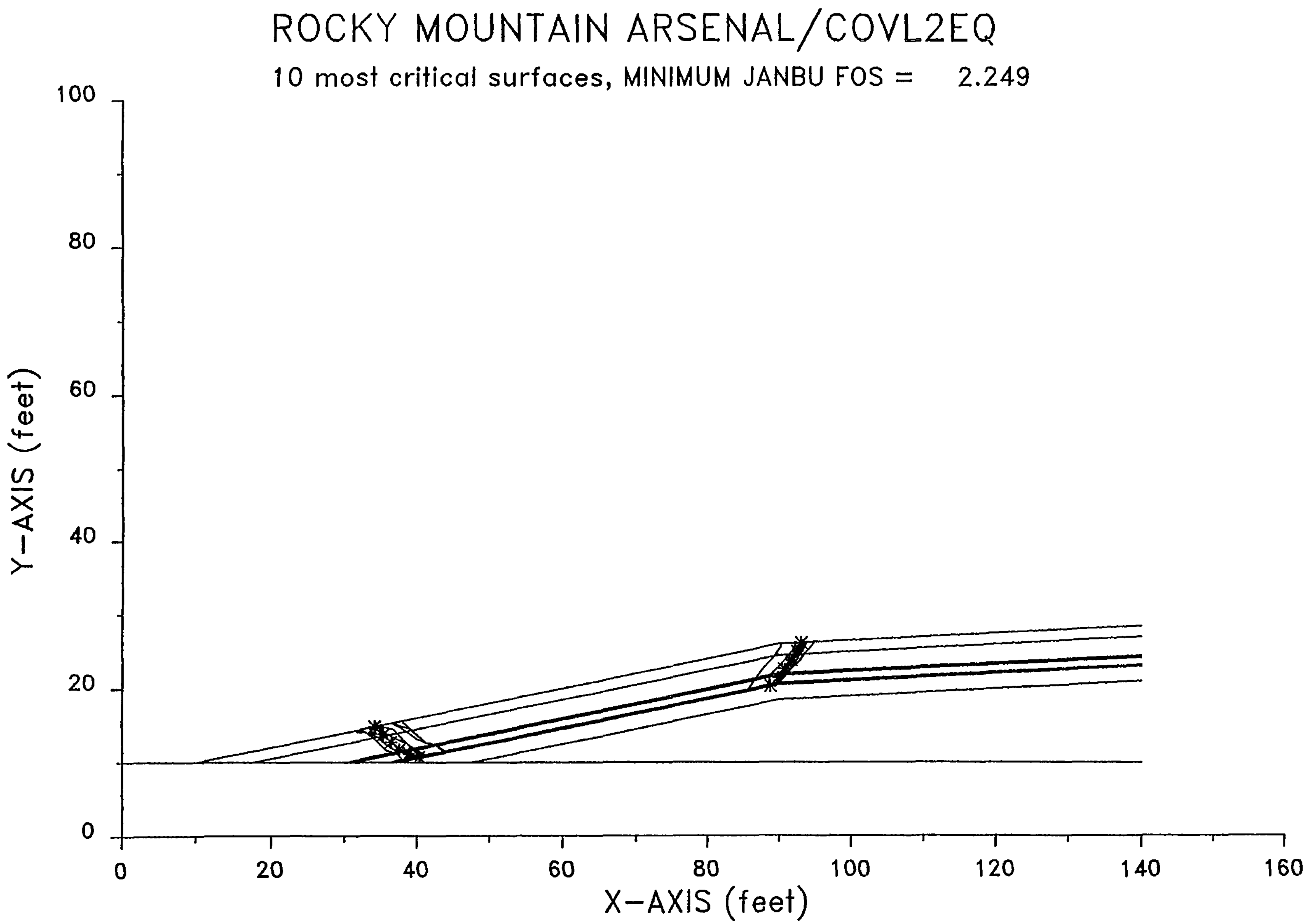
DATE 2/13/96
COMPUTED BY A. Herlache
CHECKED BY D Burg

Horizontal earthquake coefficient of 0.05 gravities. The value was taken from a USGS map prepared by Algermissen, et al (1990) and represents the peak ground acceleration with a 90% chance of not being exceeded in 250 years. Typically the peak ground acceleration values are factored down to arrive at a psuedo-static coefficient for stability calculations; however, we conservatively used the peak ground acceleration value directly. The psuedo-static calculations indicated a minimum factor of safety of 2.2.

The attached output presents the results of the stability analyses.

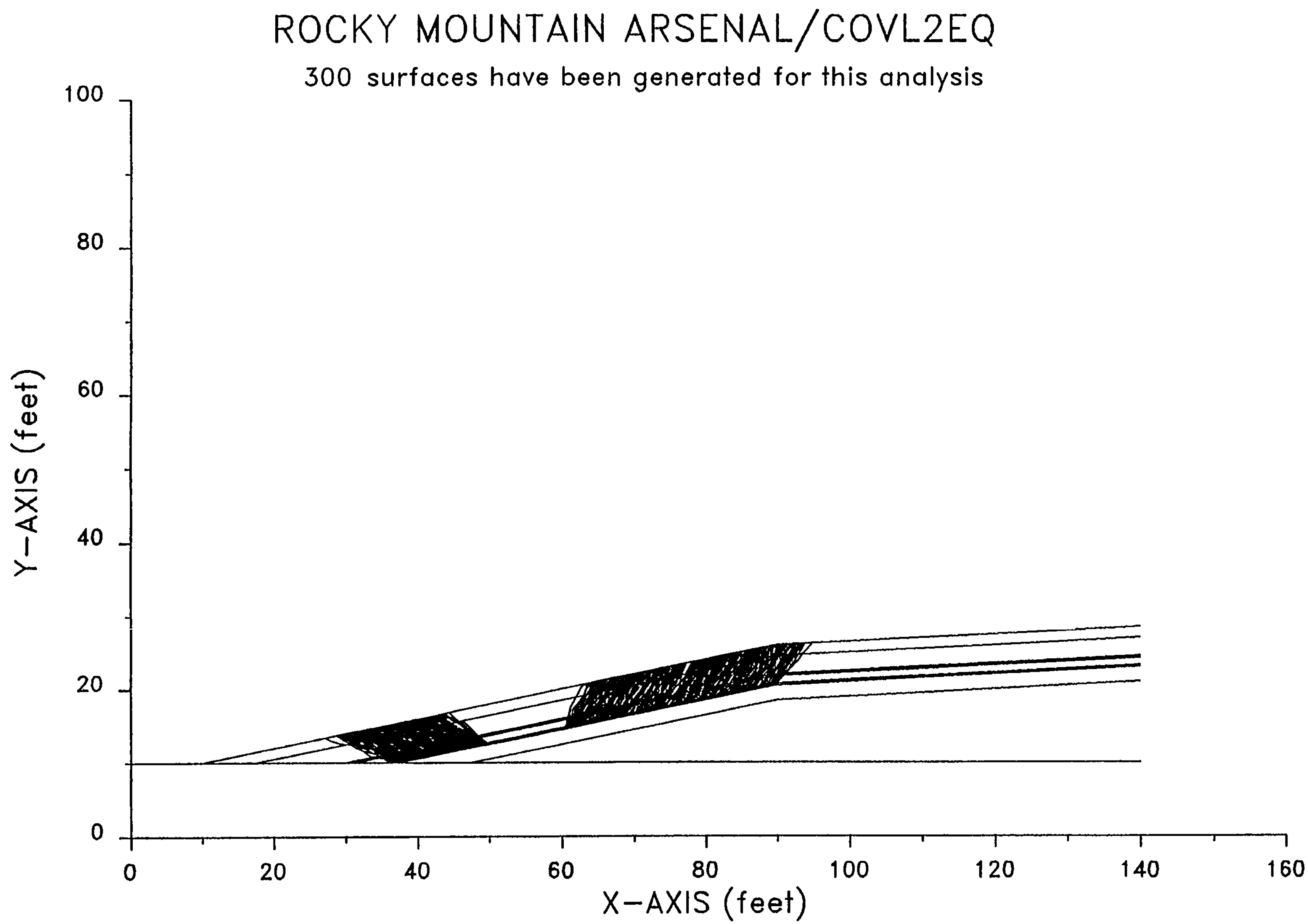
Conclusions:

The calculated factors of safety for both static and seismic loading are above the commonly accepted factor of safety = 1.5. Therefore, the stability of the cover system on perimeter slopes is acceptable.



ROCKY MOUNTAIN ARSENAL/COVL2EQ
10 most critical surfaces, MINIMUM JANBU FOS = 2.249
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160

pg 21 of 67


ROCKY MOUNTAIN ARSENAL/COVL2EQ
300 surfaces have been generated for this analysis
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160

```
*******************************************
*                XSTABL                   *
*                                         *
*     Slope Stability Analysis using      *
*   Simplified BISHOP or JANBU methods    *
*                                         *
*           Copyright (C) 1990            *
*   Interactive Software Designs, Inc.    *
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*                                         *
*           Jean Lou Chameau              *
*          Purdue University              *
*       W. Lafayette,  IN 47907           *
*                                         *
*  Ver. 3.00                      1002    *
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Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	10.00	10.00	10.00	8
2	10.00	10.00	90.00	26.00	1
3	90.00	26.00	140.00	28.50	1

19 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	10.00	10.00	17.50	10.00	8
2	17.50	10.00	90.00	24.50	2
3	90.00	24.50	140.00	27.00	2
4	17.50	10.00	30.00	10.00	8
5	30.00	10.00	90.00	22.00	3
6	90.00	22.00	140.00	24.50	3
7	30.00	10.00	31.25	10.00	8
8	31.25	10.00	90.00	21.75	4
9	90.00	21.75	140.00	24.25	4
10	31.25	10.00	36.25	10.00	8
11	36.25	10.00	90.00	20.75	5
12	90.00	20.75	140.00	23.25	5
13	36.25	10.00	37.50	10.00	8
14	37.50	10.00	90.00	20.50	6
15	90.00	20.50	140.00	23.00	6
16	37.50	10.00	47.50	10.00	8
17	47.50	10.00	90.00	18.50	7

18	90.00	18.50	140.00	21.00	7
19	47.50	10.00	140.00	10.00	8

ISOTROPIC Soil Parameters

8 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	30.0	0.000	0.0	1
2	125.0	125.0	1000.0	0.0	0.000	0.0	1
3	100.0	100.0	0.0	20.0	0.000	0.0	1
4	120.0	120.0	0.0	37.0	0.000	0.0	1
5	100.0	100.0	0.0	12.0	0.000	0.0	1
6	125.0	125.0	700.0	0.0	0.000	0.0	1
7	125.0	125.0	2000.0	0.0	0.000	0.0	1
8	115.0	115.0	0.0	35.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	36.87	10.10	50.00	12.62	0.20
2	60.00	14.62	90.00	20.62	0.20

Factors of safety have been calculated by the :

* * * * * MODIFIED JANBU METHOD * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.14	14.83
2	34.19	14.78
3	35.32	13.79
4	36.41	12.76
5	37.52	11.76
6	38.93	11.24
7	40.35	10.77
8	88.72	20.31
9	89.77	21.39
10	90.62	22.63
11	91.60	23.76
12	92.48	24.97
13	92.99	26.15

** Corrected JANBU FOS = 2.829 ** (Fo factor =1.038)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.26	14.65
2	33.85	14.07
3	35.27	13.59
4	36.52	12.75
5	37.68	11.80
6	38.79	10.79
7	40.28	10.66
8	89.62	20.45
9	90.67	21.52
10	91.57	22.72
11	92.41	23.96
12	93.21	25.24
13	93.73	26.19

** Corrected JANBU FOS = 2.834 ** (Fo factor =1.037)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	32.32	14.46
2	33.42	13.70
3	34.58	12.75
4	35.65	11.70
5	37.08	11.24
6	38.22	10.27
7	88.93	20.41
8	89.97	21.50
9	91.03	22.56
10	91.92	23.77
11	92.58	25.12
12	93.00	26.15

** Corrected JANBU FOS = 2.855 ** (Fo factor =1.037)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	36.55	15.31
2	37.52	14.82
3	38.80	14.04
4	40.02	13.16
5	41.44	12.68
6	42.85	12.19
7	44.13	11.40
8	89.60	20.45
9	90.65	21.52
10	91.67	22.62
11	92.72	23.68
12	93.62	24.89
13	94.65	25.97
14	94.73	26.24

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.039)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.95	14.79
2	34.01	14.74
3	35.13	13.75
4	36.36	12.90
5	37.47	11.89
6	38.94	11.58
7	40.14	10.68
8	88.33	20.36
9	88.76	21.79
10	89.81	22.86
11	90.80	23.99
12	91.81	25.10
13	92.24	26.11

** Corrected JANBU FOS = 2.960 ** (Fo factor =1.039)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	37.01	15.40
2	37.42	14.99
3	38.88	14.64
4	40.05	13.71
5	41.15	12.69
6	42.60	12.32
7	43.82	11.44

8	88.74	20.31
9	89.78	21.39
10	90.72	22.56
11	91.58	23.79
12	92.58	24.91
13	93.57	26.03
14	93.59	26.18

** Corrected JANBU FOS = 2.984 ** (Fo factor =1.039)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	31.57	14.31
2	31.73	14.19
3	33.22	14.00
4	34.61	13.42
5	35.69	12.38
6	36.96	11.59
7	38.46	11.49
8	39.61	10.53
9	85.51	19.71
10	86.38	20.93
11	87.27	22.14
12	88.22	23.30
13	89.27	24.37
14	90.14	25.59
15	90.16	26.01

** Corrected JANBU FOS = 3.023 ** (Fo factor =1.039)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.53	14.91
2	34.76	14.77
3	35.87	13.76
4	37.24	13.14
5	38.64	12.61
6	39.72	11.58
7	41.04	10.86
8	89.59	20.53
9	90.52	21.71
10	91.25	23.02
11	91.82	24.41
12	92.87	25.48
13	93.56	26.18

** Corrected JANBU FOS = 3.087 ** (Fo factor =1.038)

Failure surface No. 9 specified by 12 coordinate points

Point	x-surf	y-surf

No.	(ft)	(ft)
1	37.98	15.60
2	39.00	14.63
3	40.18	13.69
4	41.28	12.68
5	42.76	12.43
6	43.87	11.42
7	89.00	20.33
8	89.89	21.54
9	90.55	22.89
10	91.55	24.01
11	92.37	25.26
12	93.02	26.15

** Corrected JANBU FOS = 3.096 ** (Fo factor =1.040)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	29.15	13.83
2	29.48	13.51
3	30.94	13.16
4	32.06	12.17
5	33.54	11.93
6	35.03	11.79
7	36.29	10.96
8	37.56	10.17
9	86.34	19.95
10	87.10	21.24
11	88.04	22.41
12	88.71	23.75
13	89.72	24.86
14	89.83	25.97

** Corrected JANBU FOS = 3.124 ** (Fo factor =1.037)

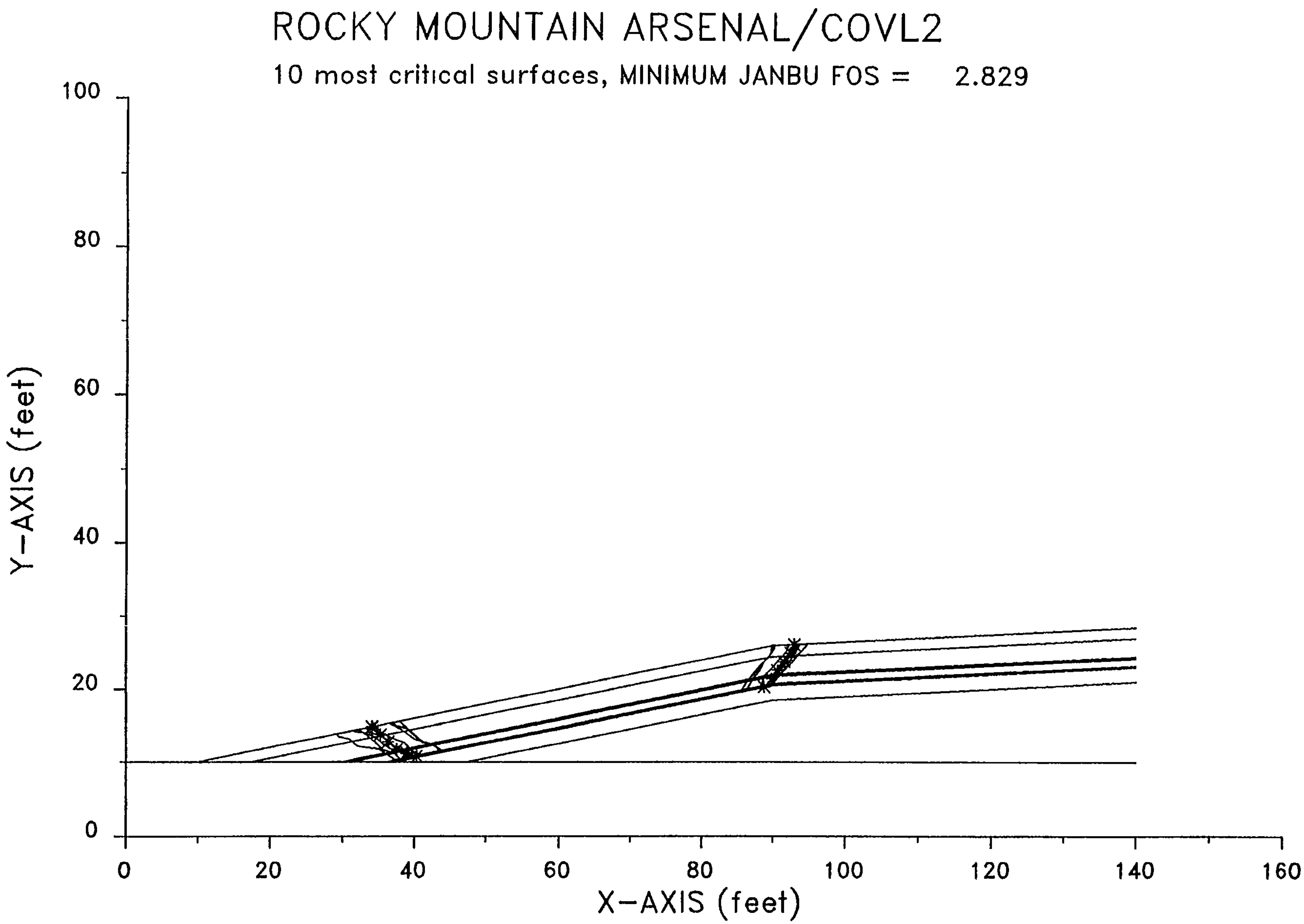
The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.829	1.038	34.14	92.99	6859.
2.	2.834	1.037	33.26	93.73	6998.
3.	2.855	1.037	32.32	93.00	7077.
4.	2.943	1.039	36.55	94.73	6546.
5.	2.960	1.039	33.95	92.24	6745.
6.	2.984	1.039	37.01	93.59	6402.
7.	3.023	1.039	31.57	90.16	6708.
8.	3.087	1.038	34.53	93.56	6753.

9.	3.096	1.040	37.98	93.02	6390.
10.	3.124	1.037	29.15	89.83	6997.

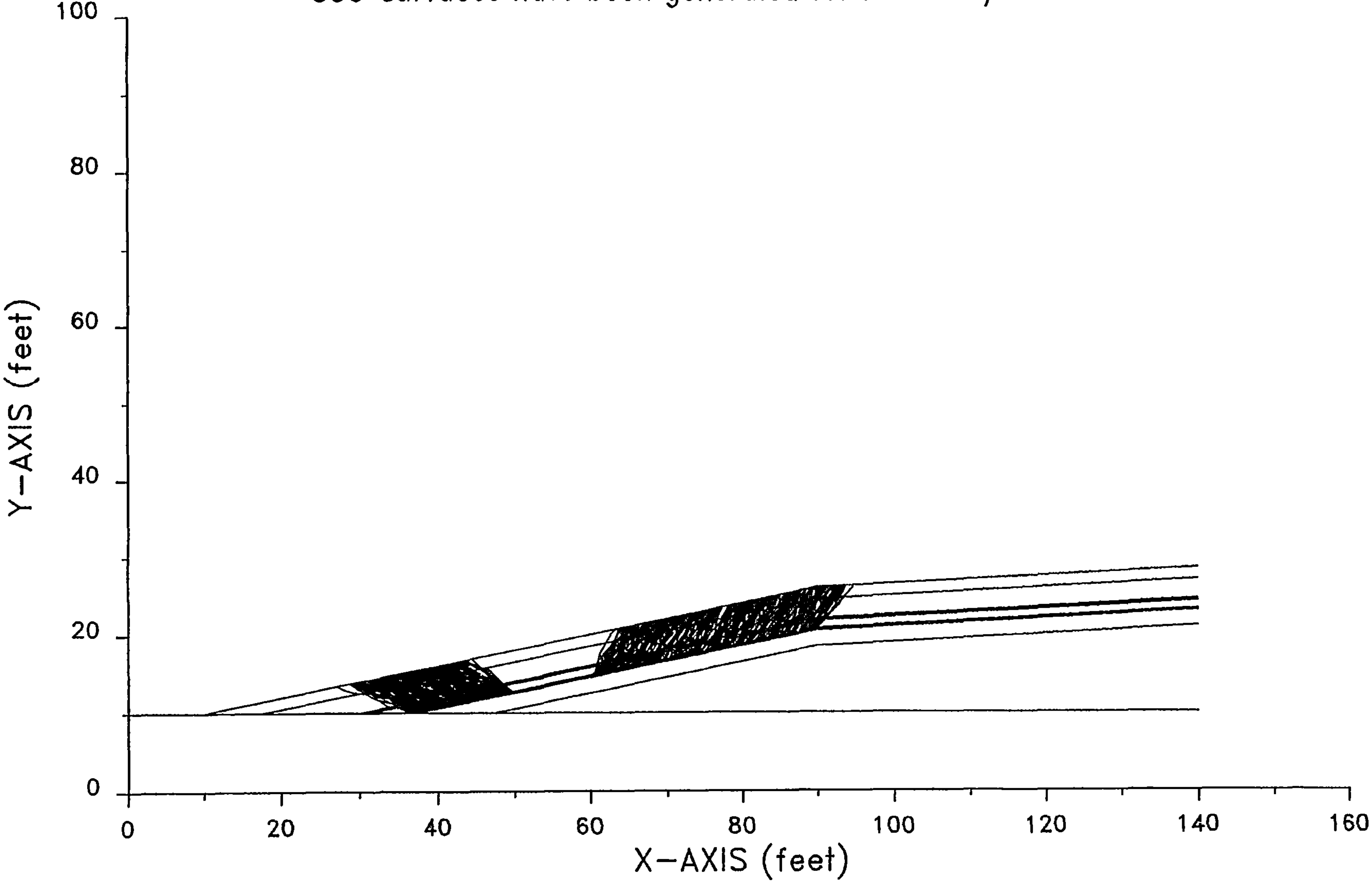
* * * END OF FILE * * *


ROCKY MOUNTAIN ARSENAL/COVL2
10 most critical surfaces, MINIMUM JANBU FOS = 2.829
Y-AXIS (feet)
X-AXIS (feet)
0
20
40
60
80
100
120
140
160

Pg 30 of 67

ROCKY MOUNTAIN ARSENAL/COVL2

300 surfaces have been generated for this analysis



Pg 31 of 67

XSTABL OUTPUT

```
*****************************************
*                XSTABL                 *
*                                       *
*    Slope Stability Analysis using     *
*   Simplified BISHOP or JANBU methods  *
*                                       *
*          Copyright (C) 1990           *
*   Interactive Software Designs, Inc.  *
*          All Rights Reserved          *
*                                       *
*           Jean Lou Chameau            *
*           Purdue University           *
*        W. Lafayette,  IN 47907        *
*                                       *
*  Ver. 3.00                      1002  *
*****************************************
```

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

SEGMENT BOUNDARY COORDINATES

3 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	0.00	10.00	10.00	10.00	8
2	10.00	10.00	90.00	26.00	1
3	90.00	26.00	140.00	28.50	1

19 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	10.00	10.00	17.50	10.00	8
2	17.50	10.00	90.00	24.50	2
3	90.00	24.50	140.00	27.00	2
4	17.50	10.00	30.00	10.00	8
5	30.00	10.00	90.00	22.00	3
6	90.00	22.00	140.00	24.50	3
7	30.00	10.00	31.25	10.00	8
8	31.25	10.00	90.00	21.75	4
9	90.00	21.75	140.00	24.25	4
10	31.25	10.00	36.25	10.00	8
11	36.25	10.00	90.00	20.75	5
12	90.00	20.75	140.00	23.25	5
13	36.25	10.00	37.50	10.00	8
14	37.50	10.00	90.00	20.50	6
15	90.00	20.50	140.00	23.00	6
16	37.50	10.00	47.50	10.00	8
17	47.50	10.00	90.00	18.50	7

18	90.00	18.50	140.00	21.00	7
19	47.50	10.00	140.00	10.00	8

ISOTROPIC Soil Parameters

8 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	115.0	0.0	30.0	0.000	0.0	1
2	125.0	125.0	1000.0	0.0	0.000	0.0	1
3	100.0	100.0	0.0	20.0	0.000	0.0	1
4	120.0	120.0	0.0	37.0	0.000	0.0	1
5	100.0	100.0	0.0	12.0	0.000	0.0	1
6	125.0	125.0	700.0	0.0	0.000	0.0	1
7	125.0	125.0	2000.0	0.0	0.000	0.0	1
8	115.0	115.0	0.0	35.0	0.000	0.0	1

A critical failure surface searching method, using a random technique for generating sliding BLOCK surfaces, has been specified.

300 trial surfaces have been generated.

2 boxes specified for generation of central block base

Length of line segments for active and passive portions of sliding block is 1.5 ft

Box no.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Width (ft)
1	36.87	10.10	50.00	12.62	0.20
2	60.00	14.62	90.00	20.62	0.20

Factors of safety have been calculated by the :

* * * * *   MODIFIED JANBU METHOD   * * * * *

The TEN most critical of all the failure surfaces examined are displayed below - the most critical first

Failure surface No. 1 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	34.14	14.83
2	34.19	14.78
3	35.32	13.79
4	36.41	12.76
5	37.52	11.76
6	38.93	11.24
7	40.35	10.77
8	88.72	20.31
9	89.77	21.39
10	90.62	22.63
11	91.60	23.76
12	92.48	24.97
13	92.99	26.15

** Corrected JANBU FOS = 2.829 ** (Fo factor =1.038)

Failure surface No. 2 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.26	14.65
2	33.85	14.07
3	35.27	13.59
4	36.52	12.75
5	37.68	11.80
6	38.79	10.79
7	40.28	10.66
8	89.62	20.45
9	90.67	21.52
10	91.57	22.72
11	92.41	23.96
12	93.21	25.24
13	93.73	26.19

** Corrected JANBU FOS = 2.834 ** (Fo factor =1.037)

Failure surface No. 3 specified by 12 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	32.32	14.46
2	33.42	13.70
3	34.58	12.75
4	35.65	11.70
5	37.08	11.24
6	38.22	10.27
7	88.93	20.41
8	89.97	21.50
9	91.03	22.56
10	91.92	23.77
11	92.58	25.12
12	93.00	26.15

** Corrected JANBU FOS = 2.855 ** (Fo factor =1.037)

Failure surface No. 4 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	36.55	15.31
2	37.52	14.82
3	38.80	14.04
4	40.02	13.16
5	41.44	12.68
6	42.85	12.19
7	44.13	11.40
8	89.60	20.45
9	90.65	21.52
10	91.67	22.62
11	92.72	23.68
12	93.62	24.89
13	94.65	25.97
14	94.73	26.24

** Corrected JANBU FOS = 2.943 ** (Fo factor =1.039)

Failure surface No. 5 specified by 13 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	33.95	14.79
2	34.01	14.74
3	35.13	13.75
4	36.36	12.90
5	37.47	11.89
6	38.94	11.58
7	40.14	10.68
8	88.33	20.36
9	88.76	21.79
10	89.81	22.86
11	90.80	23.99
12	91.81	25.10
13	92.24	26.11

** Corrected JANBU FOS = 2.960 ** (Fo factor =1.039)

Failure surface No. 6 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	37.01	15.40
2	37.42	14.99
3	38.88	14.64
4	40.05	13.71
5	41.15	12.69
6	42.60	12.32
7	43.82	11.44

8	88.74	20.31
9	89.78	21.39
10	90.72	22.56
11	91.58	23.79
12	92.58	24.91
13	93.57	26.03
14	93.59	26.18

** Corrected JANBU FOS = 2.984 ** (Fo factor =1.039)

Failure surface No. 7 specified by 15 coordinate points

Point No.	x-surf (ft.)	y-surf (ft)
1	31.57	14.31
2	31.73	14.19
3	33.22	14.00
4	34.61	13.42
5	35.69	12.38
6	36.96	11.59
7	38.46	11.49
8	39.61	10.53
9	85.51	19.71
10	86.38	20.93
11	87.27	22.14
12	88.22	23.30
13	89.27	24.37
14	90.14	25.59
15	90.16	26.01

** Corrected JANBU FOS = 3.023 ** (Fo factor =1.039)

Failure surface No. 8 specified by 13 coordinate points

Point No.	x-surf (ft.)	y-surf (ft)
1	34.53	14.91
2	34.76	14.77
3	35.87	13.76
4	37.24	13.14
5	38.64	12.61
6	39.72	11.58
7	41.04	10.86
8	89.59	20.53
9	90.52	21.71
10	91.25	23.02
11	91.82	24.41
12	92.87	25.48
13	93.56	26.18

** Corrected JANBU FOS = 3.087 ** (Fo factor =1.038)

Failure surface No. 9 specified by 12 coordinate points

Point	x-surf	y-surf

No.	(ft)	(ft)
1	37.98	15.60
2	39.00	14.63
3	40.18	13.69
4	41.28	12.68
5	42.76	12.43
6	43.87	11.42
7	89.00	20.33
8	89.89	21.54
9	90.55	22.89
10	91.55	24.01
11	92.37	25.26
12	93.02	26.15

** Corrected JANBU FOS = 3.096 ** (Fo factor =1.040)

Failure surface No.10 specified by 14 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	29.15	13.83
2	29.48	13.51
3	30.94	13.16
4	32.06	12.17
5	33.54	11.93
6	35.03	11.79
7	36.29	10.96
8	37.56	10.17
9	86.34	19.95
10	87.10	21.24
11	88.04	22.41
12	88.71	23.75
13	89.72	24.86
14	89.83	25.97

** Corrected JANBU FOS = 3.124 ** (Fo factor =1.037)

The following is a summary of the TEN most critical surfaces

Problem Description : ROCKY MOUNTAIN ARSENAL/COVL2

	Modified JANBU FOS	Correction Factor	Initial x-coord	Terminal x-coord	Driving Force
1.	2.829	1.038	34.14	92.99	6859.
2.	2.834	1.037	33.26	93.73	6998.
3.	2.855	1.037	32.32	93.00	7077.
4.	2.943	1.039	36.55	94.73	6546.
5.	2.960	1.039	33.95	92.24	6745.
6.	2.984	1.039	37.01	93.59	6402.
7.	3.023	1.039	31.57	90.16	6708.
8.	3.087	1.038	34.53	93.56	6753.

9.	3.096	1.040	37.98	93.02	6390.
10.	3.124	1.037	29.15	89.83	6997.

* * * END OF FILE * * *

Appendix C

GUIDANCE FOR THE DEVELOPMENT OF AN OPERATIONS NARRATIVE

CONTENTS

1.0 INTRODUCTION

This guideline for the development of an Operations Narrative has been prepared as an appendix to the CAMU Designation Document (CDD) in support of the designation of a Corrective Action Management Unit (CAMU) as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA) located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Purpose and Scope

This document has been prepared as a guideline for the development of an Operations Narrative for the waste management activities to be conducted as part of the CAMU Detailed operational requirements cannot be completely developed until the design of the CAMU facilities is completed. Appendix C describes the general approach, that will be utilized in the development of the Operations Narrative, for specifying remediation waste management practices for the CAMU The Operations Narrative will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of the CDD

Additionally, the CDD contains other appendixes that provide requirements and/or guidance for the development of additional plans that will supplement the operational requirements For clarity, the contents of these related appendixes were not included in this document. Instead, the related appendixes are intended to be used in conjunction with this document. The related appendixes include the following

- Appendix B - Design Narrative This appendix describes the design parameters and design guidelines for the design of the CAMU
- Appendix D - Waste Analysis Plan This appendix outlines the procedures for evaluating the compatibility of waste to be managed within the CAMU
- Appendix G - Inspection Plan Outline This appendix outlines the inspection requirements and frequencies during operation of the CAMU
- Appendix J - Operating Record System Plan Outline This document outlines the documentation during the operation of the CAMU
- Appendix N - Action Leakage Rate and Response Action Plan Outline This appendix provides the calculation of an action leakage rate of a landfill cell based on the amount of water collected in a leak detection system and the appropriate response actions if the action leakage rate is extended
- Appendix O - Health and Safety Plan (HASP) Outline This appendix outlines the HASP for the CAMU and includes site and program descriptions, identification of waste types and hazards, and decontamination, disposal, and emergency procedures
- Appendix Q - Contingency Plan Outline This appendix outlines the response procedures for events that potentially threaten the public health and/or environment (i.e , spills, tornados)

This appendix is organized in nine sections Section 2.0 addresses the operational requirements and procedures for the landfill Section 3 0 addresses the operational procedures and requirements for the Basin F Waste Pile drying unit. Sections 4 0 and 5 0 address the operational procedures and requirement for the decontamination facility and the waste staging/consolidation areas, respectively Section 6.0 addresses the operational procedures and requirements for the run-on/runoff control systems The operational requirements for roadways are addressed in Section 7 0 Section 8 0 addresses emergency response and preparedness Sections 9 0 and 10 0 present an acronym list and bibliography, respectively

2.0 LANDFILL

This section describes general operational procedures that are anticipated to be incorporated into the final Operations Narrative The operational procedures described below will be consistent with the operational provisions for landfills specified in 6 Code of Colorado Regulations (CCR) 1007-3, Part 264 301

2.1 Waste Placement

This section describes typical operational procedures for placement of waste within the landfill cells at RMA These procedures will be refined and incorporated into the final Operations Narrative during the landfill design phase Landfill cell construction waste placement, and closure may be performed in progression such that the three activities would be performed concurrently

2.1.1 General Waste Placement

Landfill cell construction, waste placement, and closure may be performed in progression such that these three activities would be performed concurrently Waste, may be placed within a cell once the components of the cell in the vicinity of waste placement have been completed including the liner system, operations layer, and access ramp Construction of the cap may commence once a portion of the cell has been filled

Waste placement procedures (fill sequence, lift thickness, compaction requirements) will be specified based on the requirements of the design Measures will be taken to prevent runoff from exiting the landfill cell, the generation of windblown waste, and to control odor and/or vapor emissions Transport and placement of waste in the landfill will be halted when wind speeds exceed those specified in the design. Equipment and vehicles leaving the landfill cell that have come in direct contact with waste will be externally cleaned, if necessary, at the decontamination facility (see Section 4 0)

2.1.2 Ignitable, Reactive, and Incompatible Waste Placement

If ignitable, reactive, and incompatible wastes are placed in the landfill, the wastes will be isolated and/or segregated to prevent ignition and reaction. Waste materials that potentially exhibit these properties will be tested and classified as such in accordance with the procedures developed during preparation of the final Waste Analysis Plan (WAP) Specific procedures for the isolation and/or segregation of these wastes will be developed during the design phase

2.1.3 Containerized Waste Placement

Except for very small containers, such as an ampule, containers will be either

- At least 90 percent full when placed in the landfill
- Emptied and crushed flat, shredded, or similarly reduced in volume to the maximum practical extent before placement within the landfill

Additional requirements or procedures for placement of containerized waste may be identified during the design process

2.2 Daily Cover Placement

Daily cover consisting of soil, foaming agents, a geosynthetic cover, a combination of these materials, or other materials will be placed over the waste to prevent airborne dispersion of waste particulates and for odor and/or vapor controls The possibility of using a structural cover or building to reduce leachate generation and control air emissions was discussed during the value engineering meetings held February 13 and 14, 1996 Further evaluation of the requirements for air emission and leachate generation controls will be performed during design

2.3 Leachate Collection System and Leak Detection System(s)

The leachate collection system (LCS) and leak detection system(s) (LDS) will be operated to prevent leachate accumulation over the liner in excess of 1 foot and to minimize clogging of the systems Leachate removed from these systems will be treated The detailed procedures for removal of leachate will be developed during design Monitoring and evacuation of these systems will be in accordance with the frequencies specified within the Inspection Plan (Appendix G) The leachate removed from the LCS and LDS will be appropriately managed either onsite or offsite in accordance with applicable regulatory requirements at the time of generation Details regarding how this leachate will be managed will be determined during design.

Surface water within the landfill will typically be directed into temporary sumps on the landfill surface formed from the waste fill progression and daily cover This water will be removed using vacuum trucks and/or pumps and piping to reduce the amount of water that reaches the LCS The surface water will be managed in accordance with applicable regulatory requirements at the time it is collected. Collected surface water may be placed in a storage facility for testing prior to discharge or treatment.

The LCS and LDS may be flushed, if necessary The procedures for flushing the LCS and LDS will be determined based on the history of the Basin F Waste Pile and the requirements of the individual cell operation. The specific procedures for flushing will be developed as part of the individual cell design

2.4 Odor/Vapor Controls

The expected amount of odor and/or vapor emissions for specific waste streams to be placed within an individual cell will be estimated during the design of the specific landfill cell receiving that specific waste stream Cell-specific odor/vapor controls may be necessary for the landfill cells that will contain waste from the Basin F Waste Pile and may also be necessary for cells containing other waste streams

Odor/vapor controls may consist of one, or a combination of, the following

- Enclosures with internal air handling systems placed over the cell
- Specific types of daily cover (i e , foams)
- Specific types of placement procedures
- Specific monitoring requirements
- Other control systems developed during design

The odor/vapor control requirements will be completed as a part of design and will consider the design of the landfill cell, the work plan for the excavation, treatment (if necessary), transport of the particular waste stream, and the operating requirements of the landfills

3.0 BASIN F WASTE PILE DRYING UNIT

The Basin F Waste Pile drying unit will be constructed and operated to dry Basin F Waste Pile material that does not pass the paint filter test. The drying unit will be operated and maintained in accordance with manufacturer's instructions, applicable regulations, and other requirements identified during design. Methods and procedures for handling and placement of soils after drying to address exposure to precipitation and production of leachate will be evaluated during design.

Environmental controls including containment systems, odor/vapor controls, and run-on and runoff controls will be operated and maintained to protect human health and the environment and prevent releases that may have adverse impacts to soil, groundwater, surface water, and air The details and requirements for these systems will be determined during design

4.0 DECONTAMINATION FACILITY

Decontamination facilities will be constructed and operated to decontaminate equipment used during operation and closure of the CAMU Decontamination facilities will be operated and maintained to ensure proper functioning of equipment and achievement of design performance standards The decontamination facility will be operated in accordance with the manufacturer's instructions, applicable regulatory requirements, and the requirements of the design

Equipment leaving the active waste management areas (i e , landfill cells, waste handling/drying facility) will be visually inspected prior to leaving the area If contaminants are found during the inspection or if the vehicle or equipment has come in direct contact with contaminated materials, the equipment will be washed in a decontamination facility before leaving the active waste management areas

Rinsate collected during decontamination will be characterized and either recycled, treated, or disposed of in accordance with applicable regulations Details of how the rinsate will be managed will be determined during design.

5.0 WASTE STAGING/CONSOLIDATION AREAS

Waste staging/consolidation areas will be used during operations for temporary staging, waste sizing, and/or storage of soil/debris between processing steps or to temporarily stockpile remediation wastes for transport Waste staging areas will be located within the CAMU area Equipment, facilities, and systems at the waste staging/consolidation areas will be operated and maintained in accordance with manufacturer's recommendations, applicable regulatory requirements, and other requirements identified during design. Environmental controls and safety systems will be operated and maintained to protect human health and the environment and prevent releases that may have an adverse impact on soil, groundwater, surface water, and air

The waste staging/consolidation areas will incorporate run-on/runoff controls for the management of surface water in these areas In general, run-on will be prevented from flowing onto these areas through the use of curbs, diversion channels, grading, and other hydraulic structures Run-on will be diverted to existing drainages outside the CAMU Runoff from these areas will be collected through the use of curbs, sumps, channels, grading, and other hydraulic structures and diverted to a retention pond(s) Details of how runoff will be managed will be developed during design. Waste staged, sized, and/or stored in these areas will be managed in a manner that minimizes the potential for wind or water dispersion and excessive odor/vapor emissions This may be done through the use of one, or a combination of, the following

- Enclosures with internal air handling systems
- Covers consisting of soils, geosynthetics, or other materials
- Other control systems or strategies specified in design
- Unit-specific operating requirements
- Unit-specific inspection and monitoring requirements

6.0 RUN-ON/RUNOFF CONTROL SYSTEMS

Water collected from the run-on control system will be directed to existing drainages outside the CAMU Water collected from the runoff control system will be diverted to a retention pond(s) within the CAMU Run-on and runoff water will be managed in accordance with applicable regulatory requirements at the time of collection These systems may include drop structures, berms, channels, culverts, and curbs and will be inspected in accordance with the Inspection Plan (Appendix G) These systems will be operated and maintained to meet the design performance standards Operational activities will typically consist of grading, excavation, and general repair work to ensure the following

- The drainage structures do not become obstructed with debris or sediment
- Positive drainage is maintained and ponding does not occur
- Adequate flow capacity and freeboard are maintained in accordance with design requirements
- Excessive erosion does not occur
- Run-on system integrity is maintained to prevent flow onto active waste management areas
- Runoff system integrity is maintained to prevent the release of potentially contaminated runoff from active waste management areas

7.0 ROADWAYS

Roadways outside the active waste management areas will be operated and maintained in the same manner as other roadways at RMA Roadways within active waste management areas will be operated and maintained to verify that

- The roadways are in a good state of repair
- The roadways are safe for travel
- Runoff is properly collected and diverted to retention ponds, testing prior to release may be required
- Waste has not accumulated on the roadway

Visual inspections for obstructions, excessive cracking, and proper drainage will be performed periodically in accordance with the Inspection Plan (Appendix G) Repairs, cleanup, and maintenance will be performed as necessary to ensure that the roadways are functioning as designed

8.0 EMERGENCY RESPONSE AND PREPAREDNESS

Emergency response equipment for the CAMU will typically include alarm/communication systems, fire protection equipment, spill control equipment, and decontamination equipment The actual components of the systems necessary to provide for emergency response and preparedness will be determined during design These systems will be tested, operated, and maintained in accordance with manufacturer's instructions and applicable regulatory requirements to assure proper operation in the event of an emergency Adequate access will be maintained during operation of the CAMU to allow unobstructed movement of personnel and equipment to any area where an emergency may occur Arrangements with local authorities may be established to familiarize the authorities with the operations and facilities at the landfill and secure support in the event of an emergency A Contingency Plan (see outline in Appendix Q) specific to the CAMU will be developed and appended to the RMA Contingency Plan for implementation in the event of a release or other emergency

9.0 ACRONYMS

Army	U S Department of the Army
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWMA	Colorado Hazardous Waste Management Act
FFA	Federal Facilities Agreement
HASP	Health and Safety Plan
HLA	Harding Lawson Associates
LCS	Leachate collection system
LDS	Leak detection system
O&M	Operation and maintenance
RMA	Rocky Mountain Arsenal
State	State of Colorado
WAP	Waste Analysis Plan

10.0 BIBLIOGRAPHY

Foster Wheeler Environmental Corporation 1995. *Final detailed analysis of alternatives, Rocky Mountain Arsenal, Commerce City, Colorado version 4 1,* October

Appendix D

GUIDELINES FOR DEVELOPMENT OF A WASTE ANALYSIS PLAN

CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

This guideline for the development of a Waste Analysis Plan (WAP) has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 CAMU Description

In June 1995, an Agreement for a Conceptual Remedy (the Conceptual Remedy) for the Cleanup of RMA among the State, U S Environmental Protection Agency (EPA), the Army, Shell, and the U.S Fish and Wildlife Service (FWS) was signed The Conceptual Remedy represents agreement by the parties relative to specific components of the remedy for the final cleanup of RMA. These components of the remedy are included in the (1) Proposed Plan for the RMA Onpost Operable Unit and (2) Final Detailed Analysis of Alternatives Report (DAA) (Foster Wheeler, 1995) The Conceptual Remedy, the Proposed Plan for the Onpost Operable Unit, and the DAA are documents prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The Conceptual Remedy calls for the construction and operation of a new onsite hazardous waste landfill for disposal of principal threat and human health exceedance soil and debris (See DAA for detailed definitions of these CERCLA related terms). The portion of the CAMU that includes a state-of-the-art hazardous waste landfill is located in Sections 25 and 26 of RMA between Former Basin F and North Plants. Double-lined cells within the landfill will receive principal threat and human health exceedance material from 17 contaminated areas of RMA. In addition, **a** triple-lined **cell** will be constructed to receive principal threat and **human health exceedance** soil from the Basin F Waste Pile and **Former Basin F, human health exceedance soil from Sand Creek Lateral, and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto**. The total volume of material to be placed in the landfill will be approximately 1,200,000 cubic yards, with approximately 655,000 cubic yards to be placed in the triple-lined **cell**.

1.2 Document Objectives and Organization

This document has been prepared as a guideline for the development of a WAP for the CAMU that will be responsive to Sections 265.13 and 265.17 of 6 CCR 1007-3. The WAP will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5.0 of the CDD. The final WAP will describe procedures for obtaining and/or reviewing detailed chemical and physical analysis data for the wastes to be disposed of in the hazardous waste landfill. Detailed chemical and physical data have previously been collected during the on post remedial investigation/feasibility study (RI/FS) for the material to be disposed in the onsite CAMU. To the extent applicable, the final WAP will incorporate any existing data in developing the final procedures for characterization of disposed waste streams. The objectives of the WAP will be as follows:

- Summarize existing chemical and physical data for each of the waste streams to be disposed in the landfill area of the on post CAMU, and identify more detailed data sources for reference as necessary during disposal operations (6 CCR 265.13(a))
- Specify any restrictions and/or pre-disposal requirements for the disposed wastes (6 CCR 265.17)
- Describe additional chemical and physical analyses to complete the characterization of each waste for the purposes of disposal. These additional analyses will be performed as necessary to assess compatibility of the waste streams with potentially commingled waste streams in the landfill and with the liner/cover components. The description of additional analyses will include identification of analytical parameters and the rationale for parameter selection, (2) sampling frequency, (3) sampling methods, and (4) analytical methods (6 CCR 265.13(b)).

Existing data and reference information for the disposed waste streams used in the development of this guidance document are summarized in Section 2 0 Contemplated restrictions and pretreatment requirements for the disposed waste streams and the general approach for waste disposal are summarized in Section 3 0 Contemplated waste compatibility screening analyses to be performed on the disposed wastes, including the analytical parameters, rationale, and analytical frequency considerations, are summarized in Section 4 0 Contemplated sampling protocols and analytical methods are discussed in Sections 5 0 and 6.0, respectively Documentation of waste analysis and disposal is described in Section 7 0 A list of acronyms is presented in Section 8 0, and references are listed in Section 9 0

2.0 IDENTIFICATION AND CHARACTERIZATION OF DISPOSED WASTES

Considerable analytical data have been generated during historical onpost investigations at RMA for the designated waste streams that will be placed into the CAMU This large body of analytical data will support the general waste characterization requirements stated in Part 265 13(a) of 6 CCR 1007-3 These analytical data are summarized in the sections which follow, and references are provided to indicate additional, more detailed sources of information concerning the characteristics and composition of the disposed waste streams

2.1 Wastes Disposed in Double-Lined Cells

Table D1 identifies the waste streams designated under the Agreement for a Conceptual Remedy for disposal in double-lined cells of the onsite CAMU landfill, and summarizes the chemical composition of these wastes In general, the chemical composition information shown in Table D1 is based on analytical data collected during the onpost RI/FS as summarized in the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995) In addition to the waste streams listed in Table D1, the Army may dispose of drummed wastes generated during RI/FS activities in the double lined cells These wastes are currently stored in warehouses at RMA Wastes characterization data generated at the time of generation, and other RMA site characterization data will be summarized for these drummed waste in the final WAP

Preliminary surveys of physical characteristics data obtained for individual soil samples collected near or within the soil waste bodies designated for disposal were performed by HLA in preparation of this WAP HLA's surveys indicated that the soil waste streams listed in Table D1 generally were of neutral to slightly alkaline pH (6 80 to 9 73), but that pH ranged as high as 11 to 12 in soil associated with the Secondary Basins and Lime Basins Soil organic carbon content ranged from less than 500 milligrams per kilogram (mg/kg) to as high as 10,300 mg/kg in the soil waste streams, with the highest occurrences observed in the South Plants Central Processing Area Soil and the South Plants Balance of Area Soil Moisture content ranged from approximately 5 to 30 percent for the soil waste streams to be disposed. Sources of more detailed physical characteristics information are referenced in Section 2.3.

2.2 Wastes Disposed In Triple-Lined Cells

Table D2 identifies the **three** waste streams designated under the Agreement for a Conceptual Remedy for disposal in enhanced, triple-lined cells of the onsite CAMU landfill, and summarizes the chemical composition of these wastes. In general, the chemical composition information shown in Table D2 is based on analytical data collected during the onpost RI/FS as summarized in the Final Detailed Analysis of Alternatives Report, Version 4.1 (Foster Wheeler, 1995). Additional data for the Basin F solids are from historical analyses of drummed Basin F soil.

Considerable analytical data have been generated for leachate from Basin F solids as part of the Interim Response Acton (IRA) at Basin F. A summary of these data is presented in Table D3 to provide additional information related to the Basin F Waste Pile soil to be disposed in triple-lined cells of the CAMU landfill. Table D3 also includes chemical composition data for Basin F liquid as obtained from the Rocky Mountain Arsenal Contingency Plan (Weston, 1991).

2.3 Sources of Additional Data

More detailed summaries of existing chemical data and physical characteristics data for the material comprising the waste streams will be compiled during preparation of the final WAP, as necessary to meet the general waste characterization requirements. Detailed data are available from the documents listed in Table D4. These and other documents containing detailed analytical data are available from the RMA Technical Information Center (RTIC). Chemical data for specific samples collected from the media to be disposed, as identified through review of the documents in Table D4, can also be obtained from the RMAED through DP Associates, the RMA data management subcontractor

3.0 SUMMARY OF THE WASTE DISPOSAL PROCESS

This section summarizes the process of waste disposal contemplated at the RMA onsite CAMU, including contemplated waste restrictions, pretreatment requirements, and the overall approach to landfill disposal for the waste streams identified in Section 2 0 This summary of the waste disposal process will form a basis for development of final waste analysis requirements

3.1 Waste Restrictions and Pretreatment Requirements for Disposed Wastes

The specific waste streams to be disposed in the RMA CAMU are described in Section 2 0 As these waste streams will be managed within a CAMU, land disposal restrictions defined in Part 268 of 6 CCR 1007-3 will not apply However, the following general restrictions are expected to apply to the waste streams as they are generated and disposed

- Pyrophoric materials discovered during excavation and disposal operations that are observed to react with atmospheric air or water will be neutralized prior to placement in the hazardous waste landfill
- Explosives-containing munitions discovered during excavation and disposal operations will be transported offsite for detonation at an approved facility If not considered safe for removal and transport, they will be detonated in place, prior to placement in the hazardous waste landfill
- Liquid wastes will not be disposed of in the hazardous waste landfill

In addition the conceptual remedy has specified the following requirements for disposed waste streams

- M-1 Pits principal threat and human health exceedance soil will be pretreated with a solidification technology prior to disposal
- Hex Pits principal threat soil will be treated with either an in situ or ex situ treatment technology If an ex situ process is selected, treatment of the Hex Pit soil will occur prior to disposal in the CAMU landfill
- Agent-contaminated building material and soil will be caustic washed as necessary prior to disposal
- Basin F Waste Pile soil that fails the paint filter test (U S Environmental Protection Agency [EPA] Method 9095) will be dried prior to disposal

The WAP will outline waste characterization analyses that may be required for wastes exhibiting potential compatibility concerns with other waste streams or with the disposal process Compatibility testing will be performed in accordance with Appendix B, Section 3 3 3, during the landfill design phase prior to disposal Threshold index parameters will be established as part of the compatibility testing program implemented during the design phase The threshold index parameter(s) will define screening-level analysis that may be used to confirm that waste streams to be disposed of in the landfill are not significantly different from those that were demonstrated to be compatible with liner components in the compatibility testing program conducted in conjunction with the landfill design. Thus, analysis for threshold index parameters may also occur during the landfill disposal phase If, during the disposal phase, analysis indicates that waste streams do not fall within threshold index parameter limits, additional compatibility testing will be required

3.2 Approach for Waste Disposal

Figure D1 presents a summary of the generalized conceptual approach for disposal of each waste stream from excavation through final placement in the landfill The figure identifies the major decision steps in the evaluation and clearance of each waste for final disposal As shown, preliminary clearance of each waste stream by the Program Manager for Rocky Mountain Arsenal (PMRMA) for disposal in the landfill will be based on reviews of existing data (see Section 2 0), as well as on additional data collected during the CAMU design phase Final clearance of the wastes for landfill disposal will be based on additional waste compatibility analyses that will be addressed in the WAP Information regarding compatibility testing of the waste streams and liner system components can be found in the Preliminary Scope of Work and Schedule of Design Activities for the RMA CAMU (Table 5 1) and in the Design Narrative (Appendix B, Section 3 3 3)

4.0 SPECIFIC WASTE ANALYSIS REQUIREMENTS FOR LANDFILL DISPOSAL

The disposal of principal threat and human health exceedance waste in the RMA onsite hazardous waste landfill is based on a large body of historical data as discussed in Section 2 0, which is expected to support meeting the general waste characterization requirements stated in Part 265 13a of 6 CCR 1007-3. A sampling and analysis program for the waste streams is contemplated during the design phase Additional analyses of each waste stream may occur during the disposal phase, as necessary, to assess its chemical compatibility with the liner components (e g , index testing may be conducted to verify waste stream characteristics are consistent with those found to be compatible during the design phase) Analyses conducted during waste disposal will also address the compatibility of each waste stream with commingled waste Waste compatibility screening analyses may be required for each waste stream, and will be performed if visual inspection of the waste and/or historical data reviews imply potential compatibility concerns Screening analysis data will be used to identify incompatible or reactive waste that may require segregation, pretreatment, and/or specific health and safety precautions

In addition to the compatibility screening program, some wastes will undergo field screening for Army Agents during disposal to assess whether pretreatment (i e , caustic washing) is necessary prior to placement in the landfill The general compatibility screening and agent screening analyses requirements prior to disposal are presented in the following subsections

4.1 Compatibility Screening Analyses

The WAP will specify the procedures for waste compatibility screening analysis to be conducted prior to disposal Those procedures will be similar to those presented below

For waste streams that exhibit potential compatibility concerns based on historical data review and/or inspection, initial screening will occur prior to disposal through the collection of samples from the waste body or from initial excavations of the waste These samples will be analyzed for any or all of the parameters described below, as deemed necessary by field personnel, to assess waste compatibility A preliminary assessment of the analytical parameters and methods for waste analysis is discussed in Section 6 0

- **Corrosivity** Corrosivity shall be assessed based on the ability of the waste to corrode steel at a rate and temperature set by the National Association of Corrosive Engineers standard TM-01-69 or equal (40 CFR 261 22[1])
- **pH** pH shall be measured to further assess corrosivity and waste compatibility
- **Free Liquids** Free liquid present in the waste shall be assessed visually or by the paint filter test (EPA Method 9095) Assessments of free liquids will estimate the number of phases, volume percent of aqueous liquid, volume percent of organic liquid, and volume of sediment in the liquid phase
- **Ignition Test.** Waste materials that exhibit a positive result when tested for ignition by spark at temperatures below 140 degrees Fahrenheit (° F) shall be identified
- **Compatibility with Commingled Waste.** If a waste stream is to be mixed with other wastes during disposal, then a sample of the waste stream shall be mixed with the wastes with which it is to be commingled to determine compatibility Any reaction which generates excessive heat or liberates excessive gases will identify incompatibility Wastes shall be segregated within the landfill if incompatibility is identified and cannot be remedied
- **Threshold Index Testing·** Threshold index testing parameters developed as part of the design phase compatibility testing program will be conducted, if necessary If the established index parameters are exceeded, then appropriate liner system compatibility testing will be performed

As accumulation and disposal of each waste stream proceeds, one or more of the above tests may be repeated as necessary if physical characteristics of a waste stream are observed to change significantly and compatibility concerns are raised Any significant change in color, odor, reactivity with ambient air or water, and/or number of media or phases present (e g., free liquids) for a given waste stream as assessed by field personnel, may result in verification analyses for compatibility.

Segregation and/or pretreatment alternatives may be considered on the basis of the screening results for wastes that exhibit the following characteristics

- Observable reactivity with commingled waste
- Corrosivity as indicated by a steel degradation or by pH below 2 0 or above 12 5

- Flash as indicated by ignition below 140°F
- Free liquids Drying and/or solidification may be considered as a pretreatment step for wastes exhibiting free liquids
- Observable reactivity with liner components

4.2 Agent Screening Analyses

Of the waste streams identified for disposal in the onsite hazardous waste landfill, 10 waste streams may contain potential agent contamination as indicated in the Final DAA Report (Foster Wheeler, 1995) The preferred alternative identified by the Final DAA Report for these soil and building material waste streams is to screen for agent materials during removal of the wastes and treat any contaminated material by caustic washing prior to placement in the landfill Therefore, screening of these waste streams for the Army Agents GB, VX, mustard (H), and Lewisite (L) will occur as part of the waste analysis program during the disposal phase The screening of these wastes will occur as they are excavated or otherwise accumulated by field monitoring methods currently established by PMRMA (see Section 6 0) Any suspected field detections of agent in the waste streams will be confirmed by collecting samples from the suspect material for laboratory analysis

5.0 WASTE SAMPLING PROCEDURES

As presented in Section 2 0, the types of waste media to be sampled during disposal operations include the following

- Excavated soil and sediment
- Building material and munitions debris

The general procedures, which will be in the final WAP, for sampling these two classifications of waste media are presented below In addition, a general summary of sampling documentation and decontamination procedures are presented in this section.

5.1 Waste Sampling

Where sampling is necessary for waste compatibility screening, composite grab samples will be collected from the subject area, initial excavations of waste soil and/or sediment, initial debris accumulations, or from initial pre-processed waste streams, as appropriate Specific standard operating procedures (SOPs) for sampling of these materials will be developed during remedial design These SOPs will be designed to comply with "Test Methods for Evaluating Solid Waste" specified in 6 CCR 1007-3, 260 1 Alternative methods may be used if prior approval is obtained from CDPHE

5.2 Sample and Document Custody Procedures

Sample and document custody procedures applicable to waste sampling are summarized in the following subsections These procedures are consistent with quality assurance (QA) and documentation protocols established by PMRMA (1993) and by EPA (1986, 1992, 1994) The procedures below are considered general and are subject to alteration and refinement during the design phase

Waste samples scheduled by the PMRMA Laboratory Support Division (LSD) for offsite analysis will be delivered to the PMRMA Receiving Office, Building 618, for shipping by the Program Manager

Support Division (PMSD) to one or more laboratories contracted by the PMRMA LSD Waste samples scheduled for onsite laboratory analysis will be delivered directly to the PMRMA Environmental Analytical Laboratory (EAL)

Field Documentation

Appropriate waste sampling forms will be used to record sample and field data collection activities performed onsite At the beginning of each day, the date, start time, weather conditions, field personnel present, level of personal protective equipment (PPE) being used, and name of the person making the entry will be recorded The names of visitors and the purpose of their visit will also be recorded All information pertinent to a field survey and/or sampling event will be recorded in the waste sampling form Typically, the waste sampling form will include the following information

- Name and title of author, date and time of entry, and physical/environmental conditions during field activity
- Location of sampling or field activity
- Name(s) and title(s) of field crew
- Type of media sampled or measured
- Sample collection or measurement method
- Number and volume of samples(s) collected
- Description of measuring reference points
- Date and time of sample collection
- Sample identification numbers(s)
- Field observations and comments
- Field measurements recorded (e g , pH, photoionization detector [PID])
- Sample documentation, including dates and methods of sample shipment

An example waste sampling form is attached as Figure D2 By the end of each day, samples should be brought back to the sample handling trailer for packaging

Sample Classification, Handling, and Shipping

Sample classification is necessary to ensure the protection of personnel involved in the offsite shipment of analytical samples and to maintain the integrity of the samples When sent by common carrier, the packaging, labeling, and shipping of hazardous materials is regulated by the U S Department of Transportation (DOT)

Designated sampling personnel will contact the PMSD no later than 9 00 a m daily for assignment of courier air bill numbers Sample shipments to each laboratory will receive a unique airbill number Containers shipped by the PMRMA shipping custodian will receive a different airbill number than those shipped by RMA Security Therefore, if necessary, two airbill numbers should be requested each day for each laboratory because samples will normally be delivered to the PMRMA shipping custodian (before 4 00 p m) or to RMA Security (after 4 00 p m)

Samples will be shipped with approximately 10 percent air space so that the container is not full at 130 °F unless otherwise required by the method of analysis Glass containers used for all types of analyses will be wrapped in bubble wrap and placed inside a DOT-approved shipping container (Coleman Sample Manager®) and packed to prevent breakage Sample shipments will be preserved by cooler packs around the sample containers Any remaining space will be filled with bubble wrap or vermiculite Samples scheduled for offsite analysis will be delivered to the PMRMA Receiving Office, Building 618, until approximately 4 00 p m and to RMA Security, Building 135, from approximately 4 00 p m until 7 00 p m for shipping to the contract laboratory(ies) for analysis Samples scheduled for onsite analysis will be delivered no later than 3 00 p m to the PMRMA EAL analytical laboratory Additional details of the waste analytical program are described in Section 6 0

The chain-of-custody (COC) record for each sample shipment will be enclosed in a sealed, waterproof envelope attached to the inside of the cooler lid and for delivery to the PMRMA Receiving Office or the PMRMA EAL The Field Operations Coordinator (FOC) will be responsible for notifying the project Quality Assurance Coordinator (QAC) of the number of samples delivered to the PMRMA Receiving Office and/or the PMRMA LSD and the time of delivery The project QAC (or designated representative) will contact the PMRMA Receiving Office and PMRMA LSD daily, as necessary, to inform them of the incoming samples, arrival time, and special handling or analytical procedures required

Required sample containers, sample preservation methods, and maximum holding times for each sample type are summarized in the RMA Chemical Quality Assurance Plan (CQAP) (PMRMA, 1993) Containers will be obtained from the PMSD supply office, based on availability, and supplied to field personnel before sampling

Sample Identification and Labeling

Sample labels and COC records will be provided to sampling personnel by the project QAC Labels will be attached to each bottle in which a sample is collected If labels are lost, voided, or damaged, the sample information will be noted on the waste sampling forms

Each sample will be identified by a separate sample label and associated tag number The information recorded on the label generally includes, but is not limited to, the following information

- Label tag number
- Site identification number
- PMRMA-approved site type code
- Date a six-digit number indicating the day, month, and year of collection
- Time a four-digit number indicating the 24-hour clock time of collection
- Media type the type of sample (e g , groundwater)
- Sample depth
- Sampler's signature
- Preservative the type of preservative used, if required

- Analysis the type of analysis requested
- The PMRMA-approved sampling technique used during collection

An example of a sample label to be used during the program is shown in Figure D3

Custody seals (evidence tape) will be used to preserve the integrity of the samples in the regular nonlocking shipping containers from the time of collection until they are opened in the laboratory Field personnel will prepare the shipping coolers with custody seals prior to releasing the samples The seal will be attached in such a way that it will break when the sample shipping container is opened Samples shipped in the Coleman Sample Manager® cooler will be sealed using wire custody seals The seals will carry the following information

- PMRMA sample shipping custodian's initials
- Date and time of sealing

Chain-of-Custody Records

To establish the documentation necessary to trace sample possession from the time of sample collection at RMA through sample analysis, a COC record will be completed and will accompany every sample This record will document sample custody transfer from the sampler, to other sampling team members (if necessary), to the laboratory, and back to RMA for disposal

For offsite analyses, the COC process will be maintained by PMRMA using a commercial shipper for shipment of bottles to the site and shipment of samples back to the laboratory The field personnel or sample custodian will write the courier airbill number on the COC record, and sign the COC record and the courier airbill form The PMRMA sample shipping custodian or RMA Security will arrange the shipping and prepare the courier airbill form

The COC record typically contains, at a minimum, the following information

- List of sampling team members
- Label identification number
- Date of sample bottle preparation and shipment
- Signature of sampler or bottle preparer
- Date and time of sample collection
- Sample location and depth
- Medium type
- Airbill number
- Sample preservation
- Type of requested analysis
- Signatures of persons involved in the chain of sample possession
- Inclusive dates of possession
- PMRMA-approved sampling technique and site type

The laboratory portion of the COC record will be completed by laboratory personnel and typically contains the following information

- Date of sample receipt by the laboratory
- Name of person receiving the sample at the laboratory
- Sample condition and temperature upon receipt at the laboratory

Samples will be appropriately packaged for shipment and will be dispatched to the laboratory for analysis with a separate COC record accompanying each shipment. The method of shipment, courier name(s), if any, and other pertinent information should be entered in the remarks section of the COC record An example COC record that will be used for water samples collected during the program is presented in Figure D4

Each COC record consists of three sheets of pressure-sensitive paper (white, yellow, and pink) After the shipping courier name and airbill have been written on the COC and the COC has been signed, additional copies of the original will be made for the Logistic Branch of the Army and the PMRMA LSD The two colored backing sheets of the COC will be removed, and the sample container with the original white COC record inside the lid will be sealed by the field personnel or sample custodian The yellow original will be retained in the sampling contractor's files, and the pink original will be retained by PMRMA

After the field COC record is signed by the laboratory, the laboratory will initiate an internal COC record to track the sample through analysis The original COC record will be retained in the laboratory's files, and a photocopy of the original COC record will accompany the unused portion of the sample back to RMA for final disposal Under no circumstances is an offsite laboratory to send extracted or spent samples to RMA for storage

Corrections to Documentation

Unless prohibited by cold weather conditions, data recorded in field logbooks, sample labels, and COC records will be completed with waterproof ink. None of the accountable, serialized documents will be destroyed or discarded, even if the documents are illegible or contain inaccuracies that require a replacement document

Errors on field documents will be corrected by drawing a line through the error and entering the correct information Errors on a field document should be corrected by the person who made the original entry, and the erroneous information should not be obliterated Corrections to documentation will be initialed and dated

5.3 Decontamination Procedures

Generalized decontamination procedures for sample collection are as follows and will be further defined as necessary during the CAMU design phase Sampling equipment including sampling scoops, bowls, picks, and chisels will be thoroughly cleaned prior to use and between discrete sampling locations using a detergent solution (Liquinox® or equivalent) followed by a distilled water rinse and allowed to air dry Samples will be collected in laboratory-certified clean sample containers and placed on ice in insulated coolers

Decontamination water used will generally be Contracting Officer's Representative (COR)-approved or distilled water Tap water may be used instead of COR-approved water for use in steam cleaning and detergent solutions provided that distilled water is used afterward to rinse equipment COR-approved water consists of the potable water supplied to RMA that is treated with an activated carbon treatment unit. Decontamination will consist of combinations of steam cleaning and/or detergent solution (Liquinox® or equivalent) wash, water rinse, and distilled water rinse Detergent solution is prepared by mixing approximately 1 teaspoon of detergent (Liquinox® or equivalent) per 5 gallons of COR-approved water or tap water This section details decontamination procedures as well as types of equipment to be decontaminated

Decontamination Pad

A temporary mobile decontamination pad will be set up near the work area to provide onsite decontamination Each temporary pad will include a steam cleaner and a sump to collect decontamination solids and wastewater Decontamination solids and wastewater will be removed from the sump will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

Personnel

Procedures for personnel decontamination are described in the Health and Safety Plan

6.0 WASTE ANALYTICAL PROCEDURES

It is contemplated that the WAP will specify that the PMRMA EAL will be the onsite laboratory responsible for performing waste characterization analyses Additional external laboratories may be identified by the PMRMA LSD to assist in waste sample analysis The laboratories and methods employed for waste analysis will be approved by PMRMA, and method performance and proficiency will be demonstrated prior to sample analyses in accordance with the PMRMA Chemical Quality Assurance Plan (PRMRA, 1993)

6.1 Analytical Methods

Analytical parameters and methods for waste samples that will be included within the WAP are summarized in Table D5 As shown, waste extracts to be screened and analyzed for agent parameters will be analyzed according to approved PMRMA-approved field screening methods Laboratory verification analyses to confirm suspected agent detections based on field screening results will be performed by the PMRMA EAL Analyses for the remaining parameters listed in Table D5 will be performed according to standard EPA or American Society for Testing and Materials (ASTM) screening-level methods

6.2 Quality Assurance Protocols

The WAP will specify that quality assurance and quality control (QA/QC) protocols for waste analyses and reporting will be approved by the PMRMA LSD and will be consistent with the requirements of the PMRMA CQAP (PMRMA, 1993)

7.0 DOCUMENTATION FOR WASTE ANALYSIS AND DISPOSAL

Specific documentation and data management requirements for waste analysis data during disposal operations will be developed in the operations plans of the contractors performing disposal Because the details of the CAMU design and operation are still being developed, specific documentation processes, formats, and requirements cannot be defined at the present time However, in general, the WAP will specify the following general documentation requirements will be met during disposal

Waste Analysis Data

- Management, review, and reporting of analytical data by the PMRMA LSD will conform to the requirements of the RMA CQAP (PMRMA, 1993)
- Analytical data generated prior to disposal will be reported from the PMRMA LSD to the remediation contractor, who initiated the waste compatibility characterization request (see Section 3 2) The remediation contractor will submit the historical data to the PMRMA Remedial Action Branch (RAB) and to the landfill operations contractor for evaluation and clearance of the waste. Based on initial data evaluation, the PMRMA RAB may identify additional parties to assess the waste compatibility data (e g , a pretreatment contractor)
- Official documentation of preliminary and final clearance for disposal in the onsite CAMU landfill will be transmitted from the PMRMA RAB to the excavation and landfill operation contractors (as well as appropriate pretreatment contractors) for each disposed waste stream Such documentation will include the basis for clearance for each waste stream
- A complete file of current and historical analytical data for each waste stream will be maintained by the remediation contractor, the landfill operations contractor, and PMRMA. Hardcopy data files will be maintained by PMRMA at the RMA Technical Information Center (RTIC), and electronic data will be maintained in the RMAED

Waste Disposal

- Logs may be maintained by remediation contractors for excavation, pretreatment (if necessary), and landfill disposal Excavation logs may include location information for each allotment of waste that is excavated for disposal Landfill disposal logs may include grid location information for each waste allotment in the landfill cells
- Transfer logs may be employed by the excavation, pretreatment, and landfill operations contractors to document the transfer of waste allotments and their locations within the disposal cells

Additional, more detailed requirements for documentation and reporting of waste disposal activities, including formats for logs and forms, will be defined during the design phase and will be included in the disposal operations plans

8.0 ACRONYMS

Army	U S Department of the Army
As	Arsenic
ASTM	American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, xylene
CAMU	Corrective Action Management Unit
CCR	Colorado Code of Regulations
Cd	Cadmium
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHWMA	Colorado Hazardous Waste Management Act
CLC2A	Chloroacetic acid
COC	Chain of custody
COR	Contracting Officer's Representative
CPMSO	p-Chlorophenylmethyl sulfoxide
$CPMSO_2$	p-Chlorophenylmethyl sulfone
CQAP	Chemical Quality Assurance Plan
Cr	Chromium
CWTS	Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Wastewater Treatment System
DAA	Detailed Analysis of Alternatives
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethyl phosphonate

DMMP	Dimethylmethyl phosphonate
DOT	U S Department of Transportation
EAL	Environmental Analytical Laboratory
EC	Exchangeable Cations
EPA	U S Environmental Protection Agency
ESE	Environmental Science and Engineering
FFA	Federal Facilities Agreement
FOC	Field Operations Coordinator
GB	Isopropylmethylphosphonofluoridate
GC	Gas chromatography
H	Mustard
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
HLA	Harding Lawson Associates
IRA	Interim Response Action
L	Lewisite
LSD	Laboratory Support Division
mg/kg	Milligrams per kilogram
MKE	Morrison-Knudsen Environmental
NH_3	Ammonia
OCP	Organochlorine pesticide
OPC	Organophosphorous compound
OPP	Organophosphorous pesticide
OSC	Organosulfur compound
Pb	Lead
PID	Photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal

PMSD	Program Manager Support Division
PNA	Polynuclear aromatic hydrocarbon
PPE	Personal protective equipment
ppm	Parts per million
QA/QC	Quality assurance/quality control
QAC	Quality Assurance Coordinator
RAB	Remedial Action Branch
RI/FS	Remedial Investigation/Feasibility Study
RMA	Rocky Mountain Arsenal
RMAED	RMA Environmental Database
RTIC	RMA Technical Information Center
S^2	Sulfide
SOPs	Standard Operating Procedures
State	State of Colorado
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total dissolved solids
TOC	Total organic carbon
TSS	Total suspended solids
UXO	Unexploded ordnance
VHO	Volatile halogenated organic
VX	Ethyl S-2-diisopropylaminoethylmethyl phosphorothiolate
WAP	Waste Analysis Plan
yd^3	Cubic Yard
$^\circ F$	Degrees Fahrenheit

•

9.0 BIBLIOGRAPHY

Ebasco 1992 *Final remedial investigation summary report,* Version 3 2, Contract No DAAA15-88-D-0024 January

Ebasco 1994 *Final report, Feasibility Study Soil Volume Refinement Program,* Version 2 0, DAAA 05-92-D-0002, June

Environmental Science and Engineering 1988 *Determination of partition coefficients for the primary contaminant sources of section 36,* Version 2 2, Contract No DAAK11-84-D-0016, September

Federal Register, Part III 1979 *Guidelines establishing test procedures for the analysis of pollutants* v 44, no 233, p 69464-69475, RTIC #81292R08, December 3

Foster Wheeler 1995 Final Detailed Analysis of Alternatives Document, Version 4 1, Volumes I through VII, Contract No DAAA 05-92-D-0002, October

Harding Lawson Associates 1992 *RMA innovative technology studies program summary results report for soil vapor extraction bench-scale testing (draft-final),* December 2

——— 1993 *Quality assurance management plan for the Harding Lawson Associates Program, Rocky Mountain Arsenal, Commerce City, Colo* , March 5

——— 1994 *Final Basin F Waste Pile annual data collection report,* Contract No DAAA05-92-D-0003 November

——— 1994 *Final technical report task 93-04, soil vapor extraction screening program,* Rocky Mountain Arsenal, Commerce City, Colo , June

J P Walsh. 1988 *Soil investigation and inventory of RMA,* Report prepared for Morrison-Knudsen Engineers, Inc , October

Program Manager for Rocky Mountain Arsenal 1993 *PMRMA chemical quality assurance plan,* Commerce City, Colorado (version 1 0) RTIC No 89244R01, September

Roy F Weston, Inc 1991 *Rocky Mountain Arsenal contingency plan,* Revision 4 0

U S Environmental Protection Agency 1979b *Methods for chemical analysis of water and wastes* Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, EPA-600/4-79-020

——— 1980 *Guidelines and specifications for preparing quality assurance project plans* Municipal Environmental Research Laboratory, Cincinnati, Ohio, MERL/QA-2

——— 1982 *Test methods Technical additions to methods for chemical analysis of water and wastes* Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, EPA-600/4-82-055

——— 1984a *Characterization of hazardous waste sites - a methods manual* - v II, available sampling methods, second edition Environmental Monitoring Systems Laboratory, Las Vegas, Nev., EPA 600/4-84-076

——— 1984b *Remedial investigations guidance document* Office of Emergency and Remedial Response, Washington, D C

——— 1985 *Guidance for remedial investigations under CERCLA* April

——— 1986 *Test methods for evaluating solid waste* Office of Solid Waste and Emergency Response (OSWER) Directive SW-846

——— 1987a *A compendium of Superfund field operation methods* Office of Emergency and Remedial Response, Washington, D C , EPA/540/P-87/001

——— 1987b *Data quality objectives for remedial response activities (development process)* Office of Emergency and Remedial Response, Washington, D C., EPA/540/G-87/003, March

——— 1992 *Test methods for evaluating solid waste, physical/chemical methods, SW-846,* 3rd edition, Final Update I, July

——— 1993a *USEPA contract laboratory program statement of work for organics and inorganics analysis multi-media, multi-concentration*, September

——— 1993b *Data quality objectives process for Superfund interim final guidance, Office of Emergency and Remedial Response,* Washington, D C , September, EPA/540/R/93/071

——— 1994 *Test methods for evaluating Solid Waste, Physical/Chemical Methods,* SW-846, 3rd edition, Final Update II, September

Woodward-Clyde Consultants 1993a *Final technical report, phase II on-post feasibility study field data collection,* Version 3 0, Volumes I and II, Contract No DAAA15-88-D-0022, April

——— 1993b *Final technical report, phase I on-post feasibility study field data collection,* Version 3 1, Volumes I and II, Contract No DAAA15-88-D-0022, April

Table D1: Summary of Wastes Disposed in Double-lined Cells at the RMA Onsite Hazardous Waste Landfill

Waste Identification	Basis for Disposal in Hazardous Waste Landfill	Chemical Composition (ppm)[a,b]	
South Plants Central Processing Area Soil	Principal Threat and Human Health Exceedance for OCPs, VHOs, DBCP, CLC2A, As, Hg, trace metals Potential agent presence[c]	OCPs	7 5 to 580
		VHOs	1 9 to 580
		DBCP	275
		CLC2A	13
		HCCPD	28
		DCPD	6 7
		As	230
		Cd	5 1
		Cr	20
		Hg	300
		Pb	310
Balance of South Plants Area Soil	Principal Threat and Human Health Exceedance for OCPs, HCCPD, As, trace metals Potential agent and UXO presence[c]	OCPs	0 53 to 33
		HCCPD	23
		Cr	62
		Hg	500
		Pb	340
Section 36 Balance of Area Soil	Human Health Exceedance for OCPs, CLC2A Potential agent and UXO presence[c]	OCPs	0 10 to 24
		CLC2A	52
		As	2 4
		Hg.	0 46
Secondary Basin Soil	Human Health Exceedance for OCPs, Cr	OCPs	0 68 to 28.2
		Cr	120[d]
North Plants Soil	Human Health Exceedance for As	As	2,800
M-1 Pits Soil	Principal Threat and Human Health Exceedance for OCPs, HCCPD, DCPD, As, Hg Potential agent presence[c]	OCPs	0 099 to 0 55
		HCCPD	44
		DCPD	195
		As	17,000
		Cd	320
		Hg	4,300
Hex Pits Soils	Principal Threat and Human Health Exceedance for OCPs, HCCPD	OCPs	1,000[d]
		HCCPD	40,000[d]
Burial Trenches Soil	Human Health Exceedance for Cr, Pb Potential agent and UXO presence[c]	Cr	20
		Pb	190

Table D1 (continued)

Waste Identification	Basis for Disposal in Hazardous Waste Landfill	Chemical Composition (ppm)[a,b]
Sand Creek Lateral Soil	Human Health Exceedance for OCPs, CLC2A, Cr	OCPs 0 04 to 27 8 CLC2A 230[d] Cr 180 Pb 800
Buried Lake Sediments	Human Health Exceedance for OCPs	OCPs 0 8 to 40
South Plants Ditches Soil	Principal Threat and Human Health Exceedance for OCPs, trace metals	OCPs 0 17 to 270 As 0 42 Cr 12 Hg 0 30
Upper Derby Lake Soil (Lake Sediments)	Human Health Exceedance for OCPs	OCPs 0 7 to 11 8
Chemical Sewer System Soil (outside of the South Plants Central Processing Area)	Human Health Exceedance for OCPs, VHOs, HCCPD, DBCP, CLC2A, As Potential agent presence[c]	OCPs 20,000[d] VHOs 400[d] HCCPD 4,000[d] DBCP 32,000[d] CLC2A 230[d] As 740[d]
Agent-contaminated Building Material	Potential agent presence[c]	Data to be obtained during building demolition prior to pretreatment
Munitions Testing Group Debris and Nearby Soil	Toxicity characteristic as assessed by TCLP Potential UXO presence[c]	TCLP data to be generated during excavation as necessary prior to disposal
Toxic Storage Yard	Human Health exceedence for CLC2A, Arsenic Potential agent presence[c]	CLC2A 115 As 1,600
Sanitary Landfills	Human Health exceedence for OCPs, metals	OCPs 0 02 to 3 0 Cr 18 Pb 65 Cd. 5 8 Hg 0 11

Table D1 (continued)

As	Arsenic
Cd	Cadmium
Cr	Chromium
CLC2A	Chloroacetic acid
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
OCPs	Organochlorine pesticides
Pb	Lead
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total organic carbon
UXO	Unexploded ordnance
VHOs	Volatile halogenated organics

a Unless otherwise noted, chemical composition data have been collected from the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995)

b Unless otherwise noted, concentrations listed below are modeled mean concentration values in parts per million (ppm) within the human health and/or principal threat exceedence volume to be disposed

c Based on historical site use information, as noted in the Final DAA Report (Foster Wheeler, 1995)

d No modeled mean concentration reported, value represents a single detection or a modeled maximum value in an isolated area.

Table D2: Summary of Wastes Disposed in Triple-lined (Enhanced) Cells at the RMA Onsite Hazardous Waste Landfill

Waste Identification	Basis for Hazard Classification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Principal Threat Soil	**Principal threat exceedances for OCPs**	**Est. pH and TOC: assumed to be same as those for Basin F Waste-Pile Soil**	**OCPs: 0.1 to 23,000** **DCPD: 8 to 22,000** **VOCs: 40 to 2,000**
Sand Creek Lateral Soil	**Human Health Exceedance for: OCPs**	**Same as above**	**OCPs: 0.04 to 27.8** **Pb: 9-1070**
Basin F Waste Pile Soil	Principal Threat and Human Health Exceedance for: OCPs, Volatiles, DCPD, CLC2A	pH: 6.38 to 8.72 density: 2022 to 2711 lb/yd^3 loadbearing: 2 5 ton/ft^2 flash point: 70 to > °F reactive: S^{2-}: C 5 ppm reactive: CN^-: < 2 ppm reactive: NH_3: 15 ppm TOC (TCLP): 420 ppm TOX (TCLP): < 5 ppm	**Total Analyses** Ammonia (as N): 9200 Cyanide: 0 581 Nitrate: 600 OCPS 0 1 to 3,100 HCCPD: 5.5 DCPD: 1,500 to 2,000 CLC2A: 110 to 760 BTEX: 0.02 to 51 PNAs: 17 to 48 Ketones: 0.5 to 3.2 Methanol: 54.3 VHOs: 0.06 to 110 **TCLP Analyses** Endrin: < 0.0001 to 0 003 Antimony: 0.036 to 0.039 Arsenic: < 0.015 to 0.134 Barium: 0.183 to 1 Cadmium: <0.005 to 0.055 Chromium: <0.006 to 0.151 Lead: < 0.030 Nickel: 0.161 to 0.324 Selenium: < 0.038 Silver: < 0.009 Thallium: < 0.110 Mercury: <0.0005 to 0.0006

BTEX	Benzene, toluene, ethylbenzene, xylene
CLC2A	Chloroacetic acid
CN	Cyanide
DCPD	Dicyclopentadiene
HCCPD	Hexachlorocyclopentadiene
HLA	Harding Lawson Associates
Ketones	Acetone, 2-butanone
Major cations	Calcium, magnesium, potassium, sodium
MKE	Morrison-Knudsen Environmental

Table D2 (continued)

NH_3	Ammonia
OCPs	Organochlorine pesticides
PNAs	Polynuclear aromatic hydrocarbons
S^2	Sulfide
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total organic carbon
TOX	Total organic halogens
VHOs	Volatile halogenated organics

a Physical characteristics data reported for Lime Basin Soil are estimates based on soil samples collected near the Lime Basins during the Phase II Onpost Feasibility Study (Woodward-Clyde, 1993b) and on lime-containing soil samples collected by HLA (HLA, 1994) Chemical composition data for Lime Basin Soil are modeled mean concentration values in parts per million (ppm) within the exceedance volume to be disposed, as presented in the Final Detailed Analysis of Alternatives (DAA) Report, Version 4 1 (Foster Wheeler, 1995)

b Physical characteristics data reported for Basin F Waste Pile Soil were collected for drummed Basin F soil by HLA (1994) Chemical composition data for Basin F Waste Pile Soil are ranges or maximum concentrations that have been condensed from the Final DAA Report (Foster Wheeler, 1995), and from data reported for drummed Basin F soil by MKE in 1989 and HLA in 1994

Table D3: Summary of Basin F Waste Pile Leachate Data and Basin F Liquid Data

Waste Identification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Waste Pile	pH 7 92 to 9 42	Sulfate 23 to 54,533
Soil Leachate	TDS 0 6 to 37 2 %	Chloride 1032 to 190,000
	TSS <4 to 1721 ppm	DMMP 0 01 to 5 6
	SC 217,000 to 530,000 µmhos/cm	$CPMSO_2$ 0 02 to 19
	Total hardness 56,000 to 217,000 ppm	VHOs 0 026 to 1 1
	TOC 18 to 49 ppm	BTEX 0 006 to 0 046
	TOX 80 to 220 ppm	DIMP 0 74 to 1 3
	COD 49 to 280 ppm	CPMS 0 23 to 0 31
		CPMSO 2 8 to 4 0
		Ketones 0 005 to 15
		IMPA 560 to 730
		OSCs 0 007 to 580
		Cyanide 0 42 to 0 87
		Fluoride 32 to 36
		Nitrate (as N) 870 to 930
		Alkalinity 17 to 30
		Ammonia nitrogen 21 to 23
		Phosphorus 20 to 21
		Sulfide 26 to 32
		As 1 1 to 1 4
		Hg 0 012 to 0 016
		Trace metals 0 033 to 250
		Major cations 7 0 to 100,000
		OCPs 0 0002 to 0 170
		OPPs 0 006 to 0 013
		DCPD 0 042 to 0 050
Basin F Liquid		OCPs 0 1 to 2 9
		HCCPD 1 9
		OSCs 0 1 to 120
		CPMSO 25 8
		CPMSO2 200
		OPPs 0 1 to 0 9
		VHOs 0 003 to 0 1
		DIMP 123
		DMMP 2,000
		Major cations 250 to 61,000
		Trace metals 0 4 to 5,860
		BTEX 0 008 to 0 01
		As 3 9
		Hg 340
		Fluoride 170
		Chloride 160,000
		Sulfate 47,000

Table D3 (continued)

Waste Identification	Physical Characteristics[a]	Chemical Composition (ppm)[a,b]
Basin F Liquid (continued)		Cyanide 1 55 Nitrate 1,300 Total nitrogen 104,000 Total phosphorous 16,200

As	Arsenic
BTEX	Benzene, toluene, ethylbenzene, xylenes
CPMS	p-Chlorophenylmethyl sulfide
CPMSO	p-Chlorophenylmethyl sulfoxide
$CPMSO_2$	p-Chlorophenylmethyl sulfone
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethylphosphonate
DMMP	Dimethylmethylphosphonate
HCCPD	Hexachlorocyclopentadiene
Hg	Mercury
IMPA	Isopropylmethylphosphonic acid
Ketones	Include methyl ethyl ketone, acetone, and methyl isobutyl ketone
Major cations	Calcium, magnesium, potassium, sodium
N	Nitrogen
OCPs	Organochlorine pesticides
OPCs	Organophosphorus compounds
OPPs	Organophosphorus pesticides
OSCs	Organosulfur compounds, include dithiane, benzothiazole, 1,4-oxathiane, thiodiglycol, thiodiglycolic acid, and dimethyl disulfide
ppm	Parts per million
TDS	Total dissolved solids
Trace metals	Aluminum, antimony, barium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, zinc
TSS	Total suspended solids
VHOs	Volatile halogenated organics

a Data for Basin F Waste Pile leachate have been condensed from the Final Basin F Waste Pile Annual Data Collection Report (HLA, 1994), the Rocky Mountain Arsenal Contingency Plan, Revision 4 0 (Weston, 1991), and from leachate data collected by HLA in March, 1994, (see Appendix A of the CDD)

b Chemical composition data for Basin F Liquid have been summarized from the Rocky Mountain Arsenal Contingency Plan, Revision 4 0 (Weston, 1991)

Table D4: References Presenting Characterization Data for Waste Streams Disposed in the Onpost CAMU at RMA

RTIC Reference Number	Document Name	Data Presented
95290R01	Final Detailed Analysis of Alternatives Report, Version 4 1, Volumes I through VII (Foster Wheeler, 1995)	Statistical summaries of target chemical characterization data for all designated waste streams (includes all waste streams designated for disposal in the onpost CAMU)
92017R01	Final Remedial Investigation Summary Report, Version 3 2, Vol I, Appendices A, C, E (Ebasco, 1992)	Summaries of target chemical characterization data for contaminated areas and media at RMA
91081R01	Soil Investigation and Inventory of RMA (J P Walsh, 1988)	Physical characterization data for RMA soil media Includes chemical indicator parameter data (pH, EC, exchangeable bases, CEC, moisture, lime content, organic carbon content) Data are reported for soil boring samples collected across the site
88344R01	Determination of Partition Coefficients for the Primary Contaminant Sources of Section 36, Version 2 2 (ESE, 1988)	Presentation of partition coefficients for RMA chemicals in contaminated soil and wastes at RMA Includes discussions of soil chemical and physical properties relating to contaminant transport
93137R02	Final Technical Report, Phase II On-Post Feasibility Study, Version 3 0, Volumes I and II, (Woodward-Clyde, 1993b)	Chemical and physical characterization data for RMA soil media Includes data for RMA target chemicals, chemical indicator parameters (CEC, extractable sulfur, pH, organic carbon), soil classification, soil testing (grain size, Atterberg limits, moisture) Data were collected for major study areas of RMA (e g , South Plants Study Area, North Plants Study Area, North Central Study Area, etc)

Table D4 (continued)

RTIC Reference Number	Document Name	Data Presented
93137R01	Final Technical Report, Phase I Feasibility Study, Version 3 1, Volumes I and II, (Woodward-Clyde, 1993a)	Chemical and physical characterization data for RMA soil media Includes data for RMA target chemicals, chemical indicator parameters (CEC, extractable sulfur, pH, organic carbon), soil classification, soil testing (grain size, Atterberg limits, moisture)
94187R01	Final Report, Feasibility Study Soil Volume Refinement Program, Version 2 0 (Ebasco, 1994)	Total and TCLP analysis results for soil boring samples from contaminated areas of RMA Analyses for agent and agent degradation products are included
93014R02	RMA Innovative Technology Studies Program, Summary Results Report for Soil Vapor Extraction Bench-scale Testing (Draft Final) (Harding Lawson Associates, 1992)	Chemical and physical characterization data for soil boring samples from former Basin F
94168R01	Final Technical Report, Task 93-04 Soil Vapor Extraction Screening Program, Rocky Mountain Arsenal, Commerce City, Colorado (Harding Lawson Associates, 1994)	Chemical and physical characterization data for soil samples from South Plants and former Basin F

CAMU Corrective Action Management Unit
CEC Cation Exchange Capacity
EC Exchangeable cations
ESE Environmental Science and Engineering
RMA Rocky Mountain Arsenal
RTIC RMA Technical Information Center
TCLP Toxicity Characteristic Leaching Procedure

Table D5: Analytical Parameters and Methods for Waste Analysis

Army Agent Analysis

1 Field Screening Analysis for GB, VX, mustard, and Lewisite by Miniature Continuous Air Monitoring Systems (MINICAMs)

2 Laboratory verification analysis for GB, VX, mustard, and Lewisite by gas chromatography (GC)

Waste Compatibility Tests

1 Corrosivity by EPA Method 1110

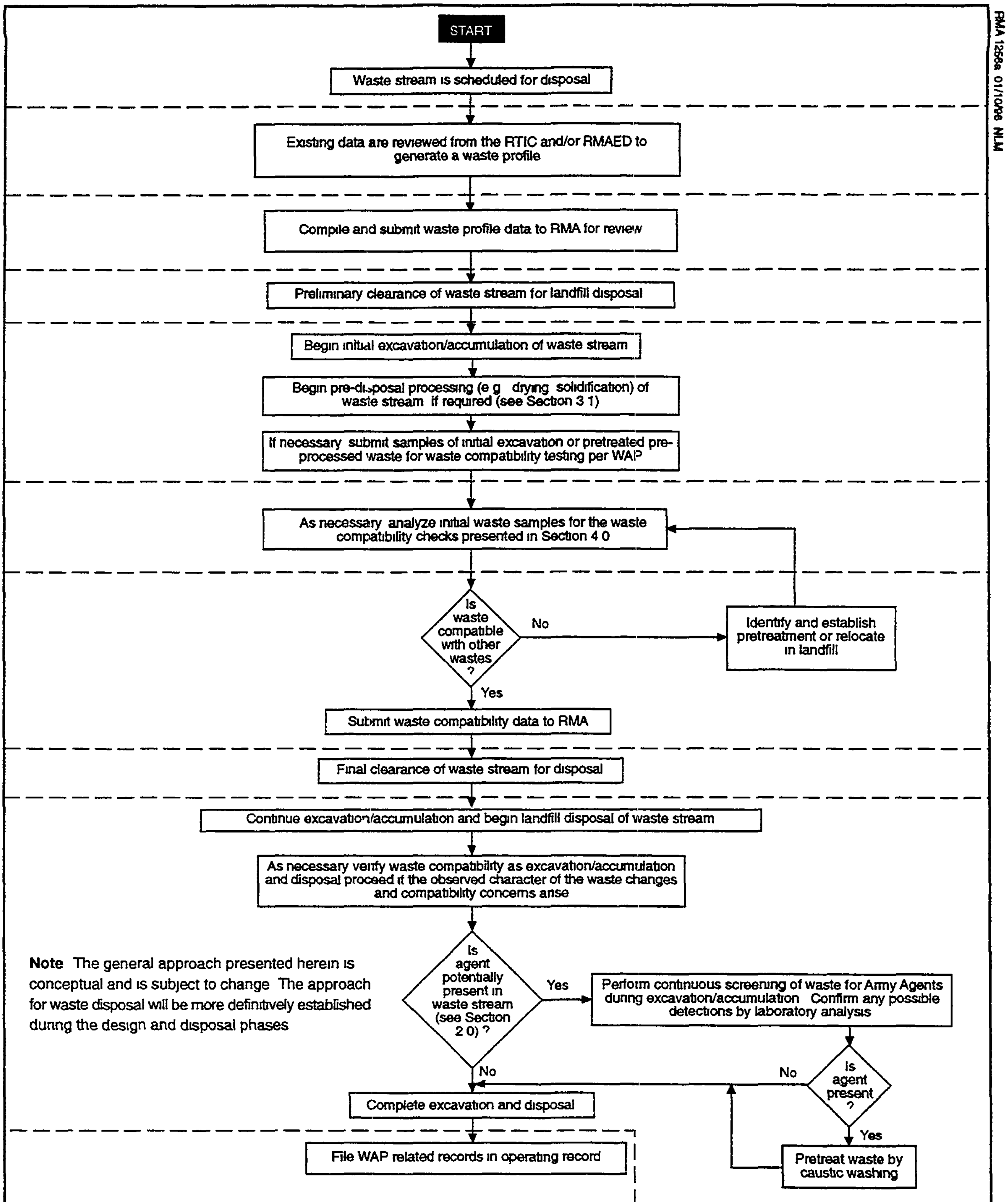
2 pH by EPA Method 9045A

3 Ignitability by EPA Method 1010

4 Free liquids by EPA Method 9095 (paint filter test)

5 Compatibility with commingled wastes by ASTM D-5058 90

ASTM American Society for Testing and Materials
EPA U S Environmental Protection Agency
GB Isopropylmethyl phosphonofluoridate (Sarin)
VX Ethyl S-2-diisopropylaminoethylmethyl phosphorothiolate



Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure D1

Conceptual Waste Characterization Approach for Wastes Disposed in the RMA CAMU Landfill

RMA 1257 1/8/98 LAH

Harding Lawson Associates
WASTE SAMPLING DATA SHEET

Log Book ______
Pages ____ to ____

Sample ID	Sample Media: ☐ Soil/Sediment ☐ Debris ☐ ______	Time	Date
Waste Stream ID	Sample Type ☐ Discrete Grab ☐ Composite Grab ☐ ______	Sampling Crew Members	Organization/Title
Waste Stream Description	Sampling Equipment: ☐ Shovel ☐ Trier ☐ Hand Auger ☐ Scoop ☐ ______	Site Conditions	

Description of Sample Collection Activities

Time	Location	Procedures	Visual Description	Bottles Collected

EXAMPLE

Analyses Requested	Sampling Site Health and Safety Measurements		
	☐ HNu ☐ OVM ☐ Microtip ☐ ______ Serial #	Site Readings	Sample Readings
Comments	Protective Level A B C D HSO Signature __________ Sampler's Signature __________		

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
Harding Lawson Associates

Figure D2

Example Waste Sampling Data Sheet

Harding Lawson Associates
Denver, CO 80202

707 Seventeenth Street, Suite 2400
303/292-5365

Sample Number:
Sample Type:
Depth.
Analysis
Preservative
Container
Remarks:
Sampler's Signature·

Tag Number:
Sample Technique:
Date/Time:

EXAMPLE

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

Figure D3

Example Sample Label

RMA 1113 1/8/96 LAM

Harding Lawson Associates
2400 ARCO Tower
707 Seventeenth Street
Denver, CO 80202
303/292-5365
Telecopy 303/292-5411

Lab I D.: ______________

Work Authorization Number: ______________

CHAIN-OF-CUSTODY RECORD

Sample Round/Episode ______________

Project Name/Project No	Sample Date	Sample Technique	Site Identification.
Sampler: (Signature)	Sample Depth (Ft)	File-Type/Matrix	Site Type

TIME	TAG NO	ANALYSIS REQUIRED	CONTAINER	PRESERVATIVE/REMARKS

EXAMPLE

Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Airbill Number		

Laboratory Copy White | Project Office Copy Yellow | Field or Office Copy Pink

19108 H

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by.
Harding Lawson Associates

Figure D4

Example Chain-of-Custody Form

Appendix E

SECURITY PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

    1 1 Purpose and Scope

    1.2 Organization

2 0 Access Control

    2 1 Rocky Mountain Arsenal Access

    2 2 CAMU Access

    2 3 Active Waste Management Areas Access

3 0 Perimeter Controls

4 0 Warning Signs

5 0 Acronyms

6 0 References

Appendix F

PERSONNEL TRAINING PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 General

- 2 1 Instructor Qualifications
- 2 2 Training Schedule
  - 2 2 1 On-the-Job Training
  - 2 2 2 Classroom Training

3 0 Curriculum

- 3 1 Emergency Response
  - 3 1 1 Spill Response
  - 3 1 2 Fires and Explosions
  - 3 1 3 Natural Forces
  - 3 1 4 Other Emergencies
  - 3 1 5 Emergency Shutdown Procedures
- 3 2 Emergency Equipment
- 3 3 Alarm and Communication Systems
- 3 4 Waste Management

4 0 Recordkeeping

- 4 1 Job Descriptions
- 4 2 Training Descriptions
- 4 3 Training Records

5 0 Acronyms

6 0 References

Appendix G

INSPECTION PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix. During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 Inspection Requirements

- 2 1 Landfill Cells
- 2 2 Run-on/Runoff Control Systems
- 2 3 Decontamination Facilities
- 2 4 Basin F Waste Pile Drying Unit
- 2 5 Waste Staging/Consolidation Areas
- 2 6 Emergency Response Systems
- 2 7 Other Areas

3 0 Inspection Schedule

- 3 1 Daily Inspections
- 3 2 Weekly Inspections
- 3 3 Monthly Inspections
- 3 4 Quarterly Inspections
- 3 5 Annual Inspections

4 0 Deficiency Correction Requirements

5 0 Recordkeeping Requirements

- 5 1 Inspection Logs
- 5 2 Deficiency Correction Logs

6 0 Acronyms

7 0 References

Appendix H

CONSTRUCTION QUALITY ASSURANCE PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

1 1 Purpose and Scope

1 2 Organization

2 0 General

2 1 Applicability

2 2 Construction Quality Assurance Personnel

2 2 1 Organization

2 2 2 Qualifications

2 2 3 Responsibilities

2 3 Terminology

2 3 1 Construction Parties

2 3 2 Definitions

2 4 Reference Standards

3 0 Earthwork Construction Quality Assurance

3 1 Foundations

3 1 1 Cell Subgrade

3 1 2 Cover System Subgrade

3 2 Structural Fill

3 2 1 Embankments

3 2 2 Anchor Trenches

3 2 3 Other Areas

3 3 General Fill

3 3 1 Operations/Frost Protection Layers

3 3 2 Other Areas

Appendix I

CONCEPTUAL TEST FILL WORK PLAN

CONTENTS

TABLES

FIGURES

1.0 INTRODUCTION

This Conceptual Test Fill Work Plan (Work Plan) has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado This Work Plan will be used as a guide for development of the final procedures for the construction of Test Fill 3, and subsequently for specifications and Construction Quality Assurance Plans for landfill liner and capping systems The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act. The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3

The CDD has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Background

Two compacted clay liner (CCL) tests fills (Test Fills 1 and 2) were constructed in the southeast portion of Section 25 during the summer of 1994 The primary objective of this program was to demonstrate that a hydraulic conductivity of 1×10^{7} centimeters per second (cm/s) or less can be achieved with the onsite clayey soils These soils were obtained from borrow areas located within 2 miles of Section 25 The field-scale hydraulic conductivity of each of these two test fills was evaluated using a sealed double-ring infiltrometer (SDRI) and two-stage borehole permeameters (TSBP) The results of these field-scale tests indicated that a hydraulic conductivity of 1 x 10^{-7} cm/s or less was achieved The results of Test Fills 1 and 2 are presented in the Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program, (Landfill FS report) (HLA, 1995a) included as Appendix R of the CDD

While the Test Fill 1 and 2 results indicated that the minimum hydraulic conductivity can be achieved with onsite soils, the Colorado Department of Public Health and Environment (CDPHE) in an August 30, 1995, letter to Program Manager for Rocky Mountain Arsenal (PMRMA), raised general questions regarding clay liner moisture conditioning, placement, and compaction. In addition to the questions raised by CDPHE, the Army identified data needs relative to the development of CCL construction specifications that were not objectives in the initial test fill program Thus, Test Fill 3 will be constructed to

- Respond to the comments made by CDPHE
- Provide additional test fill data that will allow the landfill designer to prepare construction specifications and construction quality assurance procedures for CCLs

1.2 Purpose and Scope

The purposes of the test fill program described in this Work Plan are described below

1 To provide the Army with CCL construction specifications that provide the flexibility to construct full-scale CCLs using equipment and procedures for CCL moisture conditioning, placement, and compaction that will allow for more productive construction than the equipment and procedures used for Test Fills 1 and 2

2 To evaluate the clayey soil within the footprint of the CAMU landfill cell excavation for suitability of use as CCL material and possibly use this material to construct Test Fill 3

3 To evaluate the geotechnical property consistency of the five potential CCL material borrow areas at RMA Four of these areas are identified in the Final Feasibility Soil Support Program (Borrow Study Report) (HLA, 1995b) The fifth area is the clayey soil within the footprint of the landfill cell excavations

4 To select which of these five areas are sufficiently similar and which of these areas are significantly different.

5 To select the borrow area for Test Fill 3 based on the landfill and the borrow area design being performed by the U S Army Corps of Engineers, and the borrow area consistency evaluation described in Item 4 above

6 To define any additional test fill data needs for future landfill construction that exist after the construction and testing of Test Fill 3

The scope of this test fill program includes the following activities

- Preparing, submitting, and obtaining approval of this Conceptual Test Fill Work Plan
- Preparing, submitting, and obtaining approval of the Final Test Fill Work Plan At the request of CDPHE, the Final Work Plan may include detailed drawings and specifications for the construction of Test Fill 3, or further development and refinement of the procedures described in this Conceptual Plan.
- Tabulating and analyzing the geotechnical index properties (i e , proctor values, percent times, Atterburg limits, hydraulic conductivity), submitting proposed borrow area consistency criteria along with the supporting documentation to CDPHE for approval, and selecting which of the five potential borrow areas (likely to be the landfill cell footprint area) will be used for Test Fill 3 construction (discussed in Section 3.0)
- Performing preconstruction testing and laboratory testing to obtain additional geotechnical index parameter data and to establish the relationship between moisture, density, and hydraulic conductivity of the Test Fill 3 borrow material (discussed in Section 4 0)
- Constructing the test fill using the most productive equipment, procedures, and specifications necessary to obtain a hydraulic conductivity of 1×10^{-7} cm/s or less (discussed in Section 5.0)
- Performing CQA monitoring and testing during construction of the test fill (discussed in Section 6 0)
- Performing post-test fill construction laboratory testing to verify that a hydraulic conductivity of 1×10^{-7} cm/s or less was achieved (discussed in Section 7 0), preparing CCL construction specifications using the procedures and equipment used to construct Test Fill 3, and preparing and submitting a summary report.
- Review data from all test fills and identify additional future data needs

A CQA effort will be incorporated into the construction of the test fill The test fill will be constructed by an earthwork contractor (Contractor) experienced in low-permeability soil (clay) liner construction. CQA will be performed by a CQA Engineer who will perform tests and observations to evaluate the effectiveness of the construction procedures and equipment in achieving the required hydraulic conductivity at a workable moisture content range and at an achievable dry density range

Test Fill 3 will be constructed on both a flat (5 percent or less) slope and a side (40 percent or less) slope The slopes used for the test fill will be similar to those selected during design of the landfill cell floor and sideslopes The test fill will be constructed near the location of Test Fills 1 and 2 using either soil from one of the borrow areas identified in the Final Feasibility Study Soils Support Program Report (Borrow Study Report) (HLA, 1995b) or onsite clayey soils excavated from within the expected footprint of the CAMU landfill cells (Sections 25 and 26) Figure I1 shows the locations of Test Fills 1 and 2 and the borrow areas used to construct them Figure I1 also shows the location of the borrow areas identified the Borrow Study Report (Areas 1 through 4) and the landfill area of the CAMU (Area 5) Figure I2 shows a typical plan view and cross sections of Test Fill 3

Large-scale hydraulic conductivity will be evaluated by obtaining large diameter (typically 12 inches) undisturbed soil liner samples and testing them in specially designed flexible wall permeameters in the same manner as small diameter (2 8 inches) sleeve (Shelby) samples and in accordance with American Society for Testing and Materials (ASTM) D5084 The large diameter undisturbed samples are commonly referred to as "block" samples in published literature Published comparisons between the hydraulic conductivity of large-scale block samples and the hydraulic conductivity of SDRIs have shown little variation in the test results (Benson, 1993) except in cases where little or no Construction Quality Assurance (CQA) was performed

1.3 Organization

The remainder of this appendix is divided into seven sections Section 2 0 provides a discussion of recent U S Environmental Protection Agency (EPA) guidance and other reference documents applicable to test fill construction Section 3 0 presents the scenario for comparing the geotechnical property data for the five potential Test Fill 3 borrow areas, selecting which of these areas are significantly different and which are sufficiently similar, and selecting which of these areas will be used for Test Fill 3 construction Section 3 0 also provides a discussion of the CCL volumes needed for the landfill construction, a discussion of the volume of potential CCL material available, and a discussion of how these volumes will effect Test Fill 3 and future test fill construction Section 4 0 describes the preconstruction laboratory sampling and testing activities and data interpretation methodology Section 5 0 provides the procedures for construction of the test fill Section 6 0 provides the CQA procedures for construction of the test fill Section 7 0 provides the requirements of the post-construction testing and the report to be generated at the conclusion of the test fill construction and post-construction laboratory testing Section 7 0 also provides a discussion of the correlation between the measured hydraulic conductivity of large diameter undisturbed (block) samples and that of field-scale hydraulic conductivity measurements Section 8 0 provides a list of acronyms, and Section 9 0 is a bibliography

2.0 REFERENCED DOCUMENTS

EPA guidance documents entitled "Quality Assurance and Quality Control for Waste Containment Facilities" (EPA, 1993) and "Requirements for Hazardous Waste Landfill Design, Construction, and Closure" (EPA, 1989) discuss test fill design and construction and were used to prepare this work plan Other older EPA guidance documents discuss test fill construction and the contents of these were also considered in preparing this work plan. However, the two EPA documents referenced above, the published information these EPA documents referenced, and other recently published documents were used as the primary references in preparing this work plan References used to compile this work plan are given in the bibliography in Section 9 0 Copies of the referenced documents will be made available for review upon request

3.0 BORROW AREA EVALUATION AND SELECTION

In January 1995, the Army published the Borrow Study Report This report evaluated potential CCL material borrow areas at RMA and defined four areas that, based on geotechnical property data from each of the areas, contained potentially acceptable CCL material in substantial volumes The four areas identified in the Borrow Study Report are shown on Figure I1 and are described below

Area 1 Area 1 is divided into two subareas located immediately north of the landfill CAMU boundary in the southern portion of Section 24 Area 1 contains approximately 1 2 million cubic yards of potential CCL material

Area 2 Area 2 is divided into two triangle-shaped subareas One of the subareas is located in the extreme southeast corner of Section 25 and the other subarea is located in the extreme northeast corner of Section 36 Area 2 contains approximately 800,000 cubic yards of potential CCL material

Area 3. Area 3 is a larger area encompassing the central portion of Section 29 This area is located within the Bald Eagle Management Area (BEMA) Area 3 contains approximately 5 5 million cubic yards of potential CCL material

Area 4· Area 4 is located immediately north of Area 3 in Section 20 Area 4 is also located within BEMA Area 4 contains approximately 5 0 million cubic yards of potential CCL material

As part of this test fill program, a fifth area (Area 5) will be evaluated for inclusion as a potential CCL borrow area The limits of Area 5 have been initially set as the limits of the landfill CAMU boundary The subsurface soil located within the landfill CAMU boundary and within 30 feet below ground surface (bgs) contains roughly 3 5 million cubic yards or more of material meeting the same geotechnical target criteria as used for determination of Areas 1 through 4 The majority of this volume is located within the central and eastern portions of the landfill CAMU area

Once the final areal extent and depth of excavation of the individual landfill cells within the landfill area have been developed, Area 5 will be reduced to include the soil located within the general excavation footprint of the individual landfill cells that meets the target criteria given in Table I1 The Army does not anticipate excavating borrow soil from other areas within the landfill boundary Utilizing Area 5 borrow soil will potentially allow the Army the flexibility to use excavated material from the landfill cells to construct CCLs Utilizing clayey soil excavated from the landfill cells as

CCL material will help the Army meet U S Fish and Wildlife Service's (FWS's) goal of minimizing the area disturbed for borrow soil excavation.

The geotechnical property target criteria for low-permeability soil in Area 5 is the same as used in the Borrow Study Report The Area 5 target criteria is given in Table I1 Table I2 summarizes the geotechnical properties of borehole samples in Area 5 that meet the target criteria

Once Area 5 has been reduced to include only clayey soil that will be excavated as part of cell construction, an evaluation will be made of the volume of CCL material needed for construction and the volume of potential CCL material available from excavation. If the volume required for cell construction is greater than the volume available from cell excavation, Test Fill 3 will likely be constructed using material from either Area 1 or Area 2 If the volume required for construction is less than the volume available from excavation, Test Fill 3 will likely be constructed using material from Area 5

Areas 1 through 5 are all located within two miles of each other Due to their proximity, Areas 1 through 5 will be evaluated for consistency of geotechnical index properties as part of this test fill program Section 2 4 4 1 of Chapter 2, Compacted Soil Liners in the EPA Technical Guidance Document entitled, "Quality Assurance and Quality Control for Waste Containment Facilities (EPA, 1993), states that relatively homogeneous materials produce similar proctor value results and that

> "As an approximate guide, a relatively homogenous borrow soil would be considered a material in which W_{OPT} (optimum moisture) does not vary by more than ± 3 percentage points and $\gamma_{d,max}$ (maximum dry density) does not vary by more than $\pm 0\ 8$ KN/ft³ (5 pcf) "

Using this guidance as a basis, the geotechnical property data (i e , proctor values, percent fines, Atterburg limits) for material meeting the geotechnical property target criteria in Areas 1 through 5 will be tabulated and analyzed Once this is completed, proposed criteria for selecting which borrow areas are significantly different and which borrow areas are sufficiently similar will be developed

This criteria will then be applied to Areas 1 through 5 and a preliminary selection made of the areas that are significantly different and the areas that are sufficiently similar The proposed criteria, proposed consistency determination of Areas 1 through 5, and the supporting data will be submitted to CDPHE for review

The required volume of CCL material needed to construct and close all of the landfill cell(s) is not known as of February, 1996 If the double-lined cells are assumed to cover 60 acres and use 6 feet of CCL in the base liners, if the triple-lined cells are assumed to cover 40 acres and use 9 feet of CCL in the base liners, and if all the cells use 2 feet of CCL in their covers, approximately 1 5 million cubic yards of CCL material will be required Of the five borrow areas, only Areas 3 and 4 contain the required volume The FWS has requested in working sessions that Areas 3 and 4 be avoided to the extent possible. Therefore, designation of one of the potential borrow areas as the sole source of all CCL material may not be feasible However, Areas 1, 2, and 5 may contain sufficient volume to construct the base liner CCLs or the cover CCL of individual cells If the consistency evaluation described above does not result in any of the areas being considered as sufficiently similar, the need to construct additional test fills will be further evaluated

4.0 PRECONSTRUCTION SAMPLING AND LABORATORY TESTING

A preconstruction sampling and laboratory testing program will be completed prior to the test fill construction and after selection of the Test Fill 3 borrow area If Area 5 is used for Test Fill 3, further sampling and testing of the clay soils in this area will be performed as part of the work described in the Work Plan for the Hydrogeologic and Geotechnical Program (Field Work Plan) (HLA, 1995c) Sampling will be performed over the area expected to be disturbed for Test Fill 3 borrow soil This area will be approximately 100 feet by 200 feet Approximately ten samples will be obtained from the near-surface of this area at evenly distributed locations

4.1 Preconstruction Testing

After the near-surface clay samples are obtained, laboratory testing will be performed following the general methodology set forth by Daniel (1990b) and Trast (1993) Index tests (Atterberg limits and particle size analysis) will be performed to evaluate the clay soils for suitability as CCL material A minimum of 10 index tests on the Test Fill 3 borrow soil will be initially performed Additional index tests will be performed on samples obtained during construction of Test Fill 3 (discussed in Section 6 0)

The average of the index test results must meet the requirements of Table I1 The minimum index properties for the Test Fill 3 borrow soil are as follows

Property	Test Method	Specification
USCS classification	ASTM D2487	SC, CL, or CH
Percent fines	ASTM D422	≥ 30 percent
Liquid Limit	ASTM D4318	≥ 30
Plasticity Index	ASTM D4318	≥ 11

In addition to the properties shown above, the final Work Plan may include "maximum particle size" as a criteria However, the evaluation for inclusion of "maximum particle size" as an index property will consider that

- Oversized materials are more critical for the top lift of a soil liner, which is the lower component of a composite liner
- Observation by CQA personnel is a very effective way to verify that oversized materials have been removed from the top lifts

The USCS classification specification is the same specification as used for Test Fills 1 and 2 The other specifications were not included in the Test Fills 1 and 2 specifications The Test Fill 1 and 2 specifications are included are included in Appendix R (Landfill FS Report)

When the index testing is complete, the relationship between moisture, density, and hydraulic conductivity of the clay will be established for soil meeting the minimum index properties The establishment between the moisture, density, and hydraulic conductivity of the borrow soil will follow the procedure set forth by Benson (1993) Standard Proctor (ASTM D698), modified Proctor (ASTM D1557), and reduced Proctor tests will be performed on a composite sample of the individual samples The reduced Proctor test procedure will follow the same procedure as for a standard Proctor test with the exception that 15 blows per lift will be used instead of the 25 blows per lift required by ASTM D698

The results of the three composite Proctor tests will be plotted on a moisture content versus dry density graph along with the zero air voids curve The optimum moisture content for each Proctor test will then be determined, and a "line of optimums" will be created by connecting the three optimum moisture contents Benson's research has shown that a hydraulic conductivity of 1×10^{7} cm/s or less will nearly always be achieved when samples are moisture conditioned and compacted such that a plot of moisture content and density will fall between the line of optimums and the zero air voids curve This area will define the Potential Acceptable Zone (PAZ) A typical moisture/density graph showing a plot of the three Proctor tests, the line of optimums, and the PAZ is shown in Figure I3(a)

The PAZ will be verified in the laboratory by remolding hydraulic conductivity samples (5 to 10 samples) to a range of moisture contents and dry densities within the PAZ The upper boundary of the PAZ will be initially set as a vertical line located at the modified Proctor optimum moisture content The lower boundary of the PAZ will be initially set as a horizontal line located at 100 percent of the reduced Proctor maximum dry density Figure I3(b) shows a typical PAZ and the approximate sample moisture contents and densities for remolded hydraulic conductivity testing

4.2 Data Interpretation

The results of the remolded hydraulic conductivity testing will then be plotted on similar moisture/density graph with an open circle symbol for those samples with a hydraulic conductivity of greater than 1 x 10^{-7} cm/s and a closed circle symbol for those samples with a hydraulic conductivity of equal to or less than 1 x 10^{-7} cm/s The Acceptable Zone (AZ) will then be defined by reducing the PAZ to include only the range of moisture content/dry density that results in passing hydraulic conductivity The AZ will in no case extend to the left of the line of optimums This is shown in Figure I3(c)

After the AZ of moisture and density is established based on the laboratory hydraulic conductivity test results the limits of the AZ may be further modified depending on other factors required by the preliminary CAMU design One such factor would be that the lower boundary may be raised based on the minimum required shear strength requirements for slope stability and bearing capacity This may be necessary because a CCL compacted near the lower boundary of the AZ will have less shear strength (due to lower density and higher moisture content) than a CCL compacted near the upper boundary of the AZ

When the final AZ is defined based on the preconstruction laboratory testing program and the preliminary CAMU design, the AZ will become the "Placement Window" (PW) for test fill construction. The PW will then be divided into two approximately equal zones These zones will be identified as the Upper Placement Window (UPW) and the Lower Placement Window (LPW)

The UPW and LPW will be used as target zones during the test fill construction to establish the relationship between number of compactor passes, moisture, density, and hydraulic conductivity. Figure I3(d) shows a typical PW and the UPW and LPW. Section 5.0, Construction Quality Assurance Procedures, explains in detail the CQA monitoring, testing, and documentation requirements for each lane and each lift of the test fill.

5.0 TEST FILL CONSTRUCTION PROCEDURES

The test fill will be constructed to the dimensions shown in Figure I2 CQA procedures to be implemented by the Engineer are given in Section 6 0 The construction procedures and specifications to be adhered to by the Contractor are given below The Engineer will be responsible for the Contractor's adherence to requirements given below The Test Fill 3 Contractor will be working under the direction of the Engineer

The intent of this test fill program is to furnish the data that will provide the technical basis to establish the detailed construction specifications for full-scale CCL construction. The specifications will be based on the equipment and procedures used to construct Test Fill 3, as opposed to writing detailed construction specifications for full-scale CCL construction and then constructing a test fill to verify the adequacy of the specifications The specifications given below detail the minimum requirements for the test fill construction, but yet allow some flexibility for some experimentation with different procedures and equipment in the construction of the lower two lifts

5.1 Site Preparation

The Test Fill 3 location is shown in Figure I1 The test fill subgrade will be constructed over an existing slope located approximately 100 feet east of Test Fills 1 and 2 The footprint of the test fill, processing area, and borrow area will be cleared and grubbed of all vegetation, debris, or other deleterious material, as directed by the Engineer, and disposed of at a location designated by the Army

5.2 Grading and Structural Fill Placement

Structural fill will be placed as necessary to construct a smooth, uniform surface for the test fill as shown in Figure I2 and to the grades selected during the CAMU design. The material for the structural fill will be obtained from the cleared and grubbed surface of the borrow area (Figure I1) Structural fill will consist of soil classified as SC, CL, or CH using the USCS. Structural fill will be free of vegetation and debris and will contain a maximum particle size of 4 inches The material will be placed ın maxımum 10-ınch loose lıfts and compacted to 95 percent of the maxımum standard Proctor densıty (ASTM D698) at a moısture content ±3 percent of optımum Monıtorıng, testıng, and documentatıon of the structural fıll placement wıll be performed by the Engıneer After the subgrade ıs constructed to the dımensıons shown ın Fıgure I2, the subgrade wıll be proof rolled to achıeve a smooth, unıform subgrade surface free of soft zones, ırregularıtıes, and loose earth The Engineer wıll observe the proof rollıng, and any unacceptable areas of the subgrade wıll be repaıred to the satısfactıon of the Engıneer

5.3 Soil Liner Conditioning

Soıl to be used for the test fıll constructıon wıll be obtaıned as dırected by the Engıneer from the borrow area and placed ın the processıng area The soıl wıll contaın no more than a neglıgıble amount of organıc or other deleterıous materıals and wıll contaın no more than 5 percent gypsum or calcıum carbonate Gypsum concretıon, nodules, or other deleterıous materıal wıll be less than 1 ınch ın largest dıameter The soıl wıll be processed and moısture condıtıoned to a maxımum clod sıze of 2 ınches and to the specıfıed moısture contents gıven ın Table I3 Whenever more than 3 percent moısture ıs added to the soıl, a mınımum hydratıon tıme of 24 hours wıll be requıred prıor to compactıon. Monıtorıng, testıng, and documentatıon of the condıtıonıng by the Engıneer wıll be as outlıned ın Sectıon 5 0 A water truck equıpped wıth a spray bar for even dıstrıbutıon of water over a gıven area wıll be used for addıng moısture to the soıl The equıpment lısted below wıll be evaluated to raıse the ınıtıal moısture condıtıonıng up to approxımately the optımum moısture content

- A Rome dısc and tractor
- A Caterpıllar SS250 soıl stabılızer (pulvamıxer) or equıvalent

A Caterpıllar SS250 soıl stabılızer (pulvamıxer) or equıvalent wıll be used for fınal moısture condıtıonıng (above optımum moısture content) A mınımum two passes of the stabılızer wıll be made durıng fınal moısture condıtıonıng

5.4 Soil Liner Placement and Compaction

The soil liner material will be placed and compacted using the following procedures

1 The processed soil liner will be removed from the processing area using scrapers or other hauling equipment approved by the Engineer

2 The processed soil liner will be placed directly on the base section of the test fill and initially spread to a nominal loose lift thickness of approximately 8 inches The first soil liner lift will be placed to a nominal loose lift thickness of 10 inches to minimize subgrade contamination A bulldozer, approved by the Engineer, will be used to spread the loose lift In no case will the loose lift thickness exceed the length of the penetrating foot of the compactor

3 The placed loose lift will be compacted by a Caterpillar 825c compactor The compactor will make the minimum number of passes on each lift and in each lane as directed by the Engineer and described in Section 6 6 Each compacted lift will be a nominal 6 inches or less The loose lift thickness may be adjusted by the Engineer after the placement of the second or third lift based on layer bonding observations.

4 Prior to placement of subsequent lifts, the preceding lift will be scarified using either a sheepsfoot compactor, the tracks of a bulldozer, or other method approved by the Engineer

5 A total of seven compacted lifts of the soil liner will be placed to achieve 6 compacted lifts After completion of Lift 7, the test fill surface will be graded to a minimum thickness of 3 feet

6 The finish grade surface of the test fill will be rolled smooth using a smooth-drum roller approved by the Engineer

Numerous testing and inspection activities will occur during and between lift placement These activities are described in detail in Section 6 0 The Contractor will spray water on the test fill surface and surrounding areas as directed by the Engineer to prevent fugitive dust emissions and soil liner desiccation cracking

5.5 Soil Liner Surface Protection

After the test fill construction and CQA sampling and testing activities are completed, the Contractor will immediately cover the test fill surface with a separator geomembrane or geotextile approved by the Engineer The Contractor will then cover the separator geomembrane or geotextile with a minimum soil thickness of 4 inches This surface protection will remain in place until the test fill results have been received and the test results approved by CDPHE

5.6 Drainage Control and Revegetation

The Contractor will regrade and revegetate all areas disturbed by the test fill construction as directed by the Engineer Areas to be regraded and revegetated include, but are not limited to, the borrow area, haul roads, and the processing area Regrading will consist of grading all areas to be relatively free-draining All regrading will be done as directed by the Engineer Revegetation will be done in accordance with the procedures given below

- The topsoil will require grading, raking, and rolling with a roller weighing not more than 100 pounds per linear foot and not less than 25 pounds per linear foot
- The seed will meet the requirements of the U S Fish and Wildlife Service
- Seeds will be sown by dividing the seed equally and sowing at 90 degree angles to produce a uniform broadcast.
- The seed will require raking into the ground and rolling with a roller, or other technique approved by the Engineer
- Seeding will not be allowed on rain compacted surfaces
- Seeding will not be allowed when the wind velocity exceeds 6 miles per hour
- No fertilizer will be applied
- Native grass hay mulch will be provided by the Army
- Mulch will be applied immediately after seeding
- Mulch will be applied at a rate of 2 tons/acre
- The mulch will be crimped immediately after application to prevent it from blowing away
- The mulch must be placed loosely enough to allow some sunlight to penetrate and air to circulate, but thick enough to shade the ground, conserve soil moisture, and minimize erosion

6.0 CONSTRUCTION QUALITY ASSURANCE PROCEDURES

CQA procedures to be implemented during construction of the test fill will be carried out by the Engineer The Engineer will be responsible for the surveying, testing, observation, and documentation requirements set forth below The Engineer will subcontract survey activities as necessary to properly lay out and document the test fill construction

This section presents the conceptual CQA requirements for the Test Fill 3 construction. After completion of the test fill program, detailed CQA requirements for full-scale CCL construction will be prepared based on the observations and test results obtained during completion of the test fill program

Testing frequency for index tests (Atterberg limits and particle-size analysis) for borrow material used to construct Test Fill 3 will be developed following completion of borrow area evaluation presented in Section 3 0 It is anticipated that the index testing frequency selected for the test fill will be representative of the frequency contemplated for full-scale CCL construction

6.1 Site Preparation

The Engineer will be responsible for layout of the borrow area, Test Fill 3, the processing area, and any associated haul roads The Engineer will monitor, direct, and document the Contractor's site preparation activities set forth in Section 5 1 to verify compliance with this Test Fill Work Plan.

6.2 Grading and Structural Fill Placement

The Engineer will direct the Contractor's removal of structural fill borrow soil The Engineer will observe, test, and document placing, compacting, proof rolling, and grading the structural fill to verify that the specifications given in Section 5 2 are met, that the test fill subgrade is shaped to the dimensions shown in Figure I2, and that the base and sideslope subgrade sections are graded to the slopes provided in the preliminary CAMU design The Engineer will survey the surface of the test fills subgrade to verify compliance with the requirements of this Test Fill Work Plan

6.3 Soil Liner Excavation and Testing

The Engineer will lay out and direct the Contractor's excavation of the borrow area and will perform index testing at a rate selected following the findings of the borrow area evaluation (see Section 3 0) The index test results must meet the minimum requirements given in Section 4 1 A minimum of two in situ moisture content tests (ASTM D4643 and/or D2216) per day will be performed on material excavated from the borrow area Index testing will consist of the following.

- Particle size analysis, including hydrometer testing (ASTM D422 and D1140)
- Atterberg limits (ASTM D4318)
- Soils classification (ASTM 2487)

In addition to the index testing, it is anticipated that the Proctor tests listed below will be performed at a rate that will be representative of the frequency contemplated for full-scale CCL construction.

- Modified Proctor (ASTM D1557)
- Standard Proctor (ASTM D698)
- Reduced Proctor (ASTM D698 with 15 blows per lift)

The Engineer will observe and document the borrow area excavation to verify that only clay soils are excavated The Engineer will observe and document that calcareous lenses and other deleterious materials within the clay zones are not excavated and placed in the processing areas. At the conclusion of excavation activities, the Engineer will verify that the Contractor regrades the borrow area to be relatively free draining and also that the Contractor revegetates the borrow area in accordance with the specifications given in Section 5 6

6.4 Soil Liner Conditioning

The Contractor will excavate the soil liner material from the borrow area and place it in the processing area for conditioning The Engineer will direct and document the Contractor's conditioning of soil liner material to verify that the equipment and procedures set forth in Section 5 3 are met The

Engineer will observe and document the processing and moisture conditioning of the soil liner material to evaluate the following

- The amount and distribution (evenness) of water applied by the water truck with spray bar The ability of the water truck to travel over the moistured clay will also be evaluated
- The workability of the clay within the process area at various moisture contents
- The number of passes, range of moisture contents, the distribution (evenness) of moisture content, and the ranges of clod sizes that the Rome disc can effectively condition prior to conditioning with the soil stabilizer The Engineer will observe, test, and document the initial and final moisture contents of the soil liner material and the amount of moisture that can be evenly and productively added to the soil liner material with the Rome disc
- The number of passes, range of moisture contents, the distribution (evenness) of moisture content, and the range of clod sizes that the Caterpillar SS250 soil stabilizer or equivalent can effectively condition Experimentation with the soil stabilizer may be performed to evaluate whether this apparatus can be productively and effectively used for initial moisture conditioning The Engineer will observe, test, and document the initial and final moisture contents of the soil liner material and the amount of moisture that can be evenly and productively added to the soil liner material with the soil stabilizer

6.5 Soil Liner Lift Placement

After conditioning, the Contractor will haul the soil liner material from the processing area and place it over the base section of the test fill Lift 1 will be placed in a 10 inch loose lift thickness This will be done to avoid subgrade mixing with the first lift during compaction All subsequent lifts will be placed in 8-inch maximum loose lifts The Engineer will observe and document the Contractor's placement of soil liner material to verify that the material is placed over the entire test fill area at the specified lift thickness

Due to the heavily textured nature of lifts compacted with a sheepsfoot compactor, it will be difficult to physically measure the loose and compacted lift thickness The Engineer will visually monitor the lift thicknesses and will take physical measurements where possible. Experimentation may be done on Lifts 2 and 3 with various thicknesses to ascertain the most effective loose lift thickness

6.6 Soil Liner Compaction and Testing

Soil liner compaction and testing activities will performed in accordance with Table I3 and in the test fill lanes shown in Figure I2 Table I3 gives the target number of compactor passes for each lane and each lift of the test fill Table I3 also gives the testing and sampling locations and frequencies for each lane and lift of the test fill Due to the heavily textured nature of sheepsfoot compacted lifts and the 8-inch nominal length of the compactor feet, it will be necessary to test each lift after placement and compaction of the overlying lift. The size of compactor and lift thickness were chosen so that the feet of the compactor will penetrate the underlying lift. Compaction in this manner will result in a kneading action of the overlying lift and compaction of the underlying lift. It also promotes layer bonding between lifts

6.6.1 Number of Compactor Passes

The Engineer will document the number of passes made over each lane of each lift (three lanes per lift) This will be done to establish a correlation between the number of passes and dry density at a specific moisture content range The number of passes shown for each lane of each lift in Table I3 is only a preliminary estimate of the number of passes that will be required The Engineer will test each lane of each lift after the minimum number of passes is made If the test results indicate that the target area of the placement window (UPW for Lifts 1 and 2, LPW for Lifts 3 and 4, or the entire PW for Lifts 5, 6, and 7) is met for that lift, no more passes will be made on that lift If the target density area of the PW is not met, additional passes will be made until the target area is met. If the target moisture content of the PW is not met, the area will be repaired or replaced as discussed in Section 6 6 4

When the minimum number of passes necessary to meet the target area of the PW is defined, additional passes, in increments of two to four, will be made in the next lanes to define the range of the target area that can be met. This will be done to allow the Engineer to evaluate whether soil liner material at various moisture contents can be compacted to within the PW This will also allow hydraulic conductivity samples to be obtained at a variety of locations within the PW

6.6.2 Moisture and Density Testing

The Engineer will perform nuclear moisture/density tests (ASTM D3017 and D2922) at a minimum frequency of six per lift The six test locations will be taken at a frequency of two tests per lane, one on the base section and one on the sideslope section. One sandcone (ASTM D1556) or rubber balloon (ASTM D2167) correlation test will be performed on each lift. The Engineer will perform both oven (ASTM D2216) and microwave (ASTM 4643) moisture content tests at the six test locations when testing both Lifts 1 and 2 This will be done to establish a correlation between nuclear, microwave, and oven-dried moisture contents The Engineer may increase the testing frequencies based on previous test results

6.6.3 Hydraulic Conductivity Sampling and Testing

Hydraulic conductivity sampling will be performed at the locations given in Table I3 Hydraulic conductivity sampling will consist of two types sample sleeves (2 8-inch diameter) and block (12-inch diameter) sampling

Sample sleeve sampling will be performed at nuclear test locations after completion of the nuclear test. The samples will be obtained by pressing the tube into the test location using a hydraulic jack and back pressure from a piece of heavy equipment (i e , the blade of a bulldozer or compactor) The samples will be extracted by digging the soil liner away from the sides of the tube using hand labor Upon removal, the samples will be immediately sealed to prevent moisture loss After sealing, the samples will be labeled and prepared for archiving or shipment to the laboratory for hydraulic conductivity testing

Section 2 5 1 of "Quality Assurance and Quality Control for Waste Containment Facilities" (EPA, 1993) states that one of the objectives of a test fill is, "To verify that the materials and methods of construction will produce a compacted soil liner that meets the hydraulic conductivity objectives defined for a project, hydraulic conductivity should be measured with techniques that will characterize the large-scale hydraulic conductivity and identify any construction defects that cannot be observed with small-scale laboratory hydraulic conductivity tests "

The SDRI and TSBP field-scale test methods were developed to measure the large-scale hydraulic conductivity of low-permeability soil liners Of these field-scale test methods, the SDRI has become the most widely used method primarily due to the large area tested (up to 25 square feet) compared to the TSBP method (approximately 10 inches) However, the calculated hydraulic conductivity obtained from an SDRI is only an approximation of the true hydraulic conductivity Errors can easily be introduced into SDRI calculations due to the effects of soil (matric) suction, soil swell, and inaccurate wetting front measurements (Benson, 1994)

The paragraph above lists one reason why the large-scale block samples were chosen to measure the final hydraulic conductivity of the test fill Another reason for using block testing instead of SDRI testing is that SDRIs (and TSBPs) cannot be practically performed on sideslopes when the soil liner is constructed in lifts parallel to the sideslope A significant amount of research has been performed on block-scale testing, particularly the minimum block size (diameter) necessary to accurately reflect field-scale hydraulic conductivity This research has indicated that a block sample diameter of approximately 12 inches can accurately reflect field-scale hydraulic conductivity (Benson, 1993).

Block test samples will be obtained by placing an approximately 12-inch-high by 14-inch-diameter sampling ring with a beveled cutting edge over the area to be sampled A trench around the outside of the sampling ring will then be excavated by hand to a depth of approximately 16 inches The excess soil between the trench and the inside of the sampling ring will then be trimmed off using trowels and knives until the sampling ring can slide easily downward around the test sample This process will continue until 2 or more inches of the test sample are above the top of the sampling ring

The portion of the block test sample protruding from the top of the sampling ring will then be trimmed flush with the sampling ring The top of the sample will then be sealed with plastic wrap (such as Visqueen) and duct tape to prevent moisture loss The base of the sample will be freed from the test fill using a wire saw or flat-headed shovels The sample will then be turned over carefully and the bottom trimmed and sealed in the same manner as the top The sample will then be labeled, sealed an additional time, and placed on a shipping palette for transportation to the testing laboratory After removal of the block sample, the Engineer observe the resultant hole in the test fill and document the layer bonding between lifts

Hydraulic conductivity testing for both the sampling tube and the block samples will be performed in accordance with ASTM D5084

6.6.4 Other CQA Requirements

The Engineer will perform and document other CQA activities during the test fill construction These activities will include repairing test holes, evaluating loose and compacted lift thickness, evaluating layer bonding between lifts, evaluating the effectiveness of repair or removal and replacement of soil liner areas failing to meet the placement specifications, evaluating the ability of the heavy equipment to travel over the process area and test fill and to place and compact soil liner on the sideslopes and documenting all aspects of the test fill construction.

Nuclear probe holes will be repaired by compacting granular bentonite into the bottom half of the probe hole using the driving pin used to create the probe holes and then hydrating the bentonite with water The upper half of the probe hole will be backfilled and hydrated in the same manner as the bottom half Sample sleeve and sandcone or rubber balloon test locations will be repaired by compacting processed clay and/or bentonite into the test locations using a sledge hammer or tamping rod Sand used in sandcone tests will be removed prior to backfilling Block samples will be obtained after the test fill construction is completed at the locations given in Table I3 These locations will be filled with loose soil and compacted lightly using available equipment These observations will be documented by the Engineer

As stated previously, the evaluation of loose and compacted lifts will be difficult to physically measure The Engineer will visually monitor loose lift thickness and will obtain physical measurements where possible Compacted lift thickness will be measured by using a rod and level and taking numerous measurements over a cross-sectional area before a lift is placed and after that lift is compacted The nominal compacted lift thickness will then be calculated by using the average vertical difference between the measurements These observations will be documented by the Engineer

Layer bonding will be evaluated when excavating nuclear and block test locations A dozer or compactor blade will be used to trim a test pad for nuclear testing The depth the test pad is trimmed to be at or near the bottom of the sheepsfoot penetrations This depth is typically at the interface between lifts One indicator of less than desirable layer bonding is whether the top lift readily peels off when trimming the test locations Should this occur, the loose lift of the next lift placed will be lessened until no peeling of the overlying areas is observed Layer bonding will also be evaluated during or at the end of construction by trimming a vertical face along a portion or portions of the edge of the test fill The vertical face will then be inspected for stratification between lifts Effective layer bonding will be evident if no visual delineation can be observed between lifts These observations will be documented by the Engineer

The evaluation of repair or replacement of defective areas will be based on professional judgment If it is determined that the soil is excessively wet or dry during initial lift placements, attempts will be made to repair the soil liner in place If the soil is too wet, attempts will be made to dry it in place by mixing the soil using the disc and/or soil stabilizer and letting it stand If this is found to be time consuming or ineffective, the lift will be removed and replaced If the soil is too dry, attempts will be made to add moisture by adding water and mixing the soil in place using the disc and/or soil stabilizer If this is found to be time consuming or too difficult, the lift will be removed and replaced The Engineer will document these activities

The Engineer will observe the ability of the heavy equipment used to construct the test fill to travel over the loose wet clay in the process and test fill areas Certain types of equipment may be more effective working within the process area than others The overall productivity of the equipment used in the process area will be evaluated and documented The Engineer will also evaluate and document the ability of equipment to work on the sideslope section of the test fill and the efficiency of placing and compacting soil liner material on the sideslopes

Comprehensive documentation will be performed on a daily basis by the Engineer The documentation will be both written and photographic Video tapes of various aspects of construction may also be made The daily written documentation will consist of documenting all testing and observation requirements given in this work plan including weather conditions, relevant observations, equipment in use, personnel onsite, and any pertinent conversations

7.0 POST-CONSTRUCTION TESTING AND SUMMARY REPORT

Post-construction testing will consist of completing the laboratory index and hydraulic conductivity testing on samples obtained during the test fill construction. When these data are complete, the hydraulic conductivity results (both sleeves and block) will be plotted on a moisture/density graph showing the PW derived during the pre-construction testing and preliminary CAMU design The PW will then be modified as necessary to reflect the actual PW Should conflicting or questionable results be obtained, additional laboratory testing will be performed as necessary to confirm the test fill results Although additional sampling is not anticipated, additional samples may be obtained by removing a portion of the protective soil and separator geomembrane or geotextile and obtaining samples as needed

The Engineer will prepare a summary report of the test fill construction and all laboratory testing When data are assimilated and evaluated, recommended specifications for full-scale construction of the CAMU soil liners will be given at the conclusion of the summary report The summary report will include the following

- The results of the borrow area evaluation and selection
- The ability of the selected borrow area and areas that have material with similar properties to meet the total landfill borrow needs
- A summary of the pre-construction testing program, including all test results
- A summary of the test fill construction, including the materials, equipment, and procedures used, the construction schedule, personnel involved, and pertinent weather data
- A summary of the test fill CQA testing and observations, including all test results and daily field reports
- An assessment of the equipment and procedures used to construct the test fill and recommendations for full-scale construction equipment and procedures
- A summary of the post-construction testing, including test results
- Recommendations for technical specifications for full-scale soil liner construction
- An identification of any test fill data needs that may have to be addressed

8.0 ACRONYMS

Army	U S Department of the Army
ASTM	American Society for Testing and Materials
AZ	Acceptable zone
BEMA	Bald Eagle Management Area
bgs	Below ground surface
Borrow Study Report	Final Feasibility Study Soils Support Program Report
CAMU	Corrective Action Management Unit
CDD	CAMU Design Document
CDPHE	Colorado Department of Public Health and Environment
CHWMA	Colorado Hazardous Waste Management Act
cm/s	Centimeter per second
Contractor	Earthwork contractor
CQA	Construction Quality Assurance
Engineer	CQA engineer
EPA	U S Environmental Protection Agency
Field Work Plan	Work Plan for the Hydrogeologic and Geotechnical Program
FS	Feasibility Study
FWS	U S Fish and Wildlife Service
HLA	Harding Lawson Associates
Landfill FS Report	Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program
LPW	Lower placement window
PAZ	Potential acceptable zone
PMRMA	Program Manager for Rocky Mountain Arsenal
PW	Placement window
RMA	Rocky Mountain Arsenal

SDRI	Sealed double-ring infiltrometer
State	State of Colorado
TSBP	Two-stage borehole permeameters
UPW	Upper placement window

9.0 BIBLIOGRAPHY

Benson, C H 1994 Research developments in clay liner construction In *Proceedings of Solid Waste Association of North America, 32nd Annual International Solid Waste Exposition*

Benson, C H and F S Hardianto 1992 *Hydraulic conductivity assessment of compacted soil liners,* Final Report, Phase I, Environmental Geotechnics Report No 92-4

Benson, C.H , F S Hardianto, and E S Motan. 1993 *Representative specimen size for hydraulic conductivity assessment of compacted soil liners, hydraulic conductivity and waste contaminant transport in soils,* ASTM STP 1142, David Daniels and Stephen J Trautwein, eds , *American Society for Testing and Materials,* Philadelphia

Daniel, David E. 1990a. *Summary review of construction quality control for compacted soil liners* Geotechnical Special Publications No 26 Waste Containment Systems Construction, Regulation, and Performance, Rudolph Bonaparte, ed

Daniel, D E and C H Benson 1990b Water content-density criteria for compacted soil liners, *Journal of Geotechnical Engineering,* v. 116, No 12, American Society of Civil Engineers

Geosyntec Consultants 1992 *Report of results - test fill no 2, test fill program, secure cell no 2, Highway 36 hazardous waste treatment, storage, and disposal facility,* Adams County, Colorado, March

Geosyntec Consultants 1993 *Report of results - test fill no 1, test fill program, secure cell no 2, Highway 36 hazardous treatment, storage, and disposal facility,* Adams County, Colorado, January

Harding Lawson Associates 1992 *Draft work plan for geotechnical support of the offpost remediation program Rocky Mountain Arsenal,* November

Harding Lawson Associates 1994 *Final work plan for material and area feasibility studies soils support program,* November.

Harding Lawson Associates 1995a *Final landfill site feasibility report for the feasibility study soils support program,* July

Harding Lawson Associates 1995b *Final feasibility study soils support program Report,* January

Harding Lawson Associates 1995c *Draft final closure plan and post-closure plan for the basin F waste pile and former basin F capped areas,* August

Harding Lawson Associates 1995d *Draft final work plan for the hydrogeologic and geotechnical program, feasibility study soils support program, Rocky Mountain Arsenal,* October

Luettich, S M , R Bonaparte, B A Coleman, and H M Tomlinson 1995 *Preconstruction testing of two soil liner materials* Geotechnical Special Publication No 46, GeoEnvironment 2000, Y B. Acar and D E Daniel, ed

TerraMatrix 1995 *Draft test fill work plan for secure cells 3 through 7,* Highway 36 Hazardous Waste, Treatment, Storage, and Disposal Facility, Adams County, Colorado, July

Trast, J M , and C H Benson. 1993 *Hydraulic conductivity of thirteen compacted clays,* Environmental Geotechnics Report No 93-3 October 1993

Trautwein, S J., and C E Williams. 1990 *Performance evaluation of earthen liners,* Geotechnical Special Publication No 26, Waste Containment Systems Construction, Regulation, and Performance Rudolph Bonaparte, ed

U S Environmental Protection Agency 1986 *Construction quality assurance for hazardous waste land disposal facilities,* EPA/530-SW-86-031, October

U S Environmental Protection Agency 1989 *Requirements for hazardous waste landfill design, construction, and closure,* EPA/625/4-89/022, August

U S Environmental Protection Agency 1993 *Quality assurance and quality control for waste containment facilities,* Technical Guidance Document, EPA/600/R-93/182, September 1993

Wang, X , and C H Benson 1995 *Infiltration and saturated hydraulic conductivity of compacted clay*

Table I1: Geotechnical Property Target Criteria

Test	Low Permeability Soil Target Criteria
Atterberg Limits	
Liquid limit (LL)	≥ 35 percent
Plasticity index (PI)	≥ 15 percent
Grain-size distribution	≥ 50 percent passing No 200 sieve
Remolded permeability	≤ 1 x 10^{-7} cm/s

cm/s centimeters per second
≥ greater than or equal to
≤ less than or equal to

Table I2: Borrow Area 5, Geotechnical Data Summary for Soil Meeting the Geotechnical Target Criteria

Boring No	Sample Depth (feet)	USCS Soil Classification	Passing Sieve No 200 (percent)	In Situ Moisture Content (percent)	Liquid Limit (percent)	Plasicity Index (percent)	Permeability at 90 Percent (cm/s)	Permeability at 95 Percent (cm/s)	Optimum Moisture (percent)	Maximum Dry Density (pcf)
ASB11594	4	CL	69	11 3	40	22				
ASB11694	28	CH	52	16	54	36				
ASB11894	4	CL	83	10 4	44	23				
ASB11894	8	CL	61	9 4	43	24	6E-08	4E-08	14	112 4
ASB11894	12	CH	54	12 8	51	31				
ASB11894	16	CH	59	17 7	57	31				
ASB11894	20	CL	72	17 6	49	31				
ASB11894	24	CL	85	18	48	31				
ASB11994	4	CL	56	8 2	41	22				
ASB11994	8	CL	58	7 7	42	24	7E-08	1E-08	15 2	109 6
ASB12094	8	CL	57	13 7	47	27	3E-08	1E-07	15 1	111 3
ASB12094	12	CL	59	12 9	44	24				
ASB12494	4	CL	61	9 3	41	19	3E-08	2E-08	17 8	105 9
ASB12594	4	CL	78	9 5	39	20				
ASB12594	16	CL	54	7 5	38	21				
ASB12594	20	CL	70	11 1	42	24				
ASB12594	24	CH	72	16 7	60	41				
ASB12594	28	CH	77	17 7	76	56				
ASB12794	12	CL	63	12 1	43	22				
ASB12794	16	CH	88	20 6	71	46				
ASB12794	20	CL	56	9 4	35	18				
ASB12794	28	CL	81	9 2	36	18				
ASB13294	16	CL	56	7 1	38	23				
ASB13294	28	CL	80	15 3	45	29				
BRB12994	20	CL	62	9 2	37	22				
BRB13094	24	CL	53	11 2	42	27	2E-07	1E-07	16 4	113.2
BRB13094	28	CH	81	10 4	50	34				
BRB13594	12	CL	51	7 3	35	16	1E-07	1E-07	14 2	114 9
BRB13594	16	CL	51	7 4	37	20				
BRB13594	24	CL	54	9 4	48	31				
BRB13594	28	CL	60	8 3	39	20				
SAB11794	4	CH	56	10 3	57	37				
SAB12194	4	CL	74	10 4	39	19				
SAB12194	8	CL	56	7 8	39	24	8E-08	4E-08	15 3	111 8
SAB12194	20	CL	68	9 5	44	27				
SAB12194	24	CH	89	14	53	35				
SAB12194	28	CH	97	28 6	73	43				
SAB12294	4	CL	71	10	38	17				
SAB12294	8	CL	63	11 2	44	26				
SAB12294	12	CL	53	11 6	48	31				
SAB12294	16	CL	69	12 7	46	30				
SAB12394	4	CL	55	9 6	39	15				
SAB12394	12	CL	67	12 8	49	35				
SAB12394	24	CH	57	22 9	78	47				
SAB12394	28	CH	64	21 3	60	34				
SAB12694	12	CL	59	10 6	37	19				
SAB12694	20	CL	71	11 2	44	27				
SAB12694	24	CL	52	11.2	43	29				
SAB12694	28	CH	53	14 5	52	35				
SAB13194	16	CL	62	8 7	38	21				
SAB13194	20	CL	65	9 4	41	21				

Table I2 (continued)

Boring No	Sample Depth (feet)	USCS Soil Classification	Passing Sieve No. 200 (percent)	In Situ Moisture Content (percent)	Liquid Limit (percent)	Plasticity Index (percent)	Permeability at 90 Percent (cm/s)	Permeability at 95 Percent (cm/s)	Optimum Moisture (percent)	Maximum Dry Density (pcf)
SAB13194	24	CL	68	9 8	38	19				
SAB13194	28	CL	63	10 4	42	22				
SAB13194	30	CL	55	8 3	40	21				
WEB11494	8	CL	62	10 1	41	24				
WEB11494	16	CL	70	14 1	42	24				
WEB11494	20	CL	59	14 5	44	26				
AVERAGE	17	CL	65	12 1	46	27	8E-08	7E-08	15 4	111 3
STDEV	8	N/A	11	4 3	10	8	5E-08	5E-08	1 3	2 9
MAXIMUM	30	CH	97	28 6	78	56	2E-07	1E-07	17 8	114 9
MINIMUM	4	CL	51	7 1	35	15	3E-08	1E-08	14 0	105 9

CH	Inorganic clays of high plasticity
CL	Inorganic clays of low plasticity
cm/s	Centimeters per Second
pcf	Pounds per cubic foot
STDEV	Standard Deviation
USCS	Unified Soils Classification System

Screening Criteria

USCS Classification	CL or CH
Passing Sieve No 200	> 50 percent
Liquid Limit	> 30 percent
Plasticity Index	> 15 percent
Depth below Surface	< 30 feet

Table I3: Compaction and Testing Criteria for Test Fill 3

Objectives	Lane 1	Lane 2	Lane 3
Place Lift 1 Target UPW 10" loose lift	5 passes Check for subgrade contamination 1 moisture grab sample	10 passes Check for subgrade contamination 1 moisture grab sample	15 passes Check for subgrade contamination 1 moisture grab sample
Place Lift 2 Target UPW Test Lift 1 8" loose lift	5 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	10 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	15 or more passes 2 nuclear moisture/density tests One location on base section and the other on sideslope section
Place Lift 3 Target LPW Test Lift 2 (UPW) 8" loose lift	5 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	10 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	15 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 4 Target LPW Test Lift 3 (LPW) 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 5 Target PW Test Lift 4 (LPW) 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 6 Target PW Test Lift 5 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Place Lift 7 Target PW Test Lift 6 8" loose lift	4 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	6 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section	8 or more passes 2 nuclear tests and 2 Shelby tubes One location on base section and the other on sideslope section
Grade to 3 feet minimum Smooth roll surface	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section	2 nuclear tests and 2 Shelby tube samples One test/sample set on base section and the other on sideslope section
Obtain block samples	3 samples with 2 taken from the upper foot and one taken from the middle foot of the test fill	3 samples with 2 taken from the upper foot and one taken from the lower foot of the test fill	3 samples with 2 taken from the upper foot and one taken from the middle foot of the test fill

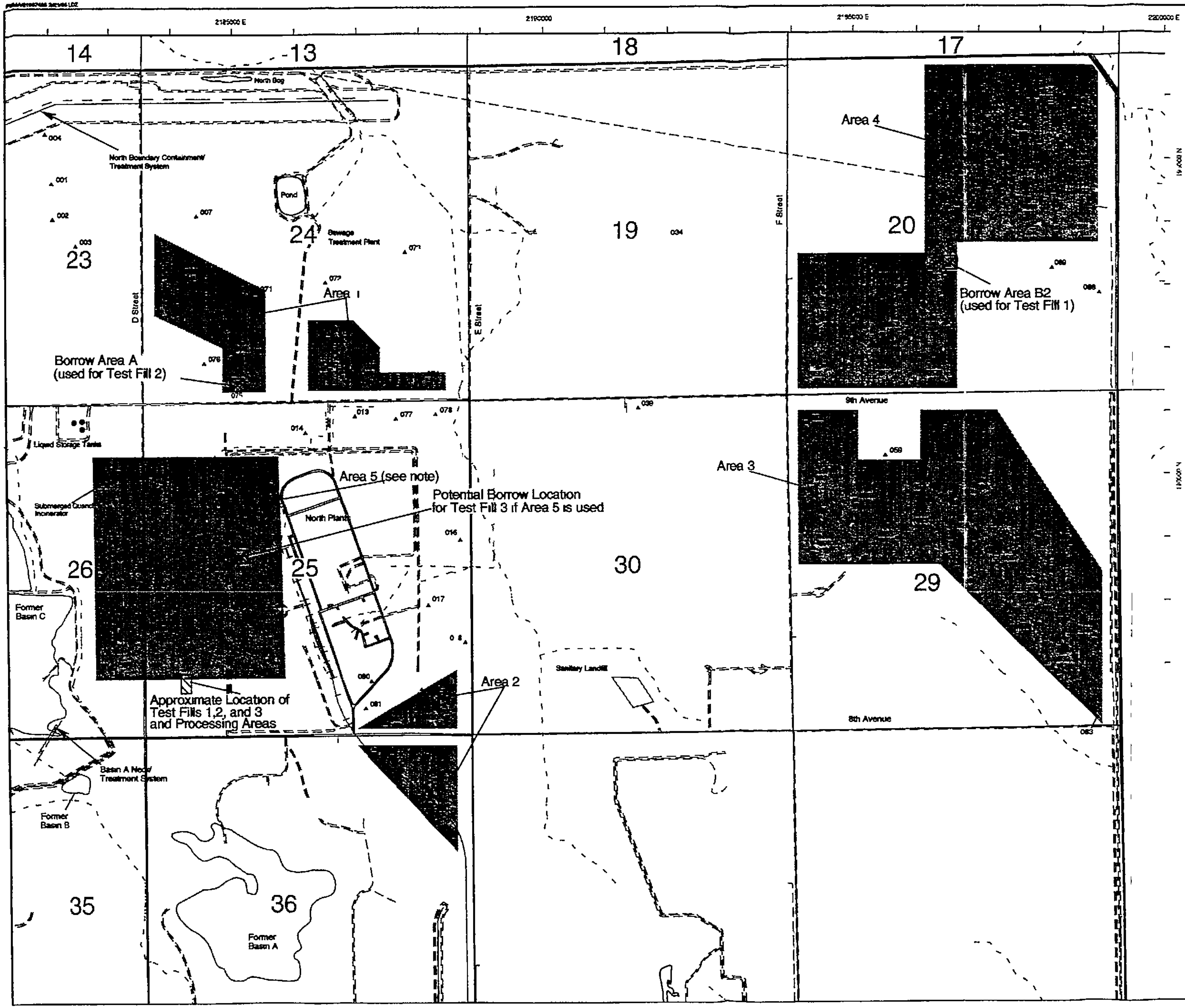
LPW Lower placement window
PW Placement window
UPW Upper placement window

1 Test and sample locations will be selected at random by Engineer in the areas specified
2 Shelby and block samples will be taken perpendicular to the lift placement direction

Table I3 (continued)

3 Not all Shelby tube samples will be tested The Engineer will select a minimum of five for initial testing The remainder will be archived Archived samples may be tested at a later date
4 Shelby tube samples will be taken beneath the nuclear test location (adjacent to probe hole)
5 Block samples will be taken after completion of construction. Block samples located below surface level will be obtained by excavating through the overlying lifts to the required sample depths
6 Microwave and oven moisture content tests will be performed on samples obtained at each nuclear test location when testing Lifts 1 and 2
7 One sandcone or rubber balloon correlation test will be performed on each lift at one of the nuclear test locations
8 Field Test Methods

Nuclear Moisture Content	ASTM D3017	Sandcone Density	ASTM D1556
Nuclear Density	ASTM D2922	Rubber Balloon Density	ASTM D2167
Microwave Moisture Content	ASTM D4643	Oven Moisture Content	ASTM D2216



Explanation

▲	Soil boring locations
⊠	Borrow areas excavated for construction of test fills
	Low-permeability soil borrow areas
	Railroad
	Ditch or stream
	Paved road
	Unpaved road
16	Section number
CAMU	Corrective Action Management Unit

Note

Area 5 has been initially set with the same areal configuration as the Landfill CAMU areal configuration. Area 5 will be further reduced in size to include only the areas that will be excavated as part of the individual landfill cell construction.

0 1500

Scale in feet

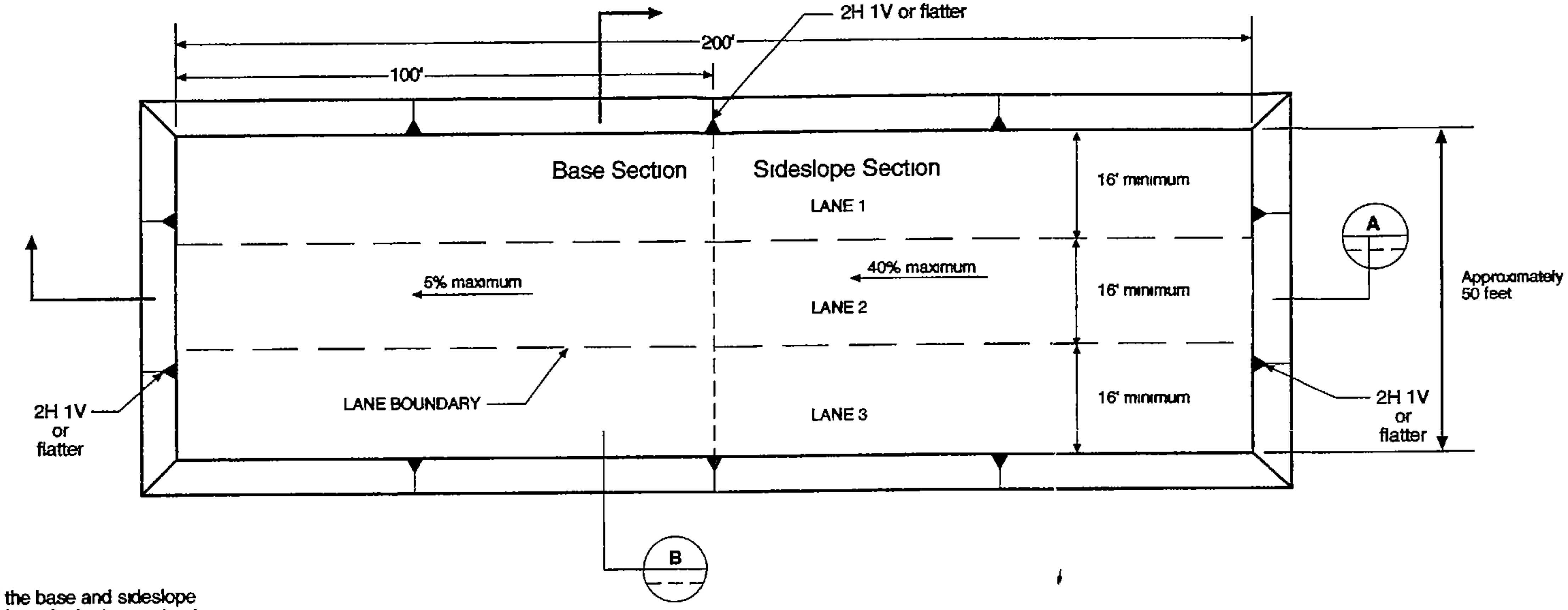
Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

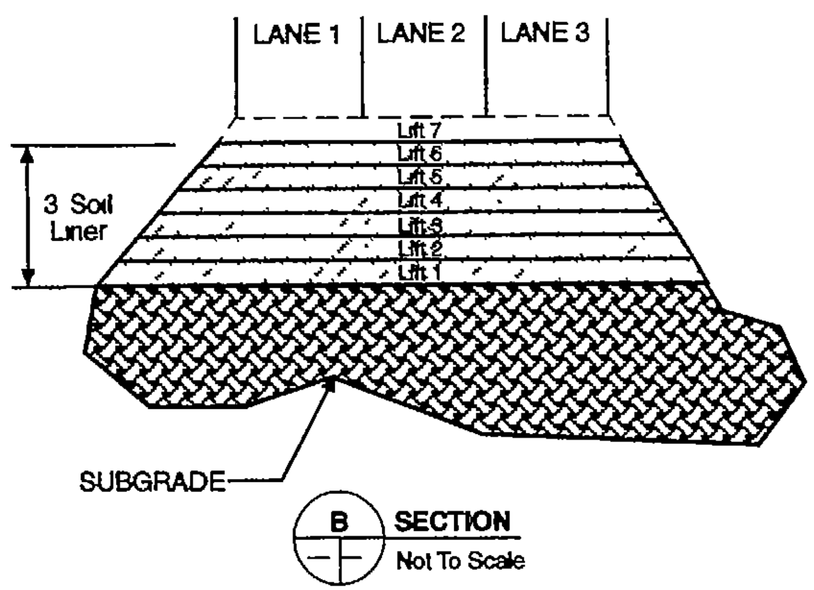
Figure I1

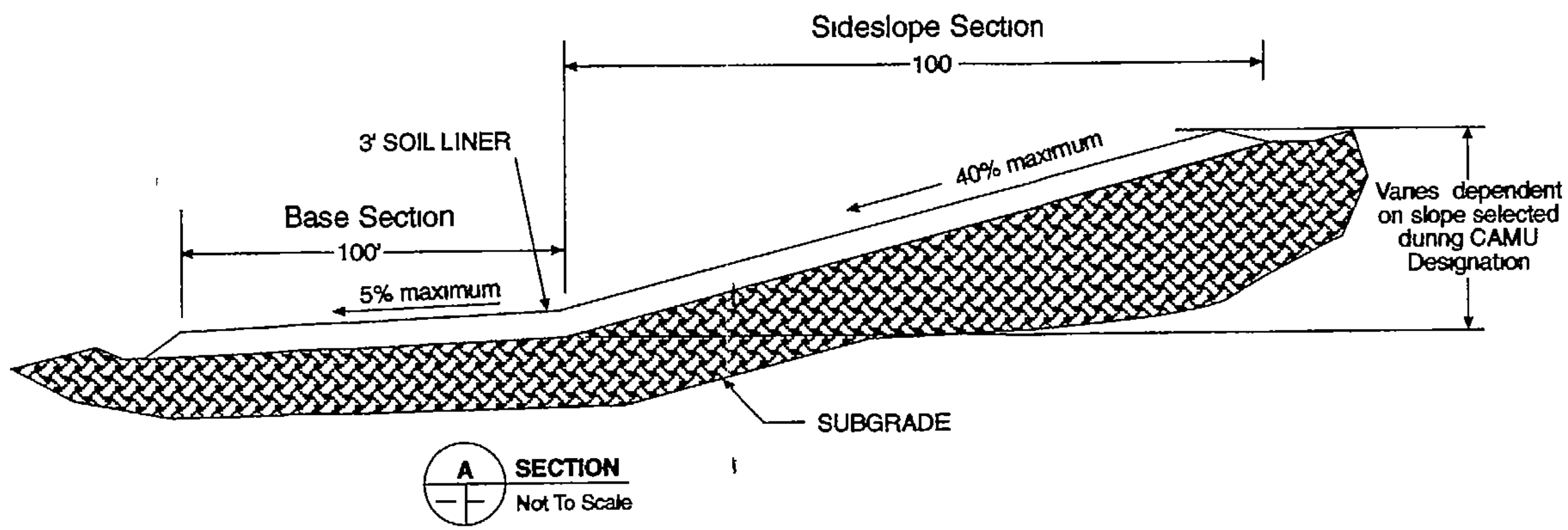
Borrow Area and Test Fill Location Map

Test Fill 3 Plan View



Notes (1) The slopes of the base and sideslope sections will be selected prior to construction during the CAMU Designation Process.





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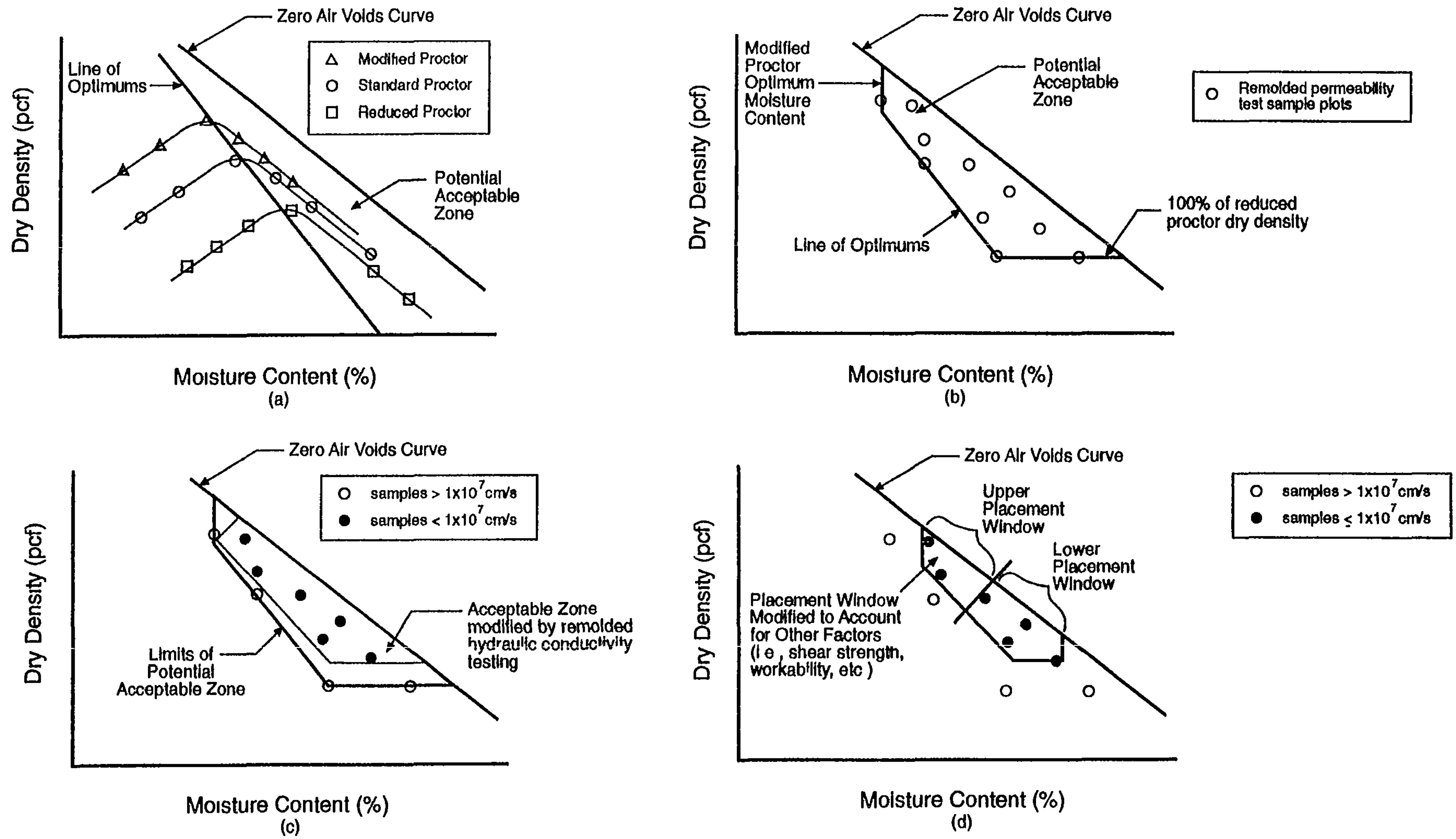
Engineering and Environmental Services

Test Fill 3 Plan View and Cross Sections
Rocky Mountain Arsenal
Commerce City CO

FIGURE 12

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
ECS	21907 705011 1		10/95	



RMA 1253 01/04/96 ECS

Harding Lawson Associates
Engineering and Environmental Services

Methodology for Selection of Test Fill 3 Placement Specifications
Rocky Mountain Arsenal
Commerce City, CO

FIGURE **13**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED DATE
ECS	21907, 705011 1		10/95	

Appendix J

OPERATING RECORD SYSTEM PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

 1 1 Purpose and Scope

 1 2 Organization

2 0 Waste Description, Quantities, and Disposition

3 0 Waste Analyses

4 0 Contingency Plan Implementations

5 0 Inspection Records

6 0 Monitoring, Testing, and Analytical Data

7 0 Records of Corrective Action

8 0 Annual Certification of Waste Minimization

9 0 Record Retention, Availability, and Disposition

10 0 Biennial Reporting Requirements

11 0 Additional Reporting Requirements

12 0 Acronyms

13 0 References

PROGRAM MANAGER
FOR ROCKY MOUNTAIN ARSENAL

U S ARMY
MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

Final Corrective Action Management Unit Designation Document
Rocky Mountain Arsenal
Commerce City, Colorado

Volume II of II

Harding Lawson Associates

This document complies with the
National Environmental Policy Act of 1969

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Final Corrective Action Management Unit Designation Document, Rocky Mountain Arsenal Commerce City, Colorado

Volume II of II

Prepared for

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Contract DAAA05-92-D-0003
Delivery Order 0007 (Task 93-03)

THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

June 12, 1996

Harding Lawson Associates
Engineering and Environmental Services
707 Seventeenth Street, Suite 2400
Denver, CO 80202 - (303) 292-5365

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Appendix K

GUIDELINES FOR THE DEVELOPMENT OF A GROUNDWATER MONITORING PLAN

CONTENTS

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ATTACHMENT

1.0 INTRODUCTION

This guideline for the development of a groundwater monitoring program has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for the cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado It is contemplated that the CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Act. The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3 This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

This appendix provides guidance for the development of a detailed Groundwater Monitoring Plan for the CAMU at RMA The objective of this appendix is to provide information on the methods, approach, implementation, and procedures that may be incorporated into the CAMU Groundwater Monitoring Program The final Groundwater Monitoring Plan will be responsive to the applicable CAMU Groundwater Monitoring requirements The Groundwater Monitoring Plan will be submitted to CDPHE for review and approval in accordance with the schedule discussed in Section 5 0 of the CDD

1.1 Purpose, Scope, and Organization

The CDD, including this appendix, will be submitted to CDPHE to support the designation of the CAMU This document presents guidelines for the methodology the Army will employ to provide groundwater monitoring activities within the landfill CAMU areal configuration as required under 6 Code of Colorado Regulations (CCR) 1007-3, Section 264 552 (e)(3) This document will not address the specific data needs for the RMA sitewide Groundwater Monitoring Program often referred to as the RMA GMP The RMA sitewide GMP as required by the Onpost Record of Decision (ROD) will be specifically addressed by the ongoing RMA sitewide GMP

This document was developed to provide a framework for development of the groundwater monitoring program that will be implemented following designation of the CAMU After designation and prior to operation, the groundwater monitoring program will provide pre-operational data to better define the existing groundwater conditions in the landfill CAMU areal configuration These pre-operational data will be utilized to further develop detailed groundwater monitoring plans that will be implemented during the operational period of the landfill Data collected through the operational period of the landfill will also be used to develop groundwater monitoring plans that will apply during the closure and post-closure care period These plans will be provided to CDPHE for review and approval according to schedules for these activities

The framework for the CAMU Groundwater Monitoring Program described in this appendix

- Provides a long-term groundwater monitoring strategy that includes the constituents of concern, monitoring locations, frequency, and analytical methods
- Provides guidance on a method and frequency for collecting groundwater-level measurements for presentation on water-table surface maps to assess groundwater flow directions and gradients
- Defines quality assurance/quality control (QA/QC) procedures for sample collection, analysis, and well maintenance
- Provides a framework for effective data management and data evaluation
- Specifies record-keeping and reporting requirements

The appendix is organized as follows Section 1 0 provides an introduction to the overall monitoring program by presenting the regulatory requirements, CAMU Boundary description, and site-specific hydrogeology and current groundwater monitoring in the area Section 2 0 presents some methods and approaches to groundwater monitoring of the landfill CAMU areal configuration through the pre-operation, operational, closure, and post-closure periods Section 3 0 provides guidance on field procedures for well installation, and groundwater sampling Section 4 0 describes quality control samples and Section 5 0 decontamination procedures Section 6 0 includes sample documentation and shipping procedures Section 7 0 includes information on laboratory analyses and Section 8 0 on data evaluation and record keeping Attachment K1 presents the results of a groundwater monitoring well efficiency model that was used to assess the predicted efficiency of the proposed operational period monitoring well network.

1.2 Regulatory Requirements

The regulatory requirements for this groundwater monitoring program are defined in 6 CCR 1007-3, Section 264 552 (e)(3) This section requires that the groundwater monitoring program for a CAMU shall

- Continue to detect and to characterize the nature, extent, concentration, direction, and movement of existing releases of hazardous constituents in groundwater from sources located within the CAMU
- Detect and subsequently characterize releases of hazardous constituents to groundwater that may occur from areas of the CAMU in which remediation wastes will remain in place after closure of the CAMU

In conformance with these regulations, the groundwater monitoring program is outlined to first characterize the existing groundwater conditions within the landfill CAMU areal configuration and subsequently monitor for potential releases within the CAMU landfill footprints

As part of Section 264 552 (e)(4)(ii), a groundwater monitoring program will be implemented to assist in verifying that all waste from these CAMU waste management activities, that will not result in waste left in place, has been removed Specific monitoring methods and approaches is not specified in this document since the location of these activities has not yet been defined (e g , waste staging and decontamination activities) The methods and approaches to monitoring specific to the regulatory requirements of Section 264 552 (e)(3) are defined below

1.3 Landfill Area Description

The CAMU boundary, components, waste types, and waste volumes were described in detail in Section 1 0 of this CAMU Designation Document The CAMU Groundwater Monitoring Program outlined here addresses the area within the landfill CAMU areal configuration This area is roughly outlined in Figure K1 based on the landfill concept developed for CAMU designation

1.4 Site-specific Hydrogeology and Current Groundwater Monitoring

This section describes the site-specific geology and hydrogeology in the landfill CAMU areal configuration The regional geology and hydrology for RMA have been discussed in detail in numerous reports including HLA (1995a), J May (1982), Morrison-Knudsen Engineers, Inc (MKE) (1988), and Ebasco Services, Inc (Ebasco) (1989) and are not repeated in the following discussion Further characterization of the site-specific geology is described in the Part 2 Siting Criteria Compliance Demonstration in Section 1 0 of Appendix A A brief overview of the geologic and hydrogeologic site conditions are described below to provide a framework for understanding the design of the CAMU Groundwater Monitoring Program

1.4.1 Geology

Immediately underlying the landfill CAMU areal configuration are Quaternary deposits that unconformably overlie the Denver Fm The Quaternary surficial deposits, commonly called the Quaternary alluvium, consist of unconsolidated alluvial and colluvial fill and eolian sand The alluvial and colluvial material is composed primarily of clay, silt, very fine- to fine-, to medium-grained sand with minor amounts of coarse-grained sands and gravel The alluvium ranges in thickness from approximately 5 to 58 feet below ground surface (bgs) as measured in 38 boreholes drilled in 1994 and 1995 within the area

Underlying the alluvial materials is the Cretaceous-Tertiary age Denver Formation (Denver Fm), which is composed primarily of claystone with interbedded siltstone, sandstone, and lignite The Denver Fm dips slightly (2 to 3 degrees) to the southeast. The top of the Denver Fm is an erosional surface at RMA. In the northern portion of Section 26 the Denver Fm is approximately 250 feet thick (Environmental Science and Engineering, Inc [ESE], 1988)

At RMA, the upper portion of the Denver Fm has undergone weathering and the thickness of this weathered zone ranges from a few feet to several tens of feet. Denver Fm bedrock at RMA is considered weathered if it is red, orange, yellow, tan, or brown, highly or moderately oxidized throughout or along fractures, closely to moderately fractured, or unconsolidated, crumbly or soft (HLA, 1995a)

Stratigraphic correlation of units within the Denver Fm is difficult because of the discontinuous nature of the sandstone lenses and the lateral variability in thickness and composition of other units. A relatively thick, laterally continuous lignite layer, known as "Lignite A," occurs within the South Plants, Basin A, and North Plants area. Lignite A has been used as a marker bed from which the other zones within the Denver Fm have been referenced (Ebasco, 1989). The stratigraphy of the landfill area illustrated in 12 cross sections is presented in Appendix A of the CDD

1.4.2 Hydrogeology

Groundwater at RMA occurs under both unconfined and confined conditions. The Quaternary alluvium and weathered Denver Fm form a generally continuous groundwater system, and the groundwater system is typically unconfined. This flow system is referred to as the unconfined flow system (UFS). Confining strata inhibit groundwater interaction between the UFS and deeper, more permeable zones in the Denver Fm, causing confined conditions to exist. The confined groundwater underlying the UFS is referred to as the confined flow system (CFS)

In the UFS, groundwater flow occurs in saturated alluvium and the upper Denver Fm. At RMA, groundwater flow in the UFS occurs primarily in the saturated alluvium, which generally has a higher hydraulic conductivity and transmissivity than the unconfined weathered Denver Fm. In the landfill CAMU areal configuration, however, groundwater flow in the UFS occurs primarily within the weathered

Denver Fm due to the limited occurrence of saturated alluvium Therefore, groundwater flow is relatively slow in the landfill CAMU areal configuration, compared to other areas of RMA where the UFS flow is primarily within saturated alluvium

Figure K2 illustrates UFS (alluvium and unconfined portions of the Denver Fm) water-table map for the landfill area as presented in the most current version of the GMP Groundwater Monitoring Report (HLA, 1995b) The 1993 water-table map indicates that groundwater flow in the UFS is generally from the southeast to the northwest In general, the configuration of the water table in the landfill CAMU areal configuration resembles the configuration of the bedrock surface The water-table surface is highest where the bedrock surface is high. The depth to groundwater in the area ranges from 20 to 70 feet bgs

The CFS consists of flow through generally unweathered Denver Fm sandstones, siltstones, and lignites

1.4.3 Current Groundwater Monitoring Program in the Landfill Area

Figure K2 illustrates the existing groundwater monitoring wells in the landfill area As listed in Table K1, there are currently 48 wells from the sitewide RMA Groundwater Monitoring Program used to monitor the water levels in the landfill area As listed in Table K1, there are 4 UFS wells used to monitor groundwater quality in the eastern portion of Section 26 landfill area (U S Geological Survey [USGS], 1995) Currently, no UFS or CFS wells are used to monitor groundwater quality in Section 25 (USGS, 1995)

2.0 GENERAL GROUNDWATER MONITORING METHODS AND APPROACH

The CAMU Groundwater Monitoring Program outlined in this document has two primary objectives to monitor the existing pre-operational UFS groundwater conditions within the landfill CAMU areal configuration and to monitor potential releases to the UFS groundwater from the landfill footprint during the operational time period This section provides information on how the framework for the Groundwater Monitoring Program for the landfill CAMU areal configuration addresses both requirements Because the approach for monitoring will differ during the pre-operational, the operational, closure, and post-closure monitoring periods, each of these phases of the program is discussed separately below

2.1 Pre-Operational Characterization Within the Landfill CAMU Areal Configuration

As discussed in Section 1 4 3, the 1995 sitewide RMA Groundwater Monitoring Program does not include groundwater sampling of any wells in Section 25 (USGS, 1995) The characterization of the pre-operational water quality conditions within the landfill CAMU areal configuration is an integral part of the CAMU Groundwater Monitoring Program The detection of potential releases of hazardous constituents to the groundwater from within the landfill CAMU areal configuration will be based on the identification of a statistically significant increase in specific indicator constituents above the known pre-operational conditions Therefore, a proposed pre-operational monitoring well network, as well as proposed sampling frequencies and a proposed groundwater sample analyte list were developed to characterize existing/background groundwater quality within the landfill CAMU areal configuration It was important to develop specifics on this program prior to design so that implementation of the program could begin as soon as practicable

The wells included in the proposed pre-operational water quality network were selected by reviewing the site-specific hydrogeologic conditions including groundwater flow directions, hydraulic gradient, and geology For existing wells, the well construction information and sampling history of each well were also reviewed

The proposed pre-operational UFS monitoring well network includes a minimum of 18 wells to monitor the groundwater within the UFS in the landfill CAMU areal configuration The proposed UFS network includes 14 existing wells and a minimum of 4 proposed new wells The location of the 18 wells included in the proposed UFS pre-operational period monitoring well network is illustrated in Figure K3 and a list of the proposed networks included in Table K2

The sampling frequency for the pre-operational UFS monitoring period will be quarterly for two years If landfilling operations do not commence immediately after the final quarter of the 8-quarter pre-operational monitoring period, a minimum of one additional quarter of UFS monitoring will be performed prior to commencement of landfilling The pre-operational sample analyte list will be the RMA Target Analyte List currently utilized for the current sitewide Groundwater Monitoring Program The proposed analyte list is presented in Table K3

Water-level data collected during each UFS sampling event will be used to evaluate the groundwater flow patterns in the landfill CAMU areal configuration Water-level data will be plotted in conjunction with the annual RMA GMP results

A plan for developing a pre-operational water quality characterization of the CFS will be submitted for CDPHE review and approval This plan will evaluate the existing water quality data for the CFS and assess the need for any additional CFS pre-operational water quality data collection If additional data is required to adequately characterize the pre-operational CFS water quality, the plan will detail the requirements for obtaining such data

Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to assess the existing background groundwater quality conditions within the landfill CAMU areal configuration Statistical methods will be used to evaluate the operational, closure, and post-closure monitoring data using standard EPA guidance or other methods as appropriate to the data (U S Environmental Protection Agency [EPA], 1989 and 1992)

EPA guidance states that the appropriateness of a specific statistical method depends on the characteristics of the data set (EPA, 1989 and 1992) Important factors to be considered in selecting an appropriate statistical method include the apparent distribution of concentrations and the number of monitoring wells, nondetects, parameters, and sampling events For the CAMU Groundwater Monitoring Program, no one specific method will be selected for evaluation of the data until at least one full year of data has been collected The statistical method will be selected at that time to take into consideration the site-specific characteristics of the data set.

2.2 Operational Detection and Characterization of Potential Releases From the Landfill CAMU Areal Configuration

The proposed operational groundwater monitoring well network and sampling frequencies are outlined in this document so that potential releases of hazardous constituents to groundwater as a result of CAMU operations within the landfill CAMU areal configuration can be detected and characterized The proposed operational period monitoring well network outlined includes 15 wells to monitor groundwater within the UFS in the landfill CAMU areal configuration If a detection is confirmed, within the landfill CAMU areal configuration, that is a statistically significant exceedance above the pre-operational concentration, monitoring of the CFS will be implemented The location of the proposed 15 wells included in the operational period monitoring well network is illustrated in Figure K4 and a list of the proposed networks is included in Table K2 As design proceeds and the footprint of the landfill is better defined, more detailed monitoring plans will be submitted to CDPHE for approval

The wells included in the proposed operational period monitoring well network were selected by reviewing the site-specific hydrogeologic conditions including groundwater flow directions, hydraulic gradient, and geology as well as construction information and sampling history of each specific existing well The proposed operational period well network has fewer wells than the pre-operational well network because as illustrated in Figure K1 2, the proposed locations of the landfill cells would most likely require abandonment of at least three well clusters If the landfill cell layout does not require abandonment of any of the three well clusters, they will be evaluated for inclusion in the proposed operational monitoring well network. Furthermore, if wells included in the proposed operational well network become damaged or otherwise unsuitable for sampling, a suitable replacement well will be installed, as necessary Installation of the replacement well will be subject to CDPHE approval

The proposed operational monitoring well network was evaluated using a Monitoring Efficiency Model (MEMO) developed by Wilson and others (1992) MEMO provides a computerized method for optimizing monitoring well locations at waste management areas MEMO quantifies the efficiency of a given well configuration by predicting areas where a chemical release would not be detected by the network. Monitoring efficiency is defined as the probability that a single source occurring in a random location within the extent of a site will be detected before resulting in detectable concentrations outside the boundary of the site

For this evaluation, because the objective was to evaluate the efficiency of the proposed operational monitoring well network, information on the site geometry, hydrogeologic characteristics, and existing monitoring well locations was input into the MEMO modeling program Figure K1 2 illustrates the site geometry and the proposed well network. Based on current understanding of the groundwater flow conditions in the area, the upgradient boundary for the site was defined as the southern boundary of the landfill CAMU areal configuration Likewise, the downgradient boundary of the site was defined as the north, east, and west boundaries of the landfill CAMU areal configuration

Based on the proposed well network, MEMO predicts a monitoring efficiency of 99 percent A 99 percent efficiency indicates that releases occurring over 99 percent of the source area would be detected by the well network The results of the modeling indicate that the proposed operational well network is an efficient system for monitoring the conditions within the landfill CAMU areal configuration. Further discussion of the modeling methods and results, and the results of a sensitivity analysis performed on the input parameters used in the model, is presented in Attachment K1

Sampling for the proposed operational monitoring period will be performed on a quarterly, semi-annual, or annual basis based on a review of the background monitoring period groundwater data and subject to CDPHE approval. The proposed operational sample analyte list will include a subset of the analytes identified in the target analyte list presented in Table K3 and will be based on the remedial waste types placed in the cells within the landfill as discussed in Section 1 0 of this CDD

2.3 Closure and Post-Closure Monitoring of the Landfill Area

After the landfill is constructed and groundwater monitoring data are available from the operational monitoring period, the Closure and Post-Closure Groundwater Monitoring Plan for the landfill area will be written and submitted by the Army to CDPHE for approval

3.0 FIELD ACTIVITIES

The field activities to be conducted during the CAMU Groundwater Monitoring Program will be performed in accordance with Program Manager for Rocky Mountain Arsenal (PMRMA) standard groundwater monitoring methods described in detail in previous documents (HLA, 1993a, 1993b, and 1995c) or consistent with procedures used in the current RMA GMP The groundwater monitoring field activities will include the following

- Drilling
- Lithologic logging
- Monitoring well installation
- Monitoring well development
- Monitoring well identification and surveying
- Water-level measurement
- Groundwater sampling

General guidelines for the field procedures are presented in this section

3.1 Monitoring Well Installation

The following sections describe the equipment and procedures to be used during monitoring well installation for the CAMU Groundwater Monitoring Program The field activities include drilling, lithologic logging, monitoring well installation, well development, well identification, and surveying Initially, a minimum of four additional alluvial or unconfined Denver Fm wells will be installed to initiate the pre-operational period groundwater monitoring well network. The proposed monitoring well locations for the four proposed additional wells are illustrated in Figure K3

3.1.1 Drilling Procedures

This section discusses drilling procedures for installing alluvial and weathered Denver Fm, monitoring wells Drilling methods that may be used during well installation activities include hollow-stem auger, and/or rotary-wash drilling methods

Techniques and procedures associated with the drilling program will be consistent with PMRMA geotechnical requirements Drilling equipment, including drilling rods, augers, samplers, tools, and water tanks, will be steam cleaned before arrival at RMA and washed with PMRMA-approved water before arrival at each boring or well site Well materials (casing, end plugs, and protector casing) will also be steam cleaned before installation Materials will be wrapped in plastic if they need to be stored before use at the well site Water used in drilling, grouting, or decontamination will be obtained from a PMRMA-approved source

Decontamination procedures are detailed in Section 4 0 Only PMRMA-approved lubricants, such as vegetable shortening, will be used on the threads of downhole drilling equipment Air usage, if any, will be fully documented with equipment descriptions and oil filter specifications Only PMRMA-approved air systems will be used

Hollow-stem Auger Drilling Procedures

Alluvial and weathered Denver Fm monitoring wells will be drilled using hollow-stem auger drilling methods During drilling, boreholes will be logged with a continuous coring device or split-spoon samplers at 4- to 5-foot intervals and at major changes in lithology

Specific drilling and sampling procedures for hollow-stem auger continuous sampling follow

1 Set up rig at staked and cleared borehole location

2 Record location, date, time, and other pertinent information on boring log form

3 Commence drilling and sampling

4 After each coring run, remove the core barrel or split-spoon sampler from the borehole and open the barrel

5 Measure each sample with an engineer's tape and lithologically log the sample as described in Section 3 1 2

6 The boring is considered complete when lithology indicates that the desired completion interval has been reached

7 The borehole will be reamed with 8-1/4-inch-inner diameter (ID) augers and installation inside the hollow-stem augers will be conducted as detailed in Section 3 1 4

8 Grout any boreholes that are not completed as wells with a cement-bentonite grout within 24 hours after drilling has been completed

9 Cuttings will be managed based on appropriate waste determination procedures established in the final groundwater monitoring plan

10 After completing each boring or well, decontaminate augers and other downhole equipment This decontamination will be accomplished after transporting the downhole equipment to the designated temporary mobile decontamination pad or at the drilling site using portable decontamination equipment

11 Have sufficient augers and core barrels available so that one set may be in use while a second set is being decontaminated

12 At the end of the each day, personnel and all equipment that are to leave the site will proceed to the temporary mobile decontamination pad where decontamination procedures will be initiated Drilling rigs will remain at the drilling location until all work has been completed Upon completion of activities at each location, the drilling rig and all associated equipment will be transported to an appropriate decontamination facility for thorough decontamination. Decontamination water and PPE will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

3.1.2 Lithologic Logging

Boring lithology will be logged by a rig geologist. Data will be recorded on boring log forms and will include the boring number, location, date, drilling equipment, driller's name, method of sampling, sample depth, and lithologic descriptions Photocopies of boring logs will be submitted to PMRMA upon completion of the boring Soil and bedrock logging procedures are explained in detail in the following sections

Soil Logging

Soil logging will be performed on the basis of cuttings or split-spoon samples, depending on the drilling method This section describes the procedures that will be used to identify and describe soil samples that are collected, regardless of the method of collection.

The Unified Soil Classification System (USCS) is the standard that will be used to classify soil by visual and manual examination Soil will be described using standard terminology and nomenclature associated with this system Each soil stratum will be identified by the following classifications in the following order (1) classification symbol, (2) classification name and content percentages, (3) Munsell color code, (4) color name, (5) consistency or relative density, (6) moisture, (7) structure (if any), and (8) modifying information, such as grain size, particle shape, cementation, plasticity, and stratification

The standard soil classification chart to be used to classify soil type is presented in Figure K5 Symbols will be sketched on the graphic portion of the boring log to assess stratigraphic relationships Color will be correctly described by comparing the soil sample with a Munsell color chart and applying appropriate designations and descriptions

An estimate of soil consistency, using standard penetration resistance as a guide, will accompany descriptions of all fine-grained soil (silts and clays) The following terminology will be used as a guide

Blows/foot[1]	Consistency	Identification Procedure
0 to 2	Very soft	Easily penetrated several inches by fist
2 to 4	Soft	Easily penetrated several inches by thumb
5 to 8	Medium stiff	Penetrated several inches by thumb with moderate effort
9 to 15	Stiff	Readily indented by thumb but penetrated only with great effort
16 to 30	Very stiff	Readily indented by thumbnail
> 30	Hard	Indented with difficulty by thumbnail

1 Blows/foot is defined as the total number of blows required to drive the second and third 6 inches of penetration (for the first 6 inches, blow count is also recorded) while driving an 18-inch sampler with a 140-pound hammer falling a free height of 30 inches

It is anticipated that samples will be collected using wire line sampling equipment rather than drive sampling equipment Therefore, estimates of soil consistency will be made on the basis of the "Identification Procedure" described above rather than on the basis of blows per foot

Descriptions of all coarse-grained soil (sand and gravel) will be accompanied by an estimate of the relative density The following terminology will be used as a guide

Blows per foot	Relative Density
less than 4	Very loose
4 to 10	Loose
10 to 30	Medium dense
30 to 50	Dense
over 50	Very dense

Evaluation of relative density in the field is assessed qualitatively

Moisture content will be estimated and described using the following terms dry, moist, wet, and saturated (below the water table) Other descriptors to be included on boring logs, if applicable, are approximate percentages of clay, silt, sand, and gravel, average grain size and maximum size of particles, shape/angularity of coarse grains, general composition or mineralogic description of grains (e g , granitic, micaceous), coatings on coarse grains, plasticity, organic content, cementation, and local or geologic name

Bedrock Logging

Bedrock logging will be performed on bedrock samples collected by split-barrel sampling or coring This section describes the procedures to be used to identify and describe bedrock samples that are collected

Written descriptions for bedrock samples will include the following information

- Lithology
- Color
- Texture, including grain size, roundness, and sorting
- Cementation and/or matrix materials
- Accessory minerals

- Hardness
- Strength
- Weatherıng
- Sedımentary/structural features

3.1.3 Monitoring Well Installation

Thıs sectıon descrıbes well ınstallatıon procedures for ınstallıng monıtorıng wells ın the alluvıum and the weathered Denver Fm Alluvıal monıtorıng wells wıll be drılled by fırst completıng a sampled borehole usıng the hollow-stem auger drıllıng procedures descrıbed ın Sectıon 3 1 1 The followıng procedures are for well ınstallatıon

1 Each borıng wıll then be reamed wıth an 8-1/4-ınch-ID hollow-stem auger a usıng center bit

2 The 8-1/4-ınch auger wıll be advanced 1 to 2 feet ınto competent bedrock and left ın place untıl well ınstallatıon begıns

3 Well completıon, whıch consısts of placıng the 4-ınch Schedule 40 polyvınyl chlorıde (PVC) slotted screen (0 010 or 0 020-ınch slot sıze dependıng on sıte condıtıons accordıng to ASTM D 5092) and 4-ınch Schedule 40 PVC well casıng, addıng the sandpack materıal, and placıng the bentonıte seal, shall be conducted ınsıde the 8-1/4-ınch-ID hollow-stem auger as the auger ıs progressıvely removed from the borehole as the ınstallatıon process contınues

4 The sand pack wıll be ınstalled through a tremıe pıpe and ıts depth measured usıng a weıghted tape or by measurıng the length of tremıe pıpe A bentonıte pellet seal wıll be slowly poured ın the well and ıts depth measured usıng a weıghted tape or by measurıng the length of tremıe pıpe The dry bentonıte pellets shall be hydrated wıth adequate tıme allowed for hydratıon The water used for hydratıon shall not contaın constıtuents that could compromıse the ıntegrıty of the well

5 Cement-bentonıte grout wıll be emplaced usıng a sıde-dıscharge tremıe pıpe ınıtıal posıtıoned approxımately 3 to 5 feet above the bentonıte seal and raısed as grout ıs added to the borehole

6 A steel protector housıng wıll then be centered over the well, and the grout wıll be allowed to cure for 24 hours After the grout has cured, a concrete well pad and a draınage port wıll be added and well development (Sectıon 3 1 4) can begın

A proposed general constructıon dıagram for an alluvıal monıtorıng well ıs presented ın Fıgure K6

3.1.4 Well Development

All monitoring wells will be developed after at least a 48-hour curing time has elapsed since installation The water generated during development will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation

Monitoring wells will be developed at least two weeks before sampling Well development will be conducted by either a submersible pump or a bottom discharge bailer, with or without a surge block. At least five times the volume of standing water in the well, sandpack, and annulus will be removed If any water is lost during drilling or completing the well, five times the volume of the lost water will be removed in addition to the previous requirement

Measurements obtained and recorded in the field will include static water levels before and after development. The pH, temperature, and conductivity of the water will also be measured before, during, and after development. The pH will be considered stabilized when three of the last five readings are within 0 1 pH units The temperature and conductivity measurements will be allowed to stabilize to within 10 percent of previous readings before the well is considered developed

3.1.5 Well Identification and Surveying

After well installation is complete, the well location, elevation of ground surface, and top of the well casing will be surveyed Well locations will be accurate to within 0 1 feet using State Planar coordinates Elevations will be surveyed to within 0 01 foot using the National Geodetic Vertical Datum of 1929

Well identification numbers, map coordinates, and elevations will be recorded in a field logbook and will be submitted to PMRMA and entered into the RMA environmental database A metal tag stamped with these data will be permanently attached to each protective casing

Monitoring well installation, groundwater sampling, and water-level measurement procedures described in this section are consistent with those developed for and used during previous investigations (HLA, 1993a and 1995b) Field personnel performing groundwater monitoring activities, depending on the level of activity required, may include a field supervisor, a safety officer, and one or more two-person field teams Equipment to be used and procedures to be followed during the sampling events are presented below

3.2 Groundwater Sampling and Water-level Measurement Procedures

The procedures for groundwater sampling and water-level measurement are described below The procedures are consistent with EPA guidance for these activities

3.2.1 Field Equipment

At the beginning of each monitoring event, the field teams will be issued field sampling kits containing field instruments (with operators' manuals), sampling equipment, and laboratory certified calibration standards Copies of the Health and Safety Program will be maintained in the field trailer Depending on the well to be sampled, the sampling equipment may include an electric submersible pump, an air-driven piston pump, a stainless-steel bailer system, an air compressor, and/or compressed air bottles

The components of each field kit will be contained within an all-weather storage locker Typical equipment that may be included in each locker is presented below

1 pH, conductivity, and dissolved oxygen meters, a complete set of spare probes, cables, and batteries for each instrument, and a flow-through cell in which to monitor groundwater parameters

2 Digital alkalinity titration kits

3 Calibration-standard solutions and detailed calibration procedure instructions for field instruments

4 Two 1-liter wash bottles and a set of two 500-milliliter (ml), two 250-ml, and two 100-ml beakers

5 A water-level measuring device

6 A 10-foot steel engineers tape

7 A roll of plastic sheeting

8 Gloves (nitrile and surgical)

9 Plastic bags

10 1/4-inch or appropriate sized nylon rope

11 A metals filtration kit (peristaltic pump, filter holder, replacement hoses, filters, 50 ml of dilute nitric acid [HNO_3] for metals preservation, and pH indicator paper)

12 A complete set of spare sample fraction containers including a set of 40-ml vials that have not been pre-preserved with hydrochloric acid (HCl)

13 A well casing volume calculation chart for 1-inch to 8-inch wells

14 Various equipment, such as marking pens, duct tape, clear tape, and tools for troubleshooting equipment

15 A 1 1 solution of sulfuric acid (H_2SO_4) for nitrate sample preservation

16 A 1 1 solution of sodium hydroxide (NaOH) for adjusting to pH greater than (>) 12 for cyanide sample preservation

17 A 1 1 solution of HCl for adjusting to pH less than (<) 2 for volatile fraction preservation

18 A detailed sampling procedure plan

Each field kit will be restocked as necessary Additional field equipment (e g , distilled water and decontamination wash basins) will be stocked as necessary by each field team It is recommended that a complete set of spare field instruments will be maintained at the onsite support facility

Data from samples collected in the field will be recorded on preprinted field data sheets and in bound field logbooks When not in use, field logbooks will be maintained in a secured area at the site support facility Logbooks will be checked in and out on a daily basis

3.2.2 Water-level Measurement Procedures

A water-level measurement program will be conducted before the initiation of each water sampling event A sufficient number of field personnel will be mobilized to ensure that water-level data are collected in a timely manner (i e , within three days) Water-level measurements and associated data are recorded on the water-level measurement form shown in Figure K7 The general procedure for obtaining water-level measurements is summarized as follows

1 Record in a bound field book the manufacturer and model of the water-level indicator used

2 Record on the water-level measurement form the well number, date, time, and initials of field personnel obtaining measurements

3 Before uncapping the well, measure and record on the water-level measurement form the photoionization detector (PID) reading in the ambient air near the well (background) Uncap the well and record on the water-level measurement form the PID reading of the headspace at the top of casing (TOC) Measure the PID reading in the breathing zone near the well Record and label the breathing zone reading in the "Comment" section of the water-level measurement form and upgrade personal protective equipment (PPE) as appropriate before obtaining further well measurements

4 Measure the length of the riser stickup from ground surface to the measuring point marked at the TOC, and record the length of the riser stickup to the nearest 0 01 foot If no mark is present, all measurements will be performed on the north side of the stickup, and a measuring point will be marked on the stickup using a permanent marker

5 Insert the water-level indicator probe until it reaches water Measure depth to water from the same measuring point marked at the TOC and record the value to the nearest 0.01 foot

6 If there is a discrepancy between the previously accepted stickup measurement and the current stickup measurement, measure and record the total depth of the well for confirmation that measurements are being performed on the correct well Total depth of each well shall be measured yearly to verify well condition.

7 Retrieve the water-level indicator probe and thoroughly rinse the cable and probe with distilled water as they are withdrawn from the well Avoid allowing rinsewater to flow into the well

8 Compare total depth, water level, and stickup measurements to previous measurements If discrepancies are observed, a second measurement will be performed and documented as such

9 Record well conditions (e g , cracked casing, missing cap, prairie dog burrows) and any other pertinent observations

10 Ensure that labels and flagging clearly indicate well location and well number

11 Police the area to ensure that equipment and materials have been retrieved, litter has been collected, and the well cap is secure

3.2.3 Groundwater Sampling Procedures

A daily schedule of field activities and prepared sample cooler will be provided to each field team Each cooler will contain sample containers, packing material, labels, chain-of-custody (COC) records, and ice Each field team will also be provided with a well information file, which will include previous water-level data, expected casing volume, and any comments generated during previous sampling events The field team will be responsible for ensuring that sample and field sampling kits are complete and that instruments and sampling equipment are clean and fully operational

Groundwater monitoring wells, in general, will be sampled in order from low to high contaminant ranking to avoid possible cross contamination of groundwater samples or wells The sampling order will be decided on the basis of historical groundwater quality data

Water sampling data are recorded for each well on the groundwater sampling form shown in Figure K8 Upon arrival at the well site, the following procedures are typically implemented

1 Uncap the well and record background, breathing zone, and casing headspace readings from the PID, as described previously for water-level measurements

2 Record well number, date, pertinent observations (e g , weather, well condition), casing diameter, screened interval, and field instrument identification numbers

3 Place a sheet of plastic on the ground surface around the well stickup for wells that will be bailed

4 Measure and record well stickup, depth to water, and total well depth to the nearest 0 01 foot Measure from the measuring point marked at the TOC and compare measured values with previous measurements, investigate and document any discrepancies Equipment used downhole to obtain water-level and total depth measurements will be decontaminated with distilled water

5 Calculate and record casing volume, compare with previously recorded casing volumes to ensure relative comparability A sheet listing casing volumes on the basis of height of the water column and well diameter will be provided to field personnel The casing volume can also be calculated using the formula $V=(0\ 0408)(D^2)h$, where D is the diameter of the well in inches and h is the height of the water column in feet

6 Calibrate field instruments for monitoring pH, temperature, conductivity, alkalinity, and dissolved oxygen (for pumped wells only) against known standards Record instrument calibration responses, times, and calibration standards used

7 Whether to pump or bail a well will be decided on the basis of the well's hydraulic characteristics In general, wells containing less than 4 gallons per casing volume will be purged and sampled by bailing and other wells will be pumped Wells that dewater when monitoring the unconfined or confined flow system and have to be resampled will be bailed for sample collection.

8 Two methods are used for purging and sampling wells, depending on whether the well is to be pumped or bailed In both cases (bailing or pumping), it is preferred that a minimum of three casing volumes be purged from the well to allow water that may have been standing in the well casing and filter pack to be removed, allowing the sample to be representative of aquifer conditions The minimum requirements are to obtain three or more consecutive stabilized parameter measurements (and no less than three casing volumes) in which each parameter measurement (pH, electrical conductivity, temperature, and dissolved oxygen) differs by no more than 10 percent from the previous parameter measurement and turbidity is less than 5 NTU

If a well is to be bailed, purge the water column from the top of the column Lower the bailer into the water slowly to minimize agitation. Monitor well parameters carefully to ensure that water standing in the well casing and filter pack is removed from the well before sampling Some wells will dewater, other wells may appear to dewater if bailed too quickly It may, therefore, be necessary to carefully monitor the well's response when bailing low-production wells to ascertain how many casing volumes can be effectively purged before sampling

If a well is to be pumped, purge the standing water column in the well from the top to the bottom of the screened interval In many cases, the pump has a higher flow capacity than the well, and the well will appear to dewater Exercise care to reduce the pump flow rate so that it equals the well's recharge potential On occasion, it may be necessary to reposition the pump to progressively deeper locations in the well After purging three casing volumes from the well and after parameter measurements have stabilized, the optimal sampling depth should be at the middle of the well's screened interval Purge water from all pumped wells will pass through an in-line flow cell fitted with the required instrument probes The flow cell allows for real-time monitoring of sample parameters (pH, electrical conductivity, temperature, and dissolved oxygen) as well as the visual characteristics of the water passing through the cell

9 Collect a portion of the initial water purged from the well and record the following information sample parameter values (pH, temperature, electrical conductivity, dissolved oxygen, and turbidity), time, air monitoring instrument readings, pumping rate, and purged volume removed Similarly, document this information as each casing volume is removed Purge water will be appropriately managed onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

a Following the manufacturer's instructions, calibrate the turbidimeter using the supplied standards and record the readings in the logbook. The ambient air temperature should be between 10°C and 40°C for calibration and measurement.

b Using a clean 500-milliliter (ml) beaker, obtain a sample (50 to 250 ml) of groundwater from the discharge hose of the development/purge pump after each ½ bore volume has been removed

c Set the sample aside for a few minutes to allow any rapidly settling coarse particulates to settle and to allow any entrained gases to escape However, the sample must not be set aside so long as to let any fines in the water settle out

d Decant some of the sample from the 500-ml beaker into a clean, scratch-free sample cuvette, and then pour the sample out to waste This is a rinse step before the actual measurement is made e   Refill the sample cuvette with groundwater from the beaker, being careful to pour the sample down the side to avoid creating bubbles

f   Cap the cuvette and wipe off the sides with a clean, lint-free cloth until the cuvette is dry and smudge-free   Handle the cuvette only by the cap, being careful not to touch the sides

g   Insert the sample cuvette into the turbidimeter and select a standard with a value that is close to what you suspect the sample value to be

h.   Be sure the sample and standard chamber lids are fully closed and the cuvettes are seated at the bottom of the chamber

i   Adjust the standardization dial to the setting that is equal to the value of the standard

j   Read the value of turbidity for the groundwater sample and record it in the field logbook.

k.   Restandardize the turbidimeter before another sample is measured or between duplicate measurements   Repeat steps 1 through 11 for each sample

10   Remove a minimum of three casing volumes from each well before sampling   However, do not collect samples until sample parameters from three consecutive casing volumes have stabilized   Wells that dewater before the removal of three casing volumes or stabilization are exempt from these requirements   If the well dewaters, collect samples based on their previously determined priority (see item 14), within 24 hours following well dewatering

11   Perform an alkalinity titration on a portion of the well water collected after the fifth or final casing volume has been removed   Record titration values required to reach colorimetric end points along with associated pH values (measured simultaneously), in accordance with the Quality Assurance Management Plan (QAMP)

12   Measure and record sample parameters immediately before sample collection   Complete sample labels to include the following information   well number, time, date, and sampler's signature

13   If the well is pumped, collect samples directly from a sampling spigot on the pump discharge line at low flow rates to avoid agitating samples and possibly degassing volatiles   Obtain these samples from the spigot that is plumbed into the discharge line upstream from the in-line flow cell   If the well is bailed, collect samples from bottom-decanting bailers

14   Use sample bottles supplied certified clean by the vendor and do not rinse them with well water before filling   In general, add preservatives to the appropriate sample bottles before sampling   Additional preservatives may be added after sample bottles are filled as described in item 15   The sample bottles listed in parenthesis may change depending on specific laboratory requirements   Samples fractions will normally be filled in the following order

a Analyses not retained on the prior sampling round

b Volatile organic aromatics (VOAs) (two 40-ml amber glass bottles)
Volatile organohalogens (VOHs) (two 40-ml amber glass bottles)
Volatile hydrocarbons (VHCs) (two 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

c Dibromochloropropane (DBCP) (three 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

d Organochlorine pesticides (OCPs) (one 1-liter amber glass bottle)

e Organophosphorus pesticides (OPPs) (one 1-liter amber glass bottle)

f Organophosphorus compounds (OPCs) (one 1-liter amber glass bottle)

g Organosulfur compounds (OSCs) (one 1-liter amber glass bottle)

h Agent degradation products (isopropylmethyl phosphonic acid [IMPA] and thiodyglycol) (four 1-liter amber glass bottles)
Note for wells that dewater or have a low production capacity, collect one 1-liter bottle for each compound (IMPA and thiodyglycol) Fill the remaining two bottles after all other sample fractions have been collected

i Inductively coupled argon plasma (ICP) metals and cations (one 500-ml plastic container)
Arsenic (one 500-ml plastic container)
Mercury (one 500-ml plastic container)

j Cyanide (one 1-liter plastic container)
Anions (one 4-ounce plastic container)
Nitrate/nitrite (one 4-ounce plastic container)

k. Volatiles by gas chromatography gas/mass spectrometry (GC/MS) (two 40-ml amber glass bottles)
Note fill bottles completely to ensure that there are no air bubbles

l Semivolatiles by GC/MS (one 1-liter amber glass bottle)
Note fill bottle completely to ensure that there are no air bubbles

m N-nitrosodimethylamine (NDMA) by gas chromatography/chemiluminescence detection (GCCD) (one 1-liter amber glass bottle)

Fill the VOA, VOH, VHC, DBCP, and GC/MS sample fractions completely ensuring that there are no air bubbles Fill the remaining sample fractions to a minimum of 90 percent capacity

15 Before sample containers are filled, add preservatives to the following sample fraction bottles as required by the laboratory

- VOA, VOH, VHC, and GC/MS volatile fractions Analyses for the volatile fractions will require seven (or nine if GC/MS analyses are being performed) 40-ml bottles prepreserved with 250 to 500 microliters (μl) of concentrated HCl One of the 40-ml bottles will be used by the field team to check for effervescence and for proper preservation of pH <2 If effervescence is readily apparent as the first pre-preserved

40-ml sample bottle is being filled, then HCl will not be used as a preservative The laboratory will be informed that the volatile fractions were not preserved, and seven-day turn-around-time will be required for analyses If effervescence is not apparent, but the pH of the sacrificial sample is greater than 2, the field team will add 100 μ/l of HCl to the sacrificial sample bottle and recheck for a pH of <2 The process will be repeated until a pH of <2 has been achieved The same number of drops of HCl will be added to each of the six or eight remaining 40-ml sample bottles before they are filled

- Nitrate/nitrite fraction Analyses for the nitrate/nitrite fraction will require one 4-ounce plastic bottle pre-preserved with 0 5 ml of 1 1 H_2SO_4 Field samplers will pour a small amount of the groundwater sample onto pH paper to check for a pH of <2 If needed, 200 μl of H_2SO_4 will be added to the nitrate sample bottle The pH will be checked again by the same procedure until a pH of <2 is measured

- Cyanide fraction Analyses for the cyanide fractions will require one 1-liter amber glass bottle prepreserved with 4-ml of 1 1 NaOH The cyanide fraction will be checked by the field team to ensure that the sample has been preserved to a pH >12 If the pH needs to be adjusted, the field team will add 200 μl of 1 1 NaOH The pH will be checked again and the procedure will be repeated if necessary until a pH of >12 is achieved

- ICP metals and cations, arsenic, and mercury fractions Analyses for the dissolved metals fractions will require three 500-ml plastic bottles preserved with 2 ml 1 1 HNO_3 If the samples are collected by pumping, the pump will be stopped and a 0 45-micron nitrocellulose or cellulose acetate in-line filter will be attached to the discharge line The pump will be restarted and the first 50 to 100 ml of filtrate will be discarded to minimize possible contamination Samples of the filtered water will then be collected in designated containers prepreserved with HNO_3 to a pH of <2 If the samples are obtained by the bailing technique, field filtration equipment will be available The filtering device will contain a filter support of plastic or Teflon® with a disposable ungridded 0 45-micron nitrocellulose or cellulose acetate filter The unfiltered groundwater will be poured from the bailer into a clean container for ease of use The unfiltered water will be pumped from the clean container through the filtering device To minimize possible contamination, the first 50 to 100 ml of filtrate will be discarded Samples of the filtered water will then be collected in designated containers prepreserved with HNO_3 to a pH of <2 The pH of the samples will be checked by pouring a small amount of the sample onto the pH indicator paper If the pH needs to be adjusted, the field team will add 200 μl of 1 1 HNO_3 The pH will be checked again and the procedure will be repeated until a pH of <2 is achieved

16 Seal sample fractions inside plastic bags and place in the cooler under ice immediately upon filling Record sampling technique, sample depth, and fractions collected on field data sheets, COC records, and the sample tag

17 The field team will sign and date field data sheets after ensuring that they have been completed and that the information has also been recorded in the field logbook. The field team will complete the COC record when relinquishing custody of the samples

18 Thoroughly decontaminate sampling equipment at the well site or at a decontamination pad immediately after sampling Bailers and sample filtration equipment will be cleaned in a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent) and triple rinsed with distilled water

To decontaminate pumps used at wells identified as requiring low-level decontamination, clean the inside of the pump by running a volume of distilled water equal to three times the volume of the pump and hoses through the line Clean the outside of the pump and hose by triple rinsing with distilled water as the pump and hose are withdrawn from the well

After sampling wells identified as requiring high-level decontamination, decontaminate the outside of the sample pumps by scrubbing with a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent), steam cleaning using PMRMA-approved water or tap water, and triple rinsing using distilled water To decontaminate the interior surface of tubing and pumps, run a solution of PMRMA-approved water or tap water and detergent (Liquinox® or equivalent) through the pump This will be followed by running a volume of distilled water equal to six times the volume of the pump and tubing through the line

Wrap and store decontaminated equipment in clean plastic sheeting Decontamination water will be managed either onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

19 The final activity at the well will be to remove all sampling equipment and debris from the area

In addition to these procedures, the following guidelines will be used to mitigate problems that could adversely affect sample integrity

1 Avoid agitation of VOC samples collected from either pumps or bailers that will reduce air stripping of volatiles and allow for the collection of more representative samples

2 Sampling equipment, including pumps, hoses, bailers, and rope, should contact only the well or a clean plastic surface Equipment should never contact the ground or any other surface that has the potential to transmit contaminants This equipment should always be encased or wrapped in clean plastic during transport

3 Change gloves frequently when handling downhole instruments Always change gloves after working with compressors or other equipment before sampling New gloves will be worn at the start of well purging and changed immediately before sample collection

4 When working with downhole equipment (e g , bailers, pumps) either decontaminate tools after use or decontaminate the equipment before re-entering the well

5 Avoid splashing waste or dirt on plastic sheeting If the sheeting becomes dirty, replace with clean plastic sheeting and dispose of the dirty sheeting in the proper manner

6 Vent gasoline engines downwind at least 30 feet from the well Gasoline tanks should never be filled in the field Keep all sampling equipment away from areas where gasoline spills or leaks may occur

7 Replace all dropped bottles, lids, or septa with counterparts from the kit Avoid contact with edges of lids or inside surfaces of sample bottles

8 Ensure that septa and Teflon® cap liners are in good condition Check that septa are oriented with Teflon® side down When full, septa bottles should be transported upside down.

9 Avoid sampling when precipitation or windblown dust may contaminate the sample

10 Do not dip pH indicator paper into acidified samples, check by pouring a small amount of sample on the paper Volatile fractions will be checked for proper preservation by collecting one additional sacrificial sample

11 To avoid unnecessary agitation of the water column, lower bailers slowly into the well A knot tied in the bailing rope approximately 2 feet above the static water level will serve as a marker below which the bailer will be lowered very slowly

12 Ensure that a stainless-steel protector is emplaced over the well head, on 2-inch-diameter wells, before bailing This protector will prevent the bailing rope from cutting into the top edge of the PVC casing

13 When using a disposable 0 45-micron filter, discard the entire assembly after filtering, disposable filters are not reused Also, discard the silicon rubber tubing used to connect the filter capsule to the spigot.

14 Fill sample bottles from a pump discharge line located upstream of the flow cell

15 When abrupt increases are observed in dissolved oxygen readings, a bailer will be used in place of the pump to sample the well When pumps malfunction, they may aerate samples and should be repaired immediately

16 Check documentation to ensure that corrections are properly recorded Also, check that all signatures and dates on forms are present and correct

17 In the field, field team members will check forms to ensure that they are legible and correct

4.0 QUALITY CONTROL SAMPLES

Investigative samples will be collected as detailed in Section 3 0 to provide data relevant to the objectives of this task. Concurrent with investigative sample collection, QC samples will be collected to evaluate the accuracy, precision, completeness, reproducibility, and representativeness of all data and observations relevant to field activities QC sample collection procedures are discussed below and detailed in the QAMP (HLA, 1993b) QC samples to be collected during field activities will include duplicate samples, rinse blanks, trip blanks, and field blanks QC samples will be collected according to procedures used for previous RMA programs, as described below

4.1 Duplicate Samples

Duplicate samples are groundwater samples collected in the identical fashion as the investigative sample Duplicate samples will be analyzed for the same analytical parameters as the related investigative samples To maximize the representativeness of duplicates, duplicates will be collected in parallel with the investigative samples For example, volatiles for the investigative and duplicate samples will be collected first as split samples, followed by those for the semivolatiles, and so forth Standard PMRMA Class 1-certified methods use a duplicate high spike in standard water to monitor method performance Native matrix spikes and matrix spike duplicates will be used if standard method protocols require modification to meet program data quality objectives (DQOs) Duplicate samples will generally be collected in an amount equal to 10 percent of the investigative samples

4.2 Rinse Blanks

Rinse blanks are samples obtained by running distilled water through nondedicated or nondisposal sample collection equipment after decontamination and collecting it in the appropriate sample containers for analysis Rinse blanks will be analyzed for the same analytical parameters as the related investigative samples. The rinse blank will be obtained by running distilled water through sample collection equipment (bailer or pump) after decontamination and placing the sample in the appropriate container Rinse blanks will be handled, transported, and analyzed in the same manner as investigative samples collected that day At a minimum, one rinse blank will be collected at the beginning and the end of each sampling round for each pump used in sampling   Generally, rinse blanks will be collected in an amount equal to 5 percent of the investigative samples   If dedicated or disposal equipment is used for groundwater sampling, no rinse blanks will be required

Samples of the distilled water used for collection of the rinse blanks will also be collected   This represents the same distilled water used for decontamination. These samples will be handled and analyzed similarly to rinse blanks   Sample fractions will be filled in the field office   Generally, distilled water blanks will be collected in an amount equal to 10 percent of the number of rinse blanks

4.3 Trip Blanks

Trip blanks are prepared by the laboratory before the sampling event by collecting analyte-free water in the actual sample bottles   Trip blanks are kept with the investigative samples throughout the sampling event, then packaged for shipment to the laboratory for analysis with the investigative samples   Trip blanks will be prepared by the laboratory to be analyzed for volatile organic aromatic compounds and volatile organic halogenated compounds   At no time after its preparation will a trip blank container be opened before it is returned to the laboratory   Generally, trip blanks will be prepared in an amount equal to 5 percent of the investigative samples

4.4 Field Blanks

Field blanks are samples prepared by collecting distilled water into the appropriate sample containers at the location where the investigative sample is being collected   Field blanks will be prepared to be analyzed for the same analytical parameters as the related investigative samples

When filled, the field blank sample will remain uncapped during collection of the investigative sample   Generally, field blanks will be prepared in an amount equal to 2 5 percent of the investigative samples

5.0 DECONTAMINATION PROCEDURES

Equipment that comes in contact with potentially contaminated groundwater, including equipment used for well installation, soil sampling, water sampling, measuring water levels, and sample preparation, will be decontaminated before and after each use   Decontamination water used will generally be PMRMA-approved or distilled water   Tap water may be used instead of PMRMA-approved water for use in steam cleaning and detergent solutions provided that deionized or distilled water is used afterward to rinse equipment   PMRMA-approved water consists of the potable water supplied to RMA that is treated with an activated carbon treatment unit. Decontamination will consist of combinations of steam cleaning and/or detergent solution (Liquinox® or equivalent) wash, water rinse, and distilled water rinse   Detergent solution is prepared by mixing approximately 1 teaspoon of detergent (Liquinox® or equivalent) per 5 gallons of PMRMA-approved water or tap water   This section details decontamination procedures as well as types of equipment to be decontaminated

5.1 Drilling Equipment, Sampling Equipment, and Well Completion Materials

Equipment used for drilling, soil sampling, and well installation will be decontaminated before initiating drilling operations   This initial decontamination will consist of steam cleaning with PMRMA-approved water   In addition, well installation materials, including surface casings, well casings and screens, protector casings, and fittings, will also be decontaminated before use   These materials will be steam cleaned, allowed to air dry, wrapped in clean polyethylene sheeting, and stored in a designated onpost area until they are needed   If necessary, clean polybutyrate tubes for soil sampling will be provided by the manufacturer and will not require further decontamination before use

During drilling operations, downhole equipment will be thoroughly decontaminated after completing each boring or well   Field decontamination will be accomplished using a trailer-mounted portable steam cleaner and a clean water tank filled with PMRMA-approved water   Field decontamination will be performed in such a manner that all rinsewater is containerized   Rinsewater will be pumped into truck-mounted storage tanks and managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation.

Well installation materials will remain wrapped in clean polyethylene sheeting until immediately before use Care will be taken to ensure that materials do not contact the ground surface or potentially contaminated equipment Before placement, materials will be visually inspected for indications of contamination and, if necessary, steam cleaned in the field using the field decontamination procedures described above Clean gloves will be worn when handling unwrapped well installation materials

Upon completion of the drilling program, equipment will be given a final decontamination rinse before leaving RMA

5.2 Well Development Equipment

Equipment used for well development will be decontaminated before and after use at each well This procedure will include decontamination of pumps, purging bailers, and downhole tubing

5.3 Water-level Measurement Equipment

The electrical (sounding) tape or steel tape used to measure water levels will be decontaminated to avoid cross contamination between wells Decontamination will consist of rinsing the tape with distilled water as it is being removed from the well

5.4 Groundwater Sampling Equipment

Either dedicated or nondedicated sampling equipment will be used for purging and sample collection If nondedicated groundwater sampling equipment is used, it will be appropriately decontaminated after each well is sampled

Probes on the pH, conductivity, and dissolved oxygen meters used to measure field parameters will be cleaned by rinsing with distilled water   After each round of sampling is completed, all non-dedicated sampling equipment will undergo decontamination.

6.0 SAMPLE DOCUMENTATION CUSTODY AND SHIPPING PROCEDURES

Sample and document custody procedures applicable to the CAMU Groundwater Monitoring Program are summarized in the following subsections Samples collected during field activities will be delivered on a daily basis to the PMRMA Receiving Office, Building 618, for shipping by the Program Manager Support Division (PMSD) to one or more laboratories contracted by the PMRMA Laboratory Support Division or carried to PMRMA's onsite laboratory for analyses of Diisopropylmethyl phosphonate (DIMP) and NDMA

6.1 Field Documentation

Field logbooks (bound field survey books) will be used to record data collection activities performed onsite Field logbooks will be assigned to field personnel for each activity and will remain in the custody of field personnel during sampling activities Each logbook will be identified by a project-specific number The cover of each logbook will bear the following information

- Name of person or organization to whom the book is assigned
- Book number
- Project name
- Start date
- End date

At the beginning of each day, the date, start time, weather conditions, field personnel present, level of PPE being used, and name of the person making the entry will be recorded The names of visitors and the purpose of their visit will also be recorded All information pertinent to a field survey and/or sampling event will be recorded in the field logbook. If appropriate, entries in the logbook will include the following information

- Name and title of author, date and time of entry, and physical/environmental conditions during field activity
- Location of sampling or field activity

- Name(s) and title(s) of field crew
- Name(s) and title(s) of site visitors
- Type of media sampled or measured
- Sample collection or measurement method
- Number and volume of samples(s) collected
- Description of measuring reference points
- Date and time of sample collection
- Sample identification numbers(s)
- Sample preservative, if applicable
- Sample distribution (e g , laboratory)
- References for all maps and photographs of the sampling site(s)
- Field observations and comments
- Field measurements recorded (e g , pH, electrical conductivity [EC], PID)
- Sample documentation, including dates and methods of sample shipment

Information included on field data sheets or COC records may not necessarily be repeated in the logbook. By the end of each day, samples should be brought back to the sample handling trailer for packaging The completed the COC records field logbooks and field data sheets will be reviewed for errors and omissions and submitted to PMRMA

6.2 Sample Classification, Handling, and Shipping

Sample classification is necessary to ensure the protection of personnel involved in the shipment of samples and to maintain the integrity of the samples When sent by common carrier, the packaging, labeling, and shipping of hazardous materials is regulated by the U S Department of Transportation (DOT)

PMSD will be contacted no later than 9 00 a.m daily or as required for assignment of courier air bill numbers Sample shipments to each laboratory will receive a unique airbill number

Samples for volatile analyses will be collected and shipped with zero headspace Samples collected for other analyses will be shipped with approximately 10 percent air space so that the container is not full at 130 degrees Fahrenheit (°F) Glass containers used for all types of analyses will be wrapped in bubble wrap and placed inside a DOT-approved shipping container, such as a Coleman Sample Manager®, and packed to prevent breakage Sample shipments will be preserved by placing sealed plastic bags of wet ice and/or cooler packs around the sample containers Any remaining space will be filled with bubble wrap or vermiculite Samples will be delivered to the PMRMA Receiving Office, Building 618, until approximately 6 00 p m for shipping to the contract laboratory(ies) for analysis

The COC record for each sample shipment will be enclosed in a sealed, waterproof envelope attached to the inside of the cooler lid and delivered to the PMRMA Receiving Office The Quality Assurance Coordinator (QAC) (or designated representative) will contact the PMRMA Receiving Office daily to inform them of the incoming samples, arrival time, and special handling or analytical procedures required

Required sample containers, sample preservation methods, and maximum holding times for each sample type are summarized in the QAMP (HLA, 1993b) Containers will be obtained from the PMSD supply office, based on availability, and supplied to field personnel before sampling

6.3 Sample Identification and Labeling

Sample labels and COC records will be provided to sampling personnel by the QAC Labels will be attached to each bottle in which a sample is collected If labels are lost, voided, or damaged, the sample information will be noted in the appropriate field logbook.

Each sample will be identified by a separate sample label and associated tag number The information generally recorded on the label may include, but not be limited to, the following information

- Label tag number
- Site identification number
- PMRMA-approved site type code
- Date a six-digit number indicating the day, month, and year of collection
- Time a four-digit number indicating the 24-hour clock time of collection
- Media type the type of sample (e g , groundwater)
- Sample depth
- Sampler's signature
- Preservative the type of preservative used, if required
- Analysis the type of analysis requested
- The PMRMA-approved sampling technique used during collection

An example of a sample label to be used during the program is shown in Figure K9

Custody seals (evidence tape) will be used to preserve the integrity of the samples in the regular nonlocking shipping containers from the time of collection until they are opened in the laboratory Field personnel will assist the RMA sample shipping custodian with custody seals The seal will be attached in such a way that it will break when the sample shipping container is opened Samples shipped in the Coleman Sample Manager® or equivalent cooler will be sealed using wire and lead seals The seals will carry the following information

- PMRMA sample shipping custodian's initials
- Date and time of sealing

Locking shipping containers will not require the use of custody seals

6.4 Chain-of-Custody Records

To establish the documentation necessary to trace sample possession from the time of sample collection at RMA through sample analysis, a COC record will be completed and will accompany every sample This record will document sample custody transfer from the sampler, to other sampling team members (if necessary), to the laboratory, and back to RMA for disposal Unused or excess samples returned to RMA will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of operation

The COC process will be maintained by PMRMA using a commercial shipper for shipment of bottles to the site and shipment of samples back to the laboratory The PMRMA sample shipping custodian will arrange the shipping, prepare the courier airbill form, write the courier airbill number on the COC record, and sign a separate cooler COC record and the courier airbill form

The COC record generally contains the following information

- Sampling program identification including contract code and delivery order number
- List of sampling team members
- Label identification number
- Date of sample bottle preparation and shipment
- Signature of sampler or bottle preparer
- Date and time of sample collection
- Sample location and depth
- Analytical laboratory identification
- Medium type and/or PMRMA-approved file type
- Airbill number
- Sample preservation
- Type of requested analysis
- Signatures of persons involved in the chain of sample possession
- Inclusive dates of possession
- PMRMA-approved sampling technique and site type

The laboratory portion of the COC record will be completed by laboratory personnel and typically contains the following information

- Date of sample receipt by the laboratory
- Name of person receiving the sample at the laboratory
- Sample condition and temperature upon receipt at the laboratory

Samples will be appropriately packaged for shipment and will be dispatched to the laboratory for analysis with a separate COC record accompanying each shipment. The method of shipment, courier name(s), if any, and other pertinent information should be entered in the remarks section of the COC record An example COC record that will be used for water samples collected during the program is presented in Figure K10

Each COC record consists of three sheets of pressure-sensitive paper (white, yellow, and pink) After the PMRMA shipping custodian at Building 618 signs the COC, additional copies of the original will be made for the Logistic Branch of the Army and the Laboratory Support Division. The two colored backing sheets of the COC will be removed, and the sample container with the original white COC record inside the lid will be sealed by the Army The yellow original will be retained in the sampling files, and the pink original will be retained by PMRMA

After the field COC record is signed by the laboratory, the laboratory will initiate an internal COC record to track the sample through analysis The original COC record will be retained in the laboratory's files, and when required, a photocopy of the original COC record will accompany the unused portion of the sample back to RMA for final disposal Under no circumstances is the laboratory to send extracted or spent samples to RMA for storage

6.5 Corrections to Documentation

Unless otherwise prohibited, data recorded in field logbooks, sample labels, and COC records will be completed with waterproof ink. None of the accountable, serialized documents will be destroyed or discarded, even if the documents are illegible or contain inaccuracies that require a replacement document.

Errors on field documents will be corrected by drawing a line through the error and entering the correct information Errors on a field document should be corrected by the person who made the original entry, and the erroneous information should not be obliterated Corrections to documentation will be initialed and dated

7.0 LABORATORY ANALYSES

Laboratory analyses of samples for evaluating chemical properties and constituents will be performed according to the PMRMA certification program protocol for investigative samples The Army anticipates that certified and uncertified laboratory analytical methods will be used during the analyses of groundwater samples Approximately 18 investigative groundwater samples will be collected quarterly Additionally, QA/QC groundwater samples will be collected and analyzed for the landfill CAMU areal configuration pre-operational monitoring program Generally, samples for GC/MS conformational analyses will be collected in an amount equal to 10 percent of the investigative samples

During the pre-operational monitoring period, groundwater samples will be analyzed using PMRMA-certified methods for the list of 61 target analytes provided in Table K3 Also provided in the table are the methods of analysis applicable to each target analyte Noncertified analyses will be performed on groundwater samples by the field sampling team for temperature, conductivity, pH, alkalinity, dissolved oxygen, and turbidity

One or more analytical laboratories may be used to perform analyses for specific target compounds One certified reporting limit (CRL), described in the QAMP (HLA, 1993b), will be established for each target compound This will eliminate the possibility of more than one CRL being reported for any specific target compound

8.0 DATA EVALUATION AND RECORD KEEPING

8.1 Data Evaluation Including Statistical Analysis of Results

Water-level data collected during each sampling event and other available data, if applicable, will be used to evaluate the groundwater flow patterns in the landfill area Water-level data will be plotted in conjunction with the annual RMA GMP results

Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to identify the background water quality conditions within the landfill CAMU areal configuration, including the CFS and the UFS Statistical methods will be used to evaluate the operational closure and postclosure monitoring data using standard EPA guidance on statistical analysis of groundwater monitoring data (EPA, 1989, 1992) as discussed in Section 2 1 After completion of the pre-operational monitoring period, a specific procedure for evaluation of the operation groundwater monitoring data will be developed by the Army and submitted for CDPHE approval as part of the Revised CAMU Groundwater Monitoring Program

8.2 Record Keeping and Reporting

The Army will keep records of the analyses and associated groundwater surface elevation throughout the closure and post-closure monitoring period Groundwater monitoring information will be reported to CDPHE on a frequency that will be established in the final groundwater monitoring plan

9.0 ACRONYMS

Army	U S Department of the Army
bgs	Below ground surface
C	Downgradient concentration of interest
C_o	Source concentration
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CFS	Confined flow system
COC	Chain of Custody
CRL	Certified Reporting Limit
CVAA	Cold vapor atomic adsorption
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
Denver Fm	Denver Formation
DIMP	Diisopropylmethyl phosphonate
DQO	Data quality objectives
DOT	U S Department of Transportation
Ebasco	Ebasco Services, Inc
EC	Electrical conductivity
EPA	U S Environmental Protection Agency
ESE	Environmental Science and Engineering, Inc
FFA	Federal Facilities Agreement
GCCD	Gas chromatography/chemiluminescence detector
GC/CON	Gas chromatography/conductivity detector
GC/ECD	Gas chromatography/electron capture detector

GC/FID	Gas chromatography/flame ionization detector
GC/FPD	Gas chromatography/flame photometric detector
GC/MS	Gas chromatography/mass spectrometry
GC/PID	Gas chromatography/photoionization detector
GC/NPD	Gas chromatography/nitrogen phosphorous detector
GMP	Groundwater Monitoring Program
HCl	Hydrochloric acid
HLA	Harding Lawson Associates
HNO_3	Nitric acid
HPLC	High phase liquid chromatography
H_2SO_4	Sulfuric acid
ICP	Inductively coupled argon plasma screen
ID	Inner diameter
IMPA	Isopropylmethylphosphonic acid
IONCHROM	Ion chromatography
ISE	Ion selective electrode
MEMO	Monitoring Efficiency Model
MIBK	Methyl isobutyl ketone
MKE	Morrison-Knudsen Engineers, Inc
ml	Milliliter
NDMA	N-nitrosodimethylamine
NaOH	Sodium hydroxide
OCP	Organochlorine pesticides
OPP	Organophosphorus pesticides
OPC	Organophosphorus compounds
OSC	Organosulphur compounds
PID	Photoionization detector

PMRMA	Program Manager for Rocky Mountain Arsenal
PMSD	Program Manager Support Division
PPE	Personal protective equipment
PVC	Polyvinylchloride
QAC	Quality Assurance Coordinator
QAMP	Quality Assurance Management Plan
QA/QC	Quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RMA	Rocky Mountain Arsenal
ROD	Record of Decision
SPDA	South Plants Decontamination Area
State	State of Colorado
TOC	Top of casing
UFS	Unconfined flow system
USCS	Unified Soil Classification System
USGS	U S Geological Survey
UXO	Unexploded ordnance
VHC	Volatile hydrocarbons
VOA	Volatile organic aromatics
VOC	Volatile organic compounds
VOH	Volatile organic halogens
°F	Degrees Fahrenheit
μg/l	Micrograms per liter
μl	Microliters

10.0 REFERENCES

Ebasco Services, Inc 1989 *Draft final water remedial investigation report, Rocky Mountain Arsenal, Commerce City, Colorado*, March

——— 1988 *Final phase I contamination assessment report site 26-1 Deep disposal well and chemical sewers, Rocky Mountain Arsenal, Adams County, Colorado*, March.

Environmental Science and Engineering, Inc 1988 *Final Phase I contamination assessment report site 26-1 Deep disposal well and chemical sewers, Rocky Mountain Arsenal, Adams County, Colorado* March.

Harding Lawson Associates 1993a *Final work plan for the groundwater monitoring program* Rocky Mountain Arsenal, Commerce City, Colorado Task 92-5, March

——— 1993b *Final quality assurance management plan for the Harding Lawson Associates Program* Rocky Mountain Arsenal, Commerce City, Colorado March

——— 1995a. *Final phase II groundwater data evaluation technical report* Rocky Mountain Arsenal, Commerce City, Colorado September

——— 1995b *Groundwater monitoring program groundwater monitoring report for 1993* Rocky Mountain Arsenal, Commerce City, Colorado March 24

——— 1995c *Draft final work plan for the hydrogeologic and geotechnical program* Rocky Mountain Arsenal, Commerce City, Colorado October

May, J 1982 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado*, Technical Report G2-82-6, July

Morrison-Knudsen Engineers, Inc 1988 *Geology of the RMA, Adams County, Colorado*, January

U S Environmental Protection Agency 1989 *Statistical analysis of ground-water monitoring data at RCRA facilities, interim final guidance* Office of Solid Waste, Washington, D C

——— 1992 *Statistical analysis of ground-water monitoring data at RCRA facilities, addendum to interim final guidance* Office of Solid Waste, Washington, D C

United States Geological Survey 1995 *Final groundwater monitoring program task plan 1995* Rocky Mountain Arsenal September

Wilson, C R , C M Einberger, R L Jackson, and R.B Mercer 1992 *Design of groundwater monitoring networks using the monitoring efficiency model (MEMO)* Ground Water 30(6) 965-970

Table K1: 1995 RMA Sitewide Groundwater Monitoring Program Monitoring Wells Located Near the Landfill Area

Water-Level Monitoring Wells

Section	Number of Wells	Well Designation–Unconfined Flow System
25	37	001, 003, 004, 008, 011, 012*, 015, 018, 022, 023, 025, 026, 028, 030, 031, 032, 033, 035, 038, 039*, 041, 042, 043, 044, 046, 047, 048, 049, 051, 052, 054, 055, 056, 057, 058, 059, 062,
Eastern 26	11	051, 037, 074, 123, 124, 143, 155, 158, 159, 164, 170

Section	Number of Wells	Well Designation–Confined Flow System
25	14	007, 009, 010, 013, 014, 016, 017, 019, 020, 021, 024, 029*, 034, 037
Eastern 26	5	055, 075, 144, 150, 156*

Water-Quality Monitoring Wells

Section	Number of Wells	Well Designation–Unconfined Flow System
25	0	none
Eastern 26	4	073, 155, 158, 170

Section	Number of Wells	Well Designation–Confined Flow System
25	0	none
Eastern 26	0	none

Source United States Geological Survey, 1995

* Flow system designation — unknown.

Table K2: Proposed CAMU Groundwater Monitoring Program Monitoring Well Networks

Well Number	Flow System Designation	Gradient Direction
Proposed Monitoring Well Network for the Background Monitoring Period		
25003	UFS	Downgradient
25008	UFS	Downgradient
25015	UFS	Downgradient
25022	UFS	Upgradient
25028	UFS	Downgradient
25031	UFS	Downgradient
25033	UFS	Downgradient
25035*	UFS	Downgradient
26073	UFS	Downgradient
26097	UFS	Downgradient
26123	UFS	Downgradient
26143	UFS	Downgradient
26155	UFS	Downgradient
26159	UFS	Upgradient
(plus 4 new wells)	UFS	1 upgradient and 3 downgradient
Proposed Monitoring Well Network for the Operational Monitoring Period		
25003	UFS	Downgradient
25015	UFS	Downgradient
25022	UFS	Upgradient
25028	UFS	Downgradient
25031	UFS	Downgradient
25033	UFS	Downgradient
25035*	UFS	Downgradient
26073	UFS	Downgradient
26123	UFS	Downgradient
26155	UFS	Downgradient
26159	UFS	Upgradient
(plus 4 new wells)	UFS	1 upgradient and 3 downgradient

The monitoring well network for the closure and post-closure monitoring period will be developed after groundwater data are available from the operational monitoring period

CAMU Corrective Action Management Unit
UFS Unconfined flow system

* Well number 25035 is dry periodically and will be sampled only when sufficient water is available

Table K3: Background Monitoring Period Analyte List

Agent Products by HPLC
Thiodiglycol

Agent Products by IONCHROM
Isopropylmethylphosphonic acid

Metals by ICP
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Zinc

Organophosphorus Compounds by GC/FPD
Diisopropylmethyl phosphonate (DIMP)

Semivolatile Organic Compounds by GC/MS*
1,4-Oxathiane
2,2′-bis(Para-chorophenyl)-
1,1-dichloroethane
2,2′-bis(Para-chlorophenyl)-
1,1,1-trichloroethane
Aldrin
Atrazine
Chlordane
Dibromochloropropane
Dicyclopentadiene
Dieldrin
Diisopropylmethyl phosphonate
Dimethylmethyl phosphonate
Dithiane
Endrin
Hexachlorocyclopentadiene
Isodrin
Malathion
p-Chlorophenylmethyl sulfide
p-Chlorophenylmethyl sulfone
p-Chlorophenylmethyl sulfoxide
Parathion
Supona
Vapona

Organochlorine Pesticides by GC/ECD
2,2′-bis(Para-chlorophenyl)-
1,1-dichloroethane
2,2′-bis(Para-chlorophenyl)-
1,1,1-trichloroethane
Aldrin
Chlordane
Dieldrin
Endrin
Hexachlorocyclopentadiene
Isodrin

Organophosphorus Pesticides by GC/NPD
Atrazine
Malathion
Parathion
Supona
Vapona

Organosulphur Compounds by GC/FPD
1,4-Oxathiane
Benzothiazole
p-Chlorophenylmethyl sulfide
p-Chlorophenylmethyl sulfone
p-Chlorophenylmethyl sulfoxide
Dimethyldisulfide
Dithiane

Volatile Aromatic Organic Compounds by GC/PID
Benzene
Ethylbenzene
Toluene
m-Xylene
o- and p-Xylene

Volatile Halogentated Organic Compounds by GC/CON
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
1,3-Dichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Carbon tetrachloride

Table K3 (continued)

Volatile Halogentated Organic Compounds by GC/CON (continued)
Chlorobenzene
Chloroform
Methylene chloride
Tetrachloroethylene
Trichloroethylene

Volatile Hydrocarbon Compounds by GC/FID
Bicycloheptadiene
Dicyclopentadiene (DCPD)
Methylisobutyl ketone (MIBK)

Mercury by CVAA

Cyanide by Colorimetric

Anions by IONCHROM
Chloride
Sulfate

Cations by ICP
Calcium
Magnesium
Sodium
Potassium

Fluoride by ISE

Other Organics by GC/ECD
Dibromochloropropane

N-nitrosodimethylamine by GCCD

Volatile Organic Compounds by GC/MS*
1,1-Dichloroethane
1,1-Dichloroethylene
1,2-Dichloroethane
cis-1,2-Dichloroethylene
trans-1,2-Dichloroethylene
1,3-Dichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Benzene
Bicycloheptadiene
Carbon tetrachloride
Chlorobenzene
Chloroform
Dibromochloropropane
Dicyclopentadiene
Dimethyldisulfide
Ethylbenzene
Methylene chloride
Methylisobutyl ketone
Tetrachloroethylene
Toluene
Trichloroethylene
m-Xylene
o- and p-Xylene

Total Organic Carbon

Dissolved Organic Carbon

Other Ions by Colorimetric
Nitrate/nitrite
Ammonium nitrogen
Total Kjeldahl nitrogen

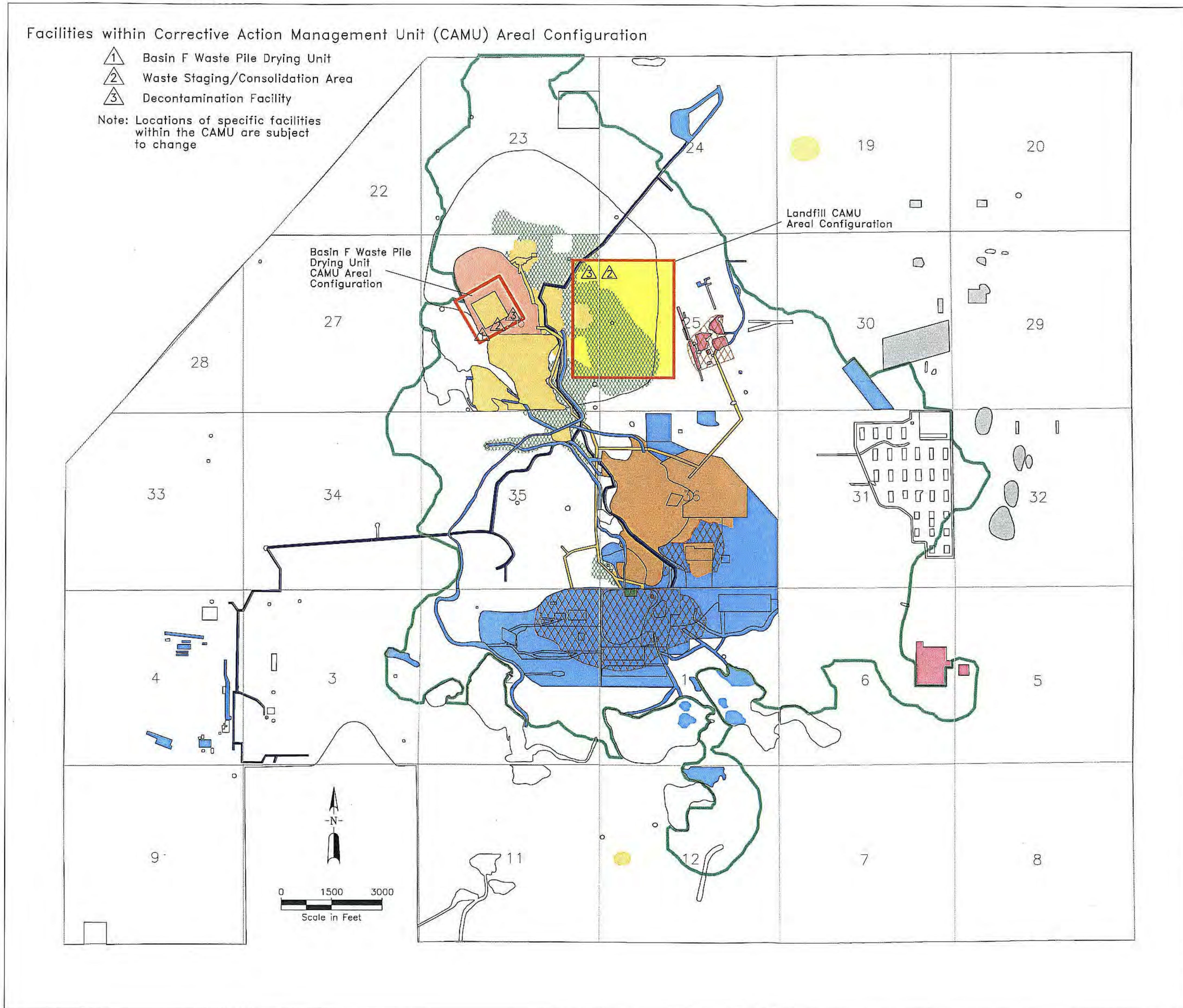
Field Parameters
Alkalinity
Conductivity
Dissolved oxygen
pH
Temperature
Turbidity

Table K3 (continued)

Source RMA Groundwater Monitoring Program Target Analyte List USGS, 1995

AA	Atomic absorption spectrometry
C	Colorimetric
CVAA	Cold vapor atomic absorption
GCCD	Gas chromatography/chemiluminescence detector
GC/CON	Gas chromatography/conductivity detector
GC/ECD	Gas chromatography/electron capture detector
GC/FID	Gas chromatography/flame ionization detector
GC/FPD	Gas chromatography/flame photometric detector
GC/MS	Gas chromatography/mass spectrometry
GC/NPD	Gas chromatography/nitrogen phosphorous detector
GC/PID	Gas chromatography/photoionization detector
HPLC	High performance liquid chromatography
ICP	Inductively coupled argon plasma screen
IONCHROM	Ion chromatography
ISE	Ion selective electrode
MIBK	Methylisobutyl ketone

* GC/MS analyses for confirmation purposes will be performed on 10 percent of samples only



Explanation

- Arsenal Boundary
- Study Area Report Boundary
- Area of Contamination Boundary
- CAMU Areal Configuration
- Landfill Principal Threat Volume; RCRA-Equivalent Cap
- Caps/Covers
- Direct Solidification/Stabilization
- Hex Pit Excavation
- Landfill Human Health Soil,[1] Consolidation of Biota Soil
- Landfill Human Health Soil[2]
- Landfill Site
- Soil Covers
- Agent Screening Area (Caustic wash/landfill)
- Unexploded Ordnance Screening Area (Detonation/landfill)
- Surficial Soil Consolidation
- Access Restrictions
- 5 Section Number

[1] Refuse from the Sanitary Landfills Medium Group will be consolidated

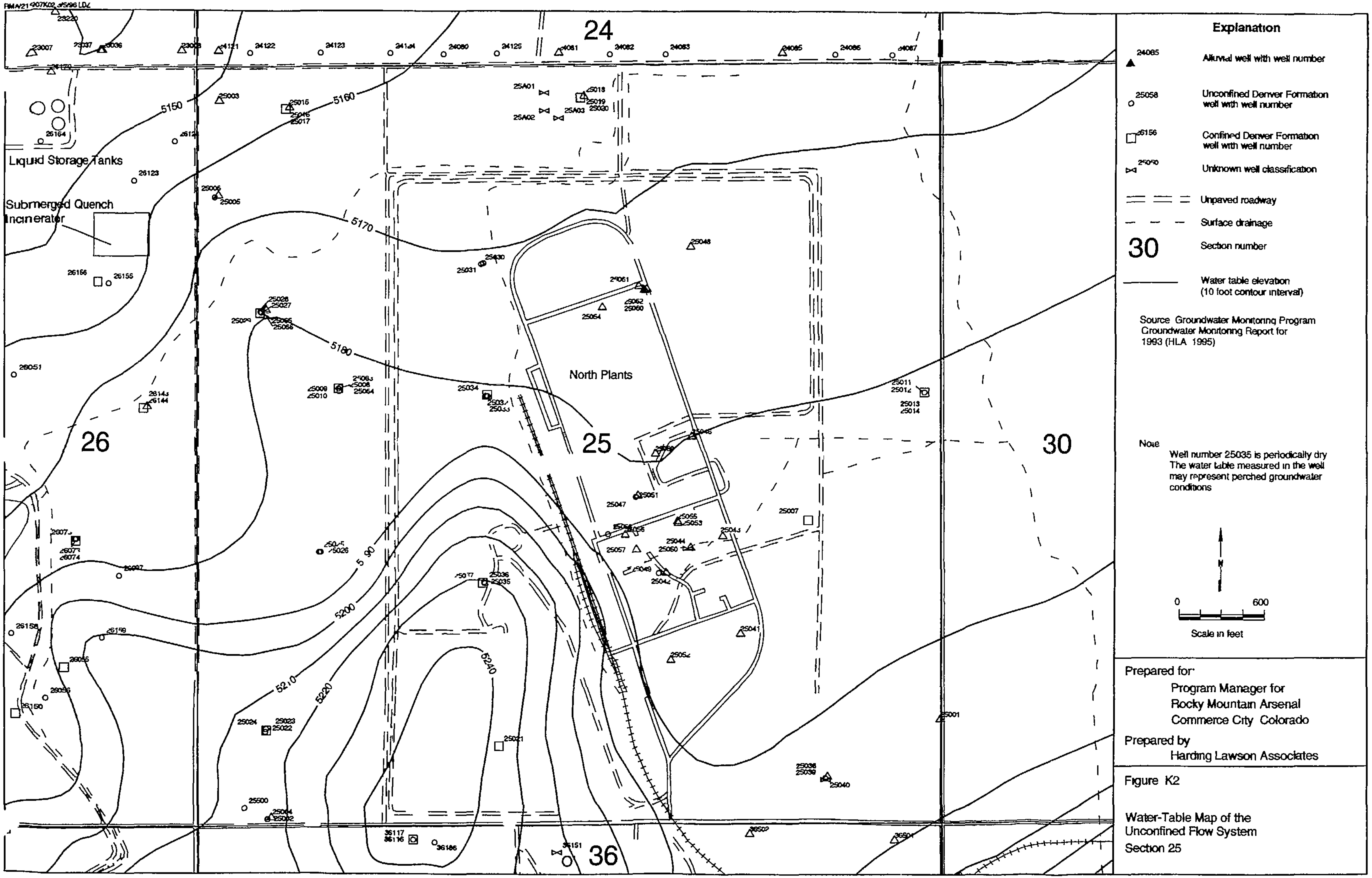
[2] Wastepile material will be dried prior to landfilling if paint filter test is failed

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by: Tetra Tech EC, Inc.

Figure K1

Proposed Corrrective Action Management Unit Areal Configuration Rocky Mountain Arsenal

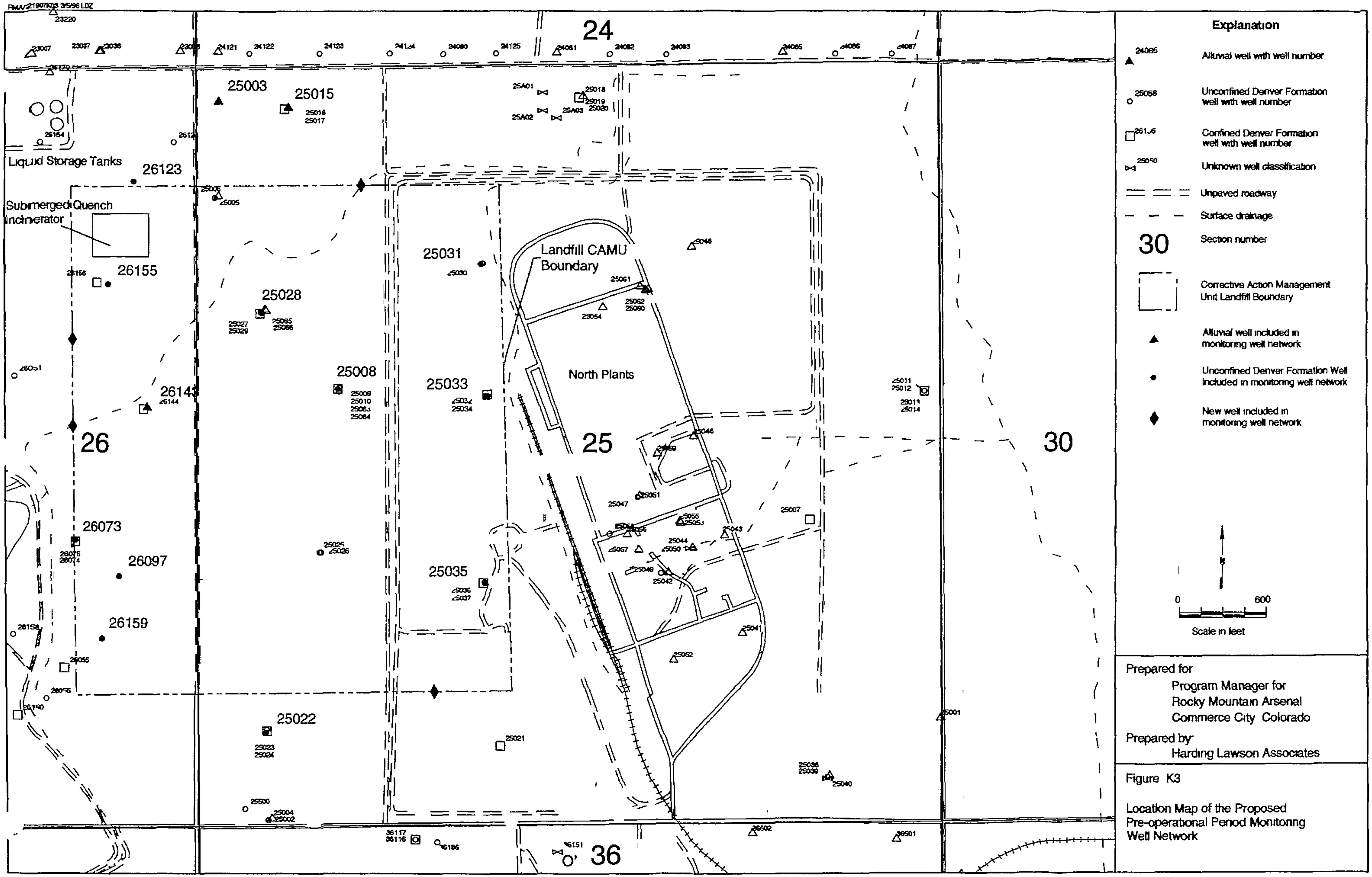


Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City Colorado

Prepared by Harding Lawson Associates

Figure K2

Water-Table Map of the Unconfined Flow System Section 25

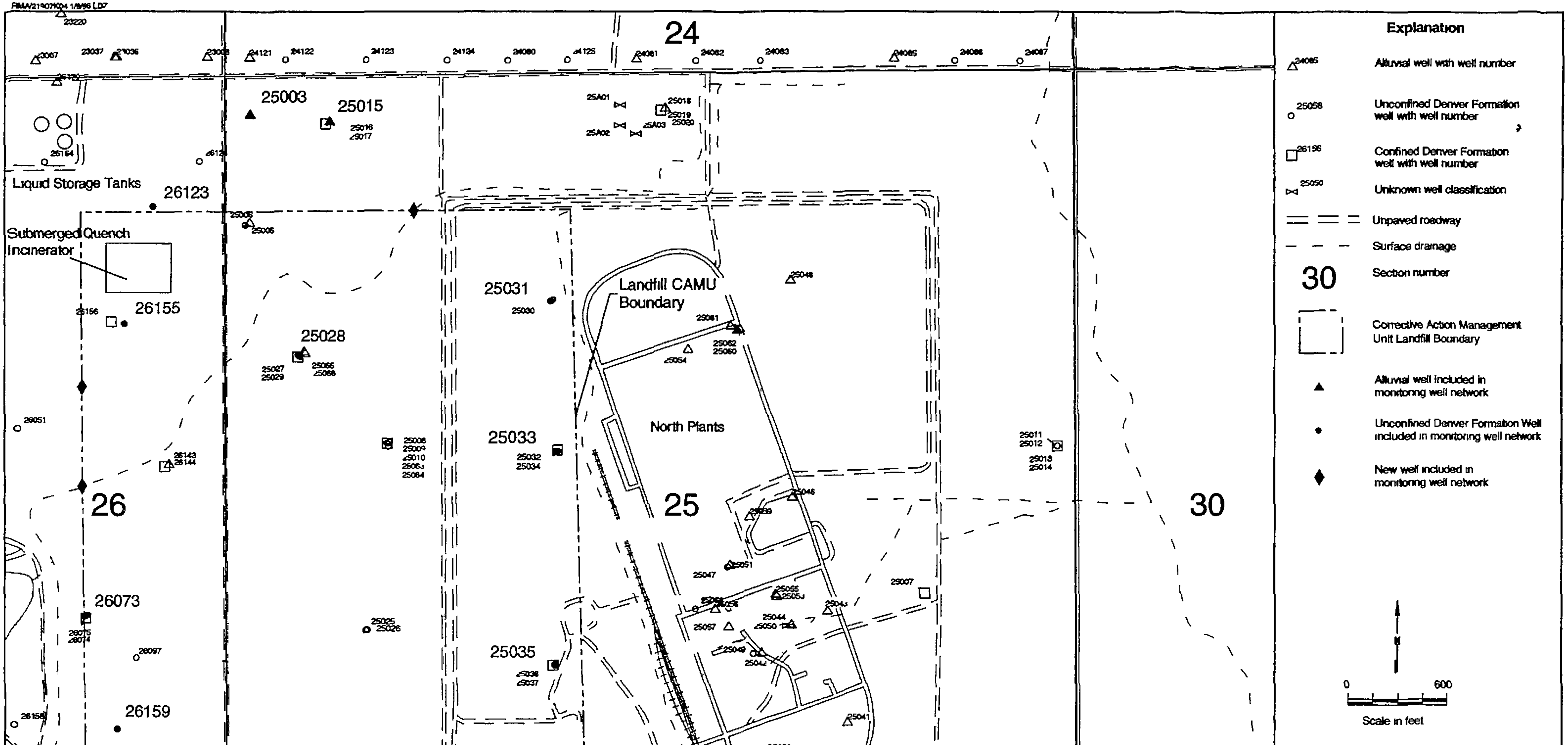


Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure K3

Location Map of the Proposed Pre-operational Period Monitoring Well Network



Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City Colorado

Prepared by
Harding Lawson Associates

Figure K4

Location Map of the Proposed Operational Period Monitoring Well Network

MAJOR DIVISIONS			SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS OVER 50%>No 200 SIEVE SIZE	GRAVELS MORE THAN 1/2 OF COARSE FRACTION> No 4 SIEVE SIZE	CLEAN GRAVELS WITH LESS THAN 5% FINES	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH OVER 15% FINES	GM	Silty gravels, gravel-sand mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS MORE THAN 1/2 OF COARSE FRACTION< No 4 SIEVE SIZE	CLEAN SANDS WITH LESS THAN 5% FINES	SW	Well-graded sands or gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH OVER 15% FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS OVER 50%<No 200 SIEVE SIZE	SILTS & CLAYS LIQUID LIMIT 50% OR LESS		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS & CLAYS LIQUID LIMIT GREATER THAN 50%		MH	Inorganic silts micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
DEBRIS ZONE*				Metal concrete plastic brick, wood, etc
CONSTRUCTION DEBRIS*				Concrete, wood, rebar, asphalt

SYMBOLS KEY

	Bulk or classification sample
	No sample recovery
	Undisturbed sample
	First-encountered groundwater level
	Static groundwater level
(10YR 4/4)	Munsell soil color chart 1990 edition

GRAIN SIZE CHART

CLASSIFICATION	RANGE OF GRAIN SIZES	
	U S Standard Sieve Size	Grain Size in Millimeters
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76 2
GRAVEL	3" to No 4	76.2 to 4.75
coarse	3" to 3/4"	76.2 to 19 1
fine	3/4" to No 4	19 1 to 4 75
SAND	No 4 to No.200	4 75 to 0 075
coarse	No 4 to No 10	4 75 to 2 00
medium	No 10 to No 40	2 00 to 0 425
fine	No 40 to No.200	0 425 to 0 075
SILT & CLAY	Below No.200	Below 0.075

Source ASTM D 2488-90, based on Unified Soil Classification System
* Not part of ASTM Classification System

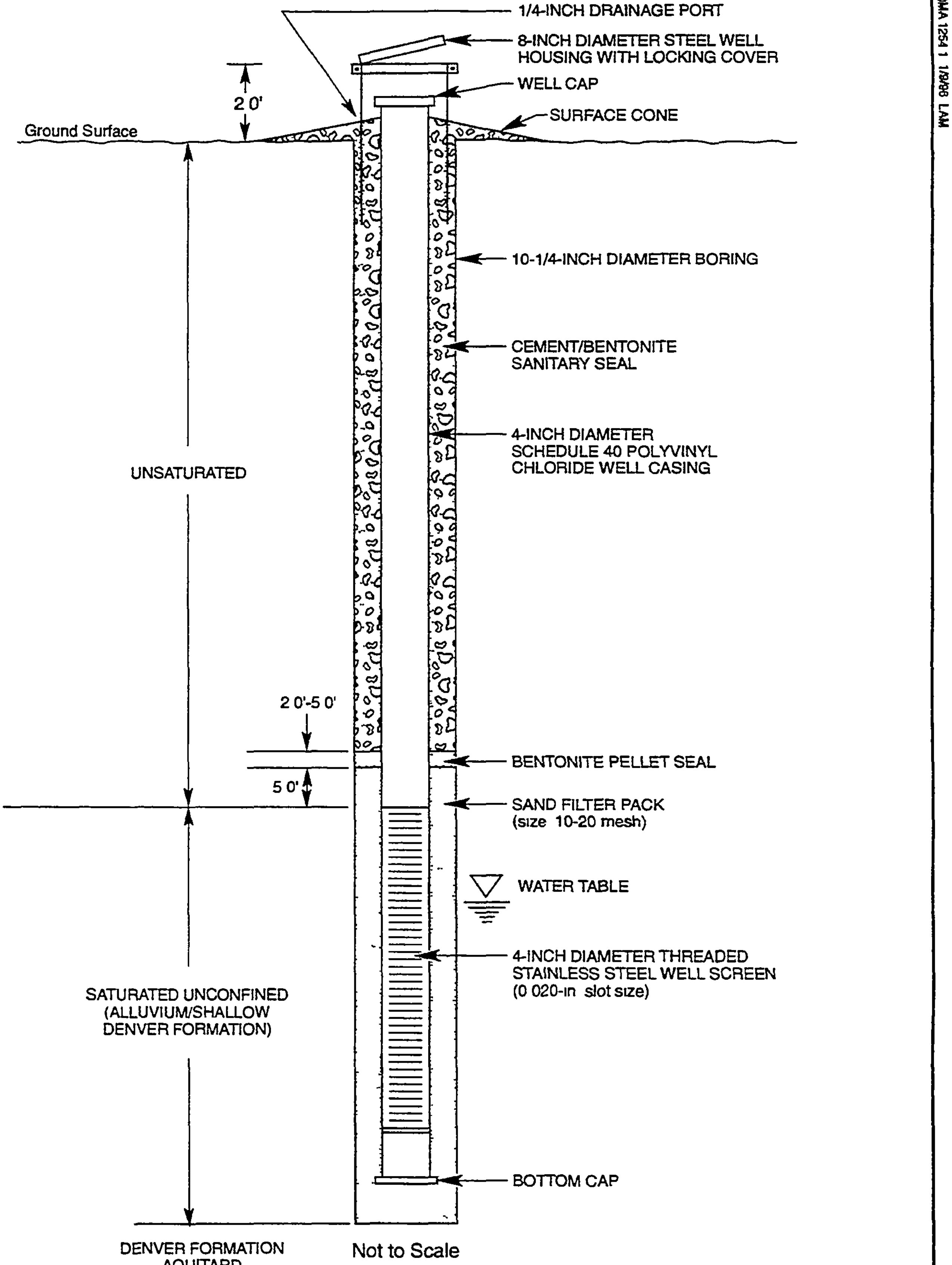
SOILCLS2

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K5

Unified Soil Classification Chart



Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure K6 Generalized Construction for Alluvial/Unconfined Denver Formation Monitoring Well

Harding Lawson Associates
2400 ARCO Tower
707 Seventeenth Street
Denver CO 80202
303/292-5365
Telecopy 303/292-5411

RMA 1254 58 1/9/96 LAM

Record of Activities at Well Sites Water Level Measurements

Project ______________________ Project Number ______________________

Location ______________________ Supervisor ______________________

Well No	Casing Dia (in)	Date	Time	PID Reading		Stick Up		Water Level		Total Depth (Feet)	Measuring Device	Sampler's Initials	Comments
				Bkgnd	TOC	(Feet)	(Tenths)	(Feet)	(Tenths)				

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K7

Water-level Measurement Form

Harding Lawson Associates

GROUNDWATER SAMPLING FIELD DATA SHEET

Log Book # ________
Page _____ of _____

RMA 1254.9a 1/9/96 LAM

Well Data	Purge / Sample Equipment	Analytical Equipment	Samplers / Calibration
Well ID No	**Purge Equipment** ☐ Dedicated Pump Settings: Charge _______ Discharge _______ ☐ Bennett Pump (Teflon Tubing) ☐ Meyers Pump (PVC Tubing) ☐ Grundfos Pump (Neoprene Tubing) ☐ 2 in. ☐ 3 in ☐ Stainless Bailer O D / LENGTH 1.65" ☐ ☐ 2 ft. 1.85" ☐ ☐ 3 ft. 3.75" ☐ ☐ 4 ft. ___ ☐ ☐ ___ft. SERIAL NO ________	**Analytical Equipment** **pH Meter** ☐ Beckman phi 21 ☐ HACH ☐ Orion SA250 ☐ Other_______ SERIAL NO ________	Samplers Initials / Time / Date
Casing Diameter ___ in		**Conductivity Meter** ☐ YSI Model 33 ☐ Curtin Matheson ☐ Other_______ SERIAL NO ________	**Meter Calibration** pH 7 00= ________ at ________ °C ________ Time pH 10 00= ________ at ________ °C ________ Time Conductance Standard ________ umhos/cm at 25 °C Measured Value ________ umhos/cm at ________ °C ________ Time
Casing Stickup ___ ft.			Calibrated Conductivity = Measured Conductance + (0 02) (measured conductance) (25°C - Actual Temp) ________ umhos/cm at 25°C ________ Time
Total Well Depth ___ ft.		**Dissolved Oxygen Meter** ☐ YSI Model 51B SERIAL NO ________	Dissolved Oxygen ________ mg/l at ________ °C ________ Time
Static Water Level ___ ft.	**Sample Equipment** ☐ Dedicated Pump Settings: Charge _______ Discharge _______ ☐ Bennett Pump (Teflon Tubing) ☐ Meyers Pump (PVC Tubing) ☐ Grundfos Pump (Neoprene Tubing) ☐ 2 in. ☐ 3 in. ☐ Stainless Bailer O D / LENGTH 1.65 ☐ ☐ 2 ft. 1.85 ☐ ☐ 3 ft. 3.75 ☐ ☐ 4 ft. ___ ☐ ☐ ___ft. SERIAL NO ________	**Temperature Meter** ☐ Beckman phi 21 ☐ HACH ☐ Orion SA250 ☐ Other_______ SERIAL NO ________	
Saturated Thickness ___ ft.		**Filtration Equipment** ☐ Geotech Peristaltic Pump ☐ Geotech 0.45 micron filter ☐ Dispos. 0 45 micron filter	Titration Results (Acid Concentration. 0 16 1 6)
Casing Volume / Annulus Vol ___ gal			
Screened Interval ___ ft.			

Titration				
pH	8.3	5 1	4.8	4.5
#Clicks				
Color				

Purge Containerized ? ☐ Yes ☐ No   Bulk ☐ Tank # ________   Barrel ☐ #s ________

Water Level Meter
Solinst ___ HLA# ___

Sample Depth. (ft.)

Time	Number of Casing Volumes	Gallons Removed	Water Level	°C	E.C umhos/cm	pH	Dissolved O_2 mg/Liter	Pump Rate GPM	Approx. Pump Depth ft.	Visual Description

Filter											
Analysis Requested											

☐ HNu
☐ OVm
☐ Microtip

Initial Readings	Sample Readings
TOC _______	TOC _______
BZ _______	BZ _______
Bkgnd _______	Bkgnd _______

Protective Level
A B C D

Serial # __________

HSO Signature

Condition of Well Remarks

Sampler Signature

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K8

Groundwater Sampling Form

RMA 1254.3a 1/9/96 LAM

Harding Lawson Associates	707 Seventeenth Street, Suite 2400
Denver, CO 80202	303/292-5365

Sample Number	Tag Number
Sample Type	Sample Technique
Depth	Date/Time
Analysis	
Preservative	
Container	
Remarks	
Sampler's Signature	

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure K9 Sample Label

Harding Lawson Associates
2400 ARCO Tower
707 Seventeenth Street
Denver CO 80202
303/292 5365
Telecopy 303/292-5411

FIMA 1254 4a 1/9/96 LAM

Lab I D ______

Work Authorization Number ______

Sample Round/Episode ______

CHAIN-OF-CUSTODY RECORD

Project Name/Project No	Sample Date	Sample Technique	Site Identification
Sampler (Signature)	Sample Depth (Ft)	File-Type/Matrix.	Site Type

TIME	TAG NO	ANALYSIS REQUIRED	CONTAINER	PRESERVATIVE/REMARKS

Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)
Relenquished by (Signature)	Date/Time	Received by (Signature)

Airbill Number

Laboratory Copy White — Project Office Copy Yellow — Field or Office Copy Pink

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K10

Water Chain-of-custody Form

Attachment K1

ANALYSIS OF THE LANDFILL MONITORING WELL NETWORK EFFICIENCIES

The predicted performance of the proposed Corrective Action Management Unit (CAMU) landfill monitoring well network for monitoring the operational period of the landfill was evaluated using the Monitoring Efficiency Model (MEMO) MEMO provides a methodology for quantitatively comparing monitoring well system configurations based on site-specific geometries This attachment summarizes the MEMO methodology and describes how the method was applied to evaluate the landfill monitoring well network The MEMO methodology and model are described in greater detail in Wilson and others (1992) and Golder Associates (1992)

METHODOLOGY

To implement MEMO methodology, a potential source area is defined and divided into a uniform grid of potential source points A constituent plume is then mathematically simulated from each potential source point using an analytical contaminant transport solution MEMO uses the two-dimensional solution of Domenico and Robbins (1985) as modified by Domenico (1987), which characterizes the source as a horizontal line of constant concentration and finite width perpendicular to groundwater flow direction, and predicts downgradient concentrations as a function of location and time The analytical solution is used to assess whether mathematically generated plumes reach a specified boundary (in this simulation the CAMU Landfill Boundary) beyond the potential source area before being detected by a monitoring well

Figure K1 1 illustrates the three possible results for each potential source point (1) the predicted plume reaches a steady state condition without intersecting the site boundary or being detected by a monitoring well (i e the source is of such diminutive magnitude that the plume does not reach a well or the site boundary), (2) the predicted plume is detected by a monitoring well before intersecting the site boundary, or (3) the predicted plume intersects the boundary before being detected by a monitoring well The current version of MEMO does not differentiate between results 1 and 3 identified above Efficiency of the system is then evaluated as the percentage of potential source points for which a successful result, or result number 2, is obtained

INPUT PARAMETERS

MEMO requires the following input parameters to assess the efficiency of a monitoring well network

- Geometry of the simulation domain (potential source area, site boundary, and monitoring well locations)
- Velocity of the simulated constituent in groundwater
- Groundwater flow direction
- Longitudinal and transverse dispersivities
- Source width
- Dilution contour (defined as the ratio of source concentration to a downgradient concentration of interest, in this case the detectable concentration)

In addition, the model will accept inputs for molecular diffusion and first-order decay mechanisms These mechanisms, however, were not considered for this analysis Neglecting all nonreversible mass transfer mechanisms (e g , decay or volatilization) results in a conservative assumption in that system efficiency will be underestimated Likewise, neglecting molecular diffusion also results in underestimation of system efficiency and is therefore considered a conservative assumption

If molecular diffusion and decay mechanisms are neglected, as they have been for this analysis, the solution for the monitoring well system efficiency is independent of the constituent velocity in the groundwater because the shape of a plume (as predicted by the Domenico and Robbins analytical solution) of a given length is independent of elapsed time For example, in the absence of molecular diffusion and decay, a plume that takes 5 years to reach a length of 500 feet will be identical to a plume that takes 50 years to reach a length of 500 feet Therefore, a determination of constituent velocity, or parameters upon which it is dependent (i e , hydraulic conductivity, hydraulic gradient, porosity, and retardation), is not required for this analysis A discussion of the other input parameters is provided in the paragraphs below

Geometry of the Simulation Domain

Geometry of the simulation domain is shown in Figure K1 2 The potential source area is considered to be the seven landfill cell footprints as illustrated in Figure K1 2 and presented in this CAMU Designation Document as a potential landfill cell layout It should be noted that this cell layout will likely change during design of the landfill When the landfill design is complete, a new simulation should be run through the MEMO model to verify the well network. The site boundary is equal to the CAMU Landfill Boundary The buffer zone is an extension of this boundary by approximately 1,000 feet to the north and south and approximately 500 feet to the east and west

Groundwater Flow Direction

For the model, the groundwater flow direction in the landfill area was subdivided into four flow directions as shown in Figure K1 2 The four flow directions are based on the water-table map illustrated in Figure K2 of Appendix K. In the western portion of the landfill area, the groundwater flows north 50 degrees west (N 50° W) There is a bedrock and groundwater high in the southeast quarter of the area East of the bedrock high groundwater flow is primarily to the east (N 90° E) North of the bedrock high groundwater flow is primarily to the N 0° E and N 50° E An evaluation of the sensitivity of the solution to flow direction is discussed in the sensitivity section

Longitudinal and Transverse Dispersivity

Dispersivity is a characteristic property of a porous medium that describes its tendency to disperse a plume of dissolved constituents migrating through the subsurface Dispersivity is generally used to characterize plume dispersion that occurs due to small-scale spatial variation in soil properties and temporal variations in the groundwater flow As noted by Wilson and others (1992), site-specific dispersivity data are rarely available At Rocky Mountain Arsenal (RMA), however, the published value for alluvial longitudinal dispersivity is 30 5 feet (Anderson, 1979) U S Environmental Protection Agency (EPA) guidance (1985) suggests that transverse dispersivity may be approximated as 0 33 times the longitudinal dispersivity Based on the published dispersivity and EPA guidance, longitudinal dispersivity was estimated as 30 5 feet and transverse dispersivity was estimated at 10 feet (0 33 times the longitudinal dispersivity) An evaluation of the sensitivity of the solution to transverse dispersivity is discussed in the sensitivity section

Source Width

For the purposes of this analysis, a source width of 20 feet was assumed The landfill area is approximately 2,000 feet in width at its widest point, and therefore a 20-foot source width represents a contaminant source point that is approximately 1 percent of the total width of the source area Larger source widths generate plumes that are more easily detectable by the monitoring well network Smaller source widths require relatively stronger source concentrations to generate a plume of sufficient magnitude to result in detectable concentrations at the site boundary An evaluation of the sensitivity of the solution to source width is discussed in the sensitivity section.

Dilution Contour

Generally, a plume contour delineates an area within which a specified concentration is exceeded Areas within the plume contour exhibit concentrations above the contour value, while areas beyond the plume contour exhibit concentrations below the contour value MEMO methodology, however, defines the plume boundary as the ratio between source concentration (C_0) and a downgradient value of interest (C), in this case the detectable concentration This is achieved by rearranging the Domenico and Robbins solution to solve for the C_0/C ratio Wilson and others (1992) refer to the line of equal ratio as the dilution contour In practice, this method generates contours that are representative of a variety of C_0/C ratios For example, a dilution contour of 100 is equally valid in describing the 1 microgram per liter (μg/l) contour resulting from a 100 μg/l source, the 2 μg/l contour resulting from a 200 μg/l source, etc An evaluation of the sensitivity of the solution to dilution contour is discussed in the sensitivity section

RESULTS

MEMO was used to evaluate various well configurations on the northern, eastern, and western perimeters of the CAMU Landfill Boundary which, based on past water-level observations, are downgradient of the landfill cells Results of numerous MEMO simulations indicate that an optimal design of

12 downgradient wells are proposed to monitor the area The selected downgradient well configuration is illustrated in Figure K1 2, and is also described in the text of Appendix K.

A sample of model results for a single simulation is provided as Figure K1 2 The hatched portion of the landfill area indicates areas from which a source would be detected Figure K1 2 illustrates that for the selected downgradient well configuration the simulated efficiency of the system in detecting a single 20-foot-wide source is approximately 99 percent The input parameters used in the model run illustrated in Figure K1 2 are as follows

- The geometry of simulated domain as illustrated in Figure K1 2 with the seven-cell landfill footprints as the potential source areas of contamination and a network of 12 downgradient monitoring wells
- The velocity of the simulated constituent in groundwater is equal to the groundwater flow rate (no retardation or attenuation of the constituents)
- The longitudinal dispersivity is 30 5 feet and the transverse dispersivity is 10 0 feet
- The source width is 20 feet
- The dilution contour is 1 0 x 10^{-3}

The input parameters were selected after performing a sensitivity analysis discussed in the following section The input parameters represent the selected values based on the results of the sensitivity analysis

Two points are worth noting about the model results, as expected, the further upgradient the potential source is from the monitoring wells and the closer it lies to a stream line that runs through a well, the easier it is to detect a release from that point. Furthermore, the definition of efficiency is the probability that a single source occurring in a random location within the source area extent will be detected before resulting in a detectable concentration at the site boundary Probability of detection greatly increases in the event of multiple sources The probability that multiple, randomly distributed sources would be detected can be calculated as $1-(1-\alpha)^n$, where α is the probability of detection for one source and n is the number of sources For example, the optimal 12-well efficiency increases from 99 percent to 100 percent if two sources exist rather than just one

SENSITIVITY OF RESULTS TO INPUT PARAMETERS

Sensitivity of the model results to the input parameters including source width, flow direction, transverse dispersivity, longitudinal dispersivity, and dilution was examined by perturbing one of the parameter inputs while keeping all other inputs fixed Results of the sensitivity tests are summarized in Table K1 1

Table K1 1 illustrates that 20 feet is a conservative source width for this analysis, as using source widths that are either an order of magnitude higher or lower both resulted in system efficiencies of greater than 90 percent As described in the results section, larger source widths result in plumes that are more easily detected by the monitoring well system, and smaller source widths result in plumes that do not increase concentrations to detectable levels at the site boundary, except at very high source concentrations Table K1 1 also illustrates that this analysis is not highly sensitive to variations in flow direction, or 50 percent changes in transverse or longitudinal dispersivity The maximum change observed in the predicted system efficiency during analysis of sensitivity was a decrease to 82 percent (from 98 percent), which resulted from a change in the groundwater flow direction from the four estimated flow directions calculated from the map in Figure K1 2 to a simplified estimate of two flow directions

REFERENCES

Anderson, M P 1979 Using models to simulate the movement of contaminants through groundwater flow systems, *Critical Reviews in Environmental Control* 9(2) 97-156

Domenico, P A 1987 An analytical model for multidimensional transport of a decaying contaminant species *Journal of Hydrology* (91) 49-85

Domenico, P A and G A. Robbins 1985 A new method of contaminant plume analysis *Ground Water* 23(4) 476-485

Golder Associates 1992 *User's manual, monitoring analysis package including MEMO, PLUME, and COPRO* (version 1 1)

U S Environmental Protection Agency 1985 *Water quality assessment, a screening procedure for toxic and conventional pollutants in surface and ground water-part II* Environmental Research Laboratory, Office of Research and Development, Athens, GA., EPA/600/6-85/002b, September

Wilson, C R , C M Einberger, R L Jackson, and R B Mercer 1992 Design of ground-water monitoring networks using the monitoring efficiency model (MEMO) *Ground Water* 30(6) 965-970

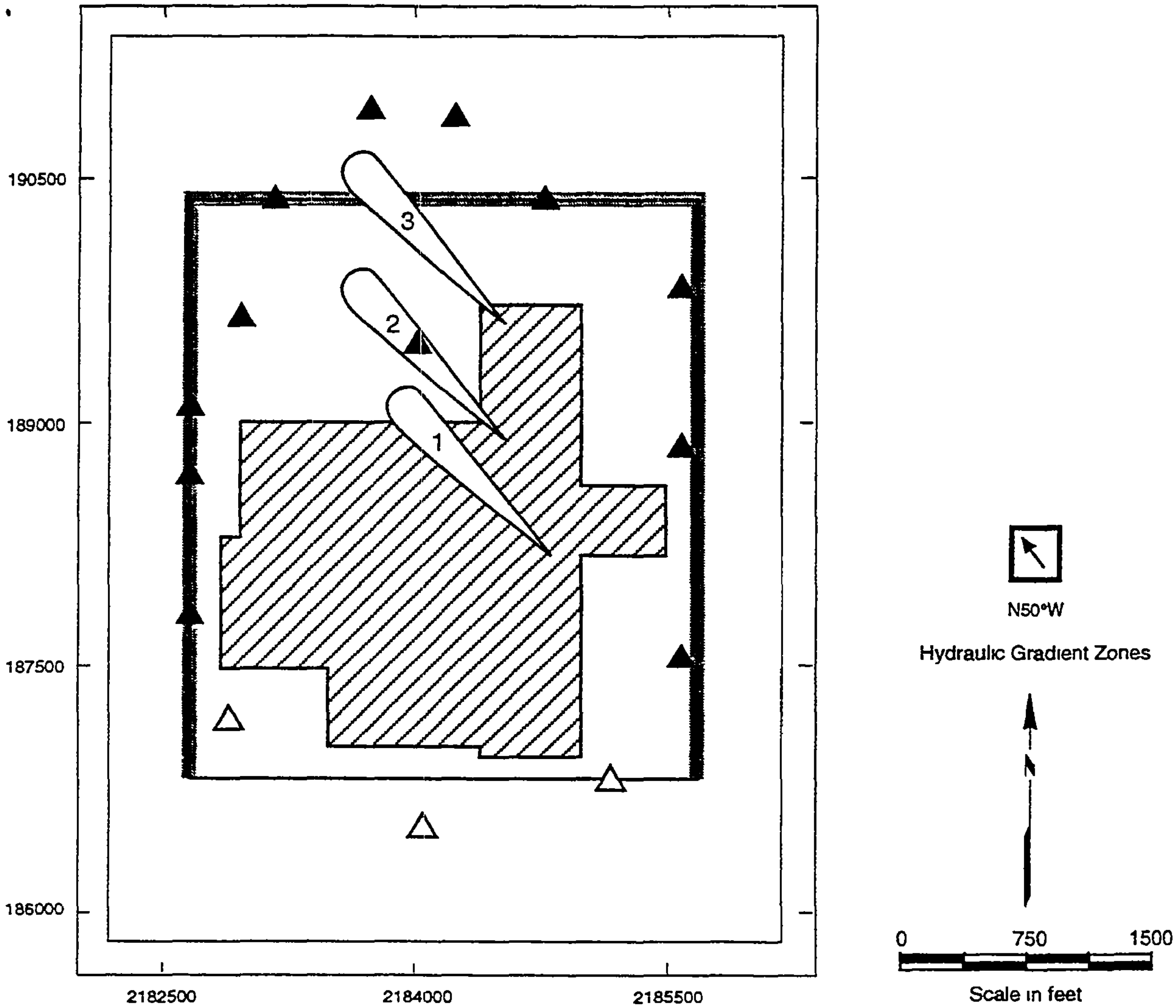
Table K1.1: Summary of Analysis of MEMO Sensitivity to Input Values Selected

Parameter	Sensitivity to Higher Value Model Input	Sensitivity to Higher Value Efficiency	Selected Value Result Model Input	Selected Value Result Efficiency	Sensitivity to Lower Value Model Input	Sensitivity to Lower Value Efficiency
Source width	200 feet	100 percent	20 feet	99 percent	2 feet	95 percent
Groundwater flow direction	N 50° W	99 percent	N 90° E N 40° E N 0° W N 50° W	99 percent	N 95° E N 45° E N 5° E N 45° W	99 percent
Transverse dispersivity	15 feet	99 percent	10 feet	99 percent	5 feet	97 percent
Longitudinal dispersivity	45 feet	99 percent	30 5 feet	99 percent	15 feet	99 percent
Dilution	10×10^4	99 percent	$1\ 0 \times 10^3$	99 percent	$1\ 0 \times 10^2$	95 percent

MEMO Monitoring Efficiency Model
N North
E East
W West
° Degrees

21907 705013
1213010696 CP

RMA 1249 03/07/96 ECS



Explanation

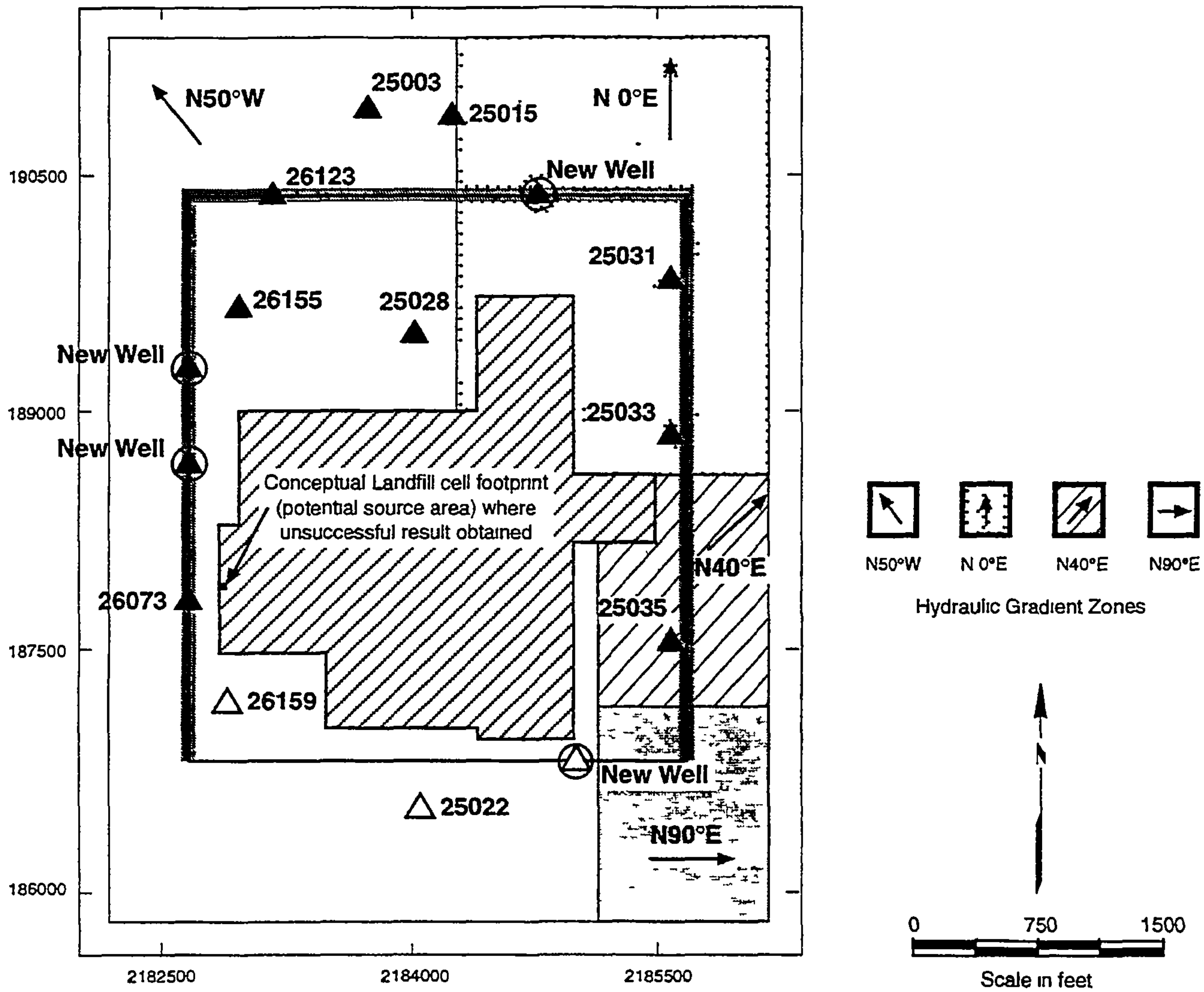
▨	Conceptual Landfill Footprints (Potential Source Areas)	N	North
▲	Downgradient monitoring well locations	°	Degrees
△	Upgradient monitoring well locations	W	West
	Three possible results for simulated constituent plumes	E	East
	Line of compliance	2182500,186000	X and Y state planar coordinates
	CAMU Landfill Boundary		

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure K1 1

Simulation Domain and Three Possible Results for Simulated Constituent Plumes



Explanation

▨	Conceptual Landfill cell footprints (potential source areas) where successful result is obtained using the selected input values	N	North
▲	Downgradient monitoring well locations	°	Degrees
△	Upgradient monitoring well locations	W	West
	Line of compliance	E	East
	CAMU Landfill Boundary	2182500,186000	X and Y state planar coordinates

Note Well numbers not available for proposed new wells

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure K1 2 Sample Simulation Result

Appendix L

GUIDELINES FOR THE DEVELOPMENT OF A CLOSURE AND POST-CLOSURE PLAN

CONTENTS

FIGURES

1.0 INTRODUCTION

This guideline for the development of the CAMU Closure and Post-Closure Plan has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for cleanup of the Rocky Mountain Arsenal (RMA), located in Adams County, Colorado The CAMU will be designated by the Colorado Department of Public Health and Environment (CDPHE) in accordance with Section 264 552(a) of 6 Code of Colorado Regulations (CCR) 1007-3 under the authority granted to CDPHE by the Colorado Hazardous Waste Management Act (CHWMA) The designation will be part of a corrective action order issued under the authority of 25-15-308 C R S The CDD and its appendixes are being submitted to the CDPHE in conformance with Section 264 552(d) of 6 CCR 1007-3 This appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03, Feasibility Study Soil Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This document has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. This document has been prepared for designation of a CAMU at RMA and should not be used for any other purpose

1.1 Purpose and Scope

The CDD, including this appendix, will be submitted to Colorado Department of Public Health and Environment (CDPHE) in support of the designation of the CAMU This document presents guidance for the development of a final Closure and Post-Closure Plans for the CAMU at RMA. A general location map for RMA is presented in Figure L1 and the CAMU areal configuration is presented in Figure L2 The final Closure and Post-Closure Plan will be prepared in accordance with the Colorado Hazardous Waste Regulations found at 6 Code of Colorado Regulations (CCR) 1007-3, Section 264 552 Although not specifically required by 6 CCR 1007-3, Section 264 552, this Closure Plan will also use as guidance many of the elements for closure and post-closure care specified in 6 CCR 1007-3, Part 265, Subpart G (Closure and Post Closure)

The final Closure Plan will specifically addresses the following areas or facilities within the CAMU that will require closure (1) landfill, (2) Basin F Waste Pile drying unit, (3) various waste staging/consolidation areas, and (4) decontamination facilities The Closure Plan will include post-closure care activities associated with the landfill 6 CCR 1007-3 Section 264 552 requires that areas within the CAMU where remediation wastes remain in-place after closure of the CAMU be managed and contained to control, minimize, or eliminate future releases to the extent necessary to protect human health and the environment The landfill is the only area identified within the CAMU boundary where remediation wastes will be placed into the CAMU as part of CAMU operations and will remain in place after closure Other facilities within the CAMU will not require post-closure care because waste will either be removed from these facilities or these facilities will be decontaminated during closure Closure performance standards will be established in the final closure plans developed for each facility Closure performance standards will be developed in consideration of existing contamination at RMA and will not be based on practical quantitation limits or other analytical detection limits

Section 2 0 of this document presents a general description of the RMA facility and the facilities within the CAMU undergoing closure Section 3 0 presents a general discussion of the closure procedures and the associated waste management activities that will be incorporated into the Closure Plan Section 4 0 describes the anticipated schedule for closure activities, and Section 5 0 provides guidance for the Post-Closure Plan Section 6 0 provides a list of acronyms, and Section 7 0 provides the reader with a list of references used in the document.

This document provides a framework for the final closure and post-closure of facilities within the CAMU The final Closure and Post-Closure Plan for each facility will be developed in the future as the design of the CAMU progresses The Closure and Post-closure Plan will be submitted to CDPHE for approval in accordance with the schedule discussed in Section 5 0 and of the CDD

2.0 FACILITY DESCRIPTION

This section describes the RMA facility Specifically, the following subsections describe (1) the RMA site location and history, (2) the physical setting of the CAMU, (3) hydrogeologic conditions in the CAMU area, (4) current air monitoring activities, (5) remediation wastes associated with the CAMU, and (6) a description of the areas within the CAMU that require closure

2.1 General Description

RMA occupies more than 17,000 acres in Adams County, Colorado, northeast of the metropolitan Denver area (Figure L1) The RMA property was primarily used for agricultural purposes prior to 1942 In 1942, RMA was purchased by the federal government and used during World War II to manufacture and assemble chemical warfare materials and incendiary munitions A significant amount of chemical warfare materials destruction took place during the 1950s, 1960s, and 1970s The last demilitarization operations ended in the 1980s, and in November 1988, RMA was reduced to inactive military status with the only remaining mission at RMA being contamination cleanup In addition to military activities, major portions of the RMA facilities were leased to private industries, including Shell Oil Company, for the manufacture of various pesticides, insecticides, and herbicides

2.2 Physical Setting

RMA is accessible only to authorized personnel The CAMU boundary is within the property boundaries of RMA, as shown in Figure L2 The ground surface elevation within the CAMU generally ranges between 5,200 and 5,300 feet above mean sea level (msl) No 100-year floodplains have been identified within the CAMU The CAMU area includes the Basin F Waste Pile drying unit area and the landfill area The Basin F Waste Pile drying unit area occupies approximately 50 acres in the vicinity of the waste pile The landfill area occupies approximately 245 acres in the western half of Section 25 and the eastern half of Section 26

2.3 Hydrogeologic Information

This section describes the general geology and hydrogeology characterizing the area in which the CAMU is located The regional geology and hydrogeology have been discussed in detail in numerous reports including reports prepared by J May (1982), Morrison Knudsen Engineers, Inc (MKE) (1988), and Ebasco Services, Inc (Ebasco) (1989) and are not discussed in detail in this Closure Plan

2.3.1 Geology

Immediately underlying the western half of Section 25 and eastern portion of Section 26 (CAMU landfill area), are alluvial Quaternary deposits that overlie the Denver Formation. The alluvium is composed primarily of clay, silt, very fine- to fine-, to medium-grained sand with minor amounts of coarse-grained sands and gravels The alluvium ranges in thickness from approximately 5 to 58 feet thick in the landfill area. The Cretaceous-Tertiary Age Denver Formation is composed of primarily claystone with interbedded siltstone, sandstone, and lignite In the northern portion of Section 26, the Denver Formation is approximately 250 feet thick (Environmental Science and Engineering, Inc [ESE], 1988)

2.3.2 Hydrogeology

Groundwater at RMA occurs under both confined and unconfined conditions The Quaternary alluvium and weathered portion of the Denver Formation form a generally continuous groundwater system where the groundwater is typically unconfined This flow system is called the unconfined flow system Confining strata inhibit groundwater interaction between the unconfined flow system and the deeper, more permeable zones in the Denver Formation, called the confined flow system Within the landfill area, the groundwater flow in the unconfined flow system is generally from the southeast to the northwest There is a water-table high associated with a bedrock high in the south central portion of Section 25 The depth to groundwater in the landfill area ranges from 20 to 70 feet below ground surface

2.4 Current Groundwater Monitoring Program

Currently, as part of the site-wide Groundwater Monitoring Program, there are 48 wells used to monitor the water levels in the landfill area (U S Geological Survey [USGS], 1995). The water quality monitoring network is less extensive and includes only 4 unconfined flow system wells used to monitor the groundwater quality in the eastern portion of Section 26. Currently no wells are used to monitor the groundwater quality in the western portion of Section 25.

2.5 Remediation Wastes Associated with the CAMU

The On-post Operable Unit Detailed Analysis of Alternatives (DAA) Dispute Resolution Agreement dated October 16, 1995, states "A CAMU incorporating the future hazardous waste landfill, Basin F Waste Pile drying units(s), and the appropriate waste staging and/or management area(s) will be designated." The DAA was prepared under various authorities of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The CAMU boundary shown in Figure L2 includes the landfill, Basin F Waste Pile drying unit, waste staging/consolidation areas, and decontamination facilities. Remediation wastes that will be placed into the landfill include (1) Basin F Waste Pile soils and (2) principal threat and human health exceedance soil or debris that will be landfilled from various areas of RMA, as defined in the Final DAA (Foster Wheeler, 1995). **Basin F Waste Pile soils and waste from Former Basin F, Sand Creek Lateral and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto will be placed in the triple-lined cells**. Basin F Waste Pile soils are listed hazardous wastes. Soil and debris from the balance of areas at RMA will be placed in the double-lined cells may be hazardous. Remediation waste placed into the CAMU does not constitute land disposal of hazardous waste for purposes of Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (LDRs) applicability

Leachate generated from the landfill will be managed appropriately either offsite or onsite in accordance with applicable regulatory requirements at the time of generation.

2.6 Description of Areas and Facilities Undergoing Closure

The following sections provide a physical description of the areas within the CAMU that will undergo closure, including the landfill, Basin F Waste Pile drying unit, waste staging/consolidation areas, and decontamination facilities. Although the Waste Pile and portions of the Former Basin F are included in the CAMU, closure of the Waste Pile and Former Basin F are addressed in a separate closure plan (BLA, 1995) and will not be addressed in the CAMU Closure Plan.

2.6.1 Landfill

A new onpost landfill will be constructed within the CAMU boundary as shown in Figure L2. The landfill will receive remediation waste from various areas at RMA and Basin F solids (currently stored in the Waste Pile). Approximately 1.8 million cubic yards of material win be placed into the landfill. The landfill CAMU area is approximately 245 acres. One or more cells (approximately 750,000 bank cubic yards [BCYI) will have an enhanced design with an additional liner and leak detection system and will contain contaminated soil from the Basin F Waste Pile, **Former Basin F, Sand Creek Lateral and other compatible remedy related wastes identified in the RMA Remediation Waste Management Plan and the Compliance Order on Consent and amendments thereto.**

2.6.2 Basin F Waste Pile Drying Unit

The Basin F Waste Pile drying unit will be constructed to dry waste pile solids that do not pass the paint filter test before placing the waste pile solids into enhanced cell(s) of the landfill. The drying system, as defined in the DAA, may consist of a direct or indirect-fired heating system to increase the soil temperature to reduce the soil moisture content. The off-gas from the drying unit will be collected and treated. A preliminary process flow diagram for the drying unit is illustrated in Figure L3. This process flow diagram and the unit processes shown are conceptual and will be finalized during the design process.

There are approximately 600,000 BCY of Basin F Waste Pile solids that will be placed into the landfill. It is currently estimated that up to 100,000 BCY (FosterWheeler,1995) of the waste pile solids will not pass the paint filter test and will require drying before being landfilled. However, this estimate is preliminary and may be revised based on additional information that may be collected before and during the design process The proposed location for the Basin F Waste Pile drying unit is illustrated in Figure L2, and is included within the CAMU boundary The proposed location is preliminary and may be revised during the design process

2.6.3 Waste Staging/Consolidation Areas

Waste staging/consolidation areas will be used for temporary staging, processing, size reduction, and/or storage of remediation waste before it is transported to a treatment facility or to the landfill Figure L2 identifies preliminary staging areas that may be used during construction The proposed locations are preliminary and may be revised during the design process

2.6.4 Decontamination Facilities

Decontamination facilities will be used to decontaminate equipment or personnel that have been in contact with remediation waste Figure L2 identifies preliminary decontamination facilities that may be used during remedial action at the site The proposed locations are preliminary and may be revised during the design process

3.0 CLOSURE PROCEDURES

Closure activities will be performed to meet the closure standards specified in 6 CCR 1007-3, Section 264 552 The components of the contemplated closure procedures presented in this section use as guidance many of the elements for closure specified in 6 CCR 1007-3, Part 265, Subpart G In accordance with 6 CCR Section 264 552, the components of closure procedures described in this plan are designed to (1) minimize the need for further maintenance and (2) control, minimize, or eliminate, to the extent necessary to protect human health and the environment, for areas where remediation wastes remain in place, post-closure escape of remediation waste, hazardous constituents, leachate, contaminated runoff, or remediation waste decomposition products to the ground, groundwater, surface waters, or the atmosphere

The detailed components of closure which will be developed during design will be designed to provide long-term protection of human health and the environment Closure of the CAMU will include the following

- Containment of remediation waste in the landfill
- Requirements for capping the landfill, where remediation waste is placed into the CAMU and will remain in place
- Requirements for removal and decontamination of equipment, devices, and structures used in remediation waste management activities within the CAMU Equipment, devices, and structures within the CAMU that will require closure may include the thermal drying unit, construction staging areas, and decontamination facilities

Specific procedures for closure of these facilities will be developed during design and will include confirmation sampling and verification of decontamination

The following sections provide a general description of contemplated closure components, procedures for handling remediation waste during closure, site security, safety and health plan, decontamination, spill prevention and response, and a survey plat Guidance for post closure care for the landfill is addressed in Section 5 0

3.1 Closure Process

The closure process will consist of three phases of work construction, certification, and post-closure care As shown in Figure L4, each phase is comprised of one or more tasks A brief summary of the anticipated closure process and a description of each task are provided below

3.1.1 Construction Phase

This section describes the contemplated tasks associated with the construction phase including final cover installation, removal and/or decontamination of equipment, devices, and structures, and restoration

Task 1 - Final Cover Installation

A final cover will be installed over each cell upon completion of waste placement in each cell The final cover will be designed to

- Provide long-term minimization of migration of liquid through the closed landfill cell
- Function with minimum maintenance
- Promote drainage and minimize erosion or abrasion of the cover
- Accommodate settling and subsidence so that the cover's integrity is maintained
- Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present

The proposed engineered cover will be a multi-layered system comprised of earthen and synthetic materials The conceptual design incorporates erosion control, water balance, and biotic barriers as primary factors Each component of the cover system performs a unique function and in some cases one component may serve multiple functions

A conceptual cross section of the anticipated cover is illustrated in Figure L5 Each of the cover components along with their intended functions is described in the CDD (Appendix B) The components selected for the final cover may change during design with CDPHE approval

The final cover will reduce the migration of remediation wastes into the surrounding environment by minimizing infiltration through the contaminated soil by isolating the contaminated media and reducing the possibility of human and biota exposure by direct contact. The cover will be designed to function with minimum maintenance The cover design will include self-sustaining vegetation and a biota barrier layer that will inhibit cover damage from burrowing animals The cover design will include a sloped surface and a vegetation layer that promotes drainage and minimizes erosion. The final cover will have a permeability less than or equal to the permeability of any bottom liner system or natural subsoil present The cover will also accommodate settling and subsidence so that the cover's integrity is maintained The details of the final cover will be developed during the design phase and submitted for CDPHE approval

Task 2 - Removal and/or Decontamination of Equipment, Devices, and Structures

Decontamination procedures for equipment, containment system components, and structures that are part of the CAMU will be developed during preparation of the final closure plan for the landfill Contaminated soil resulting from equipment, devices, or structures decontamination will be placed in the onsite landfill Decontaminated equipment, devices, and structures will be disposed or reused Specific procedures for decontamination and disposal or reuse of equipment, devices, and structures that are part of the CAMU will be developed during design

Task 3 - Restoration

After the final cover has been installed over the landfill, the cover will be revegetated The vegetation types that will be used will be selected on the basis of low maintenance requirements, ability to minimize erosion, depth of root structure, drought resistance, and factors related to wildlife use The details of restoration will be developed during the design phase

Upon completion of the Construction Phase, any wells needed for ongoing monitoring that are damaged or otherwise rendered unsuitable for groundwater monitoring will be replaced The replacement wells will be constructed according the State of Colorado requirements for monitoring well installation The damaged wells will be abandoned in accordance with state well closure requirements

3.1.2 Certification Phase

Task 4 - Closure Certification

Certification that the CAMU has been closed in accordance with the procedures outlined in the final Closure Plan will be submitted to CDPHE within 60 days of completion of final closure of the CAMU The closure certifications will be submitted to CDPHE and will be signed by the Army and by an independent Colorado registered professional engineer The professional engineer will not have participated, or belong to a firm that has participated either as a contractor or subcontractor, in the planning, construction, oversight, operation, or closure of any portion of the CAMU Documentation supporting the certifications of the independent registered professional engineer will be maintained on file by the Army

3.1.3 Post-Closure Phase

Task 5 - Post-Closure Maintenance and Monitoring

After the landfill is closed, the post-closure monitoring period will begin. Post-closure maintenance and monitoring is required for the landfill because this is the only area within the CAMU where remediation waste placed into the CAMU will remain in place after closure Procedures for the post-closure monitoring and maintenance for the landfill is described in Section 5 0 of this Closure Plan

3.2 Procedures for Handling Remediation Wastes Generated During Closure

The following sections describe the storage, transportation, and disposal of solid and liquid remediation wastes that are anticipated to be generated during closure of facilities

3.2.1 Disposal

Solid remediation waste generated during decontamination or other closure-related activities while the onsite landfill is operational may be placed in the onsite landfill Solid remediation wastes generated during decontamination or other closure-related activities after the landfill is no longer operational will be disposed at an appropriately permitted offsite disposal facility Waste that will be disposed at an offsite facility will be characterized, stored, and transported in accordance with all applicable regulations Liquid remediation waste will either be transported to an appropriately permitted offsite disposal facility or treated at an onsite treatment facility Liquid remediation waste that will be disposed at an offsite facility will be characterized, stored, and transported in accordance with all applicable regulations

3.2.2 Transportation

Any waste being transported offsite for treatment or disposal will be characterized in accordance with all applicable regulations The transportation of hazardous remediation wastes to offsite treatment or disposal facilities will follow the U S Department of Transportation (DOT) regulations for hazardous materials transport (49 Code of Federal Regulations [CFR] Parts 171 to 178) and the manifest requirements of 6 CCR 1007-3, Part 262

3.3 Groundwater Monitoring Program

The proposed groundwater monitoring program for this background period of the CAMU will be described in the Groundwater Monitoring Program (Appendix K to the CDD) Groundwater monitoring for the operational period and closure of the CAMU will be developed based on the results of the background and operational monitoring program

3.4 Site Security

The following security measures, at a minimum, are planned to be in effect during closure

- Twenty-four hour surveillance by facility personnel will control and monitor entry to the CAMU and all areas associated with closure of the CAMU
- A chain-link perimeter fence will prevent unknowing or unauthorized entry into the landfill portion of the CAMU The fence will also be maintained to minimize entry of wildlife into the landfill area
- Temporary fencing will be installed, as required to limit access to the Basin F Waste Pile drying unit, decontamination facilities, and temporary staging areas

- Signs at each entrance and at other locations on the perimeter fence, with the words "Danger - Unauthorized Personnel Keep Out" in English and Spanish, will be posted during closure activities
- Access to the CAMU during decontamination and demolition will be controlled at all times by facility personnel

3.5 Safety and Health Plan

A safety and health plan for work being performed during closure and post-closure activities will be prepared before work commences The purpose of the safety and health plan is to assign responsibilities, establish protection standards, specify safe operating procedures, and provide for contingencies that may arise during proposed site activities The Safety and Health Plan will be distributed to and followed by all personnel participating in field activities The Safety and Health Plan will be evaluated throughout the course of the field activities to incorporate any changes generated as a result of site activities The Safety and Health Plan will be submitted to CDPHE for review and approval

3.6 Decontamination

Equipment and materials used in decommissioning and closure activities will be decontaminated or disposed of as remediation waste in the landfill, or at an approved offsite disposal facility Detailed procedures for equipment and personnel decontamination for closure-related activities will be established during design Personal decontamination and support facilities will be provided and located in accordance with the appropriate Safety and Health Plans Personal protective equipment (PPE) will be decontaminated or managed as a remediation waste Washwater and sludge generated from the decontamination will be collected and disposed of as described in Section 3 2

3.7 Spill Prevention and Response

During transfer of remediation waste materials into or within the CAMU and to trucks or railcars for onsite or offsite transportation, care will be taken to minimize spills Trucks used in the transfer process will be loaded in an area designed to contain spills Liquid spills will be immediately vacuumed into tanks or trucks and/or contained with soil or a nonreacting sorbent Confirmation sampling will be performed for spills to verify spill cleanup

Soil or solid spills will be removed and disposed at an appropriately permitted offsite facility or in the onsite landfill Confirmation sampling, if necessary, will be performed to verify containment of soil or solid spills

A Spill Prevention and Response Plan will be incorporated in the above-referenced Safety and Health Plans for CDPHE review and approval

3.8 Survey Plat

A survey plat indicating the location and dimensions of landfill cells will be submitted to CDPHE and the local zoning authority or the authority with jurisdiction over local land use This survey plat will be provided at the completion of closure activities

4.0 CLOSURE SCHEDULE

4.1 Expected Year of Closure and Total Time to Close

Closure of the CAMU includes the construction phase, certification phase, and post-closure care phase Based on Foster Wheeler's current schedule for remediation, final closure of the CAMU is anticipated to occur at the end of fiscal year 2008 The schedule for remediation is preliminary and subject to change due to uncertainties associated with the funding and implementation of the remedy

The certification phase will follow the closure construction phase A record of the type, location, and quantity of remediation wastes disposed in the landfill will be submitted to CDPHE

The post-closure care phase begins after closure of the landfill is complete and includes monitoring and maintenance programs for the landfill Post-closure care will be conducted for 30 years following closure of the landfill

A detailed sequence schedule for the closure activities of the CAMU will be developed during design. However, the precise schedule of closure activities will be dependent on the overall remediation schedule

5.0 POST-CLOSURE CARE PLAN

The Army will perform post-closure care of the landfill for 30 years after certification of final closure, subject to the requirements of 6 CCR 1007-3, Section 264 552 If appropriate, the Army may request that the post-closure care period be reduced The requirements of 6 CCR 1007-3, Section 264 552 specify that post-closure care be conducted to protect human health and the environment for areas where remediation wastes will remain in-place CDPHE may extend the post-closure care period if it is found that the extended period is necessary to protect human health and the environment (Section 265 117(a)(2)(ii)) Post-closure activities include monitoring and maintenance activities to protect the integrity of the closed landfill

5.1 Post-Closure Monitoring and Maintenance Plan

Throughout the post-closure care period, ongoing monitoring and maintenance programs will be implemented The primary objectives of these programs are to assess the overall integrity of the closed landfill by performing regularly scheduled inspections, monitoring the groundwater conditions beneath the landfill, and performing regularly scheduled and periodic maintenance as required associated with the final cover, run-on/runoff controls, leachate collection and leak detection systems, groundwater monitoring wells, and surveyed benchmarks

5.1.1 Monitoring Plan

Inspections of the following items at the landfill will be performed throughout the post-closure period in accordance with the schedule established in the final closure plan

- Condition of the cover including cracks, uneven settlement, erosion features, presence of trees or deep-rooted vegetation, holes or burrows caused by wildlife, lack of vegetation, or any other condition that could hinder the effectiveness/integrity of the cover
- Run-on/runoff controls
- Condition of benchmarks
- Condition of the groundwater monitoring wells

The frequency of benchmark and groundwater monitoring well inspections will be in accordance with the schedule established in the final closure/post closure plan. It is not anticipated that there will be significant activity in the vicinity of these structures that would result in damage

Unsatisfactory items discovered during inspections will be noted and reported to CDPHE, and recommended corrective actions will be developed and implemented

The proposed groundwater monitoring program for the background period of the CAMU will be described in the Groundwater Monitoring Program (Appendix K to the CDD) Groundwater monitoring for operational post-closure care periods of the CAMU will be developed based on the results of the background and operational monitoring period

5.1.2 Maintenance Plan

Post-closure maintenance activities will be performed for the final cover, run-on/runoff controls, leachate collection and leak detection systems, groundwater monitoring wells, and surveyed benchmarks A general description of routine maintenance activities that are anticipated during the post-closure period is presented below Conditions that may warrant interim maintenance will be attended to as needed, based on the findings of routine inspections

5.1.2.1 Final Cover

Maintenance of the final cover will be performed and will, at a minimum, include repairing any desiccation cracks, erosion, gullying, holes, or burrows caused by wildlife, areas of uneven settlement, or other disruption that may effect the integrity of the cover A self-sustaining vegetative cover will be maintained

5.1.2.2 Run-on/Runoff Controls

Run-on/runoff control devices and storm-water conveyance structures will be maintained in good functional condition and prevent erosion or other damage of the final cover Maintenance of the run-on/runoff controls will be performed in accordance with the schedule established in the final closure plan The run-on/runoff control devices will be kept free of any obstructions, and any damage will be repaired as necessary for continued adequate operation

5.1.2.3 Leachate Collection and Leak Detection Systems

The leachate collection and leak detection systems will be maintained in good functional condition Pumpable leachate will be removed from the leachate collection and leak detection sumps on a regular basis to minimize the head on the bottom liner The amount of liquid removed from the leachate collection and leak detection systems will be recorded at regular intervals during the post-closure care period

Leachate collected from the landfill will be managed appropriately either onsite or offsite in accordance with applicable regulatory requirements at the time of generation The details regarding leachate treatment will be addressed during design

5.1.2.4 Groundwater Monitoring Wells

Groundwater monitoring wells will be maintained for measurement of water levels, collection of water samples, and analysis of the collected water samples for contaminant concentrations in accordance with the schedule established in the final monitoring plan. Well heads will be properly protected to prevent damage and equipped with locking caps to prevent tampering Necessary repairs to maintain the integrity of the wells will be performed, and, if necessary, abandonment and/or replacement of the wells will be performed

5.1.2.5 Surveyed Benchmarks

Benchmarks utilized for surveying the landfill during closure and grading of the final cover will be maintained in good condition throughout the post-closure period This will include making sure the benchmarks remain adequately located and easily accessible The benchmarks will be inspected and resurveyed periodically to check that consistent elevation and location control are maintained in accordance with the schedule established in the final closure plan

5.2 Certification of Post-Closure Care

After post-closure care of the landfill has been completed, post-closure monitoring results will be reviewed by the Army and an independent Professional Engineer, registered by the State of Colorado The professional engineer will not have participated, or belong to a firm that has participated either as a contractor or subcontractor, in the planning, construction, oversight, operation, or closure of any portion of the CAMU Within 60 days of completion of the post-closure care period, a certification report will be submitted by registered mail to CDPHE with certifications signed by the Army and the independent registered Professional Engineer that the post-closure care activities were conducted in accordance with the approved Post-Closure Plan.

5.3 Notation in the Deed

The post-closure certification report will include a copy of a survey plat pertaining to deed recordation in accordance with 6 CCR 1007-3, Section 264 552 that requires a notation to the deed to the facility property that will in perpetuity notify any potential purchaser of the property that the land has been used to manage remediation wastes, unless an alternative deed notation is approved by CDPHE the final closure plan will specify a deed notation for CDPHE review and approval A certification signed by the Army that the deed recordation described above has been performed will be submitted with the post-closure care certification report

6.0 ACRONYMS

Army	U S Department of the Army
BCY	Bank cubic yard
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
DAA	Detailed Analysis of Alternatives
DOT	U S Department of Transportation
Ebasco	Ebasco Services, Inc
ESE	Environmental Science and Engineering, Inc
FFA	Federal Facilities Agreement
HLA	Harding Lawson Associates
LDRs	Land disposal restrictions
MKE	Morrison-Knudsen Engineers, Inc
msl	Mean sea level
PPE	Personal protective equipment
RCRA	Resource Conservation and Recovery Act
RMA	Rocky Mountain Arsenal
State	State of Colorado
USGS	U S Geological Survey

7.0 REFERENCES

Ebasco Services, Inc 1989 *Draft final water remedial investigation report, Rocky Mountain Arsenal, Commerce City, Colorado*, March

Environmental Science and Engineering, Inc 1988 *Final phase I contamination assessment report site 26-1 Deep disposal well and chemical sewers, Rocky Mountain Arsenal, Adams County, Colorado* March

Foster Wheeler Environmental Corporation 1995 *Final detailed analysis of alternatives, Rocky Mountain Arsenal* Rocky Mountain Arsenal, Commerce City, Colorado October

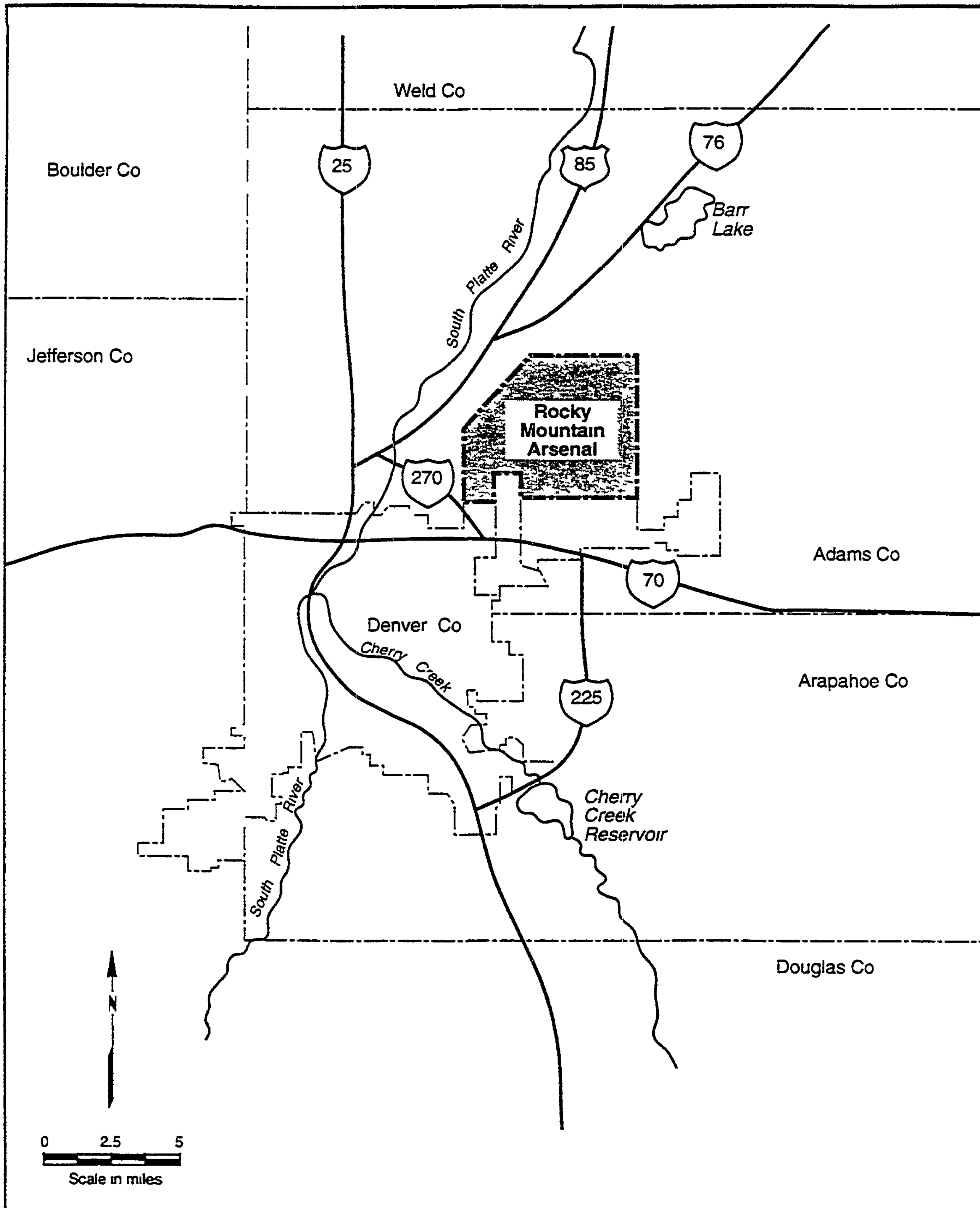
Harding Lawson Associates 1995 *Groundwater monitoring program groundwater monitoring report for 1993* Rocky Mountain Arsenal, Commerce City, Colorado March 24

May, J 1982 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado* Technical Report G2-82-6 July

Morrison-Knudsen Engineers, Inc 1988 *Geology of the RMA, Adams County, Colorado* January

Onpost Operable Unit Detailed Analysis of Alternatives Dispute Resolution Agreement between the U S Department of the Army, Shell Oil Company, the State of Colorado, the U S Environmental Protection Agency, the U S Fish and Wildlife Service 1995 October 16

United States Geological Survey 1995 *Final groundwater monitoring program task plan 1995* Rocky Mountain Arsenal September

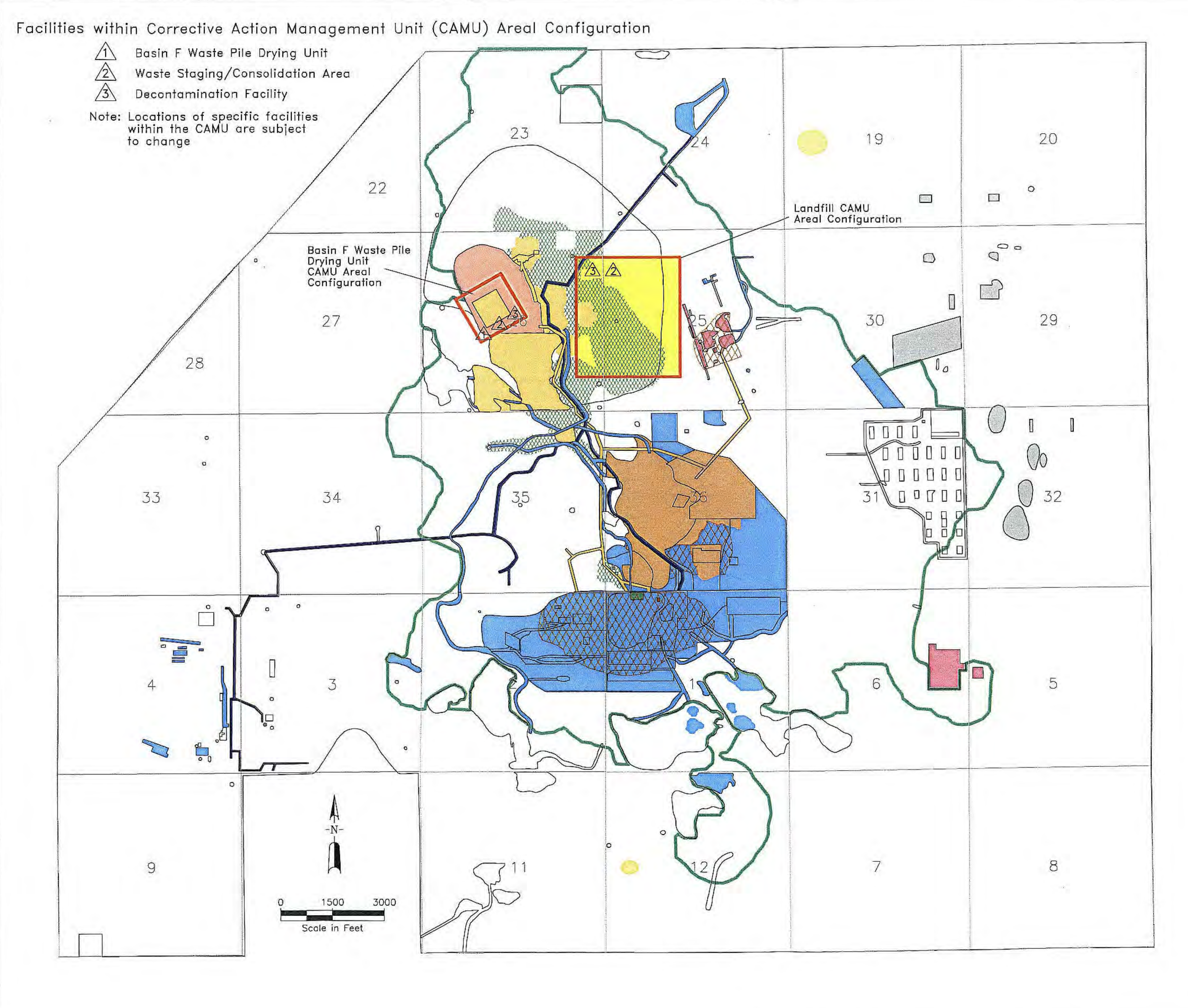


Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure L1

Site Location Map



Explanation

- Arsenal Boundary
- Study Area Report Boundary
- Area of Contamination Boundary
- CAMU Areal Configuration
- Landfill Principal Threat Volume; RCRA-Equivalent Cap
- Caps/Covers
- Direct Solidification/Stabilization
- Hex Pit Excavation
- Landfill Human Health Soil,[1] Consolidation of Biota Soil
- Landfill Human Health Soil[2]
- Landfill Site
- Soil Covers
- Agent Screening Area (Caustic wash/landfill)
- Unexploded Ordnance Screening Area (Detonation/landfill)
- Surficial Soil Consolidation
- Access Restrictions
- 5 Section Number

[1]Refuse from the Sanitary Landfills Medium Group will be consolidated

[2]Wastepile material will be dried prior to landfilling if paint filter test is failed

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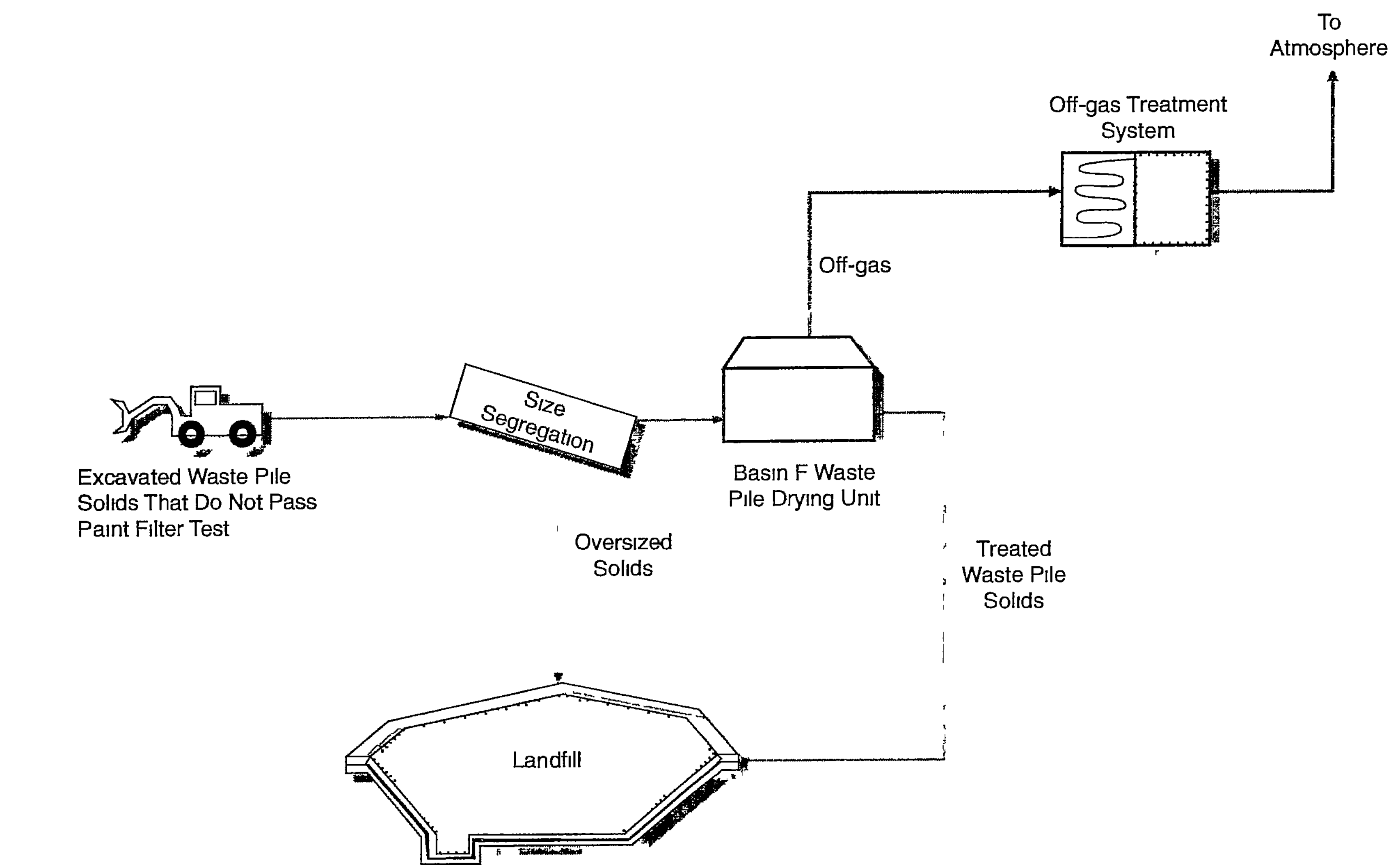
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by: Tetra Tech EC Inc.

Figure L2

Proposed Corrrective Action Management Unit Areal Configuration Rocky Mountain Arsenal



RMA 1257.2a 1/6/98 LAM

Explanation

→ Off-gas

→ Process residuals

Prepared for
Program Manager for
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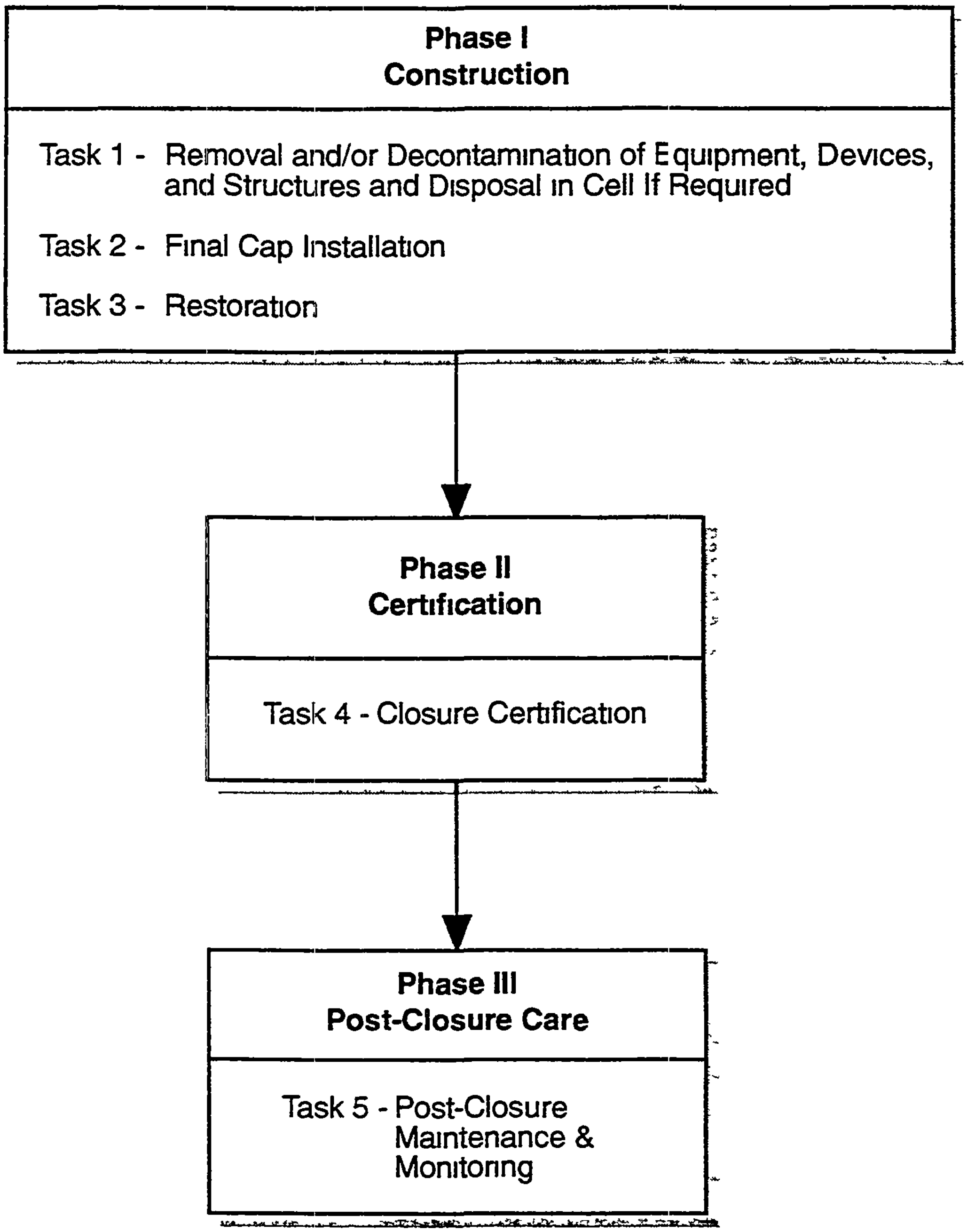
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure L3

Conceptual Process Flow Diagram for Basin F Waste Pile Drying Unit



RMA 1261.Jb 1/9/96 LAM

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Commerce City, Colorado

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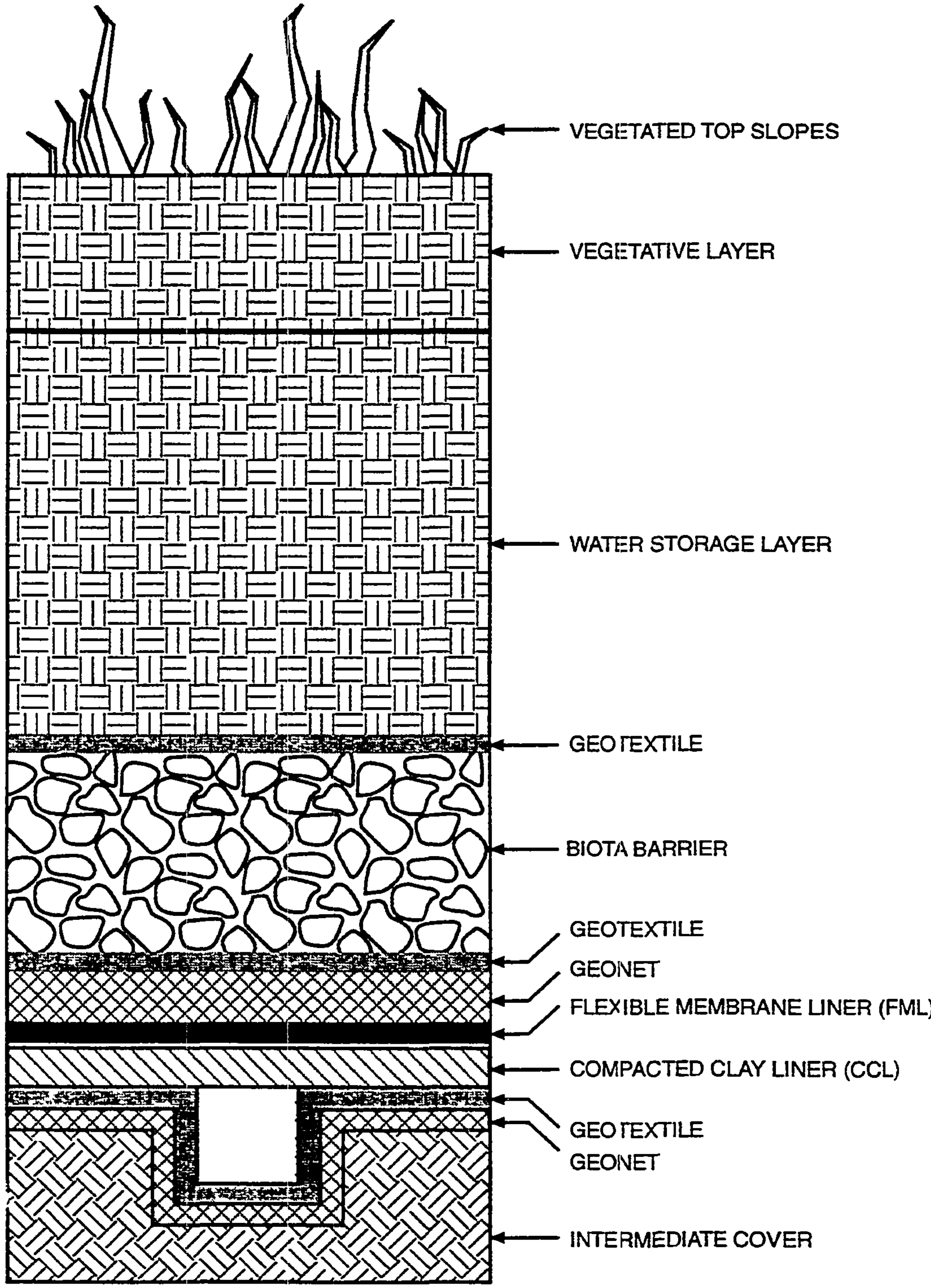
Harding Lawson Associates

Figure L4

Closure Process



RMA 1258 1/8/95 LAM

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Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure L5

Conceptual Cover Design

Appendix M

POST-CLOSURE PLAN

The Post-Closure Plan has been combined with the Closure Plan and included in Appendix L

Appendix N

ACTION LEAKAGE RATE AND RESPONSE ACTION PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

- 1 1 Purpose and Scope
- 1 2 Organization

2 0 Action Leakage Rate

- 2 1 Background
  - 2 1 1 Liner Systems
  - 2 1 2 Leachate Collection Systems
  - 2 1 3 Leak Detection Systems
  - 2 1 4 Potential Sources of Liquids in Leak Detection Systems
- 2 2 Action Leakage Rate Calculation
- 2 3 Operational Leakage Rate Calculation
- 2 4 Action Leakage Rate Exceedance

3 0 Response Action Plan

- 3 1 Initial Notification
- 3 2 Source Assessment
- 3 3 Response Actions
- 3 4 Status Notifications

4 0 Acronyms

5 0 References

Appendix O

HEALTH AND SAFETY PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

1 1 Purpose and Scope

1 2 Implementation and Modification of the Site Safety and Health Plan

1 3 Organization

2 0 Site and Facility Information

2 1 General Site Description

2 1 1 Site Status

2 1 2 Site History

2 1 3 Climate

2 1 4 Locations of Resources Available to Onsite Personnel

2 2 Chemicals Detected in Wastes Received at the Facility

2 3 Site Zones

2 3 1 Support Zones

2 3 2 Contamination Reduction Zones

2 3 3 Exclusion Zones

2 4 Site Control

3 0 Project Organization and Personnel Requirements

3 1 Organization and Safety Responsibilities

3 2 Personnel Requirements

4 0 Health and Safety Programs

4 1 Required Personnel Training

4 1 1 Regular Site Personnel Exposed to Hazardous Substances

4 1 2 Regular Site Personnel Partially Exposed to Hazardous Substance Below Permissible Exposure Limits

4 1 3 Occasional Site Personnel Potentially Exposed to Hazardous Substances Below Permissible Exposure Limits

Appendix P

PRELIMINARY SPECIFICATIONS

TABLE OF CONTENTS

- END OF TABLE OF CONTENTS -

INTRODUCTION

This appendix has been prepared as an appendix to the Corrective Action Management Unit (CAMU) Designation Document (CDD) in support of the designation of a CAMU as part of the remedy for the cleanup of the U S Army's Rocky Mountain Arsenal (RMA) located in Adams County, Colorado This Appendix has been prepared by Harding Lawson Associates (HLA) as a contract deliverable under Delivery Order 0007 (Task 93-03 Feasibility Study Soils Support Program) of Contract DAAA05-92-D0003 between HLA and the U S Department of the Army (Army) This appendix has been prepared at the direction of the Army for the sole use of the Army, the signatories of the Federal Facilities Agreement (FFA) of RMA, the State of Colorado (State), Adams County, and Tri-County Health Department, the only intended beneficiaries of this work. These Specifications are not intended to be used for construction of the RMA landfill, their sole purpose is to assist in the CAMU designation

Appendix P presents conceptual Specifications to assist in the overall demonstration of compliance with the requirements of 6 Code of Colorado Regulations (CCR) 1007-2, Part 2, Section 2 4 9, and additional guidance provided in 6 CCR 1007-3, Part 264 These Specifications are intended to demonstrate that the materials and methods are available for potential use in construction of the RMA landfill liner system, cover system, leachate collection system, leak detection system, and groundwater monitoring system that can meet regulatory requirements and satisfy the design criteria presented in Appendix B General product standards and execution procedures including material properties, testing requirements, and quality assurance/quality control procedures have been included for the primary components of the systems listed above

References to personnel (e g , Contractor, Owner's Representative) in these Specifications are general terms and are not intended to define personnel requirements during construction. Contractor refers to any company, organization, and personnel retained to assemble, fabricate, and erect the systems, facilities, and related appurtenances of the RMA landfill Owner's Representative refers to any company, organization, and personnel responsible for performing construction oversight and engineering during construction-related Work.

These Specifications typify the level of detail to be included in the final construction Specification package They will be appended and modified during design based on engineering evaluations, collection of additional site data, and other technical considerations as the design process proceeds In addition, portions of these Specifications may not be applicable to the final design and will be appropriately modified during the design process The Specifications have been prepared in Constructions Specifications Institute (CSI) format. The design Specifications may be prepared in a different format

SECTION 02200 EARTHWORK

PART 1 GENERAL

1 01 SUMMARY

A Section Includes

1 The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and other services necessary to perform general site grading, excavation, construction of roads, berms and other earthen structures, placement of the earthen components of the cover and liner systems (with the exception of compacted clay components addressed in Section 02721), disposal of unsuitable earthen materials, and all subsidiary Work required to complete such earth Work. The Work shall be carried out in accordance with these Specifications, the Construction Quality Assurance (CQA) Plan, the Drawings and other Contract Documents

1 02 REFERENCES

A American Society for Testing and Materials (ASTM) D422 - Method for Particle Size Analysis of Soils

B ASTM D698 - Test Methods for Moisture-Density Relations of Soil and Soil Aggregates Mixtures using a 5 5 lb Rammer and 12 in. Drop

C ASTM D1556 - Test Method for Density of Soil in Place by the Sand-Cone Method

D ASTM D2167 - Test Method for Density and Unit Weight of Soils in Place by Rubber Balloon Method

E ASTM D2216 or D4643 - Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures

F ASTM D2487 - Test Method for Classification of Soil for Engineering Purposes

G ASTM D2922 - Test Method for Density of Soil and Soil Aggregate In Place by Nuclear Methods

H ASTM D3017 - Test Method for Moisture Content of Soil and Soil Aggregate In Place by Nuclear Methods

I ASTM D4318 - Test Method for Liquid Limit, Plastic Limit, and Plasticity Index for Soil

J ASTM C131 - Test Method for Resistance to Degradation of Small Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine

K. ASTM C136 - Test Method of Sieve Analysis of Fine and Coarse Aggregate

L ASTM C88 - Test Method for Soundness of Aggregate

M FB85 703 06 U S Department of Transportation Federal Highways Administration - Aggregate for subbase, base or surface courses, cold asphaltic concrete pavement and road mixed asphaltic concrete pavement.

1 03 QUALITY ASSURANCE

A Field Measurements

1 Verify that survey benchmark and intended elevations for the Work are as indicated on Drawings

B Regulatory Requirements

1 Perform all excavation Work in accordance with Occupational Safety and Health Administration (OSHA) requirements, "Excavating and Trenching Operations "

2 Comply with applicable county and state codes and ordinances

1 04 SUBMITTALS

A Submit laboratory test data and Manufacturer's product data and certification

B Samples Submit samples of each type of fill to a testing laboratory in airtight containers in accordance with the requirements of the design.

1 05 PROJECT/SITE CONDITIONS

A Environmental Requirements

1 Noise

a Noise levels are to be maintained as required by applicable local and state laws and ordinances

2 Pollution

a Equipment emissions and dust levels are to be maintained as required by applicable local and state laws and ordinances

B Existing Conditions

1 Information shown on Drawings regarding existing site conditions is believed to be correct, but is not guaranteed Contractor shall visit the site for necessary information and data regarding present ground levels, groundwater level, conditions of property, location, size of obstructions, and access

2 Existing utilities may be encountered that are not shown on Drawings or evident from site inspection. Owner's Representative shall be notified immediately if such utilities are discovered

3 Provide and maintain all barricades, shoring, and bracings as required by federal and state codes

4 Construct and maintain temporary drainage routes during construction so that rainfall or snowmelt will drain from site and not accumulate or pond

5 Contractor shall assume all responsibility for damage to utilities, survey monuments, streets, monitoring wells, and structures that may be caused by this Work.

6 Contractor shall not interfere with other facility operations or operating roadways without prior consent from the Owner's Representative

C Excavation Safety

1 Provide appropriate measures to retain excavation sideslopes and prevent slope failures or rock falls to ensure that persons working in or near the excavation are protected

2 Contractor shall become familiar with and comply with all applicable codes, ordinances, and statutes and bear sole responsibility for the penalties imposed for noncompliance

1 06 DEFINITIONS

A Percent compaction The in-place dry density of the material expressed as a percentage of the maximum dry density of the same material as determined by the ASTM D698 test method

B Optimum moisture content The moisture content (expressed as a percentage of the dry weight of the material) corresponding to the maximum dry density of the same material as determined by the ASTM D698 test method

C Structural fill areas Where used in these Specifications, structural fill areas shall mean (1) within building or access road areas and for a distance of at least 5 ft beyond the outside edges of perimeter footings, (2) within exterior concrete slab areas and for a distance of 3 ft beyond slab edges, and (3) to establish berms, dikes, and other miscellaneous earthen structures as shown on the Drawings

D Soil subgrade Where used in these Specifications soil subgrade shall mean (1) within concrete slab-on-grade floor areas, the surface on which slab rock is placed, (2) within exterior concrete slab areas, the surface on which concrete is placed, (3) within asphalt paved and access road areas, the surface on which aggregate base is placed, and (4) within the extent of subgrade construction, as shown on the Drawings, including the surface on which the landfill cell liners or covers are placed

E Completed Course

1 A course or layer that is ready for the next layer or next phase of Work.

F Imported Material

1. Material obtained by the Contractor from sources offsite

1 07 DELIVERY, STORAGE, AND HANDLING

A Acceptance at Site

1 Imported Materials

a No imported materials shall be delivered to the site until the proposed source and materials tests have been accepted by Owner's Representative b Final acceptance shall be based on tests made on samples of materials taken from the completed and compacted course

B Storage and Protection

1 During the interval between the delivery of material and installation, material shall be stored in a manner affording protection and favorable conditions to prevent material loss or deterioration.

PART 2 PRODUCTS

2 01 MATERIALS

A Structural fill Structural fill material shall be free of perishable material and rocks or lumps larger than 4 in in greatest dimension All fill material shall be approved by the Owner's Representative

B Fine-grained soil fill Fine-grained soil shall be acceptable soil excavated from the project site and stockpiled, excavated from an approved borrow area, or provided from an accepted offsite source The fine-grained soil shall meet the following requirements

1 Be free of plants, roots, rubble, litter, insect infestation, and other deleterious matter

2 Be in accordance with the gradation set forth in the design, as determined by ASTM D422

C Topsoil/Gravel Admix If required by the design, the Contractor shall provide a topsoil/ gravel admixture proportioned to meet the requirements set forth during design

The topsoil portion of the topsoil/gravel admixture shall meet the following requirements

1 Be capable of sustaining healthy plant life and shall be free of noxious weeds, sticks, brush, litter, insect infestation, and other deleterious matter

2 Have a pH and soluble salt level capable of supporting vegetation

3 Meet the nutrient requirements determined during design either by natural occurrence or by means of additives as determined by American Society of Agronomy, Inc (ASA) Methods of Soil Analysis

4 Follow the gradation set forth in design, as determined by ASTM D422

The gravel portion of the topsoil/gravel admixture shall meet the following requirements

1 Be washed rock.

2 Consist of angular fragments with a percentage of wear set forth during design, as determined by ASTM C131

D Gravel Armoring If required by the design, the Contractor shall provide gravel armoring for the engineered cover in those areas designated on the design Drawings The gravel shall be washed screened rock with the gradation set forth during design. The rock shall be angular crushed rock with a percent fracture determined during design, as determined by FP-85 703 06

E Biotic Barrier Rock The Contractor shall supply material for the biotic barrier of the engineered cover The rock shall meet gradation and material requirements set forth in the design

F Sand Drainage/Vent Material If required in the design, the Contractor shall provide sand fill or other suitable media for drainage/vent layers of the cover and liner systems The material shall meet the following criteria

1 Be in accordance with the gradation provided during design, as determined by ASTM C136

G Pipe Bedding Material The Contractor shall furnish pipe bedding material for backfill around pipes in pipe trenches The bedding material shall meet the following criteria

1 The bedding material shall be in accordance with the gradation provided during design, as determined by ASTM C136

H Gravel Road Base The Contractor shall provide gravel road base material for those areas designated on the design Drawings The gravel road base shall meet the following requirements

1 The gravel road base shall be in accordance with the gradation provided during design, as determined by ASTM C136

I Imported Materials Imported material required for earthwork shall be tested by the Contractor and approved by the Owner's Representative before use The Contractor shall provide at least two weeks notice before using the imported material to enable the Owner's Representative to sample and test the material, if necessary

PART 3 EXECUTION

3 01 UTILITIES

A Utilities The Contractor shall be responsible for location and protection of all new and existing utility lines during execution of Work onsite in accordance with 1 05 B 2 of this Section Damage to any utility resulting from the Contractor's activities onsite shall be repaired or replaced by the Contractor as required by the utility Owner

3 02 DISPOSAL OF EXCAVATED MATERIAL

A. Disposal of excavated material Excavated material generated during the execution of Work specified herein, that is not used as backfill, shall be stored and disposed as directed by the Owner's Representative

3 03 OVEREXCAVATION

Excavation shall be held to those limits shown on the design Drawings unless otherwise directed by the Owner's Representative Where unsuitable sub-base is encountered, the Contractor shall notify the Owner's Representative immediately Overexcavation that is executed without prior approval of the Owner's Representative shall be at the expense of the Contractor

3 04 EXCAVATION

A Preparation

1 Identify required lines, levels, contours, and datum

2 Identify known underground, aboveground, and aerial utilities Stake and flag locations

3 Protect or replace at no cost to Owner above and below grade utilities that are to remain

4 Protect benchmarks, fences, paving, and curbs from excavation equipment and vehicular traffic

5 Removal of water during construction operations

a Provide and operate equipment adequate to keep all excavations and trenches free of water

b Avoid settlement or damage to adjacent property

c Disposition of water within Owner's property to be designated by Owner's Representative

d Dewatering open excavations shall be from outside the structural limits and from a point below the bottom of the excavation when possible

e Design dewatering systems to prevent removal of fines from existing soil

B Erection, Installation, and Application

1 General

a Perform all excavation of every description, regardless of the type, nature, or condition of material encountered as specified, shown on Drawings, or required to accomplish the construction.

b Method of excavation is optional, however, no equipment shall be operated within 5 ft. of existing structures or newly completed construction.

c Excavation that cannot be accomplished without endangering present or new structures shall be done with hand tools

2 Limits of Excavation

a Excavate to the depths and widths as shown on Drawings

b Allow for forms and working space, as required by OSHA regulatory requirements c Excavation carried below the grade lines shown on Drawings shall be replaced with the same fill material as specified for the overlying fill or backfill and compacted in accordance with this Section

d For overexcavation where the overlying area is not to receive fill, replace the overexcavated material and compact to a density not less than that of the underlying ground

e Cuts below grade shall be corrected by similarly cutting adjoining areas and creating a smooth transition

f Underpin adjacent structures that may be damaged by excavation Work including utilities and pipe chases

g Excavate subsoil required to accommodate building foundations, slabs-on-grade, paving and site structures, and construction operations

h Machine slope banks to angle of repose or less, until shored

i Excavation cut not to interfere with normal 45 degree bearing splay of foundation

j Grade top perimeter of excavation to prevent surface water from draining into excavation

k. Hand trim excavation and remove loose matter

l Notify Owner's Representative of unexpected subsurface conditions and discontinue affected Work in area until notified to resume Work.

m Stockpile excavated material in area designated onsite and remove excess material not being reused from site or place in area onsite as directed by Owner's Representative

3 05 INSTALLATION AND APPLICATION OF FILL MATERIALS

A Backfilling

1 Backfill areas with unfrozen materials to contours and elevations shown on Drawings

2 Systematically backfill to allow maximum time for natural settlement. Do not backfill over porous, wet, frozen, or spongy subgrade surfaces, unless approved by Owner's Representative

3 Place and compact fill materials in continuous layers not exceeding 8-in. compacted depth

4 Employ a placement that does not disturb or damage foundation perimeter drainage and yard piping in trenches

5 Backfill against supported foundation walls Do not backfill against unsupported foundation walls

6 Backfill simultaneously on each side of unsupported foundation walls until supports are in place

7 Remove surplus fill materials from site or place in areas designated by the Owner's Representative

8 Backfill around concrete structures only after the concrete has attained the specified compressive strength indicated in Division 3, Concrete, and concrete Work is accepted by Owner's Representative

9 Do not operate earth-moving equipment within 5 ft. of walls of concrete structures for the purpose of depositing or compacting backfill material Compact backfill adjacent to concrete walls with hand-operated tampers or similar equipment that will not damage the structure

B Fill

1 Place fill to the lines and grade as shown on Drawings

2 Make allowance for granular base material or topsoil when required

3 Remove all form materials and trash from the sub-base before placing any fill materials

C Compaction

1 Compact all materials by mechanical means Flooding or jetting shall not be permitted

2 If in-place density tests indicate that compaction or moisture content is not as specified, material placement shall be terminated and corrective action shall be taken by the Contractor before continued placement

D Moisture Control

1 Moisture condition material before placement.

2 Maintain moisture content required for compaction purposes in each lift of fill

3 Maintain moisture content uniform throughout the lift

4 At the time of compaction, the moisture content of the material shall be as specified during design.

5 Supplement, if required, by sprinkling the fill

6 Do not attempt to compact fill material that contains excessive moisture Aerate material by blading, discing, harrowing, or other methods to hasten the drying process

E Field Density and Moisture Tests

1 Owner's Representative will determine in-place density and moisture content by any one or combination of the following methods

a ASTM D1556

b ASTM D2167

c ASTM D2216

d ASTM D2922

e ASTM D3017

f ASTM D4643

2 Frequency and location of testing shall be determined solely by Owner's Representative

3 CQA firm will test any lift of fill at anytime, location, or elevation

F Disposal of Excess Excavation

1 Dispose all excess excavation not required or suitable for backfill or filling within Owner's property at an area to be designated by the Owner's Representative

G Tolerances

1 Acceptable dimensional tolerances shall be followed as set forth during design

3 06 QUALITY CONTROL

A The Contractor shall be responsible for documenting all test results and the number of compaction passes completed per lift.

B Placed materials not in accordance with the requirements of this Specification shall be repaired and/or replaced by the Contractor The Contractor shall submit a description of repair and/or replacement methods to the Owner's Representative for written approval before implementation

C Acceptance criteria for repaired and/or replaced materials shall be in accordance with the requirements of this Specification

D Areas that do not conform with the Specifications will first be investigated by the Contractor for the extent of nonconformance Areas that are of a different material type or that have failed the Specifications, after efforts to recompact the soil shall undergo additional testing regardless of the testing frequency guidelines The Owner's Representative will determine when additional testing is required Results of additional testing shall be submitted to the Owner's Representative for review and final acceptance

E Final acceptance shall be explicitly detailed by survey location, layer description, material type, and lift number

- END OF SECTION -

SECTION 02712 GEOSYNTHETIC CLAY LINERS

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geosynthetic clay liner (GCL) components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A. All Work will be monitored and tested in accordance with requirements of the CQA Plan.

B Any GCL rolls that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C If testing indicates Work does not meet the requirements of the Specifications, the Owner's Representative will establish the extent of the nonconforming area The nonconforming area shall be repaired by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2 01 GCL PROPERTIES

A The Contractor shall require that the GCL Manufacturer furnish material with minimum average roll values, as defined by the Federal Highway Administration (FHWA), meeting or exceeding the criteria that will be developed during design. The Contractor shall require that the GCL Manufacturer provide results for tests performed using the test procedures identified during design, as well as a certification that the material properties for the material delivered to the site will meet or exceed the specified values

B In addition, the GCL shall

1. Retain its structure during handling, placement, and long-term service

2 Meet any additional requirements of the Drawings

2 02 MANUFACTURING QUALITY CONTROL

A The Contractor shall require that the GCL Manufacturer sample and test the GCL to demonstrate that the material conforms to the requirements of these Specifications All Quality Control testing required by the Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor Test results shall be provided to the Owner's Representative Sampling shall, in general, be performed on sacrificial portions of the GCL material such that repair is not required The Contractor shall require that the GCL Manufacturer sample and perform the manufacturing quality control tests as specified

B Any GCL sample that does not comply with these Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

C If a GCL sample fails to meet the quality control requirements of these Specifications, the Contractor shall require that the GCL Manufacturer sample and test each roll manufactured, in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results is established as specified within the CQA Plan

D Additional sample testing may be performed, at the GCL Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A GCL rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

2 04 TRANSPORTATION

A. Transportation of GCL shall be the responsibility of the Contractor The Contractor shall be liable for damage to the GCL incurred prior to and during transportation to the site The Contractor shall repair or replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A. GCL shall be protected from moisture during shipping and storage

B Handling, storage, and care of the GCL prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the material incurred prior to final acceptance by the Owner The Contractor shall repair damage in accordance with Part 3.03 of this Section and at no additional cost to the Owner

C The Contractor shall be responsible for storage of the GCL at the site The GCL shall be stored off the ground and shall be protected from excessive heat or cold, moisture, dirt, dust, or any other damaging or deleterious condition. The GCL shall be stored in accordance with any additional requirements of the GCL Manufacturer

PART 3 EXECUTION

3.01 HANDLING AND PLACEMENT

A. If required by the design, GCL shall be installed at all locations shown on the Drawings

B The Contractor shall handle the GCL in such a manner as to ensure the GCL is not damaged in any way

C The area over which the GCL will lie should be smooth and free of standing water and protruding rocks, roots, vegetation, debris, and large voids

D Just prior to GCL placement, any geosynthetics that may underlie the GCL shall be clean and free of dust, dirt, stones, rocks, or other obstructions that could potentially damage the GCL These geosynthetics shall be swept or blown clean prior to GCL placement

E. The Contractor shall take all necessary precautions to prevent damage to underlying materials during placement of the GCL.

F In the presence of excessive wind, the GCL shall be weighted by the Contractor with sandbags or equivalent weight approved by the Owner's Representative

G If necessary, the Contractor shall position the GCL by hand and after it is unrolled to minimize wrinkles

H Only as much GCL shall be deployed as can be covered at the end of the day, or that can be covered in a reasonably short time in the event of precipitation

1 When GCL is being installed under a geomembrane liner, the leading edge of the GCL should be folded back under the membrane at the end of the construction day The leading edge of the membrane should be secured by sandbags or suitable ballast to prevent uplift and the infiltration of runoff water

I GCL panels shall be deployed in the direction of greatest slope (i e , longest dimension is parallel to slope direction)

J GCL panel deployment shall generally proceed from the highest elevation to the lowest elevation.

3 02 OVERLAPS AND SEAMS

A. Adjacent GCL panels are to be overlapped according to the match line on the bottom panel Overlaps shall be and in accordance with Manufacturer's instructions and requirements of the design

B Transverse overlaps at the ends of each roll shall be as required in the design.

C Overlaps shall be shingled in a downslope direction so that water would flow from the top sheet to the bottom sheet.

D Care shall be taken to ensure that no native soil or debris is present between overlaps

E Granular bentonite shall be placed between seam overlaps in accordance with the Manufacturer's recommendations

F The joints on adjacent GCL panels shall be staggered as required in the design

G No horizontal seams shall be allowed on slopes steeper than 4 1 (horizontal vertical), unless approved by the Owner's Representative.

3 03 REPAIR

A Any holes or tears in the GCL shall be repaired by placing a patch over the hole or tear extending beyond the edges of the hole or tear The patch shall be secured to the original GCL by applying granular bentonite between the overlap If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the GCL shall be joined in accordance with Part 3 02 of this Section

B On slopes steeper than 4 1, repairs shall be performed by removing and replacing the damaged panel

C Any GCL exposed to standing water or to any hydrocarbon fuels, chemicals, pesticides, leachates, or other such liquids during installation, shall be removed and replaced

3 04 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The Owner's Representative will identify any areas requiring repair The Contractor shall make repairs and replacements as necessary, to the approval of the CQA firm at no additional cost to the Owner

C The Owner's Representative will issue an approval of the GCL installation to the Owner prior to placement of material over the GCL in accordance with the CQA Plan

- END OF SECTION -

SECTION 02713 GEOMEMBRANE LINERS

PART 1 GENERAL

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geomembrane liners components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the CQA Plan and the Products Subsection of this Section

C Layout Drawings Contractor shall submit Layout Drawings for the geomembrane liners to the Owner's Representative describing in detail where and how the liners will be installed Work covered in this Section shall not commence until Layout Drawings are reviewed and approved by the Owner's Representative

D The Contractor shall furnish the following submittals for the geomembrane liner

1 Raw Materials

a Certification that all raw materials used in the manufacture of geomembrane for this job meet the Specifications

b Copy of quality control certificates issued by the geomembrane supplier

2 Geomembrane Roll Production

a Copy of quality control certificates

1 03 QUALITY ASSURANCE

A. The Manufacturer of the geomembrane shall be listed by National Sanitation Foundation as having met Standard 54 for Flexible Membrane Liners and shall have at least five (5) years of continuous experience in the manufacture of geomembranes

PART 2 PRODUCTS

2 01 GEOMEMBRANE PROPERTIES

A The geomembrane Manufacturer shall be a Manufacturer making geomembrane meeting the requirements of this Section. The Owner's Representative (based on concurrence with regulatory authorities) may approve an alternate material if sufficient evidence is submitted to verify that the alternate material meets the requirements of this Specification.

B Smooth or textured geomembrane shall be used based on the requirements of the Drawings

C The Contractor shall furnish geomembranes having properties that comply with the required property values specified during design and that meet the manufacturing quality control requirements in Section 2 02 below

2 02 MANUFACTURING QUALITY CONTROL

A Geomembrane Materials

1 The Contractor shall require that the geomembrane Manufacturer sample and test the geomembrane to demonstrate that the resin complies with this Specification. The Contractor shall require that the geomembrane Manufacturer certify in writing that the material meets this Specification, and the geomembrane Manufacturer be held liable for any noncompliance Any geomembrane manufactured from noncomplying materials shall be rejected

2 The Contractor shall require that the geomembrane Manufacturer comply with the submittal requirements of these Specifications

B Rolls

1 The Contractor shall require that the geomembrane Manufacturer continuously monitor the geomembranes during the manufacturing process for inclusions, bubbles, or other defects No geomembrane that exhibits any defects will be accepted

2 The Contractor shall require that the geomembrane Manufacturer continuously monitor the geomembrane thickness during the manufacturing process No geomembrane that fails to meet the specified minimum thickness will be accepted

3 The Contractor shall require that the geomembrane Manufacturer sample and test the geomembrane to demonstrate that its properties conform to the values specified

a Samples shall be taken across the entire width of the roll and shall not include the first wrapping or outer layer of the roll

4 Geomembrane rolls that do not have acceptable manufacturing quality control test results shall be rejected by the Contractor

5 In the case of the rejection of a roll of geomembrane, the Contractor shall require that the geomembrane Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results is established

6 Additional testing may be performed at the geomembrane Manufacturer's discretion and expense, to more closely identify the noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A. The geomembrane shall be labeled with the following information

1 Thickness of the material

2 Length and width of the roll or factory panel

3 Name of Manufacturer

4 Product identification

5 Lot number

6 Roll or factory panel number

2 04 TRANSPORTATION

A Transportation of the geomembrane is the responsibility of the Contractor The Contractor shall be liable for all damage to the materials incurred prior to and during transportation to the site The Contractor shall repair or replace any damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Handling, storage, and care of the geomembrane prior to and following installation at the site, is the responsibility of the Contractor The Contractor shall be liable for all damage to the material incurred prior to final acceptance of the installation by the Owner's Representative The Contractor shall repair all damage in accordance with Part 3 03 K.4 of this Specification at no additional cost to the Owner

B The Contractor shall be responsible for storage of the geomembrane at the site The Owner will provide storage space in a location (or several locations) such that onsite transportation and handling are optimized, if possible During storage, the geomembrane shall be protected from theft, vandalism, dirt, excessive heat or cold, puncture, cutting, or other damaging or deleterious conditions The geomembrane shall also be stored in accordance with any additional requirements of the geomembrane Manufacturer

PART 3 EXECUTION

3 01 EARTHWORK

A. Surface Preparation

1 Geomembrane liner shall be installed at all locations shown on the Drawings

2. The geomembrane liner shall be installed as soon as practical after the completion and acceptance by the Owner's Representative of the placement area

3 Areas to receive geomembrane liner shall be smooth and even, and free of ruts, voids, obstruction, etc The final surface to receive the geomembrane shall be prepared in accordance with requirements developed during design No rubber-tired vehicles shall be allowed on the final dressed surface without the approval of the Owner's Representative

4 The Contractor shall provide certification that the surface on which the geomembrane will be installed is acceptable The certification of acceptance for each area under consideration shall be given to the Owner's Representative prior to commencement of geomembrane installation in that area.

B Anchor Trenches

1 The anchor trench shall be excavated prior to geomembrane placement to the elevations, grades, and widths shown on the Drawings

2 No loose soil shall be allowed beneath the geomembrane in the anchor trench

3 The anchor trench shall be backfilled after the geosynthetic layers have been installed (as applicable) Care shall be taken when backfilling the anchor trench to prevent any damage to the geomembrane or other geosynthetics

4 Slightly rounded corners shall be provided in the anchor trench where the geomembrane adjoins the trench to avoid sharp bends in the geomembrane

3 02 GEOMEMBRANE DEPLOYMENT

A. Field Panel Identification

1 A geomembrane field panel is defined as a roll or a portion of a roll cut in the field

2 Each field panel must be given an identification code (number or letter-number)

B Field Panel Placement

1 Field panels shall be placed one at a time, and each field panel shall be seamed immediately after its placement

2 Geomembranes shall not be placed when the ambient temperature is below 40°F unless the Contractor has previously submitted a geomembrane cold-weather placement and seaming plan and such plan has been approved by the Owner's Representative

3 Geomembranes shall not be placed during any precipitation, in the presence of excessive moisture (e g , fog, dew), in an area of ponded water, or in the presence of excessive winds

4 The Contractor shall employ placement methods which ensure that

a No vehicular traffic shall be allowed on the geomembrane

b Equipment used shall not damage the geomembrane by handling, trafficking, excessive heat, leakage of hydrocarbons, or other means

c. Personnel working on the geomembrane shall not smoke, wear damaging shoes, have glass containers or tools not required for liner placement on the geomembrane, or engage in other activities that could damage the geomembrane

d The method used to unroll the panels shall not scratch or crimp the geomembrane and shall not damage the underlying materials

e The method used to place the panels shall minimize wrinkles (especially differential wrinkles between adjacent panels) f Temporary loads and/or anchors (e g , sandbags), not likely to damage the geomembrane, shall be placed on the geomembrane to prevent uplift by wind (in high winds, continuous loading is recommended along panel edges to minimize the risk of damage due to uplift cause by wind flow under the panels)

g The geomembrane shall be especially protected from damage in heavily trafficked areas

5 On slopes, geomembranes shall be installed in a controlled manner from the top of the slope to the bottom The geomembrane shall be temporarily anchored at the top of the slope prior to deployment Unrestrained release of the geomembrane from the top of the slope is not acceptable

6 Any field panel or portion thereof that becomes seriously damaged (torn, twisted, or crimped) shall be replaced with new material at no expense to the Owner Less serious damage may be repaired with the approval of the Owner's Representative Damaged panels or portions of damaged panels that have been rejected shall be removed from the Work area at no expense to the Owner

7 Adjacent geomembrane panels shall be overlapped as described in Part 3 03 D below Larger overlaps shall be used if thermal contraction of the geomembrane is anticipated prior to seaming Adjacent panels shall be placed under similar temperature conditions, preferably early in the day when temperatures are cooler, to minimize the potential for differential contraction

3 03 FIELD SEAMING

A Seam Layout

1 In general, seams shall be oriented parallel to the line of maximum slope (i e , oriented down, not across, the slope) In corners and at odd-shaped geometric locations, the number of field seams shall be minimized No seams shall be located in an area of potential stress concentration (i e , seams shall be along, not across, the slopes), except as part of a patch, unless approved by the Owner's Representative

B Personnel

1 All personnel performing seaming operations shall be qualified as required by this Specification

C Weather Conditions for Seaming

1 Seaming shall not be attempted at ambient temperatures below those identified during design and as specified by the Manufacturer recommendations In all cases, the geomembrane shall be dry and protected from excessive wind

2 If the Contractor wishes to perform seaming at ambient temperatures below those specified, the Contractor shall demonstrate that the seam so produced is equivalent to those produced under normally approved conditions and that the overall quality of the geomembrane is not adversely affected The Contractor shall submit a geomembrane cold-weather placement and seaming plan that details all aspects of the cold-weather seaming operation. The plan must certify that the cold-weather seaming procedure does not cause any physical or chemical modification to the geomembrane

that the seam so produced does not result in any short- or long-term damage to the geomembrane

3 To minimize geomembrane contraction stresses, seaming should ideally be carried out in the morning and later evening when the geomembrane is relatively contracted, and during the middle of the day if overcast conditions prevail If the geomembrane must be seamed in the middle of a sunny day, the Contractor shall ensure that the panels to be seamed are at the same temperature and that there is sufficient slack in the geomembrane to prevent the generation of excessive stresses or trampolining when the geomembrane contracts as cooler temperatures prevail The required amount of slack shall be determined by the Contractor and it should not be so much so as to cause significant wrinkling of the geomembrane If trampolining or excessive wrinkling of the geomembrane is observed, the Contractor will be required to make repairs so that the problem is eliminated

D Overlapping and Temporary Bonding

1 Geomembrane panels shall have sufficient overlap provided to meet requirements developed during design and allow specified tests to be performed on the seam

2 The procedure used to temporarily bond adjacent panels together shall not damage the geomembrane

E Seam Preparation

1 Prior to seaming, the seam area shall be cleaned so that it is free of moisture, dust, dirt, debris of any kind, and foreign material

2 If seam overlap grinding or other preparation procedure is required, the process shall be completed within 30 minutes of the seaming operation in a manner that does not damage the geomembrane

3 Seams shall be aligned with the fewest possible number of wrinkles and "fishmouths "

F General Seaming Requirements

1 All geomembrane overlaps shall be continuously seamed using approved procedures The sequence for seaming geomembranes will be determined jointly by the Contractor and Owner's Representative during preconstruction meetings

2 Seaming shall extend to the outside edge of panels to be placed in the anchor trench.

3 If required, a firm substrate shall be provided by using a flat board, a conveyor belt, or similar hard surface, directly under the seam overlap to achieve proper support

4 If seaming operations are carried out at night, adequate illumination shall be provided

5 Fishmouths or wrinkles at the seam overlaps shall be cut along the ridge of the wrinkle to achieve a flat overlap The cut fishmouths or wrinkles shall be seamed, and any portion where the overlap is inadequate shall then be patched with an oval or round patch of the same geomembrane that extends beyond the cut in all directions in accordance with requirements specified in the design

6 At the end of each day or installation segment, all exposed geomembrane edges shall be anchored by sandbags or other approved means If high winds are expected, boards with weighted sandbags on top may be used to keep wind from getting under the exposed edge of the geomembrane

G Seaming Process

1 Approved processes for field seaming will be identified during design. Alternate processes shall not be used unless a plan for their use has been submitted by the Contractor and approved by the Owner's Representative Seaming equipment and methods shall not damage the geomembrane

H Trial Seams

1 Trial seams shall be made on fragment pieces of geomembrane to verify that seaming conditions are adequate Such trial seams shall be made at the frequencies specified in the design Trial seams shall be made under the same conditions as actual seams

2 Specimens shall be cut from the trial seam sample by the Contractor for testing The test specimens shall not fail in the seam If a specimen fails, the entire operation shall be repeated If the additional trial seam fails, the seaming apparatus or seamer shall not be accepted and shall not be used for seaming until the deficiencies are corrected and two consecutive successful trial seams are achieved

3 The Owner's Representative will observe all trial seam procedures Successful trial seam samples will be assigned a number and marked accordingly by the Owner's Representative, who will also log the date, hour, ambient temperature, name of seamer, and pass or fail description The sample itself will be retained in the Owner's Representative's archives

I Nondestructive Seam Continuity Testing

1 Contractor shall nondestructively test all field seams over their full length, except as indicated using a test method identified during design

J Destructive Testing

1 Destructive seam tests shall be performed on samples collected from selected locations to evaluate seam strength and integrity Samples shall be collected at a minimum frequency of one sample per 500 feet of seam Destructive tests shall be carried out as the seaming Work progresses, not at the completion of all field seaming

2 Sampling

a Test locations shall not be determined prior to seaming and may be prompted by suspicion of excess crystallinity, contamination, offset seams, or any other potential cause of imperfect seaming The Owner's Representative will be responsible for choosing the locations of destructive seam samples The Contractor shall not be informed in advance of the locations where the seam samples will be taken. The Owner's Representative reserves the right to increase the sampling frequency

b. Samples shall be cut by the Contractor at the locations designated by the Owner's Representative as the seaming progresses in order to obtain laboratory test results before the geomembrane is covered by another material. Each sample shall be numbered and the sample number and location identified on the panel layout drawing. All holes in the geomembrane resulting from the destructive seam sampling shall be repaired immediately in accordance with the repair procedures described in Part 3 03 K. of this Section. The continuity of the new seams in the repaired areas shall be tested according to Part 3 03 I of this Section

K. Defects and Repairs

1. The geomembrane will be inspected before and after seaming for evidence of defects, holes, blisters, undispersed raw materials, and any contamination by foreign matter. The surface of the geomembrane shall be clean at the time of inspection. The geomembrane surface shall be swept or washed by the Contractor if surface contamination inhibits inspection

2. Each suspect location, both in seam and nonseam areas shall, at the discretion of the Owner's Representative, be either repaired or tested. Each location that fails testing shall be marked by the Owner's Representative and repaired by the Contractor

3. When seaming of a geomembrane is completed (or when seaming of a large area of a geomembrane is completed) and prior to placing overlying materials, the Owner's Representative shall identify all excessive geomembrane wrinkles. The Contractor shall cut and reseam all wrinkles so identified. The seams thus produced shall be tested like any other seams

4. Repair Procedures

a. Any portion of the geomembrane exhibiting a flaw or failing a destructive or nondestructive test, shall be repaired by the Contractor. The final decision as to the appropriate repair procedure shall be agreed upon between the Owner's Representative and the Contractor

b. In addition, the following shall be satisfied

(1) Surfaces of the geomembrane that are to be repaired shall be prepared no more than 30 minutes prior to the repair

(2) All surfaces must be clean and dry at the time of repair

(3) All seaming equipment and materials used in repair procedures must be approved by the Owner's Representative

(4) The repair procedures, materials, and techniques shall be approved in advance, for the specific repair, by the Owner's Representative and Contractor

(5) The geomembrane below large repairs shall be appropriately cut to avoid water or gas collection between the two sheets

5 Repair Verification

a Each repair shall be located, numbered, and logged and shall be nondestructively tested, as appropriate Repairs that pass the nondestructive test shall be taken as an indication of an adequate repair Failed tests will require the repair to be redone and retested until a passing test results

3 04 MATERIALS IN CONTACT WITH THE LINER

A The Contractor shall not leave any tools or equipment on the geomembrane

B The Contractor shall take all necessary precautions to ensure that the geomembrane is not damaged during its installation or during the installation of other components of the liner system or by other construction activities Installation on rough surfaces shall be performed carefully

C Equipment shall not be driven directly on the geomembrane Unless otherwise specified by the Owner's Representative, all equipment operating on materials overlying the geomembrane shall comply with maximum allowable ground pressure criteria developed during design

- END OF SECTION -

SECTION 02714 GEOCOMPOSITE

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geocomposite components of the landfill cells The Work shall be carried out in accordance with the Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A. The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A. Work will be monitored and tested in accordance with the requirements of the CQA Plan

B Any geocomposite rolls that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C If the Owner's Representative's testing indicates that Work does not meet the requirements of the Specifications, the Owner's Representative will establish the extent of the nonconforming area. The nonconforming area shall be reworked by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2 01 GEOCOMPOSITE PROPERTIES

A The Contractor shall require that the geocomposite Manufacturer furnish material with minimum average roll values, as defined by the FHWA, meeting or exceeding the criteria specified during design. The Contractor shall require that the Manufacturer provide results for tests performed, as well as a certification that the material delivered to the site meets or exceeds the specified values

B In addition to the required property values identified during design, the geocomposite shall

1 Retain its structure during handling, placement, and long-term service

2 Be capable of withstanding outdoor (i e , ultraviolet [UV] light) exposure for a minimum of 30 days with no measurable degradation in the specified physical properties

3 Meet any additional requirements of the Drawings

4 Be manufactured with a geonet that does not contain any reclaimed polymer, nor any foaming or blowing agents

2 02 MANUFACTURING QUALITY CONTROL

A The Contractor shall require that the geocomposite Manufacturer sample and test the geocomposite to demonstrate that the material conforms to the requirements of the Specifications All Quality Control testing required by the Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor Test results shall be provided to the Owner's Representative Sampling shall, in general, be performed on sacrificial portions of the geocomposite material such that repair is not required The Contractor shall require that the geocomposite Manufacturer sample and test the geocomposite at the minimum frequency specified and perform the manufacturing quality control tests defined during design.

B Any geocomposite sample that does not comply with the Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

C If a geocomposite sample fails to meet the quality control requirements of this Specification, the Contractor shall require that the geocomposite Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

D Additional sample testing may be performed, at the geocomposite Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

2 03 LABELING

A Geocomposite rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

B If any special handling is required, it shall be so marked on the geocomposite itself (e g , "This Side Up" or "This Side Against Soil To Be Retained")

2 04 TRANSPORTATION

A Transportation of the geocomposite shall be the responsibility of the Contractor The Contractor shall be liable for damage to the geocomposite incurred prior to and during transportation to the site The Contractor shall replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geocomposite shall be shipped and stored in watertight and opaque protective covers

B Handling, storage, and care of the geocomposite prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the material incurred prior to final acceptance by the Owner's Representative The Contractor shall repair damage in accordance with Part 3 03 of this Section at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geocomposite at the site The geocomposite shall be stored off the ground and out of direct sunlight and shall be protected from puncture, cutting, and excessive heat, cold, moisture, mud, dirt, dust, or any other damaging or deleterious conditions The geocomposite shall be stored in accordance with any additional requirements of the geocomposite Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A If required by the design, geocomposite shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geocomposite in such a manner as to ensure that the geocomposite is not damaged in any way

C Just prior to geocomposite placement, the geomembrane that may underlie the geocomposite shall be clean and free of excessive dust and dirt, stones, rocks, or other obstructions that could potentially damage the geomembrane The geomembrane shall be swept clean prior to geocomposite placement. At the direction of the Owner's Representative, the Contractor may be required to clean the geomembrane with water

D The Contractor shall take all necessary precautions to prevent damage to underlaying layers during placement of the geocomposite

E In the presence of excessive wind, the Contractor shall weight the geocomposite with sandbags or equivalent method approved by the Owner's Representative

F On sideslopes, the geocomposite shall be secured, by the Contractor, at the top of the slope and then rolled down the slope

G If necessary, the Contractor shall position the geocomposite by hand after it is unrolled to minimize wrinkles

H Geocomposite shall be clean when installed During installation, care shall be taken by the Contractor not to entrap stones, excessive dirt, or moisture that could damage the underlying geomembrane, clog drains or filters, or hamper subsequent seaming

I Geocomposite shall not be welded to the geomembrane liners Geocomposite shall only be cut using a cutter approved by the geocomposite Manufacturer and the Owner's Representative

J Tools shall not be left on or in the geocomposite

K. After placing the geocomposite, the geocomposite shall not be left exposed for a period in excess of 30 days unless a longer exposure period is approved by the Owner's Representative based on a formal demonstration from the Contractor (e.g., a certification from the geocomposite Manufacturer) that the geotextile component of the geocomposite is stabilized against UV light degradation for a period in excess of 30 days

L. If white geotextile is used in the geocomposite, precautions shall be taken against "snow blindness" of personnel

3.02 SEAMS AND OVERLAPS

A. The components of the geocomposite (e g , geotextile-geonet-geotextile) shall not be bonded together at the ends and edges of the rolls Each component shall be secured or seamed to the like component at overlaps

B No horizontal seams shall be allowed on slopes steeper than those specified in the design unless approved by the Owner's Representative

C Geonet Components

1 The geonet components shall be overlapped by the distance specified in the design and in accordance with Manufacturer's recommendations These overlaps shall be secured by tying

2 Tying shall be achieved by nylon strings, plastic fasteners, or polymer braid Metallic devices shall not be used Tying devices shall be provided in a color different than the geonet to allow easy inspection.

3 The spacing shall be as specified in the design.

4 When more than one layer of geocomposite is installed, joints shall be staggered as specified in the design.

5 The joints on adjacent geocomposite panels shall be staggered as specified in the design.

D Geotextile Components

1 The top layers of geotextiles shall be sewn in accordance with the requirements of the design. Geotextiles shall be overlapped prior to sewing in accordance with the design.

3 03 REPAIR

A Any holes or tears in the geocomposite shall be repaired by placing a patch extending beyond the edges of the hole or tear as required by the design The patch shall be secured over the hole or tear by tying fasteners through the geocomposite patch, and through the top geotextile and geonet beneath the patch The patch shall be secured with approved tying devices A larger geotextile patch shall be placed over the geocomposite patch and shall be heat sealed to the top geotextile of the geocomposite needing repair If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the geocomposite shall be joined in accordance with Part 3 02 of this Section.

3 04 PLACEMENT OF OVERLYING MATERIALS

A Earth fill, geosynthetic clay liner, compacted clay liner, or vegetative soil layer as required by the Drawings, shall be placed as soon as possible after placement and approval of the geocomposite Placement of each overlying material shall be in accordance with the appropriate Sections of the Specifications

B The Contractor shall place overlying soil materials in such a manner as to ensure that

1 The geocomposite and underlying geosnythetic materials are not damaged

2 Minimal slippage occurs between the geocomposite and underlying layers

3 Excessive stresses are not produced in the geocomposite

C Unless otherwise specified by the Owner's Representative, the equipment operating on soil material overlying a geocomposite shall comply with the maximum permissible ground pressure requirement specified in the design. The acceptability of equipment operating at ground pressures greater than the maximum specified will be evaluated by the Owner's Representative at the Contractor's expense

D The CQA firm will provide monitoring of the spreading of soils over the geocomposite in accordance with the CQA Plan.

3 05 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The CQA firm will identify any areas requiring repair The Contractor shall immediately make repairs and replacements necessary, to the approval of the Owner's Representative at no additional cost to the Owner

C The CQA firm will issue an approval of the geocomposite installation to the Owner's Representative prior to placement of material over the geocomposite in accordance with the CQA Plan

- END OF SECTION -

SECTION 02715 GEONET

PART 1 GENERAL

1 01 SCOPE OF WORK

A If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of the geonet components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the Products Subsection of this Section.

C Layout Drawings Contractor shall submit Layout Drawings for the geonet to the Owner's Representative describing in detail where and how the geonet will be installed Work covered in this Section shall not commence until Layout Drawings are reviewed and approved by the Owner's Representative

PART 2 PRODUCTS

2 01 GEONET PROPERTIES

A Unless otherwise noted on the Drawings, the Contractor shall require that the geonet Manufacturer furnish material having properties that comply with the required values established during design. The Contractor shall require that the geonet Manufacturer provide results for tests performed using the procedures identified in the final design, as well as a certification that the material properties meet or exceed the specified values

B In addition to the property values identified in the final design, the geonet shall

1 Retain its structure during handling, placement, and long-term service

2 Be chemically inert when immersed in a leachate representative of that from the landfill

3 Meet any additional requirements of the Drawings

4 Not be manufactured from any reclaimed polymer

2 02 MANUFACTURING QUALITY CONTROL

A The geonet shall be manufactured with quality control procedures that meet or exceed generally accepted industry standards

B The Contractor shall require that the geonet Manufacturer sample and test the geonet to demonstrate that the material conforms to the requirements set forth in design.

C Any geonet sample that does not comply with the Specifications shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

D If a geonet sample fails to meet the quality control requirements of the Specifications, the Contractor shall require that the geonet Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

E Additional sample testing may be performed, at the geonet Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

F The Contractor shall require that the geonet Manufacturer comply with the certification and submittal requirements of this project manual

2 03 LABELING

A Geonet rolls shall be labeled with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

2 04 TRANSPORTATION

A Transportation of the geonet shall be the responsibility of the Contractor The Contractor shall be liable for damage to the geonet incurred prior to and during transportation to the site The Contractor shall replace damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geonet shall be protected from damage during shipping and storage

B Handling, storage, and care of the geonet prior to and following incorporation into the Work is the responsibility of the Contractor The Contractor shall be liable for damage to the material incurred prior to final acceptance by the Owner The Contractor shall repair damage in accordance with Part 3 03 of this Section at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geonet at the site The geonet shall be stored off the ground and out of direct sunlight and shall be protected from puncture, cutting, and excessive heat, cold, moisture, mud, dirt, dust, or any other damaging or deleterious condition The geonet shall be stored in accordance with any additional requirements of the geonet Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A If required by the design, geonet shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geonet in such a manner as to ensure that the geonet is not damaged in any way

C Just prior to geonet placement, the geomembrane liner that may underlie the geonet shall be clean and free of excessive dust and dirt, stones, rocks, or other obstructions that could potentially damage the geomembrane The geomembrane shall be swept clean prior to geonet placement At the direction of the Owner's Representative, the Contractor shall clean the geomembrane with water

D The Contractor shall take all necessary precautions to prevent damage to underlaying layers during placement of the geonet.

E In the presence of excessive wind, the geonet shall be weighted with sandbags or equivalent weight approved by the Owner's Representative Such sandbags shall be installed during placement and shall remain until replaced with an overlying layer

F On sideslopes, the geonet shall be secured in the anchor trench and then rolled down the slope

G If necessary, the geonet shall be positioned by hand after being unrolled to minimize wrinkles

H Geonet shall be clean when installed During installation, care shall be taken not to entrap stones, excessive dirt, or moisture that could damage the underlying geomembrane or generate clogging drains or filters

I Geonet shall not be welded to geomembrane liners Geonet shall only be cut using a cutter approved by the geonet Manufacturer and the Owner's Representative

J Tools shall not be left on or in the geonet.

K. Geonet shall not be placed in direct contact with textured geomembrane liner unless specifically called for on the Drawings

3 02 STACKING AND JOINING

A. When two or more layers of geonets are stacked, care shall be taken to prevent the strands of one layer of geonet from penetrating the channels of an overlying or underlying layer

B A layer of Geonet shall not be installed in a direction perpendicular to an underlying layer of geonet

C In the corners of the sideslopes, where overlaps between perpendicular geonet strips are required, an extra layer of geonet shall be unrolled along the slope, on top of the previously installed geonets, from top to bottom of the slope, as shown on the Drawings

D Adjacent rolls of geonet shall be overlapped as required in the final design These overlaps shall be secured by tying

E Tying shall be achieved by nylon strings, plastic fasteners, or polymer braid Metallic devices shall not be used Tying devices shall be provided in a color to allow for easy inspection.

F Tie spacing shall be as required in the final design

G When more than one layer of geonet is installed, joints shall be staggered as required in the final design.

H The joints on adjacent geonet panels shall be staggered as required in the final design

3 03 REPAIR

A Any holes or tears in the geonet shall be repaired by placing a patch over the hole or tear extending beyond the edges of the hole or tear as set forth in the final design. The patch shall be secured to the original geonet by tying with approved tying devices If the hole or tear width across the roll is more than 50 percent of the width of the roll, the damaged area shall be cut out and the two portions of the geonet shall be jointed in accordance with Part 3 02 above

3 04 PLACEMENT OF OVERLYING MATERIALS

A An installed layer of geonet shall be covered with the overlying layer (geotextile or geomembrane), as required by the Drawings, as soon as possible after installation and approval The purpose of this action is to minimize the accumulation of dirt or dust in the geonet and the potential for damage to the geonet or the underlying geomembrane If dust or dirt accumulates in the geonet layer prior to placement of the overlying layer, the Owner's Representative will direct the Contractor to clean the geonet by sweeping or washing with water

B Soil shall never be placed in direct contact with geonets Geonets shall be separated from soil materials by a geotextile or other material, as indicated on the Drawings The only exception to this shall be at those locations shown on the Drawings (e g , pipe bedding gravel directly overlies one or more layers of geonet.)

C When soil is placed above the overlying layer the Contractor shall place the soil in such a manner as to ensure that

1 The geonet and underlying geomembrane are not damaged

2 Minimal slippage occurs between the geonet and the underlying geomembrane

3 Excess stresses are not produced in the geonet

D The CQA firm will provide continuous monitoring of the spreading of any soil materials over the geonet with earth moving equipment.

E Unless otherwise specified by the Owner's Representative, all equipment operating on soil material overlying a geonet shall comply with the maximum permissible ground pressure requirements specified in the design.

- END OF SECTION -

SECTION 02716. GEOTEXTILE FABRIC

PART 1 GENERAL

1 01 SCOPE OF WORK

A. If required by the design, the Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation of geotextile fabric components of the landfill cells The Work shall be carried out in accordance with this Specification, the CQA Plan, the Drawings, and other Contract Documents

1 02 SUBMITTALS

A In accordance with the CQA Plan and the Specifications

B Materials Submit laboratory test data and Manufacturer's product data and certification in accordance with the Products Subsection of this Section.

C Layout Drawings Contractor shall submit Layout Drawings for the geotextile fabric to the Owner's Representative describing in detail where and how the geotextile fabric will be installed Work covered in this Section shall not commence until shop Drawings are reviewed and approved by the Owner's Representative

1 03 CONSTRUCTION QUALITY ASSURANCE

A Work will be monitored and tested in accordance with the requirements of the CQA Plan.

B Any geotextile rolls that do not meet the requirements of the Specification will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

PART 2 PRODUCTS

2 01 GEOTEXTILE PROPERTIES

A The Contractor shall require that the geotextile Manufacturer furnish geotextile with minimum average roll values, as defined by the FHWA, meeting or exceeding the criteria set forth in design The Contractor shall require that the geotextile Manufacturer provide results for tests performed as well as a certification that the material properties meet or exceed all property values specified for that type of geotextile

B In addition to the required property values identified during design, the geotextile fabric shall

1. Retain its structure during handling, placement, and long-term service

2. Be capable of withstanding outdoor (i e , UV) light for a minimum of 30 days with no measurable deterioration.

3 Be chemically inert when immersed in a leachate representative of that from the landfill

4 Meet any additional requirements of the Drawings

2 02 MANUFACTURING QUALITY CONTROL

A. The geotextile shall be manufactured with quality control procedures that meet or exceed generally accepted industry standards

B The Contractor shall require that the geotextile Manufacturer sample and test the geotextile to demonstrate that the material conforms to the requirements of the Specifications

C Any geotextile sample that does not comply with this Specification shall result in rejection of the roll from which the sample was obtained The Contractor shall replace any rejected rolls at no additional cost to the Owner

D If a geotextile sample fails to meet the quality control requirements of this Specification, the Contractor shall require that the geotextile Manufacturer sample and test each roll manufactured in the same lot, or at the same time, as the failing roll Sampling and testing of rolls shall continue until a pattern of acceptable test results as determined by the Owner's Representative is established

E Additional sample testing may be performed, at the geotextile Manufacturer's discretion and expense, to more closely identify any noncomplying rolls and/or to qualify individual rolls

F Sampling shall, in general, be performed on sacrificial portions of the geotextile material such that repair is not required

G The Contractor shall require that the geotextile Manufacturer comply with all applicable certification and submittal requirements

2 03 LABELING

A Geotextile rolls shall be marked or tagged with the following information

1 Name of Manufacturer

2 Product identification

3 Lot number

4 Roll number

5 Roll dimensions

B If any special handling is required, it shall be so marked on the geotextile itself, (e g , "This Side Up" or "This Side Against Soil to be Retained")

2 04 TRANSPORTATION

A Transportation of the geotextile shall be the responsibility of the Contractor The Contractor shall be liable for all damage to the geotextile incurred prior to and during transportation to the site The Contractor shall repair or replace any damaged rolls at no additional cost to the Owner

2 05 HANDLING AND STORAGE

A Geotextile shall be shipped and stored in watertight and opaque protective covers

B Handling, storage, and care of the geotextile prior to and following installation at the site is the responsibility of the Contractor The Contractor shall be liable for all damages to the geotextile incurred prior to final acceptance by the Owner's Representative The Contractor shall repair all damage in accordance with Part 3.03 of this Specification and at no additional cost to the Owner

C The Contractor shall be responsible for storage of the geotextile at the site The geotextile shall be stored off the ground and out of direct sunlight and precipitation and shall be protected from excessive heat or cold, mud, dirt, dust, puncture, cutting, or any other damaging or deleterious conditions The geotextile shall also be stored in accordance with any additional requirements of the geotextile Manufacturer

PART 3 EXECUTION

3 01 HANDLING AND PLACEMENT

A. If required by the design, geotextile fabric of the type(s) specified in the design shall be installed at all locations shown on the Drawings

B The Contractor shall handle the geotextile in such a manner as to ensure that the geotextile is not damaged in any way

C The Contractor shall take all necessary precautions to prevent damage to underlying layers during placement of the geotextile

D Just prior to geotextile placement, the layer that will underlie the geotextile, if it is geosynthetic, shall be clean and free of dust, dirt, stones, rocks, or other obstructions that could potentially damage the liner system

E. After placing the geotextile, the geotextile shall not be left exposed for a period in excess of 30 days unless a longer exposure period is approved by the Owner's Representative, based on a demonstration from the Manufacturer (e g , a certification from the geotextile Manufacturer) that the geotextile is stabilized against UV light degradation for a period in excess of 30 days This requirement does not apply to material used as sacrificial geotextile

F If white geotextile is used, precautions shall be taken against "snow blindness" of personnel

G In the presence of wind, the geotextile shall be weighted with sandbags or equivalent weight approved by the Owner's Representative Such sandbags shall be installed during placement and shall remain until replaced with an overlying layer

H On sideslopes, the geotextile shall be secured in the anchor trench and then rolled down the slope in such a manner as to continually keep it in tension

I If necessary, the geotextile shall be positioned by hand after being unrolled to minimize wrinkles

J Geotextile shall be clean when installed During installation, care shall be taken not to entrap stones, excessive dirt, or moisture that could damage the underlying layers, clog drains or filters, or hamper subsequent seaming

K Tools shall not be left on or in the geotextile

L The Contractor and Owner's Representative shall examine the entire geotextile surface after installation to ensure that no potentially harmful foreign objects (including broken sewing needles) are present The Contractor shall remove any such foreign objects and shall replace any damaged geotextile

3 02 SEAMS AND OVERLAPS

A All geotextile overlaps shall be continuously sewn (i e , spot sewing and thermal bonding are not allowed) Geotextiles shall be overlapped in accordance with design requirements prior to sewing No horizontal seams shall be allowed on slopes steeper than those specified in the design (i e , seams shall be along, not across, the slopes), except as part of a patch, unless approved by the Owner's Representative

3 03 REPAIR

A Any holes or tears in the geotextile shall be repaired as follows

1 A patch made from the same type of geotextile Should any tear exceed 10 percent of the width of the roll, that roll shall be removed from the slope and replaced with new material, at no additional cost to the Owner

2 A patch made from the same type of geotextile shall be overlapped and stitched into place in accordance with requirements set forth in the design

B Care shall be taken to remove any soil or other material that may have penetrated the torn geotextile

3 04 PLACEMENT OF OVERLYING MATERIALS

A The Contractor shall place all overlying soil materials in such manner as to ensure that

1 The geotextile and underlying geosynthetic materials are not damaged

2 Minimum slippage occurs between the geotextile and underlying layers

3 Excess stress is not produced in the geotextile

B The Owner's Representative will provide continuous monitoring of the spreading of any soil materials over the geotextile with earth moving equipment

C Unless otherwise specified by the Owner's Representative, all equipment operating on soil material overlying the geotextile shall comply with the maximum permissible ground pressure requirements specified in the design

3 04 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B The CQA firm will identify any areas requiring repair The Contractor shall immediately make repairs and replacements necessary, to the approval of the Owner's Representative and at no additional cost to the Owner

C The CQA firm will issue an approval of the geocomposite installation to the Owner's Representative prior to placement of material over the geocomposite in accordance with the CQA Plan.

- END OF SECTION -

SECTION 02721 COMPACTED CLAY LINER

PART 1 GENERAL

This Section will be modified based on the results of the test fill program (see Appendix I) and future design

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the construction of the compacted clay liner components of the landfill cells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualifications and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A All Work shall be monitored and tested in accordance with the requirements of the CQA Plan.

B The Contractor shall be aware of all testing activities outlined in the CQA Plan and shall account for these activities in the construction schedule No additional costs to the Owner shall be allowed by the Contractor as a result of the performance of the CQA activities

C Soil testing (both field and laboratory testing) required by the CQA Plan will be the responsibility of the CQA firm All Quality Control testing required by these Specifications, the CQA Plan, and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor The Contractor shall cooperate with the CQA firm during all testing activities The Contractor shall provide equipment and labor to assist the CQA firm in sampling The Contractor shall provide access to all areas requiring testing The Contractor shall repair any damage to finished Work caused by the CQA firm's sampling or testing activities

D If the CQA firm's tests indicate Work does not meet the requirements of the Specifications, the CQA firm will establish the extent of the nonconforming area The nonconforming area shall be reworked by the Contractor at no cost to the Owner until acceptable test results are obtained

PART 2 PRODUCTS

2.01 MATERIALS

Clay liner material may only be used for construction if it has been shown to be suitable in the test fill program (see Appendix I) The test fill program will have been performed prior to construction of the landfill cells and is not part of the Work included in this Specification Depending on the results of future test fills, onsite clay may be used on the base and/or the sideslopes of the landfill cell The Specifications may be modified per the results of the test fill program

A Clay liner material shall be obtained from borrow areas or stockpiles identified by the Owner's Representative

B Clay liner material for landfill cell construction shall meet the characteristics and requirements defined during design which may include but not be limited to

1 Classification according to the Unified Soil Classification System (USCS) (ASTM D 2487) and exhibit specified minimum liquid limit and a minimum plasticity index

2 Have a percentage of gravel (i e , dry weight retained on a U S No 4 sieve) of less than that specified

3 Have a hydraulic conductivity of not more than 1×10^{7} centimeters per second (cm/s) when compacted in accordance with the Specifications and tested in the laboratory

C The water used to increase the moisture content of the clay liner shall be provided by the Owner The Contractor shall maintain an accurate record of water usage

PART 3 EXECUTION

3 01 CLAY LINER COMPACTION CRITERIA

A The compaction moisture content and the minimum dry unit weight of onsite clay shall be as defined in the design

3 02 CLAY LINER PLACEMENT

A The clay liner shall be constructed to the elevations, grades, and thicknesses shown on the Drawings The thickness of the clay liner at any location shall be measured perpendicular to the plane of the slope at the location The compacted clay liner shall be a minimum of three (3) feet thick over the bottom and perpendicular to sideslopes of the landfill cell

B Clay liner placement shall begin only after completion of all, or an approved portion of, excavation and structural fill placement in the landfill cell Placement shall not begin until the Contractor has verified that subgrade elevations and grades conform to the Drawings and CQA firm has completed testing and surveying of the subgrade as required by the CQA Plan

C The Contractor shall not place clay liner material on a surface or subgrade that contains debris, branches, vegetation, mud, ice, or frozen material If frozen subgrade material is encountered, it shall be removed and replaced in accordance with these Specifications Immediately prior to clay liner placement, the subgrade shall be proof-rolled as directed by the Owner's Representative Any excessively wet or soft areas shall be excavated and replaced with properly compacted structural fill

D The Contractor shall construct the clay liner in lifts Each lift of the clay liner shall meet the minimum requirements as defined in the design

E The loose lift thickness and the average lift thickness after compaction shall be no more than the allowable maximum lift thickness in accordance with the test fill results and design requirements

F Lift placement procedures for sideslopes and flat areas shall be performed in accordance with the requirements of the design

G Prior to placement of a lift clay liner material, Contractor shall allow the CQA firm to complete field testing in accordance with the CQA Plan The Contractor shall not place a new lift of clay liner material over a preceding lift until approval is given by the CQA firm If the Contractor fails to comply with this requirement, the Contractor will be required by the Owner to remove and replace all unauthorized Work at no additional cost to the Owner

H Prior to placement of a lift of clay liner material, the previous lift shall be thoroughly scarified in accordance with design requirements to provide good bonding between lifts

I The trafficking of prepared lift surfaces by trucks or other equipment shall not be permitted during the period between preparation and placement of the following lift

J If normal handling does not reduce the maximum clod size in onsite clay to an acceptable size, the Contractor shall use an approved equipment to break up the clods The onsite clay material shall be pulverized until the maximum soil clod size is reduced to meet size requirements The use of specific equipment shall be approved by the Owner's Representative prior to use

K. Moisture conditioning of the clay liner material shall be accomplished in the processing area prior to clay liner construction The processing area location shall be approved by the Owner's Representative Clay liner material shall be moisture conditioned using approved equipment and procedures If the clay liner material is wetter then required, it shall be repeatedly mixed to achieve drying

L No more than the percent moisture defined during design shall be added to the clay liner material at the time of compaction Clay liner material more than the defined percent moisture shall be removed, returned to the processing area, and conditioned until the proper moisture content is achieved If the in-place moisture content is too high, the clay may be dozed, windrowed, disced, and/or otherwise mixed to facilitate drying

M Clay liner material shall not be placed or compacted during a sustained period of temperature below 32 degrees Fahrenheit Clay liner material may be placed and compacted during periods of early morning freezing temperatures if above freezing temperatures are anticipated during the day

N The Contractor shall not place frozen clay nor shall the Contractor place clay on frozen ground

O If clay liner material freezes after compaction, the Contractor shall remove the frozen material, scarify the remaining unfrozen clay, and then place and compact new clay in accordance with these Specifications Frozen clay shall not be reused until it has thawed and been reworked to an acceptable moisture content. The Contractor shall be responsible for protecting compacted lifts of clay liner material from freezing If extended freezing conditions are anticipated, the Contractor shall prepare a plan for approval by the Owner's Representative, which outlines the measure that will be taken to protect finished Work.

P Clay liner material shall be placed during periods of unfavorable weather conditions, as determined by the Owner's Representative

3 03 CLAY LINER COMPACTION

A. The sequence of compaction of the clay liner for a landfill cell shall be as described in the design Specifications or as shown on the Drawings

B Compaction of clay liner on the base of the cell and on the sideslopes shall be performed using approved equipment.

C The daily Work area shall extend a sufficient distance so as to maintain soil moisture conditions within an acceptable range to allow continuous operations Desiccation and crusting of the lift surface shall be avoided as much as possible

D. The CQA firm will identify any areas of significant desiccation and crusting of a lift surface The Contractor shall scarify the surface of such areas to the nominal depth specified during design or to the depth of desiccation identified by the CQA firm and then water condition, disc, or mix as necessary and recompact the area

E. The transition from an existing full-depth Section of clay liner to the beginning of an adjacent Section that is to be constructed subsequently shall be accomplished by sloping (cutting back) the end of the full-depth Section, scarifying the slope of the exiting full-depth liner at the transition, and then immediately pacing the adjacent lifts of clay liner

F Corners and other areas inaccessible to driven compaction equipment shall be compacted using hand-operated equipment (such as a walk-behind roller) approved by the Owner's Representative

3 04 SURVEY CONTROL

A The Surveyor shall survey the final location and elevation of the top of the clay layer Surveying shall be performed in accordance with these Specifications The survey will ensure that

1 The specified thickness of compacted clay liner has been achieved

2 The top of the clay liner slopes across the landfill cell at the grade shown on the Drawings toward the collection sump

3 The top of the clay liner is at the grades and elevations specified on the contract Drawings

B The Surveyor shall provide a Record Drawing to the Owner's Representative of the final location and elevation of the top of the clay liner, including the location and elevation of the leak detection system sump, in accordance with the requirements of these Specifications. The Surveyor shall submit this Drawing prior to geomembrane liner construction unless otherwise approved by the Owner's Representative and the CQA firm The Contractor may submit a partial record to obtain approval for a portion of the Work. The Owner's Representative will define the minimum requirements for a partial submittal

3 05 FIELD QUALITY CONTROL

A. All quality control testing required by these Specifications and/or conducted at the discretion of the Contractor shall be the responsibility of the Contractor

B If the CQA firm's tests indicate that Work does not meet the requirements of the Specifications, the CQA firm will establish the extent of the nonconforming area The nonconforming area shall be reworked by the Contractor at the Contractor's own expense until acceptable test results are obtained

3 06 PROTECTION OF WORK

A The Contractor shall use all means necessary to protect all materials and partially completed and completed Work of these Specifications

B In the event of damage, the CQA firm will identify areas requiring repair, and the Contractor will make repairs and replacements necessary to the approval of the Owner's Representative at no additional cost to the Owner

C The Contractor shall minimize, to the maximum extent feasible, desiccation cracking of clay liner material The Contractor shall sprinkle the clay with water if cracking is observed or if directed by the Owner's Representative The Contractor may seal roll the surface of the clay to reduce drying and desiccation The Contractor may protect exposed surfaces using light-colored or translucent membranes, such as Visqueen, to inhibit drying of the clay The CQA firm will identify areas of significant cracking of the surface of the clay liner and the Contractor shall repair the identified area to the satisfaction of the Owner's Representative at no additional cost to the Owner

D The clay liner surface shall be seal rolled and made smooth and free from ruts or indentations at the end of every working day when precipitation is forecast and/or at the completion of compaction operations in an area

E. The Contractor shall maintain the clay liner surface in a condition suitable for geomembrane installation as specified in the CQA Plan and these Specifications until the surface is covered Desiccation cracks shall be repaired in accordance with the requirements of the design

F The layer of over-built material shall be removed as applicable prior to placement of geomembrane liner The over-built materials may be removed in sections to coordinate with geomembrane placement Where the over-built material is removed, the finished surface shall be protected and maintained as required by the Specifications The surface of the clay liner on the sideslope shall be trimmed to meet the requirements of these Specifications prior to the installation of the geomembrane liner

G No synthetic sealants or other chemical treatments may be applied to the clay liner material

H The CQA firm will issue an approval of the installation of the clay liner to the Owner's Representative prior to placement of material over the clay liner in accordance with the requirements of the CQA Plan

3 07 PERFORATIONS

A Perforations in the secondary clay liner resulting form construction and CQA activities shall be filled Such perforations may include, but are not limited to, the following

1 Nuclear density test probe locations

2 Shelby tube sample locations

3 Sand-cone or rubber balloon test locations

4 Survey stake locations

- END OF SECTION -

SECTION 02800 MONITORING WELLS

PART 1 GENERAL

1 01 SCOPE OF WORK

A The Contractor shall furnish all labor, materials, tools, equipment, supervision, transportation, and installation services necessary for the installation, development and testing of the monitoring wells The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 QUALIFICATIONS AND SUBMITTALS

A The Contractor shall abide by all qualification and submittal requirements of the CQA Plan and the Specifications

1 03 CONSTRUCTION QUALITY ASSURANCE

A All Work will be monitored and tested in accordance with requirements of the CQA Plan.

B Any materials that do not meet the requirements of these Specifications will be rejected The Contractor shall replace the rejected material with new material that conforms to the Specification requirements at no additional cost to the Owner

C Regulatory Requirements

1 The Contractor shall comply with all applicable state, county, and local codes and ordinances

D Contractor shall coordinate installation with all utilities to obtain approval of locations

1 04 SUBMITTALS

A Submittals shall include the following

1 Utility field location tickets and forms as applicable

2 Tabulated survey coordinates of staked boring locations

3 Drill rig equipment Specifications

4 Drilling Method The Contractor shall submit the proposed plan for drilling the wells The proposed plan shall take into account all information furnished and all restrictions imposed by the Drawings and Specifications Loss of a hole or well because of lack of material, inadequate or faulty equipment, or careless operating procedures will be considered cause for abandonment of the well at no cost to Owner

5 Specifications for well materials including blank riser pipe, well screen, sandpack, bentonite pellet seal, and concrete grout as applicable and in accordance with the design.

6 Specifications for development pump, bailer, and other testing equipment

7 Product Submittals Contractor shall submit Manufacturers' Specifications for each of the products listed in Section 2 0, Products

8 Tabulated survey coordinates of installed well locations Include horizontal coordinates and elevation of permanent reference point in accordance with the requirements of the design

9 Daily reports, field logs, field well completion forms, and well development data sheets as required in the design.

10 Sandpack Sieve Analysis and Sample The Contractor shall submit for approval the results of a sieve analysis of the proposed sandpack material a minimum of 7 days prior to commencement of well drilling activities

PART 2 PRODUCTS

2 01 MATERIALS

A Well screen, riser pipe, sandpack, bentonite seal, cement-bentonite grout, well casing, and all other materials shall be as specified in the design

B Water for construction shall be clean and free of contaminants The Owner will provide water and specify the source The Contractor shall be responsible for transport of the water from the source to the construction site

PART 3 EXECUTION

3 01 PREPARATION

A Location of borings

1 Stake boring locations at the locations shown on the Drawings in the presence of the Owner's Representative Following Owner's Representative approval of staked locations, survey stakes using survey methods under the direction of a surveyor registered to practice surveying the in State of Colorado Coordinate boring locations with all utilities and obtain utility approval of staked locations Submit utility field location tickets and forms

2. Tabulate horizontal and vertical survey coordinates of staked locations Coordinates shall be consistent with control points established per the design Submit tabulated survey coordinates

3 02 INSTALLATION

A. Drilling

1 Drilling Method Wells shall be drilled and installed in accordance with the methods and procedures set forth in the design. The diameter of the hole shall permit the placement of the minimum thickness of sandpack as specified in the design.

B Riser Pipe, Casing, and Screen

1 Assembly All riser pipe, casing pipe, and screen shall be new and in good condition before installation, and all joints and other accessory parts shall be securely fastened in place Particular care shall be exercised to avoid damaging the screen, centralizers, and riser pipe during installation and throughout all subsequent operations The screen, and riser pipe shall be centered in the well hole and held securely in place during placement of the sandpack using centralizers

2 Joints Sections of the riser pipe shall be joined in accordance with the methods specified in the design.

3 Installation The assembled screen and riser pipe shall be placed in the borehole in such a manner as to avoid jarring impacts and to ensure that the assembly is not damaged or misplaced Immediately after the installation of the well screen and riser pipe, the depth of the well shall be measured The top of the riser pipe shall stick up above ground level as indicated on the Drawings and be sealed after development by installing a protective cap on the top

4 Alignment and Plumbness Each completed well shall be straight and plumb Immediately before placing the sandpack and with top of riser fastened securely in a vertical and horizontal position, alignment and plumbness surveys shall be conducted by the Contractor The Contractor shall furnish all labor, tools, and equipment to perform the tests required in the design

C Sandpack Placement

1 After the screen and riser pipe have been placed and plumbness and alignment surveys are conducted, the sandpack shall be placed around the screen in such a manner as to ensure uniform placement around the screen. The sandpack material shall be placed in one continuous run. Sandpack shall be installed over the depths and at the thickness required by the design Material that may have entered the well screen and riser pipe shall be removed before development of the well is commenced

D Cement-Bentonite Grout Placement

1 Upon completion of sandpack placement, the Contractor shall determine that the sandpack extends to the correct elevation Then the Contractor shall seal the annular space between the casing and the drill hole wall with a bentonite pellet seal and a cement-bentonite seal as set forth in the design.

E Well Development

1 Development of wells shall consist of pumping to create flow from the well and bailing to remove silts Development of the well shall be continued until water entering the well during pumping is visually clear Well development procedures shall be performed as set forth in the design

F Decontamination and Materials Disposal

1. Drill cuttings, groundwater, and other wastes generated during well installation development, and testing shall be handled in accordance with the requirements of the design.

2. All downhole drilling, sampling, and hydraulic testing equipment shall be decontaminated before use at the site and following use at the site

G Survey Locations

1 Following installation, provide horizontal and vertical survey control for all wells in accordance with the requirements of the design.

3 03 CONSTRUCTION QUALITY CONTROL

A. The Contractor shall establish and maintain quality control for all well construction and development to assure compliance with contract requirements The Contractor shall maintain records of quality control for all operations

- END OF SECTION -

Division 3

CONCRETE

To Be Completed During Design

Division 4

MASONRY

To Be Completed During Design

Division 5

METALS

To Be Completed During Design

Division 6

WOOD AND PLASTICS

To Be Completed During Design

Division 7

THERMAL AND MOISTURE PROTECTION

To Be Completed During Design

Division 8

DOORS AND WINDOWS

To Be Completed During Design

Division 9

PROTECTIVE COATINGS

To Be Completed During Design

Division 10

SPECIALTIES

To Be Completed During Design

Division 11

EQUIPMENT

To Be Completed During Design

Division 12

FURNISHINGS

To Be Completed During Design

Division 13

SPECIAL CONSTRUCTION

To Be Completed During Design

Division 14

CONVEYANCE SYSTEMS

To Be Completed During Design

Division 15

MECHANICAL

SECTION 15050 PIPING SYSTEMS - GENERAL

PART 1 GENERAL

1 01 SUMMARY

A. Section Includes

1 Piping system general requirements

2. Piping identification

3 Testing piping systems

4 The Contractor shall furnish all labor, materials tools, equipment, supervision, transportation, and other services necessary to complete the construction of all facilities and systems incorporating piping and related appurtenances and all subsidiary Work required to complete such Work. The Work shall be carried out in accordance with these Specifications, the CQA Plan, the Drawings, and other Contract Documents

1 02 REFERENCES

A. Standards Referenced in This Section

1	ANSI A13 1-81	Scheme for the Identification of Piping Systems
2	MIL-STD-810C (1975)	Environmental Test Methods
3	UPC (1985)	Uniform Plumbing Code

1 03 DEFINITIONS

A Pressure terms used in this Section and elsewhere in Division 15, Mechanical, are defined as follows

1 Maximum pressure The greatest continuous pressure at which the piping system will operate

2 Test pressure The hydrostatic pressure used to determine whether piping system meets specified requirements

1 04 SUBMITTALS

A Submittals required for piping systems may include the following information (submittal requirements will be developed during design)

1 Layout Drawings showing the location and size of all pipe, fittings, valves, and thrust restraints

2 Details of connections or interfaces between pipes of different materials

3 Details of connections to new and existing structures

4 Details of flexible connections

5 Details of fittings and angles

6 Details of joints and gaskets

B Quality Control Submittals

1. Submit Manufacturers' design data, test reports, certificates, and instructions for installation and operation of pipe, fittings, and valves

2 Record of piping system tests including date of test, signature of Owner's Representative witnessing the test, and statement of test performance

C Project Record Documents

1 Record Drawings

1 05 QUALITY ASSURANCE

A Piping system identification shall conform to ANSI A13 1

PART 2 PRODUCTS

2 01 GENERAL REQUIREMENTS

A Piping Systems

1 Unless otherwise specified, piping systems and materials including pipe, gaskets, fittings, joint assemblies, linings, and coatings shall conform to Specifications for each type of pipe and piping appurtenance specified in other related Sections

2 Flanged Connections Use proper length bolts for each size flange Bolts with excessive length of exposed threads will not be permitted and will be replaced or cut to correct length at the Contractor's expense

3 Unions shall be installed in all piping connections to equipment, regulating valves, and wherever necessary for dismantling of piping or removal of valves and other items requiring maintenance Flanges on equipment may be considered as unions, unless otherwise indicated on Drawings Provide dielectric unions at connections of dissimilar metals

4 Copper tubing shall be cut so that ends are square Thoroughly clean sockets and ends of tubing before soldering Heat joints uniformly to proper temperature so that

solder will flow to all parts Where solder joint valves are provided with composition discs, remove discs before soldering

5 Pump Strainers Furnish and install temporary pump strainers for initial unit start-up where permanent strainers are not provided Temporary strainers shall be removed by the start-up crew after cleaning and flushing systems and run-in of equipment, and before general tightness test.

6 Cleaning and Protecting Exercise reasonable care to prevent entry of foreign matter during handling, assembling, and erecting Use compressed air, wire brush, solvent, and other acceptable means to remove residual scale, dirt and other foreign matter from interior of piping before final connections are made Protect open ends of pipe by capping, plugging or other acceptable means

B UNDERGROUND PIPING SYSTEMS

1 General

a The underground installation of any piping system, using any piping material (steel, concrete, cast iron, plastics, clay, etc) shall satisfy the Codes and Regulations of the authorities having jurisdiction at the site If no such Codes or Regulations exist, the ANSI Standards or recommendations of the Manufacturers, Manufacturers' associations, or other technical organizations involved in the manufacturing, fabrication, installation or utilization of the specific piping material, as indicated in the applicable Specification, shall govern.

b If tunneling or jacking is required, the subcontractor shall submit to the Owner's Representative the details of the construction method that he prefers and secure approval from the Owner's Representative prior to beginning the Work.

2 Excavating and Trenching

a Safeguards. Provide, erect, maintain, and later remove temporary safeguards such as barricades, bridges, guard rails, signs, lights, and flares for protection of personnel, the public, equipment, and materials as Owner's Representative directs and as required by federal, state, and local codes and ordinances

b Retaining Excavations Provide shoring, sheeting, and bracing necessary to retain excavations, maintain banks securely, withstand water pressure, prevent cave-ins, and protect life and property As backfilling proceeds, remove shoring, sheeting, and bracing in a manner to prevent damage or disturbance to the construction and surrounding areas

c Dimensions Run trenches straight at required elevations and dimensions Keep width of trench at pipe level to a minimum, allowing adequate space for laying pipe, constructing underground structures, and inspection. Where materials are removed below required elevations, place and compact fill as specified to correct elevations d Portions of the site contain potentially contaminated materials In areas where contaminants are present, special procedures as described in the Contractor Health and Safety Plan shall be followed to protect personnel and avoid further contamination of the site or equipment The Contractor will be advised of the location of potentially contaminated areas by the Owner's Representative.

e Excavation, removal, disposal, or stockpiling of contaminated materials shall conform to the requirements of the Health and Safety Plan Contaminated soil will be designated by the Owner's Representative Owner's Representative will be responsible for arranging for characterization, storage, and final disposal as required

f Suitable Bearing Where unsuitable material is exposed at completion of planned excavation, perform further excavation as directed by the Owner's Representative until suitable bearing is reached Place and compact fill as specified herein to correct elevations It is assumed that materials at the job site can be excavated by hand labor or with normal equipment such as a trencher, backhoe, or power shovel

g. Water Removal Maintain grades to promote water drainage Provide and operate equipment to keep excavations and construction areas free of subsurface, surface and storm water Provide necessary diversion ditches for dewatering systems Dispose of water as required so construction and storage areas, streets, roads, and other surfaces are not flooded Water removal shall be performed as described in the Health and Safety Plan if the area is designated potentially contaminated by the Owner's Representative

h. Excavating Under Foundations Obtain the Engineer's approval before excavating under footings or other foundations, or within a 45 degree slope from horizontal plane at bottom of same Stability of such foundations must be ensured by means directed by the Owner's Representative

i Material Storage and Disposal Selected excavated materials that are to be reused shall be classified and stockpiled separately Dispose of unsuitable and excess material and debris as directed by the Owner's Representative

3 Pipe Laying

a General

(1) Pipe laying in trenches shall follow excavation as closely as possible Pipe to be located underground shall be laid in dry trenches maintained free of accumulated water

(2) Carefully inspect pipe and fittings before installation. Items that are cracked or otherwise defective shall be rejected, broken, and removed from the site immediately

(3) Lay pipe in such a manner that bottom of pipe is uniformly supported in firm pipe bedding material as shown in the Drawings Fill areas excavated to lower than planned elevations with bedding material

(4) Where the frost line has penetrated the soil prior to backfilling, the soil shall be thawed out prior to backfilling Backfill must be free of frozen material

(5) Sleeves/Encasement for Piping Where required by Drawings, to accommodate passage of piping services under roads or elsewhere, furnish and install pipe sleeves of size and material noted Place a steel plate cut to closely fit pipe at each end of sleeve before backfilling Concrete cradles, arches or full encasements shall be provided as detailed on Drawings

(6) Cleaning and Protecting Clean piping interior of dirt and other foreign matter For bell and spigot pipe, keep a swab in the line and pull it past each joint after its completion Protect open ends of pipe with temporary stoppers or covers

(7) Owner's Representative must sign off on installation of all underground piping systems prior to backfilling

4 Filling, Backfilling, and Compacting

a. Fill and Backfill Materials Use approved materials as outlined Provide fill suitable for required compaction and free of debris, organic material, large rocks, frozen matter, and excessive moisture or dryness

2 02 PIPE AND VALVE IDENTIFICATION

A. Piping Identification

1. Pipe Markers

a Pipe markers shall be as manufactured by Seton Name Plate Corporation or Owner's Representative approved equal.

b Pipe identification shall include individual vinyl letters and numbers that adhere to blank pipe markers Blank pipe markers shall adhere directly to pipe

c Pipe markers style numbers PMLN1, PMLN2

d Blank pipe marker style numbers. DDBLNK, AABLNK, OPT12B.

e. Pipe markers shall include uni- and bidirectional arrows in the same sizes as the legend.

f Arrow style numbers will be identified during design.

2 Underground Warning Tape—Plastic

a Tape shall be 6-in. wide, 4 mil, acid- and alkali-resistant polyethylene

b. Tape shall be suitable for direct burial.

c A message shall be printed on the tape and read ______________- BURIED BELOW" with bold letters approximately 2-in. high. The message shall be printed at maximum intervals of 2 ft.

d The blank space in the message shall include identification of the buried utility line or pipeline

3 Underground Warning Tape—Metallic

a. Printed polyethylene tape with a metallic core for detection of nonmetal pipes and cables

b Polyethylene material, tape, and message shall be as specified in subparagraph 2 02, A.2 of this Section.

B Valve Identification

1 Identify valves by letter and valve number Identification shall be peel-off vinyl letters or as required in the design

PART 3 EXECUTION

3.01 PREPARATION

A Protection and surface preparation of piping identification materials and adhered surfaces shall be in accordance with Manufacturer's instructions

3 02 INSTALLATION

A. Piping Systems

1 Unions shall be installed where required for piping or equipment installation, even though they may not be shown on Drawings Install unions in piping systems wherever they will expedite removal of equipment and valves.

2 Changes in location of equipment or piping, advisable in the opinion of Contractor, shall be submitted to Owner's Representative for acceptance before proceeding with Work. All measurements and dimensions shall be verified at the site

3 Where schematic diagrams are used to show piping connections, Contractor is cautioned that these diagrams shall not be used for obtaining quantities

4 All pipe flanges shall be set level, plumb, and aligned Fittings shall be true and perpendicular to the axis of the pipe Bolt holes in flanges shall straddle vertical centerline of pipes

5 Where invert elevations are shown on Drawings, Contractor shall lay the pipe in a straight grade between these points

6 Locate piping and pipe supports so that they do not interfere with open accesses, walkways, platforms, or with maintenance or disassembly of equipment.

7 Piping shall be provided as shown on Drawings and as specified except for adjustments to avoid architectural and structural features and shall be coordinated with electrical construction

B Piping Identification

1 Pipe Markers

a After application of the specified coating and insulation systems, exposed piping, interior and exterior, and piping in ceiling spaces, pipe chases, pipe galleries, well vaults, and valve boxes shall be identified with pipe markers and directional arrows Pipe marking schedule will be developed during design

b Legend markers and directional arrows shall be located at each side of walls, floors, and ceilings, at one side of each piece of equipment, at piping intersections, and at approximately 20-ft centers

2 Underground Warning Tape—Plastic

a. A single line of tape as specified in this Section shall be provided 2 5 ft above the centerline of all buried ferrous pipe For ferrous pipelines buried 8 ft or greater below finished grade, Contractor shall provide a second line of tape 12 in. below finished grade, above and parallel to each buried pipe Tape shall be spread flat with message side up before backfilling

3 Underground Warning Tape—Metallic

a Tape shall be buried 12 to 18 in. below grade and shall be above and parallel to buried nonferrous and plastic-pipe pipelines For pipelines buried 8 ft or greater below final grade, Contractor shall provide a second line of tape 2 5 ft above and parallel to the buried pipe

3 03 FIELD QUALITY CONTROL

A. Tests/Inspection

1 General

a The Contractor shall perform all cleaning, flushing, and testing including conveyance of test water from Owner's Representative designated source to point of use, and including all disposal thereof, complete and acceptable, for hydraulic structures and appurtenant piping as specified herein and in accordance with the requirements of the Contract Documents

b The Contractor shall submit minimum 48-hour advance written notice of its proposed testing schedule for review and concurrence of the Owner's Representative The Contractor's proposed plans for water conveyance, control, and disposal shall also be submitted in writing The Contractor shall submit a description of all proposed test procedures to the Owner's Representative for approval No testing shall be conducted until Owner's Representative's approval of the test procedures is obtained

c Water for testing will be furnished by the Owner, however, the Contractor shall make all necessary provisions for conveying the water from the Owner-designated source to the points of use

d Piping shall be tested after installation but before backfilling of underground lines, and before insulation of aboveground piping

e Upon completion of piping installation, but before application of insulation when required on exposed piping, Contractor shall test the piping systems Pressures, media, and test durations shall be as specified Equipment that may be damaged by the specified test conditions shall be isolated Testing shall be performed using calibrated test gauges and calibrated volumetric measuring equipment to determine leakage rates Each test gauge shall be selected so that the specified test pressure falls within the upper half of the range of the gauge

f Unless otherwise specified, testing, as specified herein, shall include existing piping systems that connect with new pipe systems Existing pipe shall be tested to the nearest existing valve Any piping that fails the test shall be repaired or replaced Repair and replacement of new piping shall be furnished and paid for by Contractor at no expense to Owner

g Pipe system test record shall be submitted to Owner's Representative Test records shall include for each test

(1) Identification of piping system

(2) Testing medium

(3) Testing pressure and other appropriate test data

(4) Time of test

(5) Date of test approval

(6) Signature of test supervisor

2. Liquid Systems

   a Leakage shall be zero at the specified test pressure throughout the specified duration for the systems tested Testing procedure and requirements will be developed during design.

3.04 ADJUSTING/CLEANING

A. General

   1 Piping systems shall be cleaned following completion of testing and before connection to operating, control, regulating, or instrumentation equipment. Contractor may, at its option, clean and test sections of buried or exposed piping systems Use of this procedure, however, shall not waive the requirement for a full-pressure test of the completed system Unless specified otherwise, piping 12 in. in diameter and smaller shall first be cleaned by pulling a tightly fitting cleaning ball or swab through the system

B Temporary Screens

   1 Upon completion of the cleaning, Contractor shall connect the piping systems to related equipment Temporary screens of sizes to be determined during design shall be inserted in pipelines at the suction of pumps and compressors

   2. Temporary screens shall be provided with locator tabs that remain visible from the outside when the screens are in place

   3 Contractor shall maintain the screens during testing, start-up, and initial operating phases Screens may be removed as required for performance tests Contractor shall remove the temporary screens and make the final piping connections after the screens have remained clean for at least 24 consecutive hours of operation Systems handling solids are exempted

C Gas and Air Systems

   1 Gas and air system piping 6 in. in diameter and smaller shall be blown out, using air or the testing medium specified Piping larger than 6 in shall be cleaned by having a swab or "pig" drawn through the separate reaches of pipe After connection to the equipment, it shall then be blown out using the equipment.

   2 Upon completion of cleaning, the piping shall be drained and dried with an air-stream

D Liquid Systems

1 After completion of cleaning, liquid systems shall be flushed with service water With temporary screens in place, the liquid shall be circulated through the piping system using connected equipment for a minimum period to be determined during design and until no debris is collected on the screens

- END OF SECTION -

Division 16

ELECTRICAL

To Be Completed During Design

LIST OF ACRONYMS

ANSI	American National Standards Institute
Army	U S Department of the Army
ASA	American Society of Agronomy, Inc
ASTM	American Society for Testing of Materials
CAMU	Corrective Action Management Unit
CCR	Code of Colorado Regulations
CDD	CAMU Designation Document
cm/s	Centimeter per second
CQA	Construction Quality Assurance
CSI	Construction Specifications Institute
FFA	Federal Facilities Agreement
FHWA	U S Department of Transportation Federal Highways Administration
HLA	Harding Lawson Associates
GCL	Geosynthetic clay liner
MIL-STD	Military standard
OSHA	Occupational Safety and Health Administration
PMLN#	Pipe marker style number
RMA	Rocky Mountain Arsenal
State	State of Colorado
UPC	Uniform Plumbing Code
USCS	Unified Soil Classification System
UV	Ultraviolet
°F	Degrees Fahrenheit

Appendix Q

CONTINGENCY PLAN OUTLINE

The outline below has been prepared to describe the general content of the appendix During or after design, the outline should be reviewed for applicability and revised as necessary

1 0 Introduction

1 1 Purpose and Scope

1 2 Organization

2 0 Emergency Coordinators

3 0 Implementation of the Contingency Plan

3 1 Landfill Cells

3 1 1 Containment Failure or Failure Due to External Forces

3 1.2 Human Exposure

3 1 3 Reportable Quantities

3 2 Decontamination Facilities

3 2 1 Containment Failure or Failure Due to External Forces

3 2 2 Human Exposure

3 2 3 Reportable Quantities

3 3 Basin F Waste Pile Drying Unit

3 3 1 Containment Failure or Failure Due to External Forces

3 3 2 Human Exposure

3 3 3 Reportable Quantities

3 4 Waste Staging/Consolidation Areas

3 4 1 Containment Failure or Failure Due to External Forces

3 4 2 Human Exposure

3 4 3 Reportable Quantities

4 0 Emergency Response Procedures

4 1 Preincident Phase (Preparedness)

4 2 Incident Phase

4 2 1 Notification

Appendix R

FINAL LANDFILL SITE FEASIBILITY REPORT

Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program

Prepared for

Program Manager for Rocky Mountain Arsenal
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Commerce City, Colorado 80022-2180

HLA Project No 21907 703040
Contract No DAAA05-92-D-0003
Delivery Order No 0007 (Task 93-03)

THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

July 7, 1995

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APPENDIXES

EXECUTIVE SUMMARY

This Site Feasibility report presents the results of the Material, Area, and Site Feasibility Studies (FSs) performed by Harding Lawson Associates (HLA) in support of Task 93-03 FS Soils Support Program at Rocky Mountain Arsenal (RMA) under contract with the U S Department of the Army (Army) Task 93-03 supports the evaluation of specific remedial alternatives presented in the Proposed Final Detailed Analysis of Alternatives (DAA) (Ebasco, 1994)

The primary objective of Task 93-03 was to collect soil data in support of the DAA portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) Task 93-03 was subdivided into three separate subtasks Material, Area, and Site FSs The objectives of the three-fold FSs presented in this report are to address issues concerning the implementability of constructing a hazardous waste landfill at RMA. The objectives of each FS are described below

Material Feasibility Study

As stated above, the primary objective of the Material FS was to evaluate the suitability of onpost soil for use as landfill liner and capping material To meet this objective, soil was collected from two borrow areas identified in the Final FS Soils Support Program Report (HLA, 1995) Testfills 1 and 2 were constructed from soil excavated from the central portion of Section 20 and the southeast quarter of Section 24, respectively The two testfills were constructed to evaluate the construction methods necessary to achieve a permeability of less than 1 x 10^{-7} centimeters per second (cm/s) as required by both state and federal regulations In situ permeability tests were performed on the testfills using two testing techniques sealed double-ring infiltrometers (SDRIs) and two-stage borehole permeameters (TSB) Laboratory permeability tests were conducted on soil samples collected from the constructed testfills to further evaluate the permeability of the soil

One SDRI and five TSBs were installed and tested on each testfill The hydraulic conductivity computed for each SDRI was 1 18 x 10^{-8} cm/s from Testfill 1 and 8 30 x 10^{-8} cm/s from Testfill 2

The average vertical hydraulic conductivity measured by the TSBs on the testfills was $4\ 28 \times 10^{-8}$ cm/s from Testfill 1 and $5\ 94 \times 10^{-8}$ cm/s for Testfill 2 Laboratory permeability tests and geotechnical tests were performed on "undisturbed" Shelby tube soil samples collected from the testfills after the SDRI and TSB monitoring was complete The average hydraulic conductivity measured from the testfill soil samples was $5\ 6 \times 10^{-8}$ cm/s from Testfill 1 and $3\ 04 \times 10^{-8}$ cm/s from Testfill 2

Based on the results presented in this report, the objectives of the Material FS were met The field and laboratory test results indicate that onpost soil can be used to construct caps and liners that meet the required hydraulic conductivity of less than 1×10^{-7} cm/s

Area Feasibility Study

The primary objective of the Area FS was to identify areas within RMA that are suitable for siting a hazardous waste landfill based on current regulatory and institutional criteria. The following activities were performed as part of the Area FS to identify areas suitable for a hazardous waste landfill

- Reviewing previous landfill siting studies at RMA
- Reviewing current state and federal landfill siting regulations and combining them with institutional landfill siting policies established by the Program Manager for Rocky Mountain Arsenal (PMRMA) and the U S Fish and Wildlife Service (USFWS)
- Performing a Geographic Information System (GIS) analysis to identify areas at RMA that meet the regulatory and institutional suitability criteria

Based on the GIS analysis, an area of approximately 300 acres in the western half of Section 25 was selected as the preferred landfill location at RMA. The selection was based on achieving the following suitability criteria

- Greater than 1000 feet from a Holocene fault
- Outside the 100-year floodplain
- Not within salt formations

- No waste placed below or into surface water or groundwater
- Notification if the landfill is placed within 5 miles of a runway
- Not within a wetland
- Not located in seismic impact zone without demonstration
- Not within unstable area
- Maximized protection from wind with precipitation catchment area
- Isolation of waste from the public and environment
- Reasonable assurance that the waste is isolated for 1000 years
- Located within distance controlled by the Army to prevent adverse effects to public health
- Noise levels within limits
- Avoidance of sensitive habitats

Upon identification of the preferred area, the secondary objective of the Area FS was to obtain adequate data regarding the geologic and geotechnical characteristics of the area After the area within the western half of Section 25 was identified as suitable based on the regulatory and institutional criteria, a geologic and geotechnical investigation was performed in the identified area to

- Lithologically log the core and geophysically log three deep (approximately 150-foot) boreholes
- Drill 30 shallow (approximately 50-foot) boreholes and lithologically log and collect soil samples
- Perform geotechnical tests on the soil samples including particle size analysis, Atterberg limits, natural moisture content, standard Proctor tests, remolded permeability, shear strength, shrink and swell, and organic content.

Geologic and geotechnical results indicate the identified area is conducive to construction of a hazardous waste landfill with primarily alluvial clay and Denver Formation claystone underlying the site Bedrock sandstone units were mapped in the identified area, however, depending on the size of the landfill required, areas where the sandstone units subcrop into the alluvium may be avoided

Based on the geotechnical testing program, approximately 65 percent of the soil tested was classified as clay, which indicates it may be suitable for use in the construction of the landfill liner and cap

Site Feasibility Study

The primary objective of the Site FS was to evaluate whether a hazardous waste landfill of sufficient capacity could be constructed in the area identified in the Area FS and meet pertinent federal, state, and local regulatory requirements The Site FS also provided information regarding the conceptual landfill models, design elements, construction costs, and schedules The Site FS included the following evaluations

- Waste types, volumes, and generation rates
- Site-specific considerations and limitations
- Conceptual landfill design alternatives
- Evaluation and screening of alternatives
- Facility layout
- Material quantities and availability
- Construction and operation and maintenance (O&M) cost estimates and schedules
- O&M plans

The results of each of these evaluations are discussed briefly below

Three conceptual landfill models were evaluated to account for potential variation of waste volumes that may be generated on the basis of selected remedial action alternatives defined in the Proposed Final DAA (Ebasco, 1994) The three conceptual models were based on 1 million, 2 3 million, and 6 million cubic yards (cy) of waste Waste volumes were increased by 20 percent to account for intermittent waste cover for conceptual design purposes Waste generation rates were estimated to be in the range of 98,000 cy to 1,100,000 cy of material per year without a funding limit, and 37,000 to 280,000 cy of material per year assuming a $100 million annual funding limit.

Site-specific considerations such as climate, topography, geology, hydrogeology, and surface hydrology should not significantly impact landfill construction Based on the geologic investigation, no geologic hazard or environmentally sensitive areas were identified within the preferred siting area Additional geologic and/or geotechnical studies will be required prior to final landfill siting and design Denver Formation sandstone units are in contact with the alluvium in the vicinity of the landfill siting area and should be avoided if possible To maximize the depth to groundwater beneath the proposed landfill site, the landfill should be sited within the central portion of western Section 25 Furthermore, to facilitate long-term monitorability, areas of groundwater mounding such as in the southwest central portion of Section 25 should also be avoided

Conceptual design alternatives were developed for liner systems, leachate collection and removal systems, gas management systems, and final cover systems Six conceptual liner system alternatives and four final cover system alternatives were developed A leachate collection and removal system consisting of 12 inches of sand with a 200-foot drainage length and 2 percent slope was proposed Gas generation from landfilling of RMA waste is expected to be minimal and may be managed using a passive venting system

Conceptual liner and final cover alternatives were evaluated for effectiveness using the Hydrologic Evaluation of Landfill Performance (HELP) Model Version 3 and evaluated for cost by estimating the unit cost on a square foot basis In the HELP model simulations system, the six liner alternatives performed similarly Conceptual liner designs that included geosynthetic clay as the base layer performed only slightly better than those with compacted clay or tertiary geomembrane liner as the base As a result, the final screening of the conceptual liner designs should consider cost and constructibility because performance results for conceptual liner designs are so similar Similarly, the performance results for cover alternatives indicate that final screening of the cover systems should also consider cost and constructibility since the four cover systems evaluated performed equally well Based on a unit cost comparison of the six liner systems and four cover systems evaluated, the liner and cover systems that use geosynthetic clay liners were found to be more cost-effective

The overall landfill performance was also evaluated using the HELP model to assess the potential effectiveness of the cover and liner systems The most cost-effective cover and liner systems were used to estimate the long-term leachate production from the landfill using worst-case conditions At predicted leachate product rates, it would take from 1000 to 1200 years for soil water in the vadose zone to move downward from the base of the landfill 1 foot.

The landfill facility layouts were evaluated for the three conceptual models The landfill footprint areas for each conceptual model are as follows 19 acres (Conceptual Model 1), 35 acres (Conceptual Model 2), and 87 acres (Conceptual Model 3) The excavation depth for each landfill scenario was assumed to be average of 30 feet below the existing ground surface, with a maximum liner thickness of 5 feet. The excavation sideslopes were assumed to be 3 horizontal 1 vertical (3H.1V), and above grade sideslopes were assumed to be 6H 1V A final geotechnical investigation should be performed to refine and expand upon the testing and analyses presented in this report, and consider in its analysis any changes from these conceptual models

Material quantities for low-permeability soil and structural fill soil used in landfill liner and cover system components were estimated and compared to the estimated available volumes of onpost materials Conceptual Models 1, 2, and 3 required 270,000 cy, 510,000 cy, and 1,235,000 cy of clay soil, respectively, and 296,000 cy, 640,000 cy, and 1,635,000 cy of structural fill soil, respectively Based on the estimated volumes of onpost soil from borrow areas and the landfill excavation, it appears that sufficient onpost soil exists to meet construction requirements for even the largest landfill (Conceptual Model 3)

Construction and annual (O&M) cost estimates for three conceptual landfill models were prepared to be accurate within plus 50 percent to minus 30 percent The estimated construction cost for Conceptual Models 1, 2, and 3 are $12,500,000 ($12 50 per cy), $22,500,000 ($10 00 per cy), and $52,500,000 ($9.00 per cy), respectively Estimates of annual O&M costs were made for each conceptual model using both restricted and unrestricted funding scenarios The O&M costs range from a high of approximately $1,487,000 per year for 12 years or $18 per cy of waste for Conceptual Model 1 in the restricted funding scenario The lowest O&M costs correspond with Conceptual Model 3 at approximately $4,460,000 per year for 9 years or $7 per cy of waste with unrestricted funding Construction for cell development of an approximate 200,000-cy module that could be applied to any of the three conceptual landfill models would take approximately 34 weeks to prepare

Based on the results of the Site FS presented in this report, it is feasible to construct a hazardous waste landfill of sufficient capacity within the preferred site at RMA that would meet the applicable federal, state, and local regulatory requirements Information provided in this report can be used for rapid implementation of the preferred remedial alternative once the ROD is completed for RMA.

1.0 INTRODUCTION

This report fulfills Data Requirement A004, a contract deliverable under Delivery Order 0007 (Modification to Task 93-03 Feasibility Study [FS] Soils Support Program) of Contract DAAA05-92-D-0003 between Harding Lawson Associates (HLA) and the U S Department of the Army (Army) This report was prepared by HLA at the direction of the Army for the sole use of the Army and the signatories of the Federal Facilities Agreement (FFA) of Rocky Mountain Arsenal (RMA), the only intended beneficiaries of this work.

1.1 Site Description, Task Objectives, and Report Organization

This report presents the results of the Task 93-03 Material, Area, and Site FS Based on evaluations of the results provided, conclusions and recommendations are presented regarding the materials, area, and site for construction of an onsite hazardous waste landfill facility The site description, task objectives, and report organization are discussed in the following subsections

1.2 Site Description

RMA is located in Commerce City, Colorado (see Figure 1.1) RMA was established in 1942 by the Army as a manufacturing facility for the production of chemical and incendiary munitions Military, industrial, and agricultural chemicals, primarily pesticides and herbicides, were also manufactured at RMA by several lessees from 1947 to 1982 The industrial waste liquid produced from operations performed by the Army and its lessees was initially discharged to Basin A, an unlined basin in Section 36 Subsequently, liquid wastes were discharged to other unlined basins and, after 1956, to Basin F, which was asphalt-lined Although solid wastes were disposed of primarily in Section 36, other onpost disposal sites were also used. Some of the basins, pits, burn sites, sewers, and structures (buildings, pipes, and tanks) became sources of soil and groundwater contamination as a result of spills, leaks, or other releases

1.2.1 Task Objectives

The primary objective of Task 93-03 was to collect soil data in support of the Detailed Analysis of Alternatives (DAA) portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) The Proposed Final DAA completed by Ebasco in December 1994 presents the results of a multiyear, multidiscipline evaluation of specific remedial alternatives and their applicability to the known areas and types of contamination at RMA Based on the proposed final version of the DAA, the preferred alternative for remediation of the soils and structures at RMA includes construction of an onpost hazardous waste landfill for containment of a portion of the contaminated material and capping other areas of contamination in place The preferred alternative includes landfilling approximately 2,300,000 cubic yards of material.

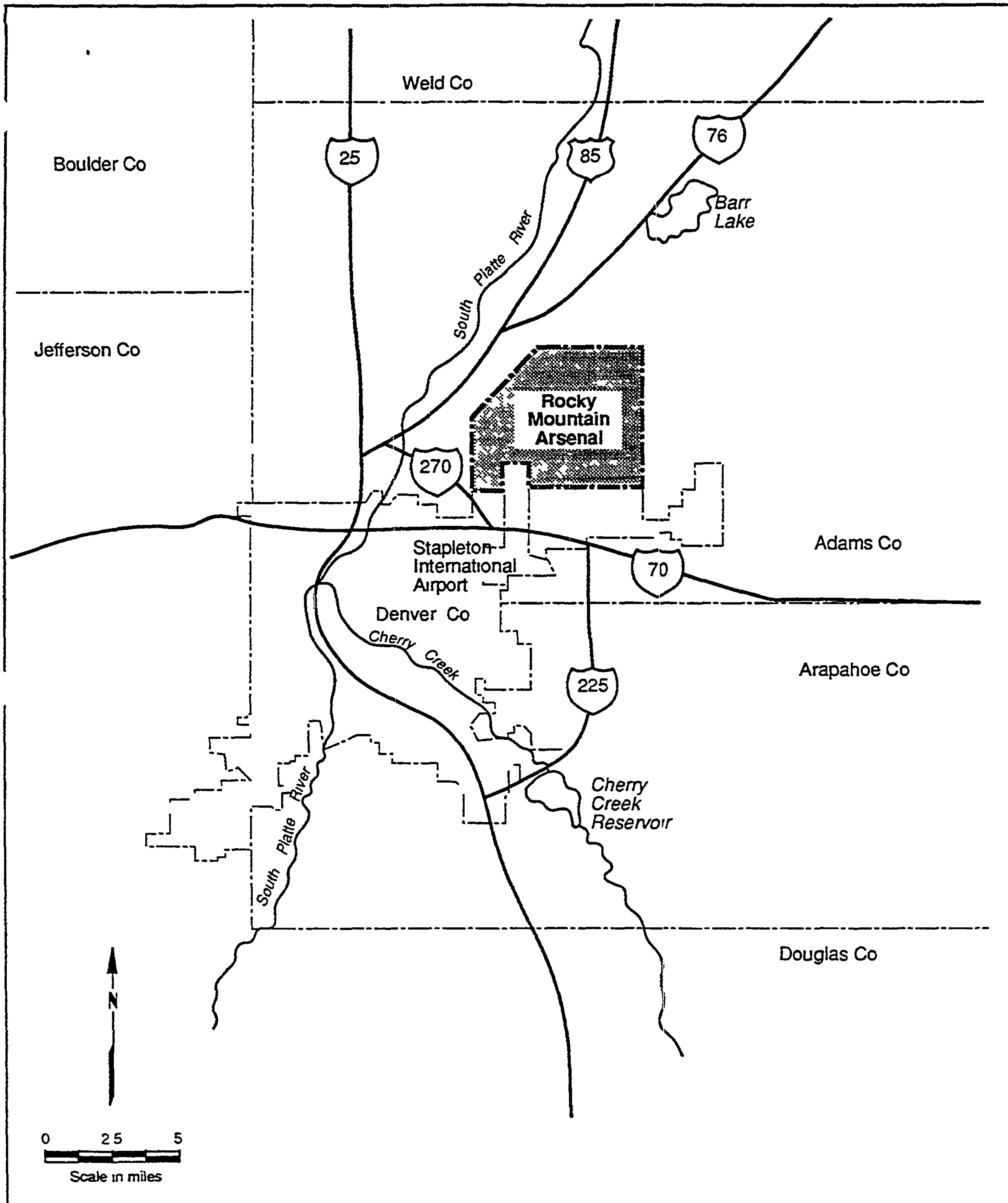
The three-fold FSs presented in this report address many of the issues raised about the implementability of the preferred remedial alternative As described above, this portion of Task 93-03 was subdivided into three separate subtasks Material, Area, and Site FS The objectives of each subtask are described below

The primary objective of the Material FS was to evaluate whether onsite soil is suitable for use as landfill liners and capping material based on field and laboratory tests The primary objective of the Area FS was to identify areas within RMA suitable for siting a landfill based on current regulatory and institutional criteria. Upon identification of the optimal site, the secondary objective of the Area FS was to obtain adequate data regarding the geologic and geotechnical characteristics of the site to evaluate the feasibility of constructing a landfill in the existing foundation materials The primary objective of the Site FS was to identify an appropriate landfill site within the area identified in the Area FS and provide information on conceptual landfill models, design elements, construction costs, and schedules

1.2.2 Report Organization

The remainder of this report is divided into seven sections Section 2 0 describes the technical approach for the three-fold feasibility studies for Task 93-03 Section 3 0 (Material FS) presents the results and conclusions of the test fill construction, and field and laboratory testing program Section 4 0 presents the results of the Area FS, which identifies the most suitable location for an onpost hazardous waste landfill at RMA based on previous studies, current regulatory criteria, and institutional criteria. Results of an extensive geologic and geotechnical testing program performed within the preferred area are also presented within Section 4 0 Section 5 0 presents the results of the Site FS, which evaluates the feasibility of constructing a hazardous waste landfill at RMA using onpost materials Also included in Section 5 0 are discussions regarding landfill construction cost estimates, construction schedules, and operation and maintenance (O&M) plans. Section 6 0 presents a summary, conclusions, and recommendations based on the results presented in this report. Section 7 0 is a list of acronyms, and Section 8 0 is the bibliography

In addition to the main body of this report, several items related to the Task 93-03 FS have been appended Appendix A presents testfill construction specifications, and Appendix B presents testfill construction photographs Testfill construction equipment is described in Appendix C Appendix D presents the sealed double-ring infiltrometer and two stage borehole (TSB) test data. Lithologic boring logs are presented in Appendix E, and the boring locations and elevations are provided in Appendix F Appendix G presents the geophysical logging data, and Appendix H presents the cost estimates for the various conceptual models described in this report. The Final Work Plan for material and Feasibility Studies Soil Support Program is provided as Appendix I



Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure 1 1

Site Location Map

2.0 TECHNICAL APPROACH

This report presents the results of a study completed to evaluate the feasibility of siting and constructing a hazardous waste landfill at RMA As stated previously, the evaluation was subdivided into three feasibility studies (1) Material, (2) Area, and (3) Site This section describes the technical approach used to accomplish the objectives established for each of the FSs Figure 2 1 presents a report overview

2.1 Material Feasibility Study

The Material FS had two main objectives (1) to evaluate the feasibility of using soil from onpost borrow areas for use in the construction of landfill liners and caps, and (2) to evaluate the construction specifications such as optimum lift thickness, soil moisture content, density, and compactive effort necessary to achieve the required permeability of 1 x 10^{-7} centimeters per second (cm/s) for the construction of landfill liners and caps To accomplish the stated objectives the following work elements were completed

- Geotechnical tests were performed on soil collected from two borrow areas identified in the Final FS Soils Support Program Report (HLA, 1995a) as containing soils thought to be suitable for construction of low-permeability soil liners and caps
- Two testfills were constructed with soil excavated from the borrow areas to evaluate the construction methods necessary to achieve the required permeability
- In situ permeability tests were performed on the constructed testfills using two testing techniques, sealed double-ring infiltrometers (SDRI) and two-stage borehole (TSB) permeameters
- Laboratory permeability tests were conducted on soil samples collected from the constructed testfills to further evaluate permeability

2.2 Area Feasibility Study

The Area FS was conducted to (1) identify areas at RMA that meet the current regulatory and institutional landfill siting criteria, and (2) further evaluate the suitability of a preferred area through geologic and geotechnical evaluations To identify areas suitable for the hazardous waste landfill at RMA the following work elements were completed

- Previous landfill siting studies conducted at RMA were reviewed with regard to current Colorado landfill siting regulations

- Regulatory and institutional landfill siting suitability criteria, such as locating the landfill outside floodplains and avoiding sensitive habitats, were established based on current regulatory and institutional requirements

- Using the established siting suitability criteria, a Geographic Information System (GIS) analysis was performed to identify areas at RMA that meet the suitability criteria

Limitations to this study included the following

- A fourth deep borehole was not drilled as originally scoped due to limited funding

- No hydrogeologic field work was scoped for this program

- No soil or groundwater chemical analyses were scoped for this program Geochemical interpretations used for this report were based on previous studies performed at RMA

Once a preferred area was identified based on the GIS analysis, a geologic and geotechnical investigation was performed at the preferred area The investigation was performed in the western half of Section 25 and included drilling 33 boreholes, downhole geophysical logging, and geotechnical property testing

2.3 Site Feasibility Study

The primary objective of the Site Feasibility Study was to determine whether a hazardous waste landfill of sufficient capacity could be constructed at this site that would meet all applicable federal, state, and local regulatory requirements

The study included a review and evaluation of the following

- Evaluate waste types, volumes, and generation rates

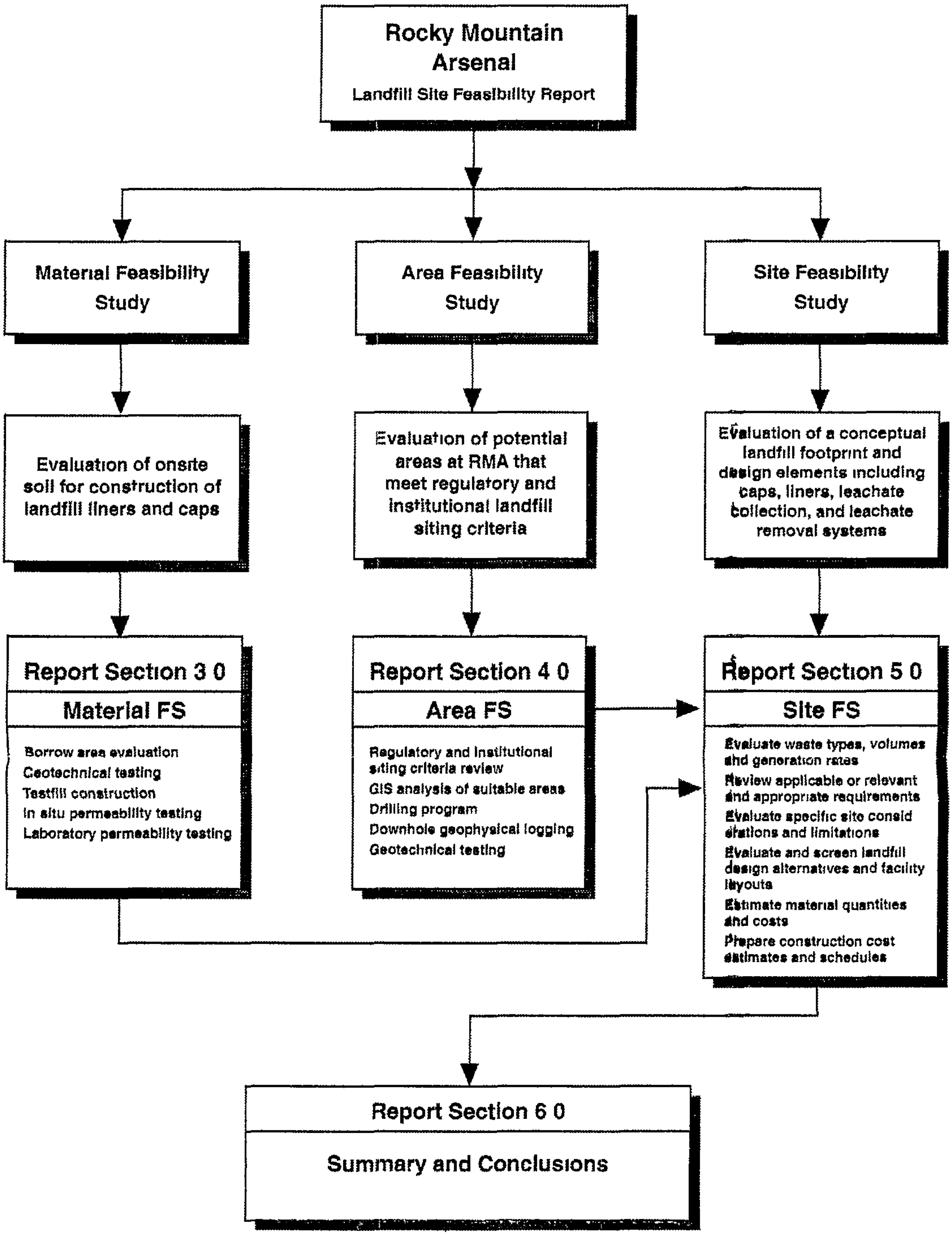
- Review regulatory criteria

- Evaluate specific site considerations and limitations

- Evaluate and screen landfill design alternatives and facility layouts

- Estimate material quantities and costs
- Prepare construction cost estimates and schedules

Three conceptual landfill models were evaluated to account for various waste volumes depending on the remedial action alternative selected for the RMA The waste volumes were considered to represent minimum, maximum, and most probable



Prepared for Program Manager for Rocky Mountain Arsenal Commerce City Colorado Prepared by Harding Lawson Associates	Figure 2 1 Technical Report Overview

3.0 MATERIAL FEASIBILITY STUDY

This section presents the results of the Material FS, which included a testfill construction and a permeability testing program The purpose of the Material FS program was to simulate construction of a low-permeability soil cap or liner by constructing two testfills then testing the constructed testfills to assess whether they meet the desired permeability of 1 x 10^{-7} cm/s

In summary, the Material Feasibility portion of the FS Soils Support Program had two main objectives (1) to verify that onpost soil from two distinct borrow areas are capable of meeting a permeability of less than or equal to 1 x 10^{-7} cm/s (the required permeability of soils used as clay caps or liners [6 Code of Colorado Regulations (CCR) 1007-2 2 5.3]) and (2) to evaluate the optimum lift thickness, moisture content, density, and compactive effort necessary to achieve the required permeability Permeability of the constructed testfills was measured both in the field and in the laboratory to evaluate the suitability of the materials and methodology used to construct the testfills

The testfills were constructed in July and August 1994 generally following the procedures presented in the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (see Appendix I) and included in Appendix A. The testfills were constructed in the southwest quarter of Section 25 (Figure 3 1) Following completion of the testfills, one sealed double-ring infiltrometer (SDRI) and five two-stage borehole permeameters (TSBs) were installed on each testfill following installation procedures provided by the manufacturer and included in the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) An HLA geotechnical engineer and a engineering technician provided construction observation and geotechnical testing required during installation. Data collection and data reduction of the SDRI and TSB testing equipment were performed by HLA in August, September, and October 1994 The following sections describe in detail the work elements performed in the Material FS

3.1 Borrow Material Excavation and Geotechnical Testing

This section describes the excavation and geotechnical testing of borrow material used in the construction of the testfills Figure 3 1 illustrates the two borrow areas used to supply the required volume of clay soil The borrow areas were identified in the Final FS Soils Support Program Report (HLA, 1995a) to contain suitable borrow material The borrow areas were approved by the United States Fish and Wildlife Service (USFWS) for excavation provided the areas were reseeded following excavation This section presents the borrow material excavation procedures along with the geotechnical test results of analyses performed on the borrow material

3.1.1 Borrow Material Excavation and Borrow Pit Closure

Topsoil was stripped from the borrow areas prior to excavation of the testfill material The topsoil was stockpiled adjacent to the respective borrow pits Borrow material was visually inspected prior to transport. Scrapers, a front-end loader, and 20-cubic-yard dump trucks were used to excavate and transport the borrow material to the testfill construction stockpile areas Upon completion of the excavations, borrow pit closure was accomplished by grading the borrow pit area, covering the affected area with the stockpiled topsoil, and reseeding

Excavation and reseeding specifications are provided in Appendix A, Testfill Construction Specifications Photographs A and B in Appendix B illustrate the excavation and reseeding operations performed

3.1.2 Geotechnical Testing of Borrow Material

Geotechnical laboratory tests were performed on samples collected from borings near the borrow pits and from samples collected from the excavation pits Results from the tests are presented in Table 3 1 The laboratory testing program included grain size analysis (American Society for Testing and Materials [ASTM] D422), Atterberg limits (ASTM D4318), and standard Proctor compaction tests (ASTM D698) The compaction test results were used to identify the optimum moisture content and maximum dry density of the soil used for construction of the two testfills Further discussion of the testfill construction specifications is presented in Section 3.2

Soil excavated from Borrow Area A was used in the construction of Testfill 2 Soil from Borrow Area A was classified as inorganic clays with low to high plasticity (Table 3 1) The Atterberg tests indicate liquid limits ranging from 46 to 55 and plasticity indices (PI) ranging from 25 to 33 The percent passing the No 200 sieve ranged from 70 9 to 81 6 The average maximum dry density and optimum moisture content, as determined by the standard Proctor compaction test, were 102 8 pounds per cubic foot (pcf) and 19 0 percent, respectively

Borrow Area B was subdivided into two subareas, B1 and B2 Following visual inspection of the borrow pit, the soil in Borrow Area B1 was not used in the construction of the testfill because of observed calcium carbonate content of the soil Calcium carbonate content greater than approximately 5 percent in soil is not recommended for use as low-permeability liner or cap material because of the potential for dissolution and subsequent increased permeability Soil used in the construction of Testfill 1 was excavated from Borrow Area B2

The soils from Borrow Area B2 are classified as inorganic clay with low to high plasticity (Table 3 1) The Atterberg tests indicate liquid limits ranging from 44 to 55 and PI ranging from 23 to 31 The percent passing the No 200 sieve ranged from 59 8 to 65 3 The average maximum dry density and optimum moisture content as determined by the standard Proctor density test, were 102 3 pcf and 19 3 percent, respectively

As indicated by the sieve analysis results, the difference between the material excavated from the two borrow areas was that the material from Borrow Area B had a higher sand content than the samples from Borrow Area A. On average, the material from Borrow Area B had approximately 10 percent more very fine-grained sand This increased sand content helped facilitate the moisture conditioning process The sandier soil from Borrow Area B2 was able to uptake the added moisture more rapidly than the material from Borrow Area A This resulted in more rapid soil processing and therefore increased construction rates

3.2 Testfill Construction

This section describes the equipment and procedures used to complete the construction of the two testfills Each testfill is approximately 100 feet long by 40 feet wide at the top (Figure 3 2) and consist of a 3-foot-thick clay test layer, underlain by a 6-inch working layer constructed over a prepared subgrade Each testfill slopes uniformly to one side at approximately 2 percent

3.2.1 Processing and Testfill Area Preparation

The soil processing areas were used to stockpile soil, break up the soil to reduce clod size, and moisture condition the soil before placement on the testfills The processing and testfill areas were prepared following the specifications included in Appendix A In summary, the following procedures were followed

The processing and testfill construction areas were stripped of topsoil The topsoil was stockpiled adjacent to the processing areas The surface of the processing areas was smoothed (proof-rolled) with the pneumatic tires of the front-end loader The testfill subgrades were graded to slope approximately 2 percent in a northerly direction, compacted with the wedge-foot roller, scarified, and proof-rolled Photographs C and D (Appendix B) illustrate the preparation procedures

Four grain size analyses were performed on the testfill area subgrade material to evaluate potential for hydraulic head build-up at the interface between the first lift of the testfill and the subgrade Head build-up at the base of the testfill could adversely affect the in situ permeability test results (SDRI) by creating an infiltration barrier The grain size analyses indicate the material is a silty sand (SM according to the Unified Soil Classification System [USCS]) Head build-up at the base of the testfill at the subgrade interface was considered unlikely because of the higher permeability of the silty sand To avoid further surface tension and capillary effects on the downward infiltration through the testfills, the subgrade was thoroughly wetted to a depth of 1 foot prior to placement of the first testfill layer (working layer)

3.2.2 Soil Processing

Soil processing, including clod size reduction, moisture conditioning, blending, and curing, was completed prior to testfill lift compaction generally following the specifications in Appendix A The soil processing was performed both in the processing area and on the test pad In general, optimum construction performance was achieved when the bulk of the moisture conditioning was performed in the processing area and final moisture conditioning was performed on the test pad

Initially, soil processing activities were performed with a bulldozer, tiller, and a water truck It was observed that this process was time consuming and only marginally effective Photograph E in Appendix B illustrates the initial processing procedures Because moisture conditioning using the tiller was not adequate to achieve the uniform moisture content required prior to lift compaction, a Caterpillar SS-250 was used for soil processing Photograph F illustrates soil processing using the pulvamixer The testfill construction equipment specifications are presented in Appendix C

3.2.3 Final Subgrade Preparation and Working Layer Placement

The testfills were constructed on a foundation of in situ sandy soils as described in Section 3 2 1 A 6-inch-thick clay working layer was placed above the prepared subgrade The working layer had a 6-inch compacted lift thickness The working layer surface was scarified using the track of the dozer to facilitate lift bonding to the first lift of the testfill

Compaction and moisture content of the working layer was measured in the field using a nuclear density gauge (ASTM Methods D2922 and D3017) The relative compaction of the working layers ranged from 96 1 to 99 8 percent in Testfill 1 and from 95 9 to 99 5 in Testfill 2 The moisture content of the completed working layers ranged from 19 96 to 21 45 percent in Testfill 1 and 20 7 to 21 3 percent in Testfill 2 A summary of the density test data is presented in Tables 3 2 and 3 3

3.2.4 Testfill Lift Placement

Upon completion of the working layer, placement of the testfill lifts was initiated The following procedures were used during construction of the testfills (Listed photographs can be found in Appendix B)

1 Prior to placement of each successive lift, the surface of the previous lift was scarified using the track of the dozer to a depth of approximately 2- to 3-inches to achieve proper bonding between lifts The surface was moisture conditioned as necessary to prevent desiccation of the soils Also, the elevation of the surface was measured using a surveyors' level and rod (Photograph G)

2 Lifts were placed on the testfills in 9-inch loose lifts using the front-end loader and a dozer (Photograph H)

3 The soils were blended, moisture conditioned, and clod size was reduced using the pulva-mixer (Photographs I)

4 Prior to compaction, the moisture content of the loose lift was measured using the nuclear gauge

5 The lifts were compacted using a Caterpillar 815C compactor The lifts were compacted in adjacent longitudinal passes One roller pass was defined as a trip up and a trip back the length of the testfill Each consecutive pass was offset the width of the roller The entire surface of the lift was compacted with a total of two passes per lift (Photograph J)

6 Compaction and moisture content of each lift were measured using the nuclear density gauge For confirmation soil samples were collected at each location and tested using ASTM D2216, an oven-drying methodology

7 If the test results indicated that the lift did not achieve the construction specifications (95 percent relative compaction and 1 to 4 percent wet of the optimum moisture content) the lift was reblended and moisture conditioned using the pulvamixer and recompacted using the compactor as described above

8 Following compaction of the final lift, the surface was bladed smooth to approximately 2 percent of grade to provide for proper surface drainage The surface was then completed with steel-wheel roller passes across the entire surface (Photograph K)

9 Throughout the construction, and upon completion of the testfill, plastic tarps were placed over the testfills to reduce the potential for desiccation of the clay soil (Photograph L)

3.2.5 Testfill Completion

The testfills were completed using a smooth-drum roller to provide a smooth, uniform surface as described above. Furthermore, to prevent desiccation of the testfill, topsoil was placed across the entire surface of the test pad except for the 12-foot by 12-foot area sealed with a tarp where the SDRI test was to be installed (Photograph M).

3.3 Field and Laboratory Permeability Testing Programs

The following section presents an overview of the field and laboratory permeability testing program used to evaluate the in situ hydraulic conductivity of the clay testfills. One SDRI and five TSB permeameter tests were performed at each testfill. Figure 3.3 illustrates the SDRI, TSB, and laboratory permeability testing sample locations.

3.3.1 Sealed Double-Ring Infiltrometer Test Method Description

The SDRI test measures the vertical infiltration rate of water through the constructed testfills. The SDRIs are specifically designed to measure low infiltration rates in the range of 1×10^{-5} to 1×10^{-8} cm/s. Based on previous laboratory results (HLA, 1995a), the remolded permeability of the soil at 95 percent of maximum dry density and at approximately 4 percent above optimum moisture content (ASTM D698) at the proposed borrow areas ranges from 4.80×10^{-8} to 1.98×10^{-8} cm/s.

A detailed summary of the SDRI test method was provided in Appendix A of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (Appendix I) along with the manufacturer's installation and operating instructions. A synopsis of the test method from the installation follows.

- The SDRI consists of 12-foot by 12-foot outer ring and a 5-foot by 5-foot sealed inner ring (Figure 3.4).
- The rings are grouted within the trench excavated into the top of the testfill.
- The outer ring is installed at 14 to 18 inches below the ground surface (bgs).
- The inner ring is installed at 4 to 6 inches bgs.
- The areas between both rings are filled with water (the outer ring to a depth of 12 inches, which completely submerges the inner ring).

The flow of water in the SDRI is monitored by filling a flexible bag with a known weight of water and connecting the bag to a port on the inner ring. As the water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag. After a specified time interval, the flexible bag is removed and weighed. The weight loss is then converted into milliliters of water that have infiltrated into the testfill. Infiltration rate is calculated using an equation with the following parameters: the volume of water loss, the area of the inner ring, and the interval of time that the bag was connected onto the inner ring. The tests are monitored until the infiltration rate reaches a steady state. Upon completion, a plot of the infiltration rate over time is prepared. For the purposes of this test, the specified permeability value to be achieved is less than 1×10^{-7} cm/s.

3.3.2 Sealed Double-Ring Infiltrometer Installation and Monitoring

The SDRIs were installed immediately following completion of the testfills between August 5 and August 9, 1994. The SDRIs were installed under the direction of the installation subcontractor, Mr. Steve Trautwein of Trautwein Soil Testing Equipment (manufacturer of the SDRIs). Photographs (N through P) of the SDRI installation are included in Appendix B.

SDRI monitoring was conducted between August 10, 1994, to November 11, 1994. SDRI monitoring procedures included flow measurements, water temperature readings, water-level measurements, swell measurements, and tensiometer readings. In general, the readings were taken on a daily basis until the infiltration rate slowed sufficiently to allow measurements to be collected once every several days. The readings were taken by field personnel trained and experienced in taking SDRI measurements. The readings were recorded in field logbooks and then transferred onto the SDRI data forms (Appendix D). Plots of the infiltration rate and hydraulic conductivity were evaluated concurrently with the testing to identify when the test could be terminated.

3.3.3 Sealed Double-Ring Infiltrometer Data Reduction and Evaluation

Data were reduced and evaluated by transferring the field measurements recorded on the data forms to computer spreadsheets for ease of computation The infiltration rate was calculated using the following equation

$I = Q/(At)$

where

I = infiltration in cm/s

Q = volume of flow in cubic cm

A = area of flow in square cm

t = time interval in seconds

The hydraulic conductivity within the SDRI is calculated using the following equation

$k = Q/(iAt)$

where

k = hydraulic conductivity in cm/s

Q = volume of flow in cubic cm

t = time interval in which Q was determined in seconds

i = $\Delta h/\Delta s$ (gradient) dimensionless

Δh = head loss

Δs = length of flow path for which Δh is measured

A = area of flow in square cm

since,

$I = Q/(At)$

then,

$k = I/i$

The calculation of k depends on calculating a value for the gradient (i). Unlike the calculations for I and k, the calculation of i is not straightforward The parameters used to calculate the gradient are as follows

$$i = (H + D + Hs) / D$$

where

H = depth of water ponded in rings

D = depth to the wetting front

Hs = suction at the wetting front

There are differing opinions on what value should be used for Hs One view is that Hs should be equal to the ambient suction in the soil below the wetting front. The ambient suction can be measured with tensiometers Values of Hs can be as high as 275 inches of water Another view is that Hs should be equal to zero, i e , the suction in the soil at the wetting front has no influence on the infiltration rate Hence, if the position to the wetting front is known, the gradient is simply $(H + D) / D$

At the SDRI manufacturer's suggestion, the second view ($Hs = 0$) was used in this study Assuming $Hs = 0$, yields a close approximation to the actual gradient Measurements made at several sites have shown that the drop in infiltration rate versus time can be accounted for by the increase in D as the wetting front moves through the soil If suction had an influence, a much larger decrease in the infiltration rate would have occurred

If suction near the wetting front has an influence on the infiltration rate, then the hydraulic conductivity calculated assuming Hs equals zero is a conservative estimate, i e , the actual hydraulic conductivity will be less

3.3.3.1 Factors that Affect Flow Measurements

Two factors that can have a significant effect on the measured amount of flow are temperature changes and swelling of the soil The total flow (Q) measured is the sum of the following

$$Q = Q_i + Q_s + Q_t$$

where

Q_i = flow due to infiltration

Q_s = flow due to swell

Q_t = flow due to temperature changes

When calculating hydraulic conductivity, the infiltration rate used should correspond to Q_i The infiltration rate corrected for swell and temperature changes is calculated as follows

$$I = Q_i / At$$

where

$$Q_i = Q - Q_s - Q_t$$

If either Q_s or Q_t are significant, greater than 10 percent of Q, then Q_i should be used to determine I Procedures for measuring Q_s and Q_t are discussed below

3.3.3.2 Temperature Effects

Flow corresponding to Q_t results from temperature changes that cause the inner ring and the water contained within it to undergo a volume change Measurements have shown that for an inner ring of the type used in this project, a 1 degree Fahrenheit (°F) change can amount to 15 milliliter (ml) to 30 ml of flow in or out of the ring If the temperature rises, the net effect of inner ring and water expansion is to expel water from the inner ring Similarly, water is drawn into the inner ring if the temperature decreases

For this project, temperature effects were minimized by following the manufacturer's monitoring procedures Measurements were taken at approximately the same time each day to minimize temperature effects When temperature changes were unavoidable due to changing weather patterns, measurements were collected for several days at a new baseline water temperature

3.3.3.3 Swell Effects

The remaining portion of flow to consider is Q_s, the flow due to soil swell The process of water infiltrating an unsaturated swelling soil is complex and difficult to analyze Presently, there is no accepted procedure to account for the effect of soil swell on the infiltration rate The SDRI manufacturer believes, however, that a close estimate of Q_s can be obtained as follows First, it is assumed that any volume change that occurs is vertical Second, it is assumed that the additional volume generated by the swelling soil is filled with water that infiltrated the soil Based on these two assumptions

$$Q_s = \Delta h \times A$$

where

Δh = vertical swell of soil beneath inner ring

A = area of inner ring

Once the wetting front passes below the bottom of the inner ring, swelling of the soil will cause the ring to rise The rise of the inner ring, Δh, was measured as discussed in the instruction manual included in Appendix A of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c)

3.3.4 Two-Stage Borehole Permeameter Test Method Description

The TSB permeameter test measures the infiltration rate of water into the test medium through a cased borehole The TSB test has been successful in evaluating both compacted and natural materials with permeabilities as low as 1×10^{-9} cm/s (Boutwell, 1992) At RMA, the permeability of compacted soil from the two borrow areas ranges from $3\ 02 \times 10^{-9}$ to 8.24×10^{-8} cm/s (HLA, 1995a), which corresponds to the TSB methodology in the measurement capabilities

Five TSB permeameters were installed and monitored on each of the constructed testfills Multiple installations of the TSBs allow for statistical confidence and further verification of the hydraulic conductivities measured by the SDRIs

A detailed summary of the TSB test method was provided in Appendix B of the Final Work Plan for Material and Area Feasibility Studies (HLA, 1994c) (Appendix I) A synopsis of the test method follows

- The TSB procedure is a falling-head infiltration test conducted in a cased borehole that is typically 4-inches in diameter (Figure 3 5)
- The first stage of the test is performed with the bottom of the borehole flush with the bottom of the casing
- The first stage of the test provides data to calculate vertical permeability (K_v)
- The second stage of the text provides data to calculate horizontal permeability (K_h)

Stage 1 of the test provides a measurement of the maximum possible value for K_v Stage 2 provides a measurement of the minimum possible value for K_h

The infiltration rate at the TSB is calculated by monitoring the flow of water into the soil from the TSB The TSB is filled with water and as water flows out of the uncased bottom of the TSB, the height of the water in a standpipe is measured (Figure 3 5) The infiltration rates are calculated over the measurement period and plotted to illustrate infiltration rates over time Further calculations are used to estimate the apparent hydraulic conductivity of the material based on the infiltration rate measurements

Temperature changes can affect the infiltration rate of water in the TSB Field measurements on previous TSBs indicate that rising temperatures cause the water column to rise and the standpipe to expand, thereby causing a lower apparent flow rate The net effect is a lower apparent permeability. If the temperatures decrease, the converse is true One temperature effect gauge (TEG) was installed and monitored on each test pad to measure the volume changes due to temperature changes over the testing period

3.3.5 Two-Stage Borehole Installation and Monitoring

Five TSB permeameters were installed at each testfill (Figure 3 3) immediately following installation of the SDRIs on August 10 and 11, 1994 The TSBs were installed following the manufacturer's installation procedures under the direction of Mr Steve Trautwein. The boreholes were excavated using a hand auger to the desired depth The bottoms of the holes were scarified as directed Polyvinyl chloride (PVC) casings were grouted in place, and the boreholes were completed with the measurement standpipe and fill tube, as illustrated in Figure 3 5

TEGs were set up and installed similarly to the typical TSB with one exception, the bottom of the casing was sealed with a cap Because there is no flow of water from the TEG, any changes in the readings must be the result of changes in the ambient air temperature and/or barometric pressure Any changes noted in the TEGs are then used as correction factors to calculate the infiltration rate using the equations described in Section 3 3 6

TSBs were monitored between August 17 and September 16, 1994 Monitoring included flow measurements, water temperature readings, and TEG readings The readings were taken by field personnel trained and experienced in TSB monitoring The readings were recorded in field logbooks and then transferred onto the TSB data forms (Appendix D)

3.3.6 Two-Stage Borehole Data Reduction

For ease of computation, data were reduced and evaluated by transferring the field measurements recorded on the data forms onto computer spreadsheets Apparent permeability for both Stage 1 and Stage 2 of the TSB tests was calculated using the following falling-head test equations as specified in the test method calculations

Stage 1 calculations (nomenclature for the various terms of the Stage 1 calculations is illustrated in Figure 3 6)

$K1 = R_T G1 \, Ln(H_1/H_2)/(t_2-t_1)$

and

$G1 = (\pi d^2/11D_1)[1+a(D_1/4b_1)]$

where

d =	inner diameter (ID) of standpipe
D_1 =	effective diameter of Stage 1 casing ID
b_1 =	depth of tested medium below bottom of casing
a =	+1 for impervious boundary
a =	0 for infinite depth of tested medium (b_1 = infinity)
a =	-1 for pervious lower boundary
k =	permeability in cm/s
H_1 =	initial head at $t = t_1$
H_2 =	initial head at $t = t_2$
t_1 =	initial time
t_2 =	final time
Ln =	natural logarithm
R_T =	kinematic viscosity correction to water at 68°F as defined in ASTM D5084

Stage 2 calculations (nomenclature for the various terms of the Stage 2 calculations is illustrated in Figure 3 6)

$K2 = R_T G2 \, Ln(H_1/H_2)/(t_2-t_1)$

and

$G2 = (d^2/16Lf) \{Ln[u(1, r_0, o)] + a \, Ln[u(1, r_0, 2b_2)]\}$

where

$f =$ 1-0 5623 Exp(-1 566 L/D)

$L =$ Length of Stage 2 cylinder below casing

$$u(1, r_0, o) = \{L/D_2 + \sqrt{1 + (L/D_2)^2}\}^2$$

$$u(1, r_0, 2b_2) = \frac{4b_2/D_2 + L/D_2 + \sqrt{1 + (4b_2/D_2 + L/D_2)^2}}{4b_2/D_2 - L/D_2 + \sqrt{1 + (4b_2/D_2 - L/D_2)^2}}$$

$D_2 =$ ID of Stage 2 extension

$b_2 =$ distance from center of Stage 2 extension to underlying boundary

Using the equations above, the apparent permeabilities calculated during Stage 1 and Stage 2 were plotted against time The tests were terminated when either steady-state conditions or a close approximation of steady-state conditions were achieved. Test termination criteria outlined in Boutwell (1992) are as follows

- The time-weighted averages do not show an upwards or downwards trend with time
- Test results do not fluctuate more than 10 to 20 percent among themselves
- The time-weighted averages do not fluctuate more than 10 to 20 percent for 12 to 72 hours
- Arithmetic time-weighted averages were calculated using the following equation

$K' = (T_i K_i)/(T_i)$

where

$K' =$ arithmetic time-weighted average permeability

$T_i =$ time duration of test increment (i)

$K_i =$ Permeability measured during test increment (i)

Throughout each stage of the tests, variations in apparent permeability were evaluated, and the test was terminated when steady-state conditions were achieved

3.3.7 Laboratory Permeability Testing

Eighteen soil samples were collected from the completed testfills for laboratory geotechnical property testing The samples were collected in 3-inch diameter Shelby tubes pushed into the testfills using a drilling rig The samples were collected adjacent to TSB locations illustrated in Figure 3 3 Flexible wall, falling head permeability tests (ASTM D5084) were performed on 6 samples Atterberg limits (ASTM D4318) and grain size analyses (ASTM D422) were performed on 12 samples The permeability tests were performed for comparison with the in situ permeability tests (SDRI and TSB) Atterberg limits and grain size tests were performed to verify the homogeneity of the individual testfills Six samples were further analyzed for unconsolidated, undrained, and consolidated undrained shear strength analyses (ASTM D4767 and D2850).

3.4 Permeability Test Data Results

The following section presents the results of the field and laboratory permeability and geotechnical test results performed on the testfills

3.4.1 Sealed Double-Ring Infiltrometer Test Results

SDRI 1 and SDRI 2 were filled with water on August 10, 1994, and monitored for 81 days Original data sheets and spreadsheet tables used for calculations are included in Appendix D The following discussion summarizes the test results

3.4.1.1 Infiltration

The infiltration rate was calculated according to procedures outlined in Section 3 3 3 Figures 3 7 and 3 8 illustrate the infiltration rate for the 81-day test period The initial infiltration rates and the final infiltration rates are summarized below:

		Infiltration Rate in centimeters per second	
SDRI Number	Test Fill	Initial	Final
SDRI 1	1	4.24×10^{-7}	1.03×10^{-8}
SDRI 2	2	3.60×10^{-7}	$1\ 15 \times 10^{-8}$

3.4.1.2 Hydraulic Conductivity

Hydraulic conductivity (k) was calculated using the equations described in Section 3 3 3 The parameters required to calculate k include the infiltration rate divided by the hydraulic gradient The hydraulic gradient (i) was calculated by using the equation outlined in Section 3.3 3, which uses the parameters of water depth and wetting front depth The depth to the wetting front was calculated using the tensiometer data as described below

To calculate the wetting front within the testfills, the average values at each group of the tensiometers is plotted over time as shown in Figures 3.9 and 3 10 The plots were used to evaluate when the wetting front reached the depths of 6, 12, and 18 inches by noting when the pressure on the tip of the tensiometers dropped to below 10 The tensiometer gauge is at a higher elevation than the tip, therefore, a positive gauge reading (less than 10) will be noted when the pressure at the tip is actually zero A summary of the wetting front advancement with time through each testfill is as follows

		Wetting Front Depth in Days		
SDRI Number	**Testfill**	**6 inches**	**12 inches**	**18 inches**
SDRI 1	1	9	55	Not attained
SDRI 2	2	10	40	Not attained

As noted in Figures 3 9 and 3 10, the wetting front did not reach a depth of 18 inches within the 81-day monitoring period Wetting front depths greater than 12 inches and less than 18 were calculated by linear extrapolation of the wetting front data It was assumed that the rate of advancement of the wetting front depth beyond 12 inches was the same as the rate between 6 and 12 inches

The values of hydraulic conductivity computed for SDRI 1 and 2 are illustrated in Figures 3 7 and 3 8 As illustrated in the figures, the hydraulic conductivity decreased over the testing period and reached a relatively steady-state condition approximately 18 days before the tests were terminated

As a conservative measure, the average hydraulic conductivity values were calculated for each test pad over the last 33 days of the test and are as follows

SDRI Number	Testfill	Hydraulic Conductivity in centimeters per second
SDRI 1	1	1 18 x 10^{-8}
SDRI 2	2	8 30 x 10^{-8}

3.4.1.3 Temperature and Swell Factors

Temperature and swell were monitored at the SDRIs to evaluate whether either may have affected the flow measurements The total flow measured includes flow due to temperature changes (Q_t), soil swell (Q_s), and flow due to infiltration (Q_i) As described in Section 3 3 3, calculations of flow due to temperature changes and soil swell were made throughout the test to evaluate the significance of Q_t and Q_s at each of the SDRIs

The measured values of water temperature in the four outer rings are recorded in Appendix D and plotted in Figure 3 11 In general, the maximum temperature difference noted during any given measurement period resulted in a flow amounting to less than or equal to 10 percent of the total flow measured The only exception to this is the second to the last reading where a 9 degree temperature difference over the measurement period was noted Overall, the effect due to temperature change was considered to be insignificant because the estimated total percent of flow attributed to temperature change was 5 percent for SDRI 1 and 3 6 percent for SDRI 2

The average vertical movement of the inner ring was measured throughout the testing period The results of the measurements are included in Appendix D Less than one centimeter of swell was measured in each of the two inner rings Overall, the effect due to soil swell was considered to be insignificant because the estimated total percent of flow attributed to soil swell was 10 percent or less

3.4.2 Two-stage Borehole Test Results

On August 17, 1994 TSB permeameter testing was initiated Each stage of the test was run until the test termination criteria were met For Stage 1 the test ran between August 17 and August 31, 1994, and Stage 2 of the test ran between September 1 and September 16, 1994 Field data sheets and spreadsheet tables used for calculations are included in Appendix D The following discussion summarizes the results

3.4.2.1 Stage 1 Hydraulic Conductivity

The apparent hydraulic conductivity for Stage 1 of the TSBs (K1) was calculated for each of the TSBs according to the equations outlined in Section 3 3 6 As stated earlier, the value for hydraulic conductivity is calculated from measurements of infiltration during Stage 1, and provides an estimate of the maximum possible value for the vertical permeability of the medium being tested

The hydraulic conductivity values for Testfills 1 and 2 are plotted against time in Figures 3 12 and 3 13, respectfully Additionally, the arithmetic time-weighted average value of the Stage 1 hydraulic conductivity (K1') for each TSB is presented below

TSB Number	Stage 1 Time-weighted Average Hydraulic Conductivity K1' in centimeters per second	Testfill Number
B1A	8 06 x 10^{-8}	1
B1B	2 29 x 10^{-8}	1
B1C	4 47 x 10^{-8}	1
B1D	2 45 x 10^{-8}	1
B1E	4 13 x 10^{-8}	1
B2A	8 20 x 10^{-8}	2
B2B	8 00 x 10^{-8}	2
B2C	3 80 x 10^{-8}	2
B2D	4 52 x 10^{-8}	2
B2E	5 16 x 10^{-8}	2

3.4.2.2 Stage 2 Hydraulic Conductivity

The apparent hydraulic conductivity for Stage 2 of the TSBs (K2) was calculated for each of the TSBs according to the equations outlined in Section 3 3 6 As stated earlier, the value for hydraulic conductivity is based on measurements of infiltration during Stage 2, and provides an estimate of minimum possible value for the horizontal permeability of the medium being tested

The hydraulic conductivity values for Testfills 1 and 2 are plotted against time in Figures 3 14 and 3 15, respectfully Additionally, the arithmetic time-weighted average value of the Stage 2 hydraulic conductivity (K2') for each TSB is presented below

TSB Number	Stage 2 Time-weighted Average Hydraulic Conductivity K2' in centimeters per second	Testfill Number
B1A	1 27 x 10^{-8}	1
B1B	1 34 x 10^{-8}	1
B1C	1 04 x 10^{-8}	1
B1D	8 27 x 10^{-9}	1
B1E	9 42 x 10^{9}	1
B2A	8 00 x 10^{9}	2
B2B	6 34 x 10^{-9}	2
B2C	1 20 x 10^{-8}	2
B2D	8 14 x 10^{9}	2
B2E	8 15 x 10^{9}	2

3.4.3 Laboratory Permeability Test Results

Table 3 4 presents the permeability, grain size, Atterberg limits, and the shear strength test results performed on samples collected from the testfills The six samples tested for falling head permeability indicate hydraulic conductivities below the required 1 x 10^{7} cm/s The average hydraulic conductivity value measured on samples from Testfill 1 was 5 80 x 10^{-8} cm/s For Testfill 2, the average hydraulic conductivity measured was 3 40 x 10^{-8} The Atterberg limits test results indicated liquid limits ranging from 40 to 50 percent and plasticity limits ranging from 22 to 32 percent The percent passing the No 200 sieve ranged from 63 to 82 percent

3.5 Testfill Construction and Testing Program Summary and Conclusions

The testfill construction and testing program included the construction of two clay soil testfills using soil excavated from two onpost borrow areas Subsequent to construction, field and laboratory tests were performed on the testfills to evaluate the permeability of the testfill's compacted clay soil This section provides a summary and conclusions about the testfill construction and testing program

3.5.1 Summary

Two onpost borrow areas were used to supply the required volume of clay soil to construct two testfills The clay soil used to construct Testfill 1 was excavated from the central portion of Section 20 in the northeast corner of RMA The clay soil used to construct Testfill 2 was excavated from the southwest quarter of Section 24, approximately 1/2 mile north of the proposed landfill location site Both soil types are classified as inorganic clay with low to high plasticity However, the soil from Section 20 contains approximately 10 percent more sand by weight than the soil from Section 24

The two testfills were constructed in the southwest quarter of Section 25 in July and August of 1994 The following summarizes the construction procedures

1 Clay used in the construction of the testfills had the following properties

	Liquid Limit (%)	Plasticity Index (%)	Percent Passing No. 200 Sieve (%)
Testfill 1	44 to 49	23 to 29	62 to 65
Testfill 2	46 to 55	25 to 33	71 to 82

2 Lifts were placed on the testfills in 9-inch loose lifts

3 The material was blended, moisture conditioned and clod size was reduced using a Caterpillar SS-250

4 The lifts were compacted with a minimum of two passes using a Caterpillar 815B compactor

5 The lifts were compacted to a minimum of 95 percent of the standard Proctor maximum dry density (102 pcf) The moisture content of the compacted lifts was 2 to 4 percent above the

optimum moisture content (19 percent) Density and moisture content were measured with a nuclear density gauge

6 Portions of the clay testfill that did not achieve the required compaction or moisture content specification were scarified to the previous lift and recompacted as described above

7 Prior to placement of the subsequent lift, each lift was scarified and moisture conditioned to achieve proper lift bonding

8 The lifts were protected from desiccation by sprinkling the surface of the testfills with water and covering the entire surface of the testfills with plastic tarps

Following testfill construction, one SDRI and five TSBs were installed for in situ permeability testing on each testfill Field permeability tests were conducted following the SDRI and TSB manufacturer's installation and monitoring procedures The SDRIs were monitored for three months from August 10 to November 11, 1994 Each stage of the TSBs was monitored for approximately two weeks beginning August 17, 1994

The field permeability tests confirmed that the procedures employed to construct the testfills were sufficient to achieve the design requirement that vertical hydraulic conductivity of the testfill be less than 1×10^{-7} cm/s The average hydraulic conductivity measured by the SDRI on Testfill 1 was $1\ 18 \times 10^{-8}$ cm/s and $8\ 30 \times 10^{-8}$ cm/s for Testfill 2 The average vertical hydraulic conductivity measured by the TSBs on Testfill 1 was $4\ 28 \times 10^{-8}$ cm/s and $5\ 94 \times 10^{-8}$ cm/s for Testfill 2

Laboratory permeability and geotechnical tests were performed on samples collected from the testfills after the SDRI and TSB monitoring was complete The laboratory permeability tests reconfirm that the construction procedures specified in this testfill construction program were adequate to achieve the required hydraulic conductivity value The average conductivity value measured on samples from Testfill 1 was $5\ 60 \times 10^{-8}$ cm/s and $3\ 04 \times 10^{-8}$ cm/s from Testfill 2

3.5.2 Conclusions

The Material FS portion of the FS Soils Support Program had two main objectives (1) to verify that onpost soils are capable of meeting a permeability of less than or equal to 1×10^{-7} cm/s (as required in the construction of clay caps or liners [6 CCR 1007-2 2 5 3]), and (2) to evaluate the optimum lift thickness, moisture content, density, and compactive effort necessary to achieve the required permeability

Based on the results presented in this report, both objectives of the Material FS were met First, the field and laboratory test results confirm that onpost soils can be used to construct caps and liners that meet the regulatory required hydraulic conductivity Second, the construction methods employed to construct the two testfills identified the lift thickness, moisture content, density and compactive effort used to achieve the required permeability Soils within the proposed borrow areas may vary and thus, require additional testing to finalize specifications for future cap and liner construction

It should be noted that the specifications included in this report as Appendix A were written specifically for testfill construction The specifications may require modification for full-scale construction

Table 3.1: Summary of Geotechnical Laboratory Test Data on Borrow Material

Borrow Area	Sample Depth (ft)	Percent Passing No 200 Sieve (%)	USCS Soil Classification	Liquid Limit (%)	Plastic Index (%)	Natural Moisture Content (%)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
A	2 0	70 9	CH	55	33	10 0	19 7	101 9
A	2 5	81 6	CH	51	30	10 2	20 5	102 5
A	3 5	70 9	CL	46	25	8 4	17 4	104 4
B2	4 0	61 7	CL	44	23	9 8	18 8	101 7
B2	4 0	65 3	CL	49	29	10 1	19 3	103 1

% Percent
CH Inorganic clays of high plasticity
CL Inorganic clays of low to medium plasticity
ft Feet
pcf Pounds per cubic foot
USCS Unified Soil Classification System

Table 3.2: Summary of Field Density Test Data, TestFill 1

Test Number	Lift Number	Test Location East/West*	North/South*	Date	Moisture Content (Nuclear Method) ASTM D3017 88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216-90 (%)	Comments
1	1 (WL)	20	C	7/20/94	20 23	103 2	100 4	NT	Failed moisture, Retest No 4
2	1 (WL)	50	E	7/29/94	19 49	100 1	97 4	NT	Failed moisture, Retest No 5
3	1 (WL)	75	D	7/29/94	17 71	102 8	100 0	NT	Failed moisture, Retest No 6
4	1 (WL)	20	C	7/30/94	17 44	102 2	99 4	NT	Failed moisture, Retest No 7
5	1 (WL)	50	E	7/30/94	18 1	105 6	102 7	NT	Failed moisture, Retest No 9
6	1 (WL)	75	D	7/30/94	19 5	103 4	100 0	NT	Failed moisture, Retest No 8
7	1 (WL)	20	C	7/30/94	21 15	96 8	94 2	NT	
8	1 (WL)	75	D	7/30/94	19 96	98 8	96 1	NT	
9	1 (WL)	50	E	7/30/94	21 45	102 6	99 8	NT	
10	2	80	E	7/30/94	19 7	101 0	102 0	NT	
11	2	55	E	7/30/94	23 26	99 6	96 9	NT	
12	2	55	E	7/30/94	24 96	96 7	94 1	NT	
13	2	20	C	7/30/94	18 86	106 8	103 6	NT	
14	2	75	C	7/30/94	21 13	104 1	102 0	21 3	
15	2	56	E	7/30/94	22 09	93 7	91 1	NT	Failed compaction, Retest No 17
16	2	22	B	7/30/94	21 00	102 5	99 7	18 8	
17	2	56	E	7/30/94	19 94	105 0	102 2	NT	Failed moisture, Retest No 17A
17A	2	56	E	7/30/94	20 77	104 2	101 4	18 95	Retest of No 15 and No 17 after compaction and moisture added
18	3	25	D	7/31/94	18 98	106 3	103 4	NT	Test failed, Retest No 21
19	3	53	C	7/31/94	23 53	100 0	98 0	NT	
20	3	78	E	7/31/94	21 3	103 0	100 2	21 5	
21	3	25	D	7/31/94	20 17	103 9	101 0	21 9	Retest of No 18, added moisture
22	4	18	C	7/31/94	20 68	105 1	102 2	21 7	
23	4	56	D	7/31/94	22 62	101 1	98 3	22 0	
24	4	80	E	7/31/94	22.52	102 4	99 6	21 3	
25	5	26	E	8/2/94	21 2	103 4	100 0	20 2	
26	5	55	G	8/2/94	23 77	96 6	95 9	22 6	
27	5	82	E	8/2/94	21 78	102 0	99 7	20 2	
28	6	20	C	8/3/94	15 68	106 6	103 1	NT	Failed moisture, Retest No 31
29	6	53	E	8/3/94	23 54	99 0	96 3	NT	Retest of No 32
30	6	88	G	8/3/94	19.87	104 4	101 6	NT	Failed moisture, Retest No 33

Table 3.2 (continued)

Test Number	Lift Number	Test Location East/West*	Test Location North/South*	Date	Moisture Content (Nuclear Method) ASTM D3017-88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216-90 (%)	Comments
31	6	20	C	8/3/94	20 24	106 1	103 2	22 5	Retest of No 28, added moisture
32	6	53	E	8/3/94	22 97	100 9	98 1	18 7	Retest of No 29
33	6	88	G	8/3/94	21 78	101 8	99 0	20 4	Retest of No 30, added moisture
34	7	25	D	8/4/94	17 79	108 4	105 4	NT	Failed moisture, Retest No 37
35	7	56	B	8/4/94	14 19	106 6	103 2	NT	Failed moisture, Retest No 38
36	7	97	F	8/4/94	19 27	106 9	104 0	NT	Failed moisture, Retest No 39
37	7	25	D	8/4/94	19 56	105 1	102 2	NT	Failed moisture, Retest No 40
38	7	56	B	8/4/94	20 71	104 1	101 3	20 6	
39	7	97	E	8/4/94	22 94	98 7	96 0	22 0	
40	7	25	D	8/4/94	22 73	100 0	97 9	20 3	
41	7	23	G	8/4/94	22 81	99 2	96 5	20 6	
42	8	24	G	8/4/94	21 88	100 0	97 2	22 2	
43	8	60	D	8/4/94	22 07	100 3	97 6	22 9	
44	8	94	F	8/4/94	20 81	104 3	101 4	20 2	
45	9	22	F	8/5/94	18 91	107 1	104 2	NT	
46	9	50	D	8/5/94	21 82	99 5	96 8	NT	
47	9	22	F	8/5/94	20 94	103 7	100 9	21 2	
48	9	50	D	8/5/94	22 84	100 0	98 0	22 5	
49	9	95	E	8/5/94	23 0	98 0	95 3	21 7	
50	10	11	F	8/5/94	20 86	103 4	100 5	21 2	
51	11	9	G	8/5/94	23 23	98 4	96 2	23 3	
52	12	7	D	8/5/94	21 91	101 7	98 9	20 4	
53	10	16	G	8/5/94	20 87	103 2	100 4	NT	
54	10	58	E	8/5/94	22 00	102 2	99 4	NT	
55	10	91	F	8/5/94	21 07	102 1	99 3	NT	

Table 3.2 (continued)

For the material tested, optimum moisture content equals 19 3 percent and maximum dry density equals 102 3 percent

ASTM	American Society for Testing and Materials
NT	Not tested
pcf	Pounds per cubic foot
WL	Working layer
%	Percent

* See Figure 3 3 for grid system used to identify the test location

\# Relative compaction refers to the in-place dry density of soil expressed as a percentage of the maximum dry density of the same material, as determined by the ASTM D 698 test procedure

Table 3.3: Summary of Field Density Test Data, TestFill 2

Test Number	Lift Number	Test Location East/West	Test Location North/South	Date	Moisture Content (Nuclear Method) ASTM D3017 88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction* (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216 90 (%)	Comments
1	1	6	Q	7/14/94	19 08	104 7	101 9	21 4	
2	1	50	N	7/14/94	19 08	104 6	101 8	21 3	
3	1	85	N	7/14/94	20 47	104 4	101 5	24 0	
4	2	25	L	7/15/94	19 27	105 2	102 3	20 6	Test failed, Retest No 7
5	2	65	M	7/15/94	17 19	104 3	101 5	20 1	Test failed, Retest No 8
6	2	84	P	7/15/94	17 70	106 1	103 2	17 0	Test failed, Retest No 9
7	2	24	K	7/18/94	21 21	103 3	100 5	21 7	Retest of No 4, added moisture
8	2	50	N	7/18/94	22 37	99 4	96 7	22 5	Retest of No 5, added moisture
9	2	84	O	7/18/94	23 93	98 8	96 1	25 1	Retest of No 6, added moisture
10	3	15	M	7/19/94	18 30	99 8	97 1	NT	
11	3	85	P	7/19/94	21 00	103 5	100 7	NT	
12	WL	5	Q	7/22/94	20 75	102 3	99 5	NT	Began using Pulvamixer
13	WL	53	N	7/22/94	21 34	98 6	95 9	20 9	
14	WL	90	K	7/22/94	20 66	107 3	99 5	20 9	
15	1	35	M	7/22/94	20 03	104 0	101 1	21 4	
16	1	65	O	7/22/94	21 18	107 5	99 7	20 5	
17	1	90	P	7/22/94	20 12	102 9	100 1	20 9	
18	2	25	R	7/22/94	22 15	101 3	98 5	22 6	
19	2	50	N	7/22/94	21 31	101 7	98 9	21 4	
20	2	80	M	7/22/94	22 00	99 9	97 2	20 9	
21	3	30	K	7/25/94	22 62	95 7	93 1	NT	Test failed, Retest No 21A
22	3	60	N	7/25/94	21 39	100 4	97 7	19 8	
23	3	85	P	7/25/94	20 87	100 5	97 8	20 1	
21A	3	30	K	7/25/94	21 33	101 4	98 6	20 0	Retest of No 21, after further compaction
24	4	25	P	7/25/94	22 02	98 7	96 1	21 1	
25	4	50	N	7/25/94	20 23	101 8	99 1	19 6	
26	4	90	L	7/25/94	20 23	103 6	100 7	19 8	
27	5	25	L	7/25/94	21 09	102 2	99 4	20 96	
28	5	50	N	7/25/94	19 54	103 7	100 9	19 4	Failed moisture, Retest No 31
29	5	80	P	7/25/94	21 14	102 3	99 5	21 9	
30	5	80	N	7/26/94	21 44	101 9	99 1	23 2	

Table 3.3 (continued)

Test Number	Lift Number	Test Location East/West	North/South	Date	Moisture Content (Nuclear Method) ASTM D3017-88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction* (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216 90 (%)	Comments
31	5	50	L	7/26/94	23 09	100 1	97 4	22 7	Retest of No 28, added moisture
32	5	10	M	7/26/94	24 34	96 6	93 9	NT	Test failed, Retest No 33
33	5	15	M	7/26/94	20 07	104 8	101 9	19 8	Retest of No 32, added dry soil and recompacted
34	6	15	L	7/26/94	25 13	98 1	95 5	NT	Test failed, Retest No 37
35	6	45	M	7/26/94	18 64	96 7	94 1	NT	Test failed, Retest No 38
36	6	75	M	7/26/94	20 41	102 6	99 8	NT	
37	6	20	N	7/26/94	20 27	102 2	99 4	19 2	Retest of No 34, after wetting dry areas, pulverizing, and compacting
38	6	45	M	7/26/94	19 73	101 3	98 6	NT	Retest of No 35 after wetting dry areas, pulverizing, and recompacting, failed, Retest No 39
39	6	45	M	7/26/94	20 54	NR	98 0	NT	Retest of No 38
40	6	45	M	7/26/94	21 44	100 5	97 8	21 0	Retest of No 38
41	7	20	P	7/27/94	17 75	103 2	100 4	NT	Test failed, Retest No 43
42	7	45	L	7/27/94	18 76	98 0	95 4	NT	Test failed, Retest No 44
43	7	20	O	7/27/94	20 36	104 3	101 4	19 02	Retest of No 41, wetted, pulverized, and recompacted
44	7	60	O	7/27/94	21 09	101 0	98 3	19 7	Retest of No 42, wetted, pulverized, and recompacted
45	7	95	N	7/27/94	20 74	103 9	101 1	19 9	
46	R1	15	L	7/29/94	21 56	102 6	99 8	21 7	
47	R1	70	L	7/29/94	20 43	105 5	102 6	21 9	
48	R2	65	L	7/29/94	20 59	102 0	99 2	20 7	
49	R2	15	K	7/29/94	20 22	104 6	107 7	22 0	
50	R3	25	L	7/29/94	19 76	105 6	102 7	NT	Test failed, Retest No 50A
51	R3	75	L	7/29/94	21 80	101 8	99 0	19 2	
50A	R3	25	K	7/29/94	20 64	104 1	101 3	19 9	Retest of No 50 after adding moisture and recompacting
51	10	19	N	7/31/94	18 65	99 5	96 8	NT	Test failed, Retest No 54
52	10	50	L	7/31/94	22 13	99.3	96 6	NT	Retest No 55
53	10	78	Q	7/31/94	18 93	98 1	95 4	NT	Test failed, Retest No 56 and No 57
54	10	19	N	8/2/94	23 64	99 3	96 6	24 2	Retest of No 54, added moisture

Table 3.3 (continued)

Test Number	Lift Number	Test Location East/West	Test Location North/South	Date	Moisture Content (Nuclear Method) ASTM D3017 88 (%)	Dry Density (Nuclear Method) ASTM D2922 91 (pcf)	Relative Compaction# (Nuclear Method) ASTM D2922 91 (%)	Moisture Content (Oven Dry Method) ASTM D2216 90 (%)	Comments
55	10	50	L	8/2/04	24 68	96 9	94 3	22 9	Retest of No 52
56	10	78	O	8/2/04	23 04	99 1	96 5	NT	Retest of No 53, added moisture
57	10	78	O	8/2/04	23 70	98 8	96 2	21 7	Retest of No 53, added moisture
58	11	23	O	8/3/04	21 62	100 7	98 0	23 4	
59	11	58	M	8/3/04	22 92	99 9	97 2	23 6	
60	11	86	Q	8/3/04	22 62	100 6	97 9	23 2	
61	12	15	M	8/3/04	21 93	100 7	98 0	20 3	
62	12	46	K	8/3/04	22 44	99 8	97 0	23 1	
63	12	92	M	8/3/04	21 20	101 8	99 0	21 8	
64		0	K	8/4/04	22 21	100 4	97 7	21 9	
65		5	K	8/4/04	22 05	100 4	97 6	22 6	
66		10	K	8/4/04	21 27	102 7	99 9	22 3	
67		12	L	8/4/04	22 09	101 6	98 8	21 8	
68	13	05	L	8/4/04	20 41	103 2	101 1	NT	
69	13	27	N	8/4/04	22 19	100 7	97 9	NT	
70	13	55	P	8/4/04	21 67	102 6	99 8	NT	

For the material tested, optimum moisture content = 19 percent and maximum dry density = 102 8 pcf

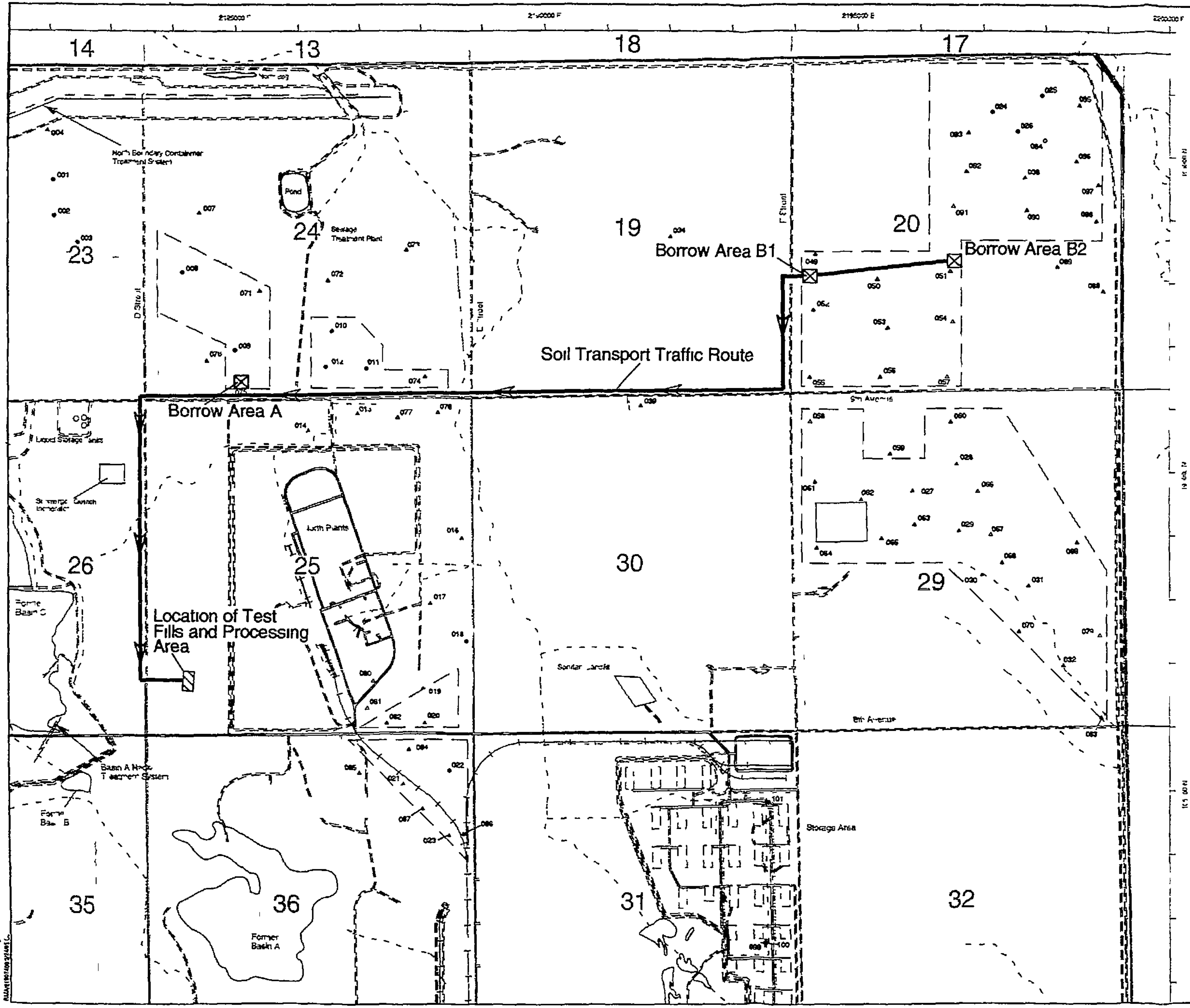
ASTM American Society for Testing and Materials
WL Working layer
% Percent
NT Not tested
pcf Pounds per cubic foot

* See Figure 3 3 for grid system used to identify test location
\# Relative compaction refers to the in place dry density of soil expressed as a percentage of the maximum dry density of the same material, as determined by the ASTM D 698 test procedure

Table 3.4: Testfill Laboratory Test Results

Testfill Number	Percent Passing No. 200 Sieve (%)	Moisture Content (%)	Liquid Limit (%)	Plasticity Index (%)	Permeability (cm/s)	USCS Classification	USCS Description
1	62.7	14.1	40	22	1.3×10^{8}	CL	Brown Sandy Lean Clay
1	71.1	19.6	42	23	5.2×10^{8}	CL	Brown Lean Clay With Sand
1	56.5	20.4	43	25	1.0×10^{7}	CL	Brown Sandy Lean Clay
2	80.9	21.5	50	32	7.9×10^{8}	CH	Brown Fat Clay With Sand
2	82.2	20.9	47	30	2.6×10^{9}	CL	Brown Lean Clay With Sand
2	81.7	20.0	47	30	9.5×10^{9}	CL	Brown Lean Clay With Sand

% Percent
cm/s Centimeters per second
psf Pounds per square foot
USCS Unified Soil Classification System



Explanation

Soil boring locations for 1993 drilling program reported in Final Feasibility Study Soils Report (HLA, 1995)

Borrow areas excavated for construction of test fills

Low permeability soil borrow areas

Railroad

Ditch or stream

Paved road

Unpaved road

16 Section number

Note:
The boring identification numbers shown have been abbreviated. The full boring identification number contains the soil unit before the number and 93 for 1993 at the end. For example, the complete boring identification number for Boring 012 is WEB01293.

0 1500
Scale in feet

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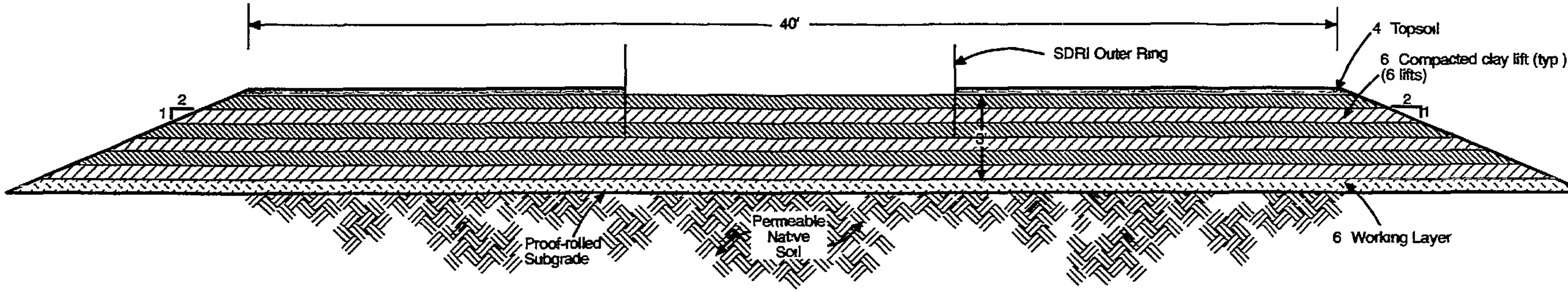
Figure 3 1

Testfill and Borrow Area Location Map

Typical Test Fill Cross Section



1.25" = 5

Note. Maximum slope shall be 2H:1V on long sides, 3H:1V on ends of test fill. Minimum slope shall be 3H:1V on long sides and 4H:1V on ends of test fill.

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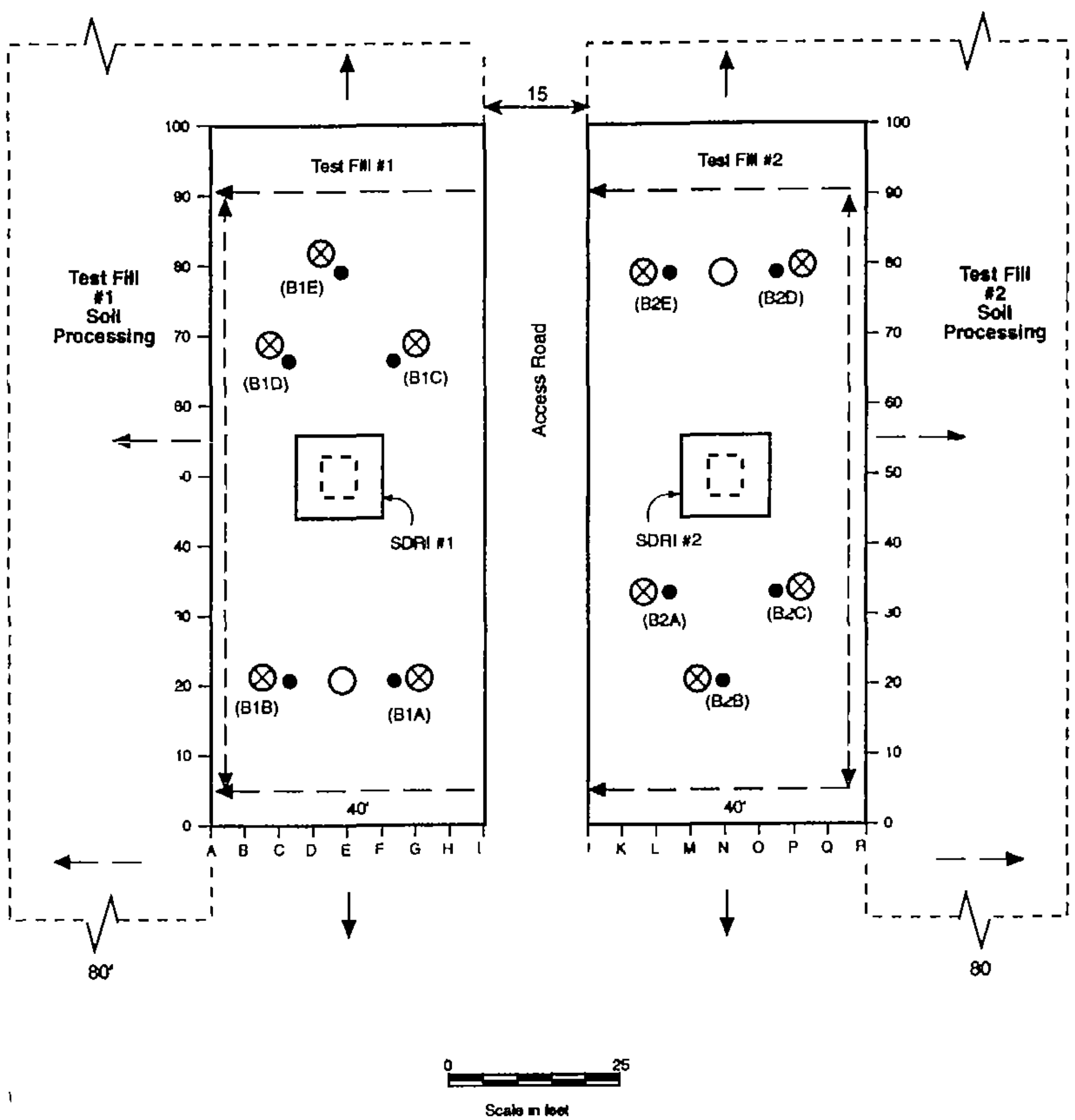
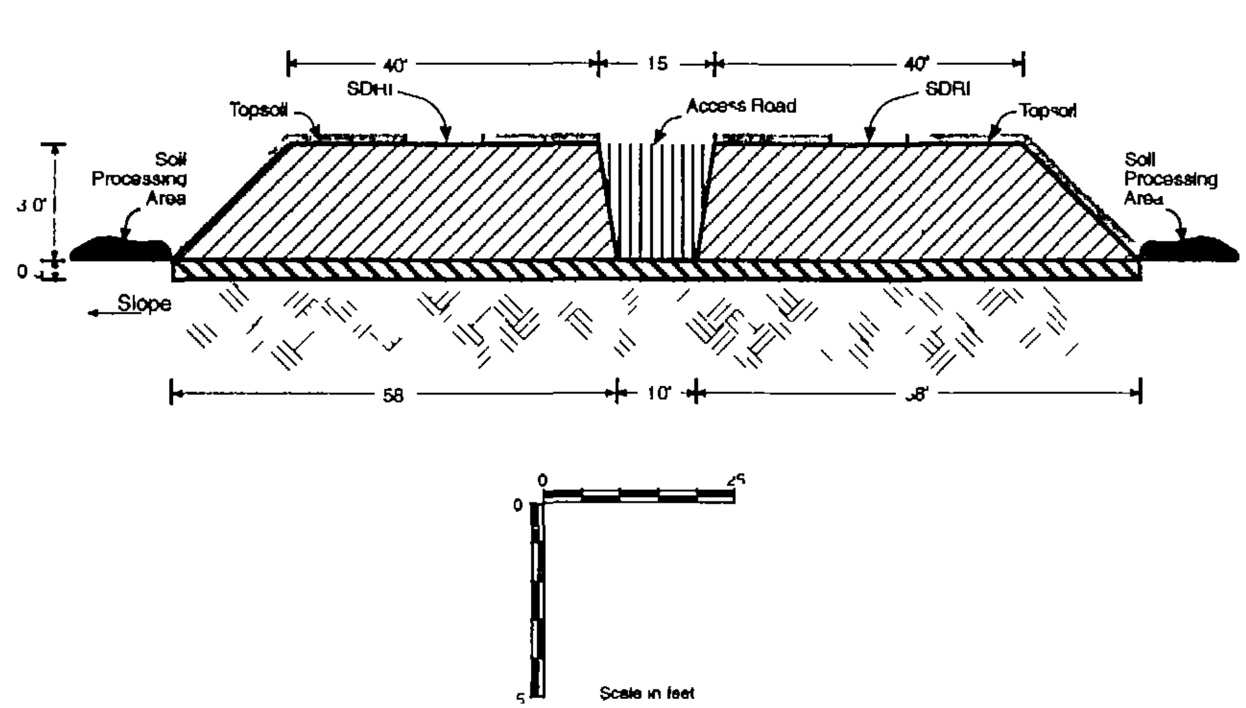
Figure 3.2

Typical Test Fill Cross Section

Plan View



Typical Cross Section



Explanation

SDRI Sealed double-ring infiltrometer

(BIA) ● Two-stage borehole (borehole number)

○ Two-stage borehole temperature effect gauge

⊗ Shelby tube sample location

Top soil

Access road

Working layer

Clay test fill

Compaction direction

Slope direction

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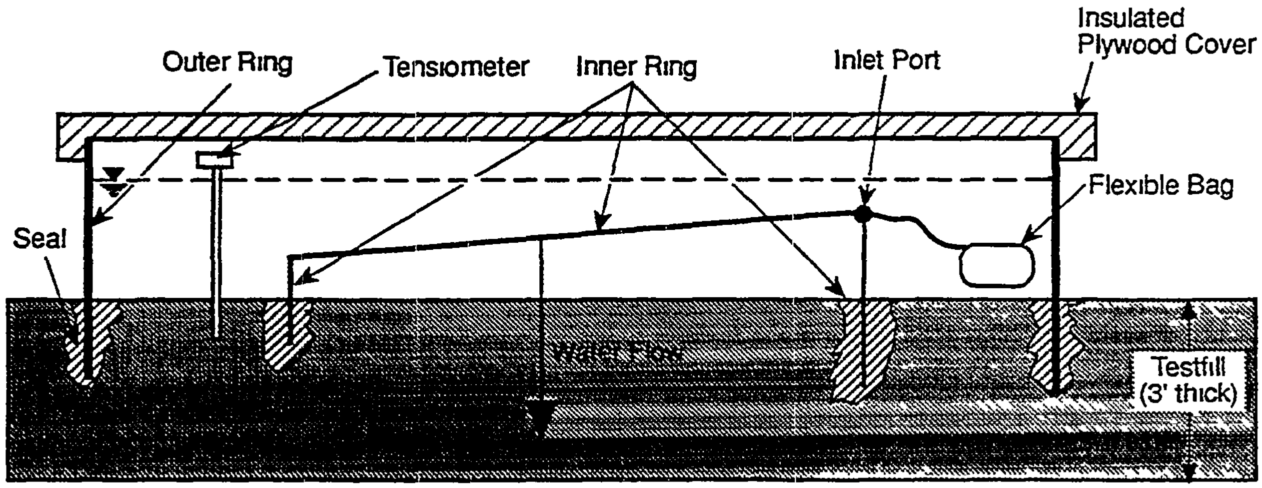
Figure 3 3

Testfill Plan View and Cross Section

RMA 1232.35 3/24/95 NLM

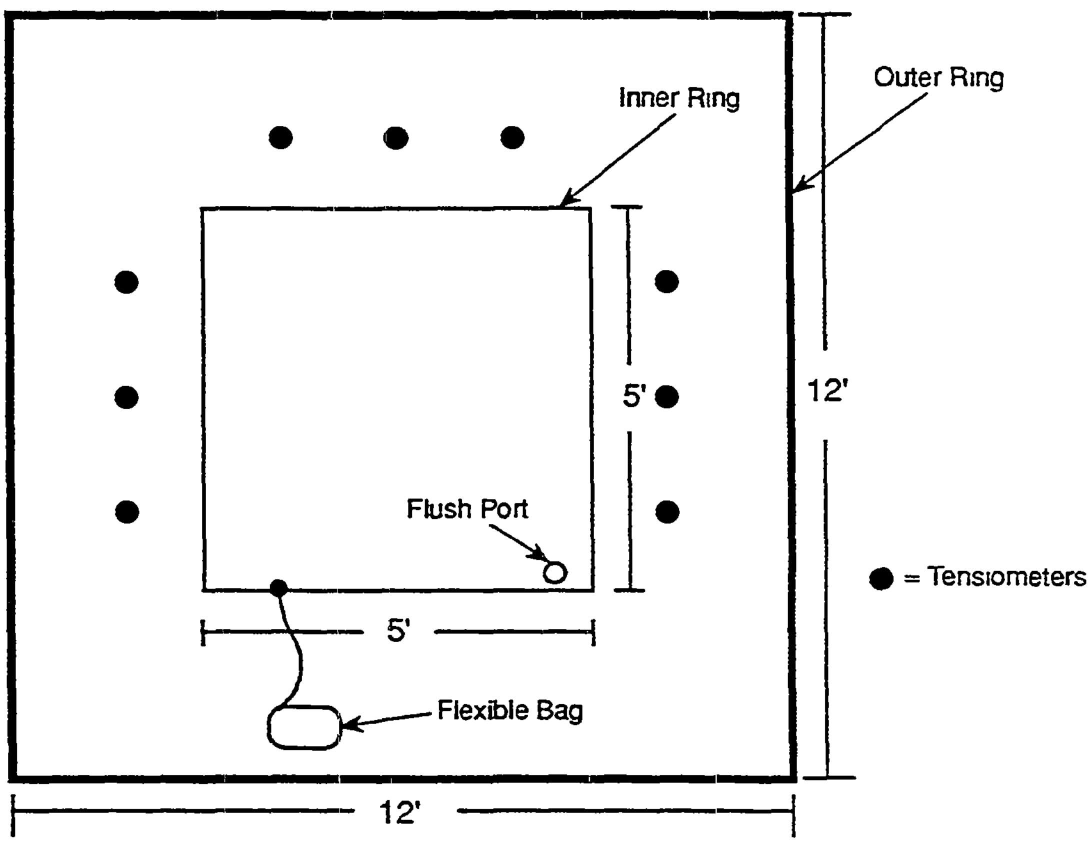
RMA 1240 3/24/94 NLM

Cross Section



Not to scale

Plan View



Not to scale

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 3 4 Sealed Double-Ring Infiltrometer Schematic

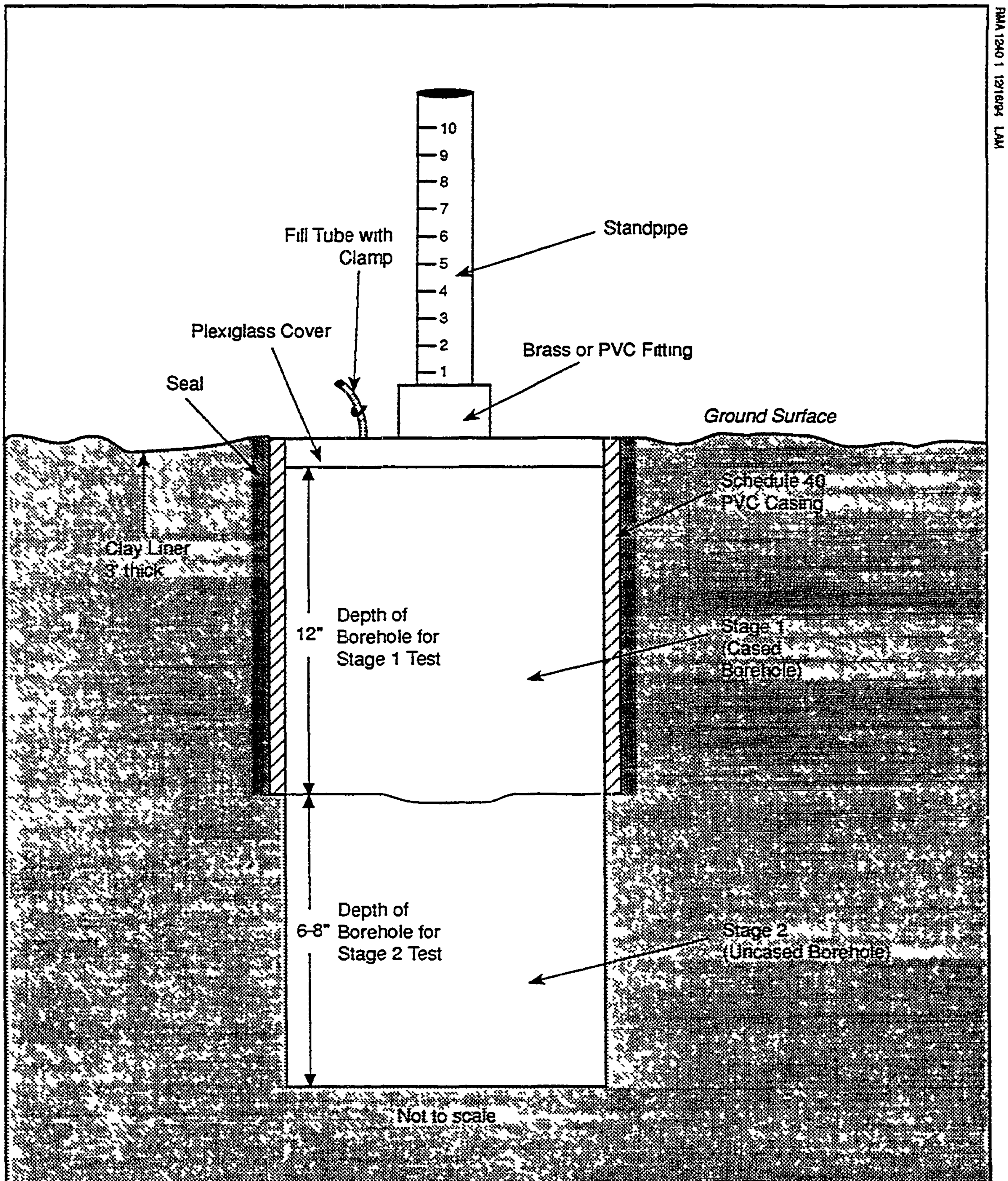


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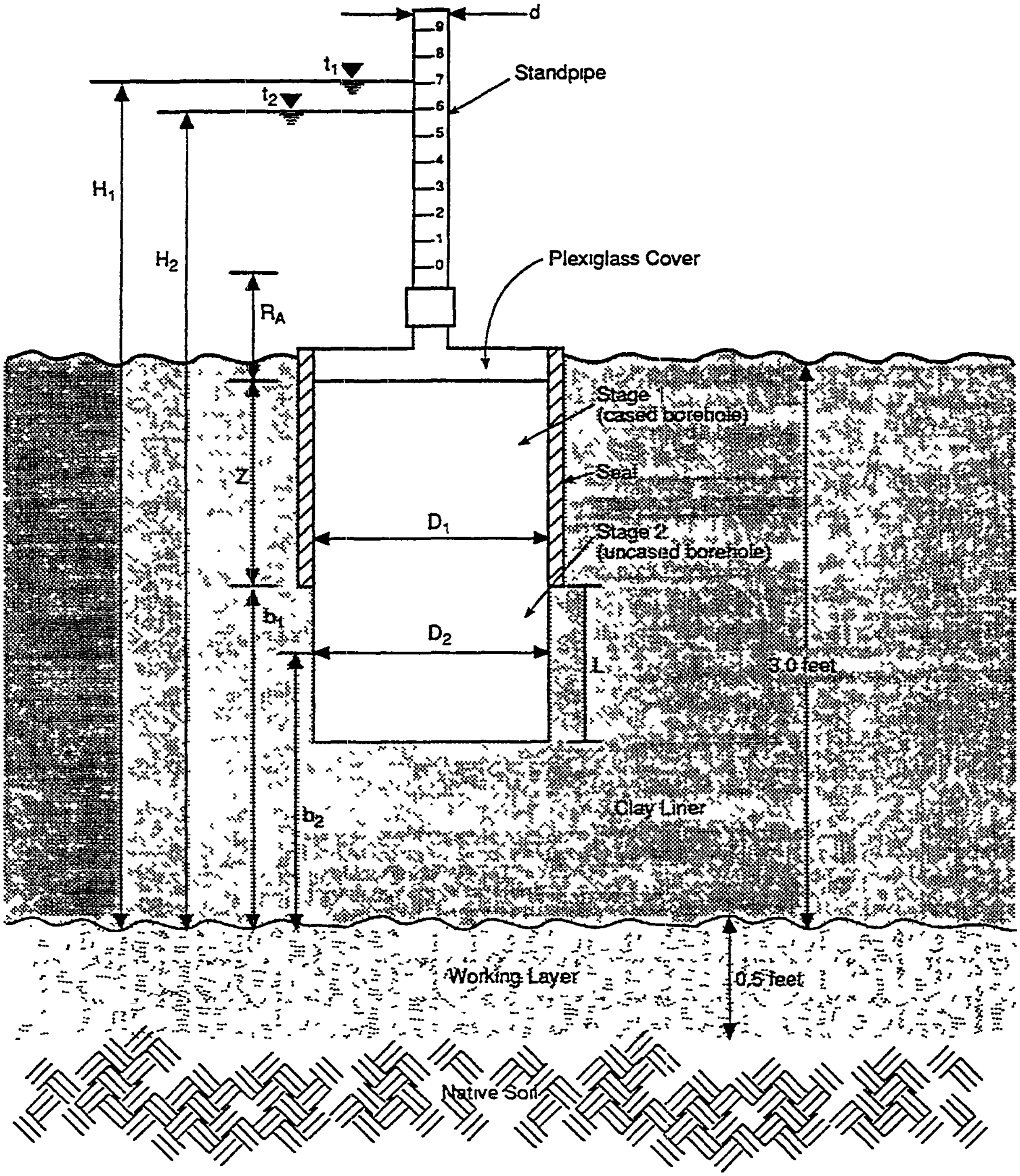
Figure 3 5

Two-stage Borehole Permeameter Installation (cross section)



Explanation

d	Inside diameter of standpipe	Z	Length of Stage 1 borehole	t_2	Final time
D_1	Inside diameter of Stage 1 borehole	L	Length of Stage 2 extension	R_a	Distance between standpipe scale and bottom of plexiglass cover
D^2	Inside diameter of Stage 2 borehole	H_1	Initial head at t_1		
b_1	Depth of test medium below bottom of casing	H_2	Final head at t_2		
b^2	Distance from center of Stage 2 extension to bottom of test medium	t_1	Initial time		

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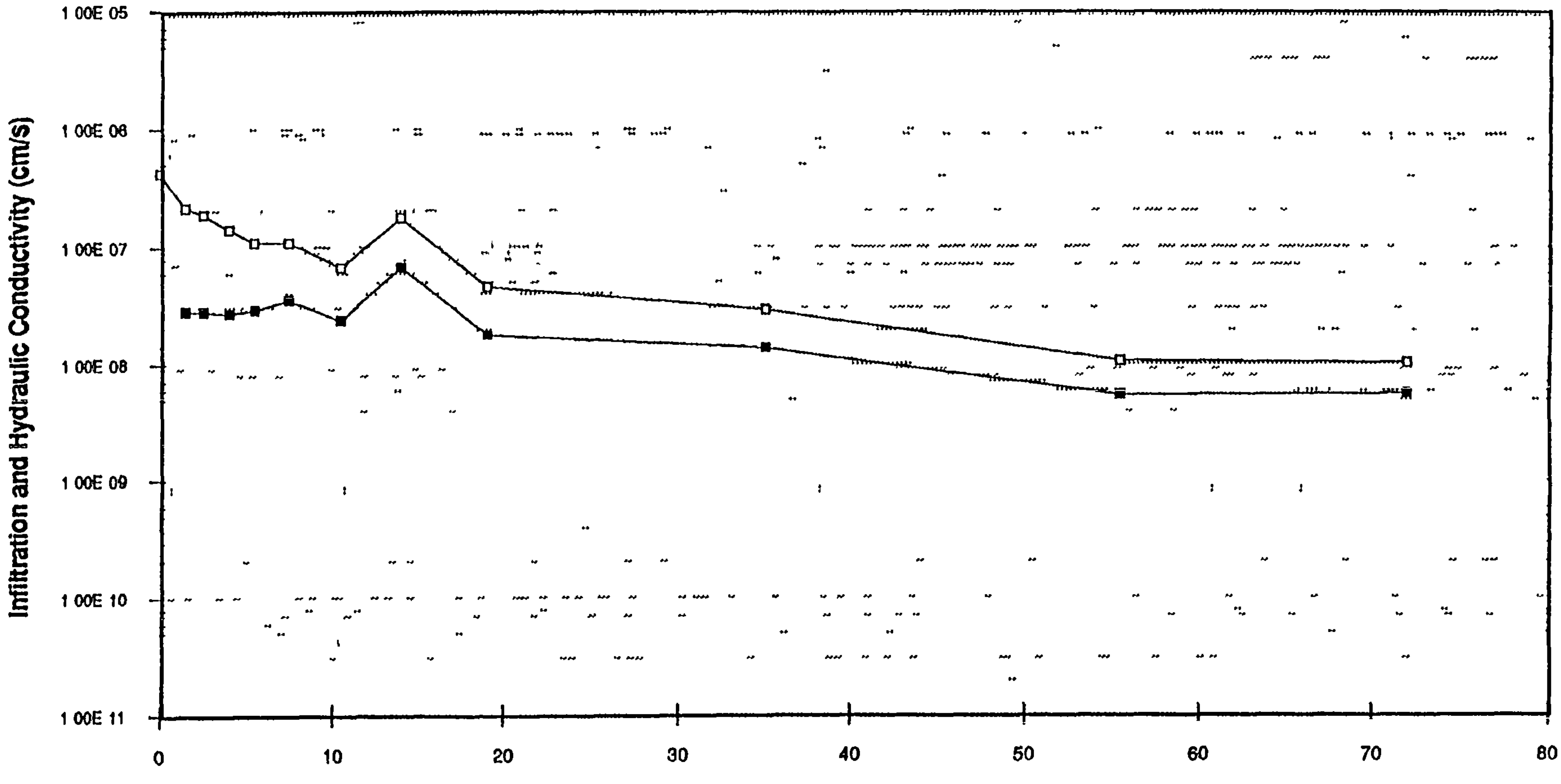
Figure 3 6

Two-stage Borehole Permeameter Nomenclature for Stage 1 and Stage 2



RMA 124C.3 3/24/95 NLM

Explanation

Hydraulic Conductivity

Infiltration

SDRI Sealed Double ring Infiltrometer

cm/s Centimeters per Second

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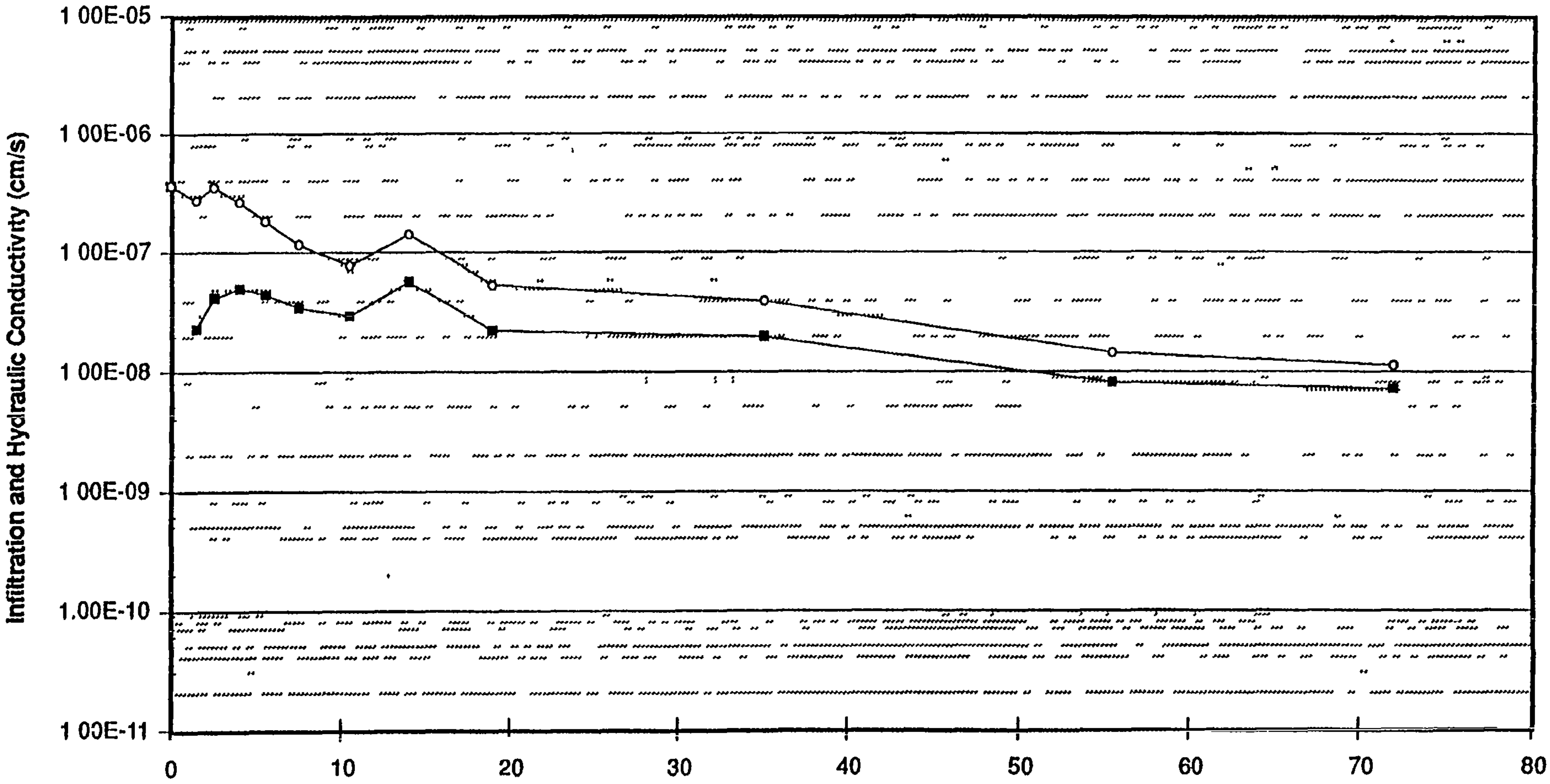


Explanation

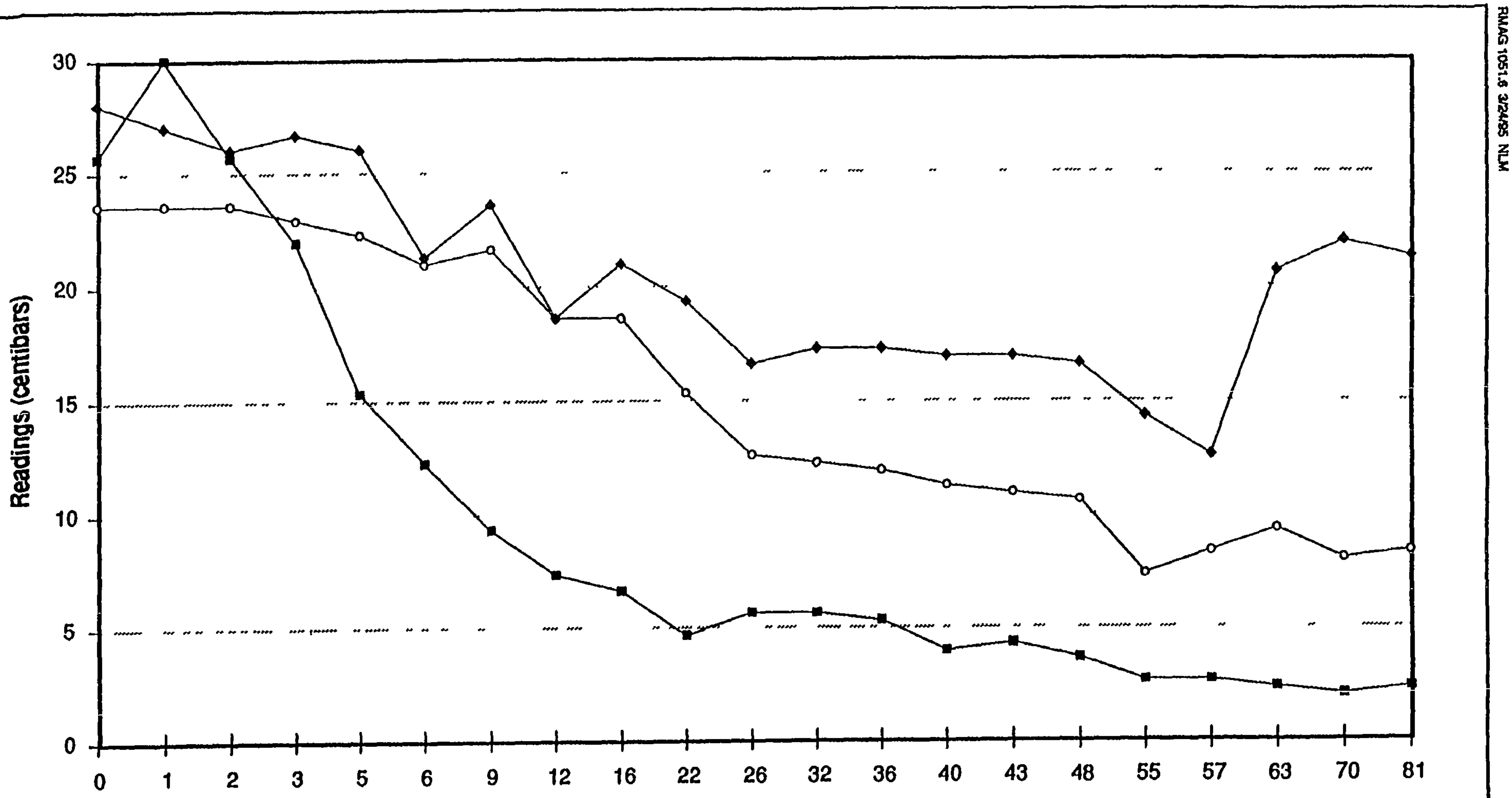
SDRI #1

SDRI #2

cm/s Centimeters per Second

SDRI Sealed Double ring Infiltrometer

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by. Harding Lawson Associates	Figure 3 8 Infiltration Rate and Hydraulic Conductivity SDRI 2 Testfill 1

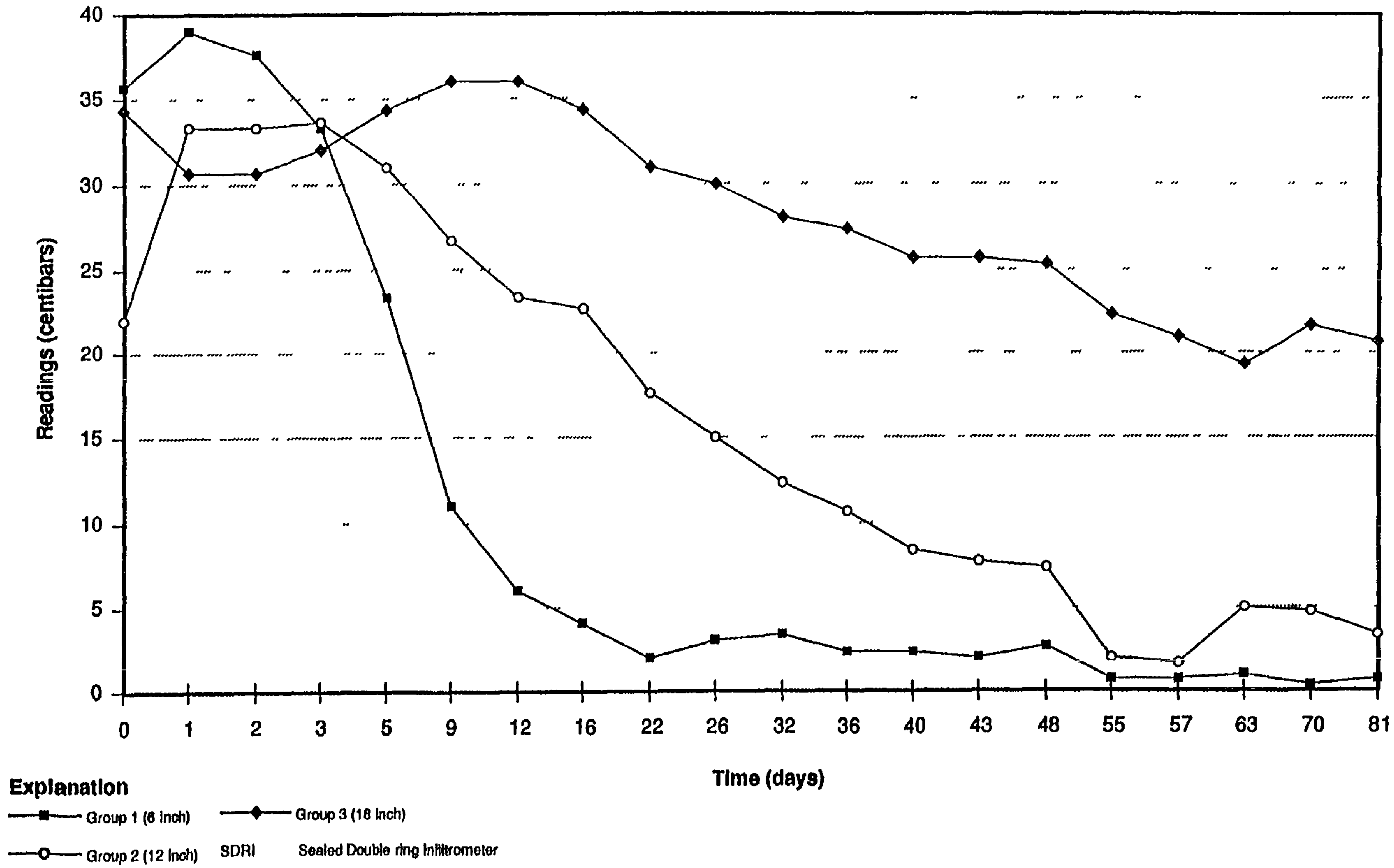


Explanation

- Group 1 (6 inch)
- Group 2 (12 inch)
- Group 3 (18 inch)

SDRI Sealed Double ring Infiltrometer

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 3 9 Average Tensiometer Readings SDRI 1 Testfill 1



Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 3 10 Average Tensiometer Readings SDRI 2 Testfill 2

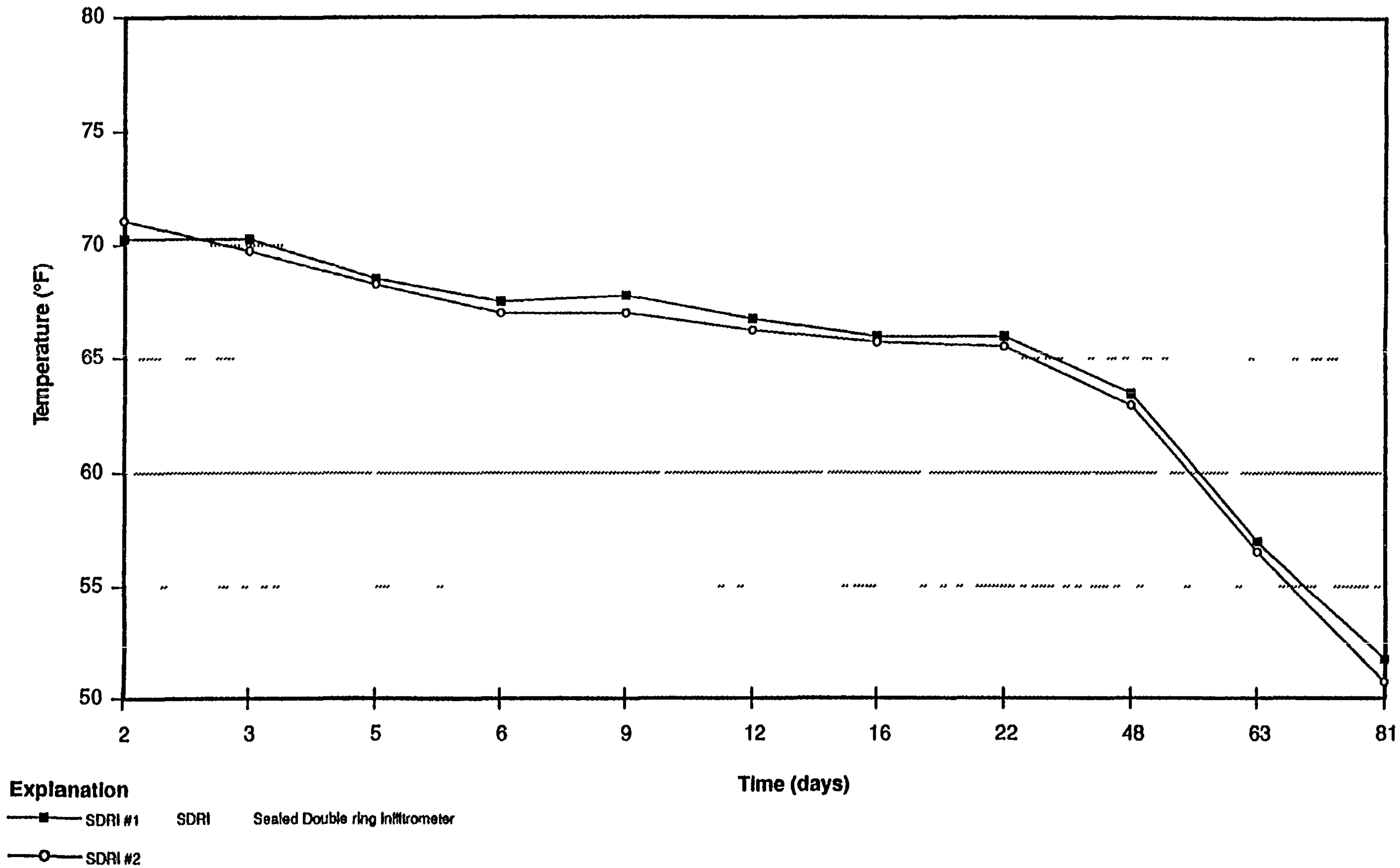


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Figure 3 11

Outer Ring Water Temperature

4.0 AREA FEASIBILITY STUDY

This section presents the results of the Area Feasibility Study that identify suitable areas for the location of the proposed hazardous waste landfill at RMA. The Area FS included a literature review, development of landfill area suitability criteria, identifying potential areas feasible for landfill construction based on the suitability criteria, and results of the geologic and geotechnical program in the identified areas (Section 25 at RMA) The Area FS was organized and performed in the following sequence

- Literature and Database Review (Section 4 1)
- Landfill Criteria and Policies (Section 4.2)
- Identification of Potential Areas (Section 4 3)
- Geologic and Geotechnical Investigation (Section 4 4)
- Area FS Conclusions

The literature and database review was performed to review existing data pertaining to landfill siting studies conducted at RMA and Highway 36 Landfill (the only commercial permitted hazardous waste landfill in Colorado) Previous landfill siting criteria and policies were reviewed and used to help develop Section 4 2, Landfill Criteria and Policies Previous geologic and hydrogeologic studies were also reviewed to evaluate if additional field investigations (Section 4 4, Geologic and Geotechnical Investigation) would be required to help evaluate area feasibility

In Section 4 2, the landfill siting criteria and policies were identified and evaluated for their relevance to siting a hazardous waste landfill at RMA. The landfill criteria and policies identified in Section 4 2 were used in Section 4 3 to screen RMA for suitable landfill siting areas that meet the relevant criteria and policies Once a suitable area for siting the landfill was selected, a geologic and geotechnical investigation was performed in the selected area. The geologic and geotechnical investigation provided further information on the suitability of the selected area for construction of a hazardous waste landfill. The results of the Area FS were used in the Site FS (Section 5 0) to further refine the preferred location for the landfill within the suitable area.

Soil and groundwater chemical analyses, geochemical interpretations, and hydrogeologic conditions used for this report were based on previous studies performed at RMA.

4.1 Literature and Database Review

The literature and database review was performed to evaluate previous landfill siting studies and geologic and hydrogeologic studies at RMA. The information provided in this section was used to assemble the landfill siting criteria and policies (Section 4 2) and perform the GIS analysis discussed in Section 4.3 The GIS analysis integrated information to screen RMA for areas that were deemed suitable for landfill construction based on the landfill siting criteria provided in Section 4 2.

4.1.1 Previous Landfill Siting Studies

Three independent studies, Waterways Experiment Station (WES), 1983, U S Army Toxic and Hazardous Materials Agency (USATHAMA), 1984, and Ebasco, 1988a, were conducted at the direction of the Program Manager for Rocky Mountain Arsenal (PMRMA) to identify potential sites for the location of a hazardous waste landfill at RMA Each of the studies is summarized below with emphasis on the objectives and approach of the report, siting criteria used, site selection, and recommendations The siting criteria and results of the three studies are compared with the latest regulatory and institutional siting criteria presented in Section 4 2

4.1.1.1 Waterways Experiment Station Report

The purpose and objective of the report entitled "Proposed Hazardous Waste Landfill Siting and Suitability, Rocky Mountain Arsenal, Denver, Colorado" (WES, 1983) was two-fold

- To identify a potential landfill site and determine the suitability of the site for hazardous waste disposal
- To provide the necessary background data and assessments for compliance with regulatory requirements

The study included the following

- Developing geotechnical landfill siting criteria
- Review of the RMA environmental database
- Evaluating RMA sites based on landfill siting criteria
- Conducting a geologic field investigation at the potential landfill site

The geotechnical landfill siting criteria were developed based on Colorado guidelines for a Resource Conservation and Recovery Act (RCRA) landfill site (Hynes and Sutton, 1980) Specifically, the report identified five siting requirements

- Above the 100-year Standard Projected Floodplain
- Depth to the water table greater than 40 feet
- No saturated alluvium
- Thirty feet or less above the top of the Denver Formation and no Denver sand channels in contact with the alluvium
- A minimum of one mile inside the RMA boundary

RMA was screened for potential landfill sites using the five siting criteria and a preliminary site was identified in Sections 25 and 36 (see Figure 4 1) Following the preliminary site selection, a field program including geologic and hydrogeologic data collection and interpretation was initiated to collect further data on the potential site Field work involved drilling 28 exploratory borings and constructing 22 monitoring wells Soil samples were collected from the borings for geotechnical property testing The monitoring wells were installed to evaluate the potentiometric surface and baseline water chemistry Additionally, two falling head slug tests were performed to evaluate groundwater flow rates

The conclusions of the WES, 1983 report included identification of the two sites in Section 25 and northern Section 36 One site was eliminated because of its concurrence with the North Plants facilities and the presence of sand channels The second site, located in the southern part of

Section 25 and the northern part of Section 36, met or exceeded the siting criteria identified in the report Features of the identified site include

- Located on a topographic high outside of the 100-year floodplain
- Underlain by unsaturated alluvium that is 5- to 20-feet thick
- On average, at least 40 feet above the water table
- An alluvial vertical permeability of less than 6 0 x 10^{7} cm/s (determined by falling head permeability slug tests at two sites)
- An estimated groundwater flow velocity of about 0 5 feet per day (based on laboratory tests)
- Low levels of contaminants detected in some of the wells (outside the boundaries of the preferred area)

4.1.1.2 USATHAMA Report

The purpose and objective of the report entitled "Decontamination Assessment for Land and Facilities at Rocky Mountain Arsenal" (USATHAMA, 1984) was to document the results of a multi-year study assessing the feasibility and cost of decontaminating all or portions of RMA. The approach for the USATHAMA report included

- Reviewing applicable federal and state requirements
- Reviewing existing data to define areas, types, and volume of contamination at RMA
- Developing technical approaches to decontaminate RMA property
- Estimating decontamination costs for both partial and total unrestricted use of RMA

Eighty-eight contaminated sites were identified at RMA. The volume of contaminated materials within the 88 sites was estimated Based on the data and volume calculations, it was estimated that about 16 million cubic yards of contaminated buildings, equipment, and soil are present at RMA.

Two technical approaches for decontamination of the 16 million cubic yards of material were evaluated The first technical approach included decontamination of the material through excavation and treatment including incineration, wet chemical processing, solar heating, ultraviolet destruction, and solidification and stabilization The second technical approach included in situ treatment of the material through soil activation, vegetative uptake, and biodegradation. Based on the feasibility, previous history, and economics, the preferred treatment technologies identified during the assessment were

- Excavation and landfilling
- Excavation, incineration, and landfilling

The study included identification of an onsite location for the landfill based on four siting criteria

- Location outside the 100-year floodplain
- Depth to groundwater greater than 20 feet
- Located greater than 200 feet from a Holocene fault
- Underlain by thick impermeable formations with no aquifers present

Based on the siting criteria, a location in the northeast quarter of Section 36 was selected for the landfill site Figure 4 1 illustrates the proposed location.

4.1.1.3 Ebasco Report

The purpose of the report entitled "Final Report, Task Number 27, Hazardous Waste Land Disposal Facility Assessment Report" (Ebasco, 1988a) was to assess the feasibility of an onpost land disposal facility that is compatible with federal and state regulations under CERCLA and capable of containing all RMA waste (estimated a 16 million cubic yards) The specific objectives were.

- Characterize the various wastes requiring land disposal
- Select the most suitable site for a land disposal facility at RMA
- Prepare a conceptualization of a land disposal facility with enough detail for a feasibility-level estimate of schedule and cost
- Estimate schedules and cost for construction and post-construction monitoring

The assessment process included two components, site selection, and design feasibility The site selection process was similar to WES and USATHAMA processes whereby criterion and site selection assumptions were made, exclusion and avoidance overlay maps were produced to identify potential sites The design feasibility process included selection of design criteria, evaluation of cell technology, evaluation of facility layouts, preparation of construction schedules, cost estimates, and constructions specifications with QC procedures. This review focuses on the site selection process Further discussion of the design feasibility process is included in Section 5 0

The site selection process included an evaluation of the entire RMA site with regard to seven siting criterion. The siting criteria included

- Location outside the 100-year floodplain
- Maximize the depth to groundwater with a target value of greater than 40 feet
- Located more than 1000 feet from a Holocene fault
- No saturated alluvium beneath the site
- Not within RMA avoidance areas of dedicated land use
- Initial target location size of greater than 1000 acres
- A minimum of 1000 feet inside the RMA boundary

Along with the site selection criteria, a list of site selection assumptions was prepared that included issues such as facility shape, number of sites, current and projected land use, and location of the waste centroid The facility shape was not considered a constraining factor in site selection because the waste cell arrangement could be changed to fit the site conditions. One contiguous site was preferred over multiple sites to minimize monitoring costs To address the current and projected land use issue, the site location was selected to avoid proximity to offsite high-density population areas and to be compatible with future onsite land uses

Based on the siting criteria and assumptions, six potential sites were identified Figure 4 1 illustrates the sites and lists the subsites identified within each of the six areas After thorough review of the sites, only two sites, 1B and 6B, were recommended based on the siting criteria achieved.

4.1.1.4 Limitations of Previous Landfill Siting Studies

The three siting studies provided PMRMA with insight into many of the pertinent issues related to siting a hazardous waste landfill at RMA. However, each siting study reviewed above contained certain limitations Specifically, the siting criteria used in the three studies are non-defensible by today's permitting standards These previous studies did not address certain regulatory criteria (as noted in Table 4 1) such as airport safety, wetlands, isolation, and sensitive habitats Each report is based on the CERCLA process and do not address other potential regulatory regimes, such as RCRA permitting The geologic and hydrogeologic databases used to evaluate RMA on a site-wide basis for geologic and hydrogeologic suitability are dated. More recent geologic and hydrogeologic information is currently available for selection of the onsite hazardous waste disposal site. Based on the current waste volumes projected for landfilling, site selection assumptions, such as site size, can be refined Finally, for the permitting process to begin (or to meet substantive RCRA requirements), site-specific geologic and hydrogeologic information, as described in Sections 5 0, must be completed.

4.1.2 Geologic Studies

The regional geology of the Front Range surrounding Denver, Colorado, has been studied for several decades and includes numerous publications The geology at RMA has been studied for more than 15 years General studies of the geology at RMA as well as specific studies of the bedrock and alluvium have been published. Site-specific geologic studies were reviewed as part of this Area FS. The regional geologic studies reviewed are included in the bibliography (Section 8 0)

Reports that provide a thorough overview of geology at RMA include Regional Groundwater Study of Rocky Mountain Arsenal, Denver, Colorado (May, 1982), Final Water Remedial Investigation Report, Volume III, Version 3 3 (Ebasco, 1989), and White Paper Evaluation of the Denver Formation at RMA (Morrison-Knudsen Environmental Services, Inc. [MKE], 1994) There are many area-specific reports that were reviewed as part of this study and are also included in the bibliography (Section 8 0)

RMA boring logs were reviewed to assist in screening areas suitable for siting a hazardous waste landfill RMA was screened to establish potential areas feasible for siting a landfill (as discussed in Section 4.3), using site suitability criteria. Based on this screening process and previous landfill siting studies, borings and cross sections from Section 25 were reviewed Cross sections from the Proposed Hazardous Waste Landfill Siting and Suitability Report, RMA (WES, 1983) and from White Paper Evaluation of the Denver Formation at RMA (MKE, 1994) were reviewed Table 4 2 presents a list of boring logs in Section 25 that were specifically reviewed (many of the boring logs are included in the cross sections constructed as part of the study and presented in Section 4 4) A detailed geologic and geotechnical study of the western half of Section 25 at RMA was conducted to gain additional geologic and geotechnical information, and to establish the feasibility of constructing a hazardous waste landfill A description of this geologic and geotechnical study and summary of the study results are presented in Section 4 4 of this report.

Geotechnical Data

Geotechnical testing results from the Landfill Siting Study (WES, 1983) and Final FS Soils Support Program Report (HLA, 1995a) were reviewed. The 20 samples collected by WES were from five borings in Sections 25 and 36 as part of a landfill siting study HLA drilled 98 borings to identify potential cap, liner, and structural fill materials Potential cap and liner materials were identified in Sections 20, 24, 25, 27, and 36 (HLA, 1995a) Additional geotechnical data were acquired in Section 25 during a shallow boring and geotechnical program performed during this task and are presented in Section 4 4 of this report. This additional geotechnical data provide information concerning the feasibility of Section 25 for locating a hazardous waste landfill

Geophysical Surveys

HLA prepared a Summary of Historical Geophysical Assessments at RMA as part of the Final Geophysical Assessment Report (HLA, 1994a) In the report, four geophysical studies were identified near the preferred potential landfill area (as identified in this section) Seismic refraction and reflection studies were performed in western Section 25 as part of the Basin F Area II study An electromagnetic and magnetic geophysical survey was performed in the southeast corner of Section 25 to investigate suspected disposal areas Electromagnetic and magnetic surveys were also performed in a suspected disposal area in north central Section 36 Plate 1 of the 1994 HLA Final Geophysical Report summarizes the locations of geophysical surveys at RMA.

Hydrogeology

The regional hydrogeology of the Front Range surrounding Denver, Colorado, has been reported in several publications The regional and site-specific hydrogeology at RMA has been studied and published for more than 15 years RMA regional and site-specific hydrogeologic studies were reviewed as part of this literature review The Front Range regional hydrogeologic studies as well as the RMA regional and specific studies are included in the Bibliography (Section 8.0)

Several reports that provide an overview of the regional hydrogeology at RMA include

- Evaluation of the Hydrogeological System and Contaminant Migration Patterns, RMA (R L. Stollar and F Van der Leeden, 1981)
- Regional Groundwater Study of Rocky Mountain Arsenal, Denver, Colorado, Report 1, Hydrogeologic Definition (May, 1982)
- Hydrogeologic Description of Rocky Mountain Arsenal Groundwater Module, (Little, 1979)
- Final Water Remedial Investigation Report (Ebasco, 1989)

Several site-specific hydrogeologic studies have been published and include Proposed Hazardous Waste Landfill Siting and Suitability, RMA (WES, 1983), the Comprehensive Monitoring Program (CMP) and Groundwater Monitoring Program (GMP) (HLA, 1992a, 1995b, Pacific Western Technologies, 1993), Results of Treatability Studies for Groundwater Containment and/or Control and

Subsurface Drains Final Report (HLA, 1992b), and Final Fourth Year Reevaluation Report for Complex Disposal Trenches Interim Response Action RMA (HLA, 1994b)

The site-specific studies mentioned above include varied hydrogeologic information. The WES 1983 report included monitoring well installation and some falling head slug tests in Section 25 and a discussion of the site-specific hydrogeology As part of the CMP and GMP, groundwater flow and chemistry were routinely monitored across RMA. As reported in the Results of Treatability Studies for Groundwater Containment and/or Control Report (HLA, 1992b), two monitoring wells were installed in Section 25 and an extended aquifer test was performed in the alluvium Wells were installed and aquifer tests were performed in Section 36, south of Section 25 The Final Fourth Year Reevaluation Report for Complex Disposal Trenches IRA (HLA, 1994b) reviews and discusses the hydrology of Section 36 (south of the preferred landfill area)

Groundwater Chemistry

Releases of a variety of contaminants to the environment of RMA have resulted in groundwater contamination both onpost and offpost (Environmental Science and Engineering, Inc [ESE], and others, 1988, HLA and ESE, 1992, Ebasco and others, 1991) The distance a groundwater contamination plume extends from its source area depends on numerous factors including the contaminants' behavior in the environment and the amount of time of release The extent of the groundwater contaminant plumes at RMA ranges from a few hundred feet from their source to several miles (HLA, 1995b) In 1975, the Army initiated regional surface-water and groundwater monitoring programs to assess both onpost and offpost contamination. The programs implemented to monitor groundwater contamination at RMA have changed in scope several times since 1975 and are currently administered under the GMP The results of the GMP were reviewed and utilized in this investigation to assess the extent of known groundwater contamination. Screening of suitable areas for the landfill includes avoiding areas of known groundwater contamination (see the discussion of Avoidance Areas in Section 4 2 1) Groundwater contamination plume maps presented in the

Proposed Final DAA (Ebasco, 1994) were also utilized in the potential landfill screening process (Section 4.3 1)

4.1.3 Highway 36 Chemical Waste Treatment/Solidification and Disposal Facility Plan

HLA reviewed the Chemical Waste Treatment Solidification and Disposal Facility Plan (Howard Needles Tammen & Bergendoff, 1981) to evaluate the requirements for siting a hazardous waste landfill in Colorado The plan was intended to meet or exceed the applicable federal requirements under the RCRA, Adams County regulations, and the Colorado Department of Public Health and Environment (CDPHE) (formerly the Colorado Department of health [CDH]) regulations for hazardous waste treatment and disposal facilities at the time it was published.

The requirements and prime considerations in 1981 for the Highway 36 Facility site selection included

- Suitable geologic conditions
- Located near waste sources
- Sparsely populated area
- Good transportation access
- No adverse environmental impact anticipated
- Availability of utilities
- Land availability and size requirements
- No nearby airports
- Favorable topography
- Soil suitable for liner material
- Not located within growth corridor
- Not within fault zone
- Not within 100-year floodplain
- Not located within wetland area

- No impact on endangered or threatened species and critical habitats
- Extensive buffer zone
- Not located in aquifer recharge zone
- Favorable evaporation rates with minimal rainfall

These regulatory requirements and siting conditions are still generally applicable as a guide for identifying potential landfill areas at RMA.

4.2 Landfill Siting Criteria and Policies

The landfill siting criteria and policies were identified using current, applicable State of Colorado and federal regulations and RMA specific policies developed by PMRMA and the USFWS These landfill siting criteria and policies were used to identify potential landfill areas in Section 4 3

The following subsections present brief discussions of each landfill siting criteria listed in Table 4.3 and the primary and secondary criteria used It should be noted that the regulatory criteria are always the primary criteria adopted and the secondary criteria are included to strengthen the site screening process for further assurance of waste isolation.

Faults

According to Colorado regulations (6 CCR 1007-3, 264 18[a]), hazardous waste landfills may not be located within 1000 feet of a fault that has had displacement in Holocene time (i e , the last 10,000 years) This regulatory citation is the primary criteria adopted No evidence of faulting during the Holocene Epoch has been established at RMA.

There has been some discussion of potential faulting within the Denver Formation (WES, 1983) at RMA. Recognizing faulting within the Denver Formation is complicated by the discontinuous nature of the sedimentary deposits Faults were generally identified by displacement of distinct lithologic units within a formation. If, however, the units within the formation are discontinuous because of lateral facies changes that occurred during deposition, it is difficult to assess whether discontinuities are due to faulting or sedimentary facies changes For this reason, the question of whether minor discontinuities within the Denver Formation are due to faulting or depositional changes is difficult to answer It is recognized, however, that any faulting that did occur within the Denver Formation probably occurred concurrently with settlement of the Denver Basin during the Laramide Orogeny in Late Cretaceous (i e , 65 million years before present) and Early Tertiary (i e , 55 million years before present) It has yet to be determined if these suspected areas are due to Denver Basin settling deformation, lithologic changes, or minor faulting The Denver Formation was deposited in the Upper Cretaceous and early Tertiary Periods, which ended approximately 65 million years ago.

Floodplain

Colorado regulations state that new landfills must be located outside the 100-year floodplain (6 CCR 1007-3, 264 18[b]), which is defined as any area subject to a 1 percent or greater chance of flooding in any given year from any source

The U S Army Corps of Engineers (COE) (1983) produced a 100-year floodplain map for the area encompassing RMA is shown in Figure 4 2 This regulatory citation is the primary criterion adopted

Salt Formations

Noncontainerized or bulk liquid hazardous waste may not be placed within salt dome formations, salt bed formations, underground mines and caves (6 CCR 1007-3, 264.18[c]). This Colorado regulatory citation is the primary criterion adopted. However, no known salt formations exist at RMA.

Surface Water/Groundwater

The Colorado regulatory citation states that "hazardous waste disposal facilities shall not place wastes directly under or into surface water or groundwater that has a potential or existing beneficial use or that is in direct communication with an aquifer" (6 CCR 1007-3, 264 18[d]) This citation is the primary criterion adopted The previous landfill siting studies at RMA (see Section 4 1) suggest using target depths to groundwater (Table 4 1) to ensure this criterion is met The secondary target criteria stated in Table 4 3 are to maximize the depth to groundwater

Airport Safety

Colorado regulations state that new landfill facilities within a five-mile radius of an airport runway shall notify the CDPHE, local governing body having jurisdiction and the Federal Aviation Administration (6 CCR 1007-2, 3 1.1) This regulatory citation is the primary criteria adopted Denver International Airport runways are within five miles of RMA but are over five miles from the preferred landfill site

Wetlands and Sensitive Habitats

According to Colorado regulations, new landfills shall not be located in wetlands, unless the restrictions set forth in 40 CFR 258.12 can be met (6 CCR 1007-2, 3 1.2). Wetlands (as defined by 6 CCR 1007-2) means those areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions Wetlands generally include swamps, marshes, bogs, and similar areas The USFWS delineated an area (shown in Figure 4 3) that is acceptable to landfill siting and does not include any areas impacted by the Endangered Species Act (ESA) (16 United States Code [USC] Sections 1531 to 1543) This area has been screened by USFWS to exclude critical habitat such as wetlands and riparian areas, raptor roosts and nesting sites within the Bald Eagle Management Area (BEMA), most prairie dog towns, unique vegetation communities, and high public use area. According to ESA, the term "critical habitat" for a threatened or endangered species means (16 USC Section 1532[5][A]).

> (i) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of this Act, on which are found those physical or biological features (1) essential to the conservation of the species and (2) that may require special management considerations or protection, and
>
> (ii) Specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the provisions of Section 4 of this Act,

> upon a determination by the Secretary that such areas are essential for the conservation of the species

This regulatory citation is the primary criterion adopted The avoidance of sensitive wildlife habitats is adopted as a secondary criterion

Seismic Impact Zones

Colorado regulations state that new landfills shall not be located in seismic impact zones, unless the owner or operator can demonstrate to CDH that all components are designed to resist the maximum horizontal acceleration in lithified earth material for the site (6 CCR 1007-2, 3 1 4) This regulatory citation is the primary criterion adopted RMA is located in an area of low seismic activity and therefore is not in a seismic impact zone.

Unstable Areas

Owners and operators of new landfills located in an unstable area must demonstrate that engineering measures have been incorporated into the facility's design to ensure that the integrity of the structural components will not be disrupted (6 CCR 1007-2, 3 1 5) Onsite soil conditions that may result in significant differential settling, geologic, or geomorphological features and onsite local or man-made features or events must be considered (6 CCR 1007-2, 3.1 5) This regulatory citation is the primary criterion adopted

Topography

The topography of the site shall maximize protection against prevailing winds onsite and minimize the amount of precipitation catchment area upgradient of the site (6 CCR 1007-2, 3.1.6) This regulatory citation is the primary criteria adopted Figure 4 4 presents a topographic elevation map of RMA. The topography of potential areas will be evaluated based on this criterion.

Isolation

Colorado regulations state that landfills shall isolate wastes from the public and environment (6 CCR 1007-2, 3.1 8) Emphasis will be placed on favorable geologic conditions over engineered improvements of marginal geological conditions (6 CCR 1007-2, 3.1 8) This regulatory citation is the primary criterion adopted (See Hydrogeology and Geology, below.)

Hydrogeology and Geology

The geological and hydrological conditions of new hazardous waste landfill sites shall provide reasonable assurance that the wastes are isolated within the disposal area and away from natural environmental pathways that could expose the public for 1000 years, or some demonstrated shorter period in which the wastes are transformed to an innocuous condition (6 CCR 1007-2, 2 5.3) The assurance of 1000-year isolation is based on the following considerations

- Geomorphic conditions either will not vary significantly from the present state or will occur to a predictable degree which can be accommodated in the facility design
- The immediate area of the site is in strata of minimal groundwater flow
- The geologic strata surrounding the site combined with engineered barriers included in the design shall provide a minimum permeability of 10^{-7} cm/s or equivalent of sufficient thickness between the disposal location and the nearest domestically or agriculturally useable aquifer to isolate any materials to be disposed therein
- The juxtaposition of the site and any free flowing or standing natural surface waters shall be such that disposal locations will not impact nor be impacted by such surface waters
- The terrain is such that good drainage exists for movement of precipitation away from the disposal area, and such that water and wind erosion will be minimal
- The geochemical characteristics of the geologic strata at the site are compatible with the waste categories proposed to be disposed at the site especially in terms of providing high adsorption, absorption, or chemical fixation of any wastes that may migrate from the immediate areas where disposed (6 CCR 1007-2 2.5 3)

This regulatory citation is the primary criterion. Secondary criteria for hydrogeology and geology were developed to help in the site screening process The secondary criterion for hydrogeology is to avoid areas containing saturated alluvium The secondary criterion for geology is to minimize the depth to bedrock.

Location

The location of any hazardous waste facility shall be within a distance controlled by the owner/operator by an acceptable means to prevent adverse effects on the public health should unexpected discharges of hazardous waste occur (6 CCR 1007-2, 2 5 6) This Colorado regulatory citation is the primary criterion adopted A secondary criterion developed by PMRMA is to centrally locate any hazardous waste facility within RMA to keep an adequate area around a facility controlled by PMRMA.

Buffer Zone

Colorado regulations state that sound levels of noise radiating from a property line at a distance of twenty-five feet or more in excess of 80 decibels (for an industrial zone) between 7:00 a.m and 7.00 p.m shall constitute a public nuisance (Colorado Revised Statute [CRS] Sections 25-12-101 to 108) This regulatory citation is the primary criterion adopted

Avoidance Areas

Avoidance areas are not a regulatory criteria but are important when considering the feasibility of siting a hazardous waste landfill. Avoidance areas at RMA include groundwater plumes containing RMA-related contaminants, human health exceedance areas, and contaminated subsurface soil areas as delineated in the Proposed Final DAA (Ebasco, 1994) Figure 4 5 shows groundwater plumes at RMA and Figure 4.6 shows human health exceedance and contaminated subsurface soil These avoidance areas are a secondary criterion adopted

Area Required

The exact area required for a hazardous waste landfill at RMA has yet to be defined, and may be adjusted depending on the preferred remediation alternative selected for cleanup and or stabilization at RMA. The area required is not a primary criterion since it is not regulatory based, however, based on the results of Section 5.0, at least 87 contiguous acres are required to accommodated the largest volume of waste to be landfilled.

National Historic Preservation Act of 1966

The National Historic Preservation Act of 1966 (NHPA) (16 USC Section 470) requires that alteration of terrain that may cause irreparable harm, loss, or destruction of significant artifacts or prehistorical,

historical, or archaeological data, be required to recover and preserve the artifacts and/or data. This citation is not considered a suitability criterion, and was not used as part of the screening process Cataloging of prehistorical, historical, and archaeological sites is currently in progress at RMA. The presence of prehistorical or archaeological artifacts should not impact the siting of the landfill However, if prehistorical or archaeological artifacts are identified, they must be recovered before construction can proceed

Archaeological and Historical Preservation Act

The Archaeological and Historical Preservation Act (AHPA) (16 USC Sections 469 to 469C-1) establishes procedures for preservation of historical and archaeological data that might be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program If archaeological artifacts are identified in potential landfill areas, AHPA may be applicable However, this does not eliminate areas from being considered for landfill siting because archaeological artifacts (if found) can be cataloged and removed before disturbance takes place as long as the site is not considered a national historic site If a site contains significant archaeological artifacts, then the Archaelogical Resources Protection Act of 1979 may apply, eliminating the area from future use

4.3 Identification of Potential Landfill Areas

The identification of potential landfill areas was performed using the literature and database review from Section 4 1 and the landfill siting criteria and policies from Section 4 2 to screen RMA. The potential landfill area identified in this section was used as the study area for the geologic and geotechnical investigation (Section 4 4)

4.3.1 Potential Landfill Areas Screening Process

Potential landfill areas were screened using the landfill siting criteria developed in Section 4 2 (Table 4.3) A series of overlay maps containing physical data, and exclusion and avoidance data, were integrated using a GIS format. The following map data were input into GIS for integration·

USFWS avoidance areas (Figure 4 3), organic contaminant groundwater plumes (Figure 4 5), 100-year floodplain avoidance areas (Figure 4 2), and human health exceedances areas (Figure 4 6) were removed from consideration as potential areas to site a hazardous waste landfill

The secondary siting criteria used to identify potential landfill areas listed in Table 4.2 for surface water/groundwater, hydrogeology, geology, and location, respectively, are

- Maximize depth to groundwater
- Avoid saturated alluvium
- Minimize depth to bedrock
- Located centrally within RMA boundary

The secondary siting criteria for groundwater hydrogeology and geology mentioned above were used to maximize hazardous waste isolation If in the event there was a breach in the landfill liner system and a leak was to occur, the leachate would flow from the base of the landfill through the vadose zone to groundwater Colorado hazardous waste regulations are written to protect the potential downstream receptors and the most probable flowpath in this scenario would be through groundwater flow Maximizing the depth to groundwater contributes to waste isolation by increasing the thickness of the vadose zone and, therefore, the time required for any potential contamination to reach groundwater Avoiding saturated alluvium contributes to waste isolation because the saturated alluvium is in general more hydraulically conductive than the saturated Denver Formation. Minimizing depth to bedrock helps isolate waste because, generally, the bedrock below the alluvium has a lower vertical hydraulic conductivity than the alluvium and, therefore, creates a longer travel time to groundwater The secondary criteria of centrally locating a landfill within RMA boundary is a policy developed by PMRMA to minimize potential waste hauling distances and create the largest buffer to the public as possible

To identify suitable potential landfill areas, a series of maps were generated by applying different combinations of suitable depths to groundwater and bedrock (five different depths to groundwater and four different depths to bedrock) The potential maximum contiguous acreage identified through this GIS analysis using the various depths to groundwater and depths to bedrock is listed in Table 4 4 and are presented and evaluated in the following subsection.

4.3.2 Potential Landfill Areas

The results of the potential landfill areas screening process are presented in six maps (Figure 4 11 through Figure 4 16) These figures represent the potential landfill areas available using the depths to groundwater and bedrock parameters in Table 4 4 The suitable areas based on the applied selection criteria increase in size as the depth to groundwater and the depth to bedrock parameters become less restrictive

The six maps (Figure 4 11 through Figure 4 16) each show a consistent grey pattern that represents the suitable areas identified using the primary landfill siting criteria A spatial analysis was performed to eliminate those areas at RMA deemed unsuitable with respect to the primary landfill siting criteria. The primary landfill siting criteria (Table 4 3) include avoidance of wetlands, sensitive habitats, 100-year floodplain, organic groundwater contamination plumes, and human health exceedance areas As noted in Table 4 3, some regulatory criteria are not relevant because they are not encountered at RMA.

The most restrictive parameters listed in Table 4 4 are

- Depth to groundwater of 70 feet or greater
- Depth to bedrock of 10 feet or less

The least restrictive parameters (while still maintaining unsaturated alluvium) listed in Table 4.4 are:

- Depth to groundwater of 40 feet for greater
- Depth to bedrock of 40 feet or less

Figure 4 11 presents the potential landfill area generated using the most restrictive parameters, and Figure 4 16 presents the potential landfill area using the least restrictive parameters The most restrictive parameters yield 1 contiguous acre of potential landfill area (Figure 4 11), while the least restrictive parameters shown in Figure 4.12 yield 371 contiguous acres A balance is required to (1) meet the siting criteria of maximizing the depth to groundwater and minimizing the depth to bedrock and (2) retain enough acreage to facilitate the construction of a hazardous waste landfill capable of containing the volume of waste generated during sitewide remediation at RMA. The potential landfill areas identified in this section indicate that the western half of Section 25 at RMA contains the most suitable area based on the landfill siting criteria and policies and screening iterations

Section 5 0 will discuss the acreage required to construct a hazardous waste landfill with three different waste volume assumptions (1 million, 2 3 million, and 6 million cubic yards).

4.4 Geologic and Geotechnical Investigation

This section presents the methods, results, and conclusions of a detailed geologic investigation performed in the western half of Section 25. As described previously, based on a GIS analysis performed as part of the Area FS study, the western half of Section 25 is the preferred area for the location of the proposed hazardous waste landfill at RMA. This geologic investigation was performed to obtain further information on the suitability of the proposed area. Section 4 4.1 presents the field and laboratory methods employed in the geologic investigation. Section 4 4 2 presents a detailed description of the results of the investigation. Section 4 4 3 summarizes the results and presents conclusions on the geologic suitability of the proposed area.

4.4.1 Geologic Investigation Methodology

A total of 33 boreholes were drilled in the western half of Section 25 for this investigation (Figure 4 17) Three of the boreholes were deep (drilled to a total depth of 175 feet bgs) and thirty were shallow (drilled to a maximum depth of 50 feet bgs) The boreholes were surveyed by a State of Colorado-licensed surveyor using the 1983 horizontal datum and the 1988 vertical datum The equipment and procedures used for drilling the two types of boreholes are summarized separately below More detailed information on the drilling, sampling, geophysical logging, and laboratory testing methodology was provided in the Final Work Plan for Material and Area FS Soils Support Program (HLA, 1994c) (Appendix I)

4.4.1.1 Deep Coring and Geophysical Logging Program

Three deep boreholes were drilled by a U.S Army Corps of Engineers (COE) WES drilling crew using a Failing 1500 rig The drilling rig was capable of both auger and rotary drilling Drilling in the alluvium was accomplished using an 8-inch-outside-diameter (OD) solid auger Continuous core samples of the alluvium were collected using a 24-inch, split-barrel sampler in the open borehole Drilling in bedrock was accomplished by mud-rotary drilling and samples were collected using a 5-foot-long, 4 5-inch-OD, 2 5-inch-inside-diameter (ID) core barrel using a wireline system. A temporary casing was set in the alluvium of each deep borehole and grouted in place to prevent the unconsolidated materials from caving into the borehole

The field crew consisted of a two-person drilling crew from WES and an HLA geologist The HLA geologist documented the daily drilling activities including the following boring number, drilling progress, pertinent observations such as equipment decontamination, photoionization detector (PID) readings, weather, and surface conditions

The HLA geologist prepared a lithologic log of the split-spoon and core samples recovered from the borehole The logs included alluvium and bedrock descriptions using the USCS and the Munsell color chart. Information on stratigraphic features such as bedding or laminations, and structural features such as fracturing or slickensides, along with other pertinent geologic information, was noted on the boring logs The soil and bedrock cores recovered from the drilling program were packaged, labeled, and stored in RMA Building 728

Immediately upon completion of the drilling and sampling, the boreholes were geophysically logged by Colog, Inc (Colog), of Golden, Colorado Colog used the following geophysical logging tools

- Normal resistivity
- Spontaneous resistivity
- Single-point resistivity
- Gamma
- Full waveform sonic
- Neutron

After the boreholes were geophysically logged, they were grouted to the ground surface with a cement/bentonite grout mixture using a tremmie pipe A stake was placed at the borehole location with the appropriate boring identification number The location and ground surface elevation of the boring was surveyed by a Colorado-licensed surveyor

4.4.1.2 Shallow Boring and Geotechnical Testing Program

Thirty shallow boreholes (Figure 4 17) were drilled by a Layne Environmental drilling crew using a mobile Central Mine Equipment (CME 75 or 750) drilling rig The rig was equipped with 3-1/4-inch hollow-stem augers and 2-foot long, 2.5-inch-ID, split-spoon soil samplers The split-spoon samplers were driven using a drilling rig-mounted 140-pound automatic slide hammer at a 30-inch drop

The field crew consisted of a two-person drilling crew from Layne Environmental, an HLA geologist, and an HLA engineering technician. As described in the deep drilling program, the HLA geologist was responsible for documentation of the daily drilling activities The HLA engineering technician was responsible for sample handling, packaging, and shipment.

The HLA geologist prepared a lithologic log of each shallow borehole in the same manner described in the deep drilling program. While drilling through the alluvium and to a depth of at least 5 feet into the weathered bedrock, continuous split-spoon samples were collected Samples were collected from the split-spoon samplers at 4-foot intervals in 500 ml plastic jars for geotechnical testing At the same 4-foot interval, 5-gallon bucket samples were collected from the auger cuttings for additional geotechnical testing Once drilling had advanced at least 5 feet into the weathered Denver Formation, no further split-spoon samples were collected (due to split-spoon refusal) and from that point on, lithologic logging and soil samples were collected from auger cuttings

Samples collected from the boreholes were shipped to HLA's laboratory in Houston, Texas, for geotechnical property testing The samples were analyzed for the following geotechnical properties·

Test Name	Test Method	Percentage of Samples Tested
Particle size	ASTM D422	100
Atterberg limits	ASTM D4318	100
Natural moisture content	ASTM D2216	100
Remolded compaction	ASTM D698	10
Remolded permeability	EM1110-2-19096	10
Shrink swell	ASTM D427 and D4546	10

Test Name	Test Method	Percentage of Samples Tested
Organic content	ASTM D2974	10
Shear strength	ASTM D4767 and D2850	1

Upon completion of the drilling and sampling, the boreholes were grouted to the ground surface using a cement/bentonite grout A stake was placed at the borehole location with the appropriate boring identification number. The location and ground surface elevation of the boring was surveyed by a Colorado-licensed surveyor.

4.4.2 Geologic Investigation Results

The following sections present the results of the geologic investigation. As described above, two types of soil borings were drilled for different data objectives and, therefore, the results of the two programs are presented separately In this section, the results of the two drilling programs are integrated and conclusions on the suitability of the proposed area are presented

4.4.2.1 Geologic Setting

The geologic setting of RMA has been described in detail by MKE (1988), and Ebasco (1989), and the groundwater hydrology beneath the site has been described by May (1982) A brief overview of the geologic site conditions is described below to provide a framework for understanding the results of the geologic investigation in Section 25

RMA is located within the Denver Basin, a north-south trending syncline The syncline is asymmetrical with steeply dipping beds that are faulted against the Colorado Front Range on the west and gently dipping beds on the east that extend into western Kansas and southwestern Nebraska. The basin extends from north of Cheyenne, Wyoming, to south of Colorado Springs, Colorado RMA is near the structural axis of the southern portion of the syncline where the uppermost beds dip on average less than 1° to the southeast.

The topography at RMA is expressed as gently rolling hills, wide plains, and shallow basins. The elevation above mean sea level ranges from 5340 feet in the southeastern part of RMA to 5120 feet in the northern part of RMA

Before the formation of the Denver Basin, the area near what is now RMA received an influx of various types of sediment as a result of primarily alluvial depositional processes The Denver Basin was downwarped to a syncline during the Laramide Orogeny in Late Cretaceous and Early Tertiary time, and the Fox Hills Sandstone, the Laramie Formation, the Arapahoe Formation. and the Denver Formation were deposited (Figure 4 18) Additional alluvial sediment was deposited over the Denver Formation until the late Tertiary period, when regional uplift caused the erosion of this additional sediment at RMA, as well as part of the Denver Formation Subsequently, Quaternary sediment was deposited at RMA

This report focuses on the Denver Formation and Quaternary deposits because they contain the principal aquifers in contact with potential contaminant sources within RMA A claystone layer forms the base of the Denver Formation and provides a confining layer between the Denver Formation and the underlying Arapahoe Formation.

Alluvium The Quaternary surficial deposits, commonly called the Quaternary alluvium, consist of unconsolidated alluvial and colluvial fill and eolian sand The alluvial and colluvial material is composed of volcaniclastic material and glacial outwash containing cobbles and boulders in a matrix of clay, silt, sand, and gravel Older coarse-grained alluvial deposits generally are in areas along the South Platte River and the western part of RMA. Paleochannels eroded into the Denver Formation are also filled with coarse-grained sand and gravel Younger eolian and alluvial deposits are finer grained than the older surficial deposits and commonly form the uppermost alluvial deposits throughout much of RMA

The Quaternary alluvium typically ranges from 0 to 50 feet in thickness but locally fills paleochannels eroded into the Denver Formation to a depth of 130 feet (May, 1982) The surficial geology at RMA is almost entirely alluvial material and the Denver Formation is exposed at the surface in only a few locations (Figure 4 19) Eolian deposits consisting of fine sand, clay, and silt occur as a thin discontinuous veneer that overlies most of the surficial material at RMA.

Denver Formation. The Denver Formation is believed to have been originally about 900 feet thick over the RMA area (MKE, 1988), but it has been eroded to a maximum of 500 feet thick in the southeastern corner of RMA. The formation thins to the northwest and is absent beneath the South Platte River, where it has been completely eroded. As much as 40 feet of the upper Denver Formation are weathered and the weathered zone is in direct contact with the Quaternary alluvium

The Denver Formation consists of a thick sequence of shale and claystone with interbedded siltstone and sandstone lenses, deposited by low-energy fluvial processes in a distal alluvial plain environment. Olive, bluish-gray, and brown colors dominate the upper part of the formation because of lithic fragments derived from the erosion of basaltic and andesitic volcaniclastic material Sandstone lenses are tan to brown and consist of well-defined fluvial channels and laterally variable crevasse splay sands and overbank deposits Lignite beds and carbonaceous shales are also present.

Stratigraphic correlation of units within the Denver Formation is difficult because of the discontinuous nature of the sandstone lenses and the lateral variability in thickness and composition of other units A relatively thick, laterally continuous lignite layer, known as lignite A, occurs within the South Plants, North Plants, and Basin A area. Lignite A has been used as a marker bed from which all other zones in the Denver Formation have been referenced (Ebasco, 1989a, 1989b) Denver Formation stratigraphy (Figure 4.20) has been interpreted using this and other lignite layers as marker beds The stratigraphy illustrated in Figure 4 20 was adopted for the stratigraphic correlations presented in this report.

The Denver Formation dips slightly to the southeast and the erosional bedrock surface slopes to the northwest. Therefore, progressively deeper stratigraphic units are erosionally truncated from southeast to northwest. Examples of the truncation of the Denver Formation due to the slope of the erosional bedrock surface are presented in the cross sections described in Section 4 4 2 3

4.4.2.2 Deep Coring and Geophysical Program Results

Three deep boreholes (BRB11094, ASB11194, and SAB11294) were successfully lithologically and geophysically logged (Figure 4.17) The lithologic boring logs for the three boreholes are included in Appendix E, and Appendix F includes the boring survey locations, and surface and bedrock elevations The geophysical logs are included in Appendix G

Geophysical logging of the three boreholes was completed by Colog Results of the investigation are presented the Geophysical Logging Services Report in Appendix G Based on the results presented in the report, there was good correlation between the geophysical log response and the lithologic core descriptions in the three deep boreholes The geophysical log responses were consistent with fine-grained, clay-rich, poorly consolidated sediments

Variations in geophysical response recorded on the geophysical logs illustrate the lithologic differences between the three borings Borings BRB11094 and SAB11194 correlate on both the lithologic and the geophysical logs The correlation of Boring ASB11294 with the other two borings is less definitive According to the geophysical logging report, the differences in the geophysical logs between ASB11294 and the other two borings may be attributed to the shallower bedrock depth and a lower depth to water table at ASB11294 A more apparent difference between the borings is lithologic. A lignitic zone identified in BRB11094 and SAB11194 between 5178 and 5184 feet elevation is not identifiable in the geophysical logs of ASB11294

Cross sections were developed using the lithologic boring logs developed during the deep boring program to evaluate the differences identified in the geophysical response between the three boreholes The cross sections are presented in Section 4 4 2.3 and illustrate the interpretations of the lithologic correlation across the study area.

4.4.2.3 Shallow Boring Geotechnical Program Results

Stratigraphic and Lithologic Relationships

The site-specific lithologic and stratigraphic relationships of the Quaternary alluvium and the Denver Formation were studied in the western half of Section 25 in detail through the construction and interpretation of 16 cross sections A cross section grid was constructed across the study area and is illustrated in Figure 4 17 Ten cross sections were oriented subparallel to strike (A-A′ to J-J′) and six were oriented subparallel to structural dip (K-K′ to P-P′) Eight of the sixteen cross sections in the grid, considered most representative of the study area geology, are included in this report to illustrate the interpretations presented herein (Figures 4 21 through 4.28)

Lithologic information used to construct the cross sections was taken from the 30 shallow borings and the 3 deep borings drilled as part of this investigation. Additionally, boring logs generated during the installation of existing monitoring wells in the study area were used in the cross sections Correlations of similar lithologic units were made for each cross section over relatively short distances and by correlating the points at which the cross sections intersect (tie points) This method of correlating site geologic data allows for an evaluation of the stratigraphy and specific lithologic intervals in a three-dimensional framework.

Quaternary Alluvium. The geologic strata characterizing the site include the Quaternary alluvium and Denver Formation The alluvium encountered in the 33 borings consists of clay, silt, very fine- to fine, to medium-grained sand and minor amounts of coarse-grained sands. On the cross sections, the different types of alluvium are grouped based on the particle size analysis performed on the soil samples Those samples with greater than 50 percent of the sample passing the number 200 sieve are identified as clay or sandy clay (CL or CH according to USCS classifications) Those samples that had less than 50 percent passing through the number 200 sieve are identified as sand, silty sand, or clayey sand (SP, SM, SC, or SW) None of the samples was classified as "gravels" according to the particle size analysis, however, if a significant amount of gravel was noted in the boring log, this was identified on the cross section. The finer grained deposits are probably loess or colluvial deposits, and the coarser grained deposits may represent alluvial channels or terrace gravel deposits

The alluvium ranges in thickness from approximately 5 to 58 feet bgs as measured in boreholes within the study area The interpretation of alluvial thickness is not always straight-forward in the study area because the differences between alluvial sand deposits and weathered sandstone deposits are often subtle and difficult to immediately recognize in the field When a question arose about the interpretation of a sand as alluvium or bedrock, the following guidelines were used: (1) increased blow counts are indicative of a weathered bedrock deposit, (2) oxidation zones such as iron and manganese oxide are indicative of weathered bedrock, and (3) fine- to medium-grained sands with little or no clay component are more indicative of weathered bedrock deposits

Denver Formation. In the study area, the Denver Formation consists of predominantly thick sequences of claystone with interbedded and interfingering thin, lenticular sands and locally thick channel sands In this area, carbonaceous and lignitic coal seams are common.

Stratigraphic correlation of the Denver Formation was based on the vertical position of sand units relative to two distinct lignite marker beds, Lignite A and Lignite B The stratigraphy shown on the cross sections is comparable to that reported in the Water Remedial Investigation and Study Area Reports (Ebasco, 1989b) and adopted by subsequent studies at RMA (HLA, 1992b, MKE, 1994). Based on the available boring data, individual "sand units" were mapped that fall within the stratigraphic Zones A, 1U, and 1 (See Figure 4 20 illustrating the stratigraphic nomenclature) Cross section D-D' (Figure 4.22) best illustrates the stratigraphy in the study area since both lignites and the three sand units are present in the cross section.

As proposed by MKE, 1994, the designation of "sand units" as distinguished from "sand zones" (from Ebasco, 1989b) was adopted for this report. The "sand unit" designation means that the sand beds identified in this report, such as "A Sand" correlate across the study area based on the cross sections presented in this report. The subtle difference between a "sand unit" in this report and a "sand zone" in the Ebasco (1989b) can be illustrated in the following manner. The sand unit identified as "A Sand" in this study is interpreted to be the depositional equivalent to, for example, the "A Sand" that underlies Lignite A identified in the South Plants area (HLA, 1992b) The sand unit "A Sand" identified in the study area is not, however, interpreted to correlate across Basin A into South Plants without further interpretation across the Basin A area. To summarize, the two "A sands" were deposited in the same stratigraphic sequence, however, the lateral correlation of this discrete package of sand, "sand unit," outside the study area is not implied

The sandstone units within the Denver Formation were deposited primarily as overbank and channel sands The channel sand facies consists of fining-upward sequences that begin with coarse gravelly sand (channel lag), fining upward to medium-grained sands, with fine-grained sands at the top The channel sand facies were deposited in meandering river belts and are flanked by the overbank sand facies The overbank sand facies consists of lenticular, laterally discontinuous sand beds composed of very fine- to fine-grained sand with an increased silt and clay-sized fraction.

On the basis of the cross section evaluation and previous investigations at RMA, the inferred lateral extent and subcrop pattern of the three sand units identified in the study area are illustrated in Figures 4 29 to 4 31 The A Sand is the uppermost sand unit encountered in the study area. It is laterally discontinuous and subcrops into the alluvium as illustrated in Figure 4.29 The 1U Sand underlies the A Sand and subcrops into the alluvium to the north of the A Sand in the north central portion of the study area. The 1U Sand (Figure 4 30) extends across most of the study area and subcrops in the northeast corner The 1 Sand unit probably represents a channel sand deposit that is oriented southwest to northeast. Thick sequences of sand (up to 50 feet in Figure 4.31) lie within the central portion of the study area and are flanked by thinner, overbank deposits

Hydrogeologic Results. A detailed hydrogeologic investigation of the hydrogeology at the preferred landfill location was not included in the scope of this investigation. For clarity, however, a brief overview of the hydrogeologic information known about the site is presented. The two groundwater flow systems of interest in the study area are the unconfined and confined flow system. In the western half of Section 25, the quaternary alluvium is primarily unsaturated which means that the flow in the unconfined flow system occurs within the weathered Denver Formation. Confined flow occurs in the unweathered Denver Formation. Figure 4 32 illustrates the water-table map and areas of unsaturated alluvium for the unconfined flow system generated under the GMP for water year 1993 (HLA, 1995b) In Section 25, since the unconfined flow system occurs primarily in the weathered bedrock, the groundwater flow direction is controlled primarily by the bedrock surface For example, as illustrated on the map (Figure 4.32), the areas of high groundwater elevation overlie areas where the bedrock surface is high.

Geotechnical Program Results

Geotechnical tests were preformed on samples collected during the shallow boring program (1) to evaluate the material at the proposed landfill site for use in the construction of the landfill, (2) to evaluate certain properties of the soil such as shear strength for engineering requirements such as slope stability (3) further characterize the site-specific geology This section presents the results of the following geotechnical properties tested

- Particle size analysis
- Atterberg limits
- Natural moisture content
- Compaction or Proctor tests
- Permeability

- Shear strength
- Organic content

Particle-Size Analyses and Atterberg Limits. Particle size analyses and Atterberg limits were performed on 335 soil samples Table 4 5 lists the results of the analyses. Of the 335 samples analyzed, 65 percent had greater than 50 percent of the sample pass through the No 200 sieve and are therefore classified as clay The remaining 35 percent of the samples were classified as follows 30 percent were clayey sand (SC), 3 percent were silty sand (SM), and the remaining 2 percent were classified as SP-SM, SW-SM, SC-SM, MH, and ML.

Additional classification of the fine-grained or clay samples was based on the plasticity chart As illustrated in Figure 4 33, the Atterberg limits indicate that 29 percent are classified as high plasticity clay (CH) and 36 percent classified as low plasticity clay (CL). The liquid limits ranged from 25 to 88 percent. The plasticity indices ranged from 5 to 75 percent.

Moisture Content. The natural moisture content was measured in 318 soil samples The results indicated the natural moisture content of the soil samples ranged from 2 to 33 percent. The average moisture content of the soil samples was 12 percent.

Compaction Tests. Compaction tests were conducted on 29 soil samples As listed in Table 4 6, the optimum moisture content ranged from 12 3 to 18 7 percent. The maximum dry densities ranged from 102 2 to 117.6 pcf.

Permeability Tests Fifty-eight permeability tests were conducted on 29 soil samples (two tests per soil sample) to evaluate the hydraulic conductivity of the compacted soil. The tests were conducted on samples compacted to 90 and 95 percent relative compaction at approximately 2 percent above optimum moisture content. Table 4.6 lists the results of the permeability tests The permeability of the compacted soil samples ranged from 1 58 x 10^{-5} to 1 11 x 10^{-8} cm/s

Shrinkage Limits and Swell Pressure Twenty-nine samples were analyzed for shrinkage limits and swell pressure and the results are listed in Table 4 6. The shrinkage limits ranged from 11 6 to 42.1 percent. The swell pressures ranged from 20 8 to 312 2 pounds per square foot (psf)

Organic Content. The organic content of 29 soil samples was measured, and Table 4 6 lists the results of the tests The organic content measured by weight of the sample ranged from 1.3 to 8 8 percent. In general, the samples with the highest organic content were collected from the surface to a depth of 4 feet. The increased organic content is primarily due to roots penetrating into this shallow zone.

Shear Strength. Shear strength tests were to be performed on samples collected in Shelby tubes from the 30 shallow borings. Shear strength tests were not performed on the samples because the samples could not be successfully extruded intact from the Shelby tubes due to the unconsolidated nature of the samples For information on shear strength of the alluvium at RMA, shear strength test results were presented in the Final FS Soils Support Program Report (HLA, 1995a) The tests were performed on soil samples collected from the proposed low permeability soil borrow areas in Sections 20, 23, 25, and 29

4.4.3 Geologic Investigation Summary

The results of the geologic and geotechnical investigation performed in the western half of Section 25 are summarized as follows The site-specific lithologic and stratigraphic relationships of the Quaternary alluvium and the Denver Formation were studied in detail through lithologic and geophysical logging techniques The site is underlain by approximately 5 to 60 feet of alluvium that unconformably overlies the Denver Formation. The alluvium consists primarily of clay, silt, and very fine- to medium-grained sand with minor amounts of coarse sand and gravel. The alluvium is unsaturated throughout most of the study area except in the northwest corner of Section 25 where it becomes saturated

In the study area, the Denver Formation consists of thick sequences of claystone, with interbedded sandstone (channel sand and overbank deposits) and lignite beds Stratigraphic correlation of the sand units within the Denver Formation was based on the vertical position of the sands in relation to lignite beds A and B that occur in the study area. Three sand units were identified in the study area as the A sand, 1U sand and 1 sand The sand units are up to 50 feet thick, and each sand unit subcrops into the alluvium within the study area as illustrated in the cross sections and subcrop maps (Figures 4 20 through 4.31) Two groundwater flow systems occur within the Denver Formation. the unconfined flow system that occurs within the upper weathered portion of the Denver Formation and the confined flow system that occurs within the primarily unweathered Denver Formation

The geotechnical test results indicate approximately 65 percent of the samples collected from the study area are classified as clay and 35 percent are clayey sands Permeability tests were performed on one compacted clay sample from each borehole Approximately half of the samples tested achieved vertical permeability values less than 1×10^{-7} cm/s Thus, approximately half of the boreholes in the study area have clay soil that could potentially be used in the construction of the landfill Further evaluation of the feasibility of using the onsite clay soil in construction of a hazardous waste landfill is presented in Section 5 0

4.5 Area Feasibility Study Conclusions

Conclusions of the Area FS are as follows

- Previous landfill siting studies conducted at RMA do not take into account current regulatory requirements for siting landfills in the State of Colorado.
- Seventeen siting criteria were adopted for use in locating a preferred area at RMA for a hazardous waste landfill The criteria are based on regulatory requirements, institutional requirements and concerns regarding future land use of RMA by the USFWS. The criteria adopted are presented in Table 4.3
- Using the siting criteria established in this report, a GIS analysis was performed to identify areas at RMA that meet the suitability criteria. Based on the GIS analysis, the western half of Section 25 was selected as the most suitable area for locating the landfill.

- Geologic and geotechnical results indicate the site is conducive to construction of the landfill with primarily clay and claystone underlying the site Sand units were mapped in the area. However, based on the size of the landfill required, the areas where the sand units subcrop into the alluvium may be avoided, if necessary, as described in the following section.

- Based on the results of this study, groundwater occurs primarily within the Denver Formation in both unconfined and confined flow systems A detailed hydrogeologic study should be conducted to evaluate groundwater flow velocities and vertical gradients between the two flow systems in the area

Table 4.1: Previous Rocky Mountain Arsenal Landfill Siting Criteria

Siting Criteria	Previous Landfill Siting Studies		
	WES, 1983	USATHAMA, 1984	EBASCO, 1988
Faults	Not addressed	>200 feet from a Holocene fault	>1000 feet from a Holocene fault
Floodplain	Outside 100 year floodplain	Outside 100 year floodplain	Outside 100 year floodplain
Salt formations	Not addressed	Not addressed	Not addressed
Surface water/groundwater	>40 feet to groundwater	>20 feet to groundwater	Maximize depth to groundwater, target >40 feet
Airport safety	Not addressed	Not addressed	Not addressed
Wetlands	Not addressed	Not addressed	Not addressed
Seismic impact zone	Not addressed	Not addressed	Not addressed
Unstable areas	Not addressed	Not addressed	Not addressed
Topography	Not addressed	Not addressed	Not addressed
Isolation	Not addressed	Not addressed	Not addressed
Hydrogeology	No saturated alluvium	Not addressed	No saturated alluvium
Geology	<30 feet to bedrock and no sand channels in the Denver Formation	Not addressed	Not addressed
Locations	Not addressed	Not addressed	Not addressed
Buffer zone	>1 mile from RMA boundary	Not addressed	>1000 feet from RMA boundary
Avoidance areas	Not addressed	Not addressed	Not within RMA avoidance areas or dedicated land use
Area required	Not addressed	Not addressed	>1000 acres initial target
Sensitive habitats	Not addressed	Not addressed	Not addressed

Ebasco Ebasco Services, Inc
USATHAMA U S Army Toxic and Hazardous Materials Agency
WES Roy F Weston Environmental Services

21907 703030
0103032495 RAF

Table 4.2 Boring Logs for Section 25

Well No	Bore No	Well No	Bore No.	Well No	Bore No
25002-25004	777	25040	LM-8 (2)	26073	804
25003	907	25041*	—	26074	804
25005-25006	824 (N-24)	25042*	—	26075	804
25007	827	25043*	—	26091	491
25008-25010	1186 (E5)	25044*	—	26097	640
25011-25014	1168 (E6)	25046*	—	26123	905
25015-25017	1195 (E9)	25047*	—	26143	825
25018-25020	1187 (E10)	25048	EP-29	26144	825
25021	1230 (AP3)	25048	EP-29A	26150	EP-49B2D3
25022	LM-2 (1)	25049*	—	26150	EP43
25023	LM-2 (3)	25050*	—	26155	EP-49B2D2
25024	LM-2 (2)	25051*	—	26159	—
25025	LM-3 (3)	25052*	—	26500	MK91261
25026	LM-3 (2)	25053*	—	36151	1229
25027	LM-4 (1)	25054*	—	—	787
25028	LM-4 (3)	25055*	—	—	156
25029	LM-4 (2)	25056*	—	—	826
25030	LM-5 (1)	25057	—	—	130
25031	LM-5 (2)	25058	—	—	L-5
25034	LM-6 (1)	25059	—	—	L-3
25035	LM-7 (1)	25060	25-1 P1	—	L-4
25036	LM-7 (3)	25061	25-1 P2	—	19
25037	LM-7 (2)	25062	25-1 EX	—	61
25038	LM-8 (1)	25500#	—	—	12
25039	LM-8 (3)	26056	644		

AP Basin F - South Plants borings
E Borings located in the east section of the arsenal (regional study)
EP Environmental Science and Engineering, Inc. borings
L Hazardous landfill borings sites
LM Hazardous landfill borings sites
N Borings located in the Basin A neck area (regional study)

* Ebasco borings
# Morrison-Knudsen Engineering (MKE) borings

Table 4.3: Current Rocky Mountain Arsenal Landfill Siting Criteria

Siting Criteria	Landfill Siting Criteria Regulations: Description	Landfill Siting Criteria Regulations: Citation	Regulatory Criteria Adopted IILA, 1994: Primary Siting Criteria Adopted	Regulatory Criteria Adopted IILA, 1994: Secondary Siting Criteria
Faults	>1000 feet from a Holocene fault >200 feet from a Holocene fault	6 CCR 1007 3, 264 18(a) 6 CCR 1007 2, 1 1 3	>1000 feet from a Holocene fault	
Floodplain	Outside 100 year floodplain Not located in "floodplain" as defined in regulation	6 CCR 1007 3, 264 18(b) 6 CCR 1007 2, 3 1 7	Outside 100 year floodplain	
Salt formations	Not within salt formations	6 CCR 1007 3, 264 18(c)	Not within salt formations	
Surface water/groundwater	No waste placed below or into surface water or groundwater No waste placed below or into surface water or groundwater	6 CCR 1007 3, 264 18(d) 6 CCR 1007 2, 3 1 9	No waste placed below or into surface water or groundwater	Maximize depth to groundwater
Airport safety	Notification if facility is within 5 miles of runway	6 CCR 1007 2, 3 1 1	Notification if facility is within 5 miles of runway	
Wetlands	Not located in wetlands	6 CCR 1007 2, 3 1 2	Not within wetland	
Seismic impact zone	Not located in seismic impact zone without demonstration	6 CCR 1007 2, 3 1 4	Not located in seismic impact zone without demonstration	
Unstable areas	Not within unstable area	6 CCR 1007 2, 3 1 5	Not within unstable area	
Topography	Maximize protection from wind and precipitation catchment area	6 CCR 1007 2, 3 1 6	Maximize protection from wind and precipitation catchment area	
Isolation	Isolate waste from public and environment	6 CCR 1007 2, 3 1 8 6 CCR 1007 2 4 1	Isolate waste from public and environment	
Hydrogeology	Reasonable assurance that waste isolated for 1000 years	6 CCR 1007 2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1000 years	Avoid saturated alluvium
Geology	Reasonable assurance that waste isolated for 1000 years	6 CCR 1007 2, Part 2, 2 5 3	Reasonable assurance that waste isolated for 1000 years	Minimize depth to bedrock

Table 4.3 (continued)

Siting Criteria	Landfill Siting Criteria Regulations: Description	Landfill Siting Criteria Regulations: Citation	Regulatory Criteria Adopted HLA, 1994: Primary Siting Criteria Adopted	Regulatory Criteria Adopted HLA, 1994: Secondary Siting Criteria
Location	Within distance controlled by Army to prevent adverse effects to public health	6 CCR 1007-2, Part 2, 2 5 6	Within distance controlled by Army to prevent adverse effects to public health	Centrally located within RMA boundary
Buffer Zone	Noise levels within limits	CRS Sections 25-12-101 to 108	Noise levels within limits	
Avoidance Areas	None	None	None	Avoid areas with future land use and areas of known groundwater or soil contamination
Area Required	None	None	None	To be evaluated
Sensitive Habitats	None	None	None	Avoid sensitive habits
Historic Preservation	Inventory, preserve or recover historical, prehistorical, or archaeological artifacts/data	NHPA, AHPA, ARPA	To be evaluated	Avoid prehistoric and historic areas

AHPA Archaelogical Historic Preservation Act
ARPA Archaeological Resources Protection Act, 1979
CCR Code of Colorado Regulations
CRS Colorado Revised Statute
HLA Harding Lawson Associates
NHPA National Historic Preservation Act, 1966
RMA Rocky Mountain Arsenal

Table 4.4 Depth to Bedrock and Groundwater Parameters Used During Geographic Information System Screening

Depth to Groundwater (feet)	Depth to Bedrock (feet)	Maximum Contiguous Acreage (acres)	Figure Number
30	10	12	NA
30	20	152	NA
30	30	301	NA
40	10	7	NA
40	20	142	NA
40	30	273	NA
40	40	371	4 12
50	10	6	NA
50	20	114	NA
50	30	217	4 15
50	40	299	4.16
60	10	4	NA
60	20	76	4.13
60	30	128	NA
60	40	138	4 14
70	10	1	4 11
70	20	13	NA
70	30	32	NA

NA Not applicable

Table 4.5: Particle Size, Atterberg Limits, and Moisture Content Results

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB11394	4 00	68 32	11 0	41	22	CL	Brown sandy lean clay
SAB11394	8 00	52 64	9 9	45	29	CL	Brown sandy lean clay
SAB11394	12 00	16 60	5 5	NA	NA	SM	Brown silty sand
SAB11394	16 00	17 41	5 6	NA	NA	SM	Brown silty sand
SAB11394	17 00	28 22	4 6	22	4	SC-SM	Brown silty clayey sand
WEB11494	4 00	18 02	10 0	41	23	CL	Brown sandy clay
WEB11494	8 00	62 32	10 1	41	24	CL	Brown sandy lean clay
WEB11494	12 00	50 90	8 9	31	13	CL	Brown sandy lean clay
WEB11494	16 00	69 50	14 1	42	24	CL	Brown sandy lean clay
WEB11494	20 00	59 46	14 5	44	26	CL	Brown sandy lean clay
WEB11494	24 00	35 92	10 7	40	24	SC	Brown clayey sand
WEB11494	28 00	23 23	10 0	39	23	SC	Brown clayey sand
WEB11494	29 60	27 65	7 4	58	36	SC	Brown clayey sand
WEB11494	30 50	80 17	13 8	66	41	CH	Brown fat clay with sand
WEB11494	31 00	98 11	21 7	72	47	CH	Brown fat clay
WEB11494	31 50	99 08	20 9	69	43	CH	Brown fat clay
WEB11494	32 50	92 87	21 9	75	50	CH	Brown fat clay
WEB11494	33 00	82 70	17 8	55	37	CH	Brown fat clay with sand
WEB11494	33 50	90 34	18 1	52	33	CH	Brown fat clay
WEB11494	33 70	79 82	19 1	56	37	CH	Brown fat clay with sand
ASB11594	4 00	69 20	11 3	40	22	CL	Brown sandy lean clay
ASB11594	8 00	14 57	9 0	43	26	CL	Light brown sandy clay
ASB11594	10 00	34 52	6 5	41	24	SC	Brown clayey sand
ASB11594	16 00	14 77	5 9	NA	NA	SM	Brown silty sand
ASB11594	20 00	18 44	4 8	28	9	SC	Brown clayey sand
ASB11594	24 00	31 65	3 8	28	10	SC	Brown clayey sand
ASB11594	27 00	16 96	4 5	30	11	SC	Brown clayey sand
ASB11694	4 00	58 39	7 3	42	24	CL	Brown sandy lean clay
ASB11694	8.00	22 63	3 8	40	17	SC	Brown clayey sand
ASB11694	12 00	14.20	3 6	NA	NA	SM	Brown silty sand
ASB11694	16 00	13 71	4 1	32	8	SM	Brown silty sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB11694	20 00	18 31	4 9	34	16	SC	Brown clayey sand
ASB11694	24 00	17 87	4 9	31	11	SC	Brown clayey sand
ASB11694	28 00	52 45	16 0	54	36	CH	Brown sandy fat clay
ASB11694	32 00	82 71	30 5	69	39	CH	Brown fat clay with sand
ASB11694	36 00	68 37	17 5	56	39	CH	Brown sandy fat clay
ASB11694	40 00	70 18	19 6	41	20	CL	Brown lean clay with sand
SAB11794	4 00	56 15	10 3	57	37	CH	Brown sandy fat clay
SAB11794	8 00	47 65	12 3	46	28	SC	Brown clayey sand
SAB11794	12 00	12 07	10 8	36	20	CL	Brown sandy clay
SAB11794	16 00	36 17	7 6	38	23	SC	Brown clayey sand
SAB11794	20 00	25 11	8 0	39	23	SC	Brown clayey sand with gravel
SAB11794	24 00	11 66	5 6	45	27	SP-SC	Brown sand with clay
SAB11794	35 00	32 06	4 6	31	14	SC	Brown clayey sand
SAB11794	40.00	36 38	6 8	31	15	SC	Brown clayey sand
ASB11894	4 00	83 11	10 4	44	23	CL	Brown lean clay with sand
ASB11894	8 00	61 15	9 4	43	24	CL	Brown sandy lean clay
ASB11894	12.00	53 50	12 8	51	31	CH	Brown sandy fat clay
ASB11894	16 00	58 61	17 7	57	31	CH	Brown sandy fat clay
ASB11894	20 00	71 76	17 6	49	31	CL	Brown lean clay with sand
ASB11894	24 00	84 52	18 0	48	31	CL	Brown lean clay with sand
ASB11894	28 00	33 05	6 2	39	17	SC	Brown clayey sand
ASB11894	32 00	37 89	5 5	45	29	SC	Brown clayey sand
ASB11994	4 00	56 46	8 2	41	22	CL	Brown sandy lean clay
ASB11994	8 00	58 37	7 7	42	24	CL	Brown sandy lean clay
ASB11994	12 00	36 32	4 0	38	20	SC	Brown clayey sand
ASB11994	16 00	23 01	3.7	37	18	SC	Brown clayey sand
ASB11994	20.00	20.18	4 1	40	21	SC	Brown clayey sand
ASB11994	24 00	21 40	4 2	39	21	SC	Brown clayey sand
ASB11994	28 00	19 16	4 8	35	17	SC	Brown clayey sand
ASB11994	32 00	19 93	3 8	29	10	SC	Brown clayey sand
ASB11994	36 00	25 14	4 7	32	15	SC	Brown clayey sand
ASB11994	40 00	25 78	4 2	30	14	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB11994	44 00	48 27	14 6	42	25	SC	Brown clayey sand
ASB11994	50 00	59 53	22 2	75	44	CH	Brown sandy fat clay
ASB12094	4 00	69 45	7 8	32	8	ML	Brown sandy silt
ASB12094	8 00	57 03	13 7	47	27	CL	Brown sandy lean clay
ASB12094	12 00	58 92	12 9	44	24	CL	Brown sandy lean clay
ASB12094	16 00	17 14	3 0	47	29	SC	Brown clayey sand with gravel
ASB12094	20 00	11 48	1 9	NA	NA	SP-SM	Brown sand with silt and gravel
ASB12094	24 00	8 25	1 6	NA	NA	SW-SM	Brown sand with silt and gravel
ASB12094	28 00	16 67	4 2	NA	NA	SM	Brown silty sand
ASB12094	32 00	28 67	4 2	39	20	SC	Brown clayey sand
ASB12094	36 00	26 48	4 2	41	24	SC	Brown clayey sand
ASB12094	40 00	23 15	4 0	42	24	SC	Brown clayey sand
ASB12094	44 00	22 04	4 3	37	17	SC	Brown clayey sand
ASB12094	48 00	26 23	5 3	40	22	SC	Brown clayey sand
SAB12194	4 00	74 40	10 4	39	19	CL	Brown lean clay with sand
SAB12194	8 00	56 05	7 8	39	24	CL	Brown sandy lean clay
SAB12194	16 00	44 92	6 9	27	10	SC	Brown clayey sand
SAB12194	20 00	67 65	9 5	44	27	CL	Brown sandy lean clay
SAB12194	24 00	88 86	14 0	53	35	CH	Brown fat clay
SAB12194	28 00	96 65	28 6	73	43	CH	Brown fat clay
SAB12194	32 00	88 64	24 9	75	52	CH	Brown fat clay
SAB12194	36 00	97 56	23 8	88	62	CH	Brown fat clay
SAB12194	40 00	90 00	16 3	66	48	CH	Brown fat clay
SAB12194	44 00	91 59	15 1	54	38	CH	Brown fat clay
SAB12194	48 00	49 15	9 0	46	28	SC	Brown clayey sand
SAB12294	4 00	71 08	10 0	38	17	CL	Brown lean clay with sand
SAB12294	8 00	63 47	11 2	44	26	CL	Brown sandy lean clay
SAB12294	12.00	52 59	11.6	48	31	CL	Brown sandy lean clay
SAB12294	16 00	69 08	12 7	46	30	CL	Brown sandy lean clay
SAB12294	20 00	53 15	8 6	44	28	CL	Brown sandy lean clay
SAB12294	24 00	29 36	4 0	37	20	SC	Brown clayey sand
SAB12294	28 00	11 75	2 5	63	42	SP-SC	Brown sand with clay and gravel

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB12294	32 00	41 21	8.4	47	27	SC	Brown clayey sand with gravel
SAB12294	36 00	93 55	22 0	50	35	CH	Brown fat clay
SAB12294	40 00	93 88	20 7	75	49	CII	Brown fat clay
SAB12294	44 00	94 71	20 3	72	53	CH	Brown fat clay
SAB12294	48 00	83 87	16 0	56	43	CH	Brown fat clay with sand
SAB12394	4 00	54 76	9 6	39	15	CL	Brown sandy lean clay
SAB12394	8.00	59 21	10 2	50	31	CII	Brown sandy fat clay
SAB12394	12.00	66 78	12 8	49	35	CL	Brown sandy lean clay
SAB12394	16 00	49 68	12 6	56	38	SC	Brown clayey sand
SAB12394	20 00	7 13	1 5	NA	NA	SW-SM	Brown sand with silt
SAB12394	24 00	56 97	22 9	78	47	CII	Brown sandy fat clay
SAB12394	28 00	63 60	21 3	60	34	CH	Brown sandy fat clay
SAB12394	32 00	74 74	14.1	56	41	CH	Brown fat clay with sand
SAB12394	36 00	86 08	16 3	64	47	CH	Brown fat clay
SAB12394	40 00	70 00	13 6	49	33	CL	Brown sandy lean clay
ASB12494	4 00	61 09	9 3	41	19	CL	Brown sandy lean clay
ASB12494	8 00	41 94	5 3	32	14	SC	Brown clayey sand
ASB12494	12 00	19.84	4 1	NA	NA	SM	Brown silty sand
ASB12494	16 00	21 82	3 0	NA	NA	SM	Brown silty sand
ASB12494	20 00	18 93	3 2	27	9	SC	Brown clayey sand
ASB12494	28 00	19 09	3 5	28	7	SC-SM	Brown silty clayey sand
ASB12494	32 00	19 55	3 2	36	18	SC	Brown clayey sand
ASB12494	36 00	17.65	3 4	51	25	SC	Brown clayey sand
ASB12494	40 00	19 92	3 4	40	21	SC	Brown clayey sand
ASB12494	44 00	81 52	17 7	61	43	CH	Brown fat clay with sand
ASB12494	48.00	91 64	17 4	65	46	CH	Brown fat clay
ASB12594	4.00	78 12	9 5	39	20	CL	Brown lean clay with sand
ASB12594	8 00	56 54	7.3	32	18	CL	Brown sandy lean clay
ASB12594	12.00	43 91	6 9	35	21	SC	Brown clayey sand
ASB12594	16.00	53 51	7 5	38	21	CL	Brown sandy lean clay
ASB12594	20 00	69 84	11 1	42	24	CL	Brown sandy lean clay
ASB12594	24.00	72.35	16 7	60	41	CII	Brown fat clay with sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB12594	28 00	77 22	17 7	76	56	CH	Brown fat clay with sand
ASB12594	32 00	83 93	18 0	94	75	CH	Brown fat clay with sand
ASB12594	36 00	86 79	13 7	59	42	CH	Brown fat clay
ASB12594	40 00	87 87	17 6	78	58	CH	Brown fat clay
ASB12594	44 00	93 76	22 8	88	65	CH	Brown fat clay
ASB12594	48 00	75 31	25 0	79	56	CH	Brown fat clay with sand
SAB12694	4 00	49 63	8 8	35	18	SC	Brown clayey sand
SAB12694	8 00	63 10	8 4	31	14	CL	Brown sandy lean clay
SAB12694	12 00	59 06	10 6	37	19	CL	Brown sandy lean clay
SAB12694	16 00	60 24	9 0	41	25	CL	Brown sandy lean clay
SAB12694	20 00	71 31	11 2	44	27	CL	Brown lean clay with sand
SAB12694	24.00	51 81	11 2	43	29	CL	Brown sandy lean clay
SAB12694	28 00	53 27	14 5	52	35	CH	Brown sandy fat clay
SAB12694	32 00	52 85	13 8	46	27	CL	Brown sandy lean clay
SAB12694	36 00	53 16	14 5	55	36	CH	Brown sandy fat clay
SAB12694	40 00	87 16	15 2	56	39	CH	Brown fat clay
ASB12794	4 00	66 62	9 4	33	13	CL	Brown sandy lean clay
ASB12794	8 00	50 78	9 0	33	14	CL	Brown sandy lean clay
ASB12794	12 00	63 06	12 1	43	22	CL	Brown sandy lean clay
ASB12794	16 00	88 10	20 6	71	46	CH	Brown fat clay
ASB12794	20 00	56 38	9 4	35	18	CL	Brown sandy lean clay
ASB12794	24 00	59 73	8 8	30	14	CL	Brown sandy lean clay
ASB12794	28 00	81 03	9 2	36	18	CL	Brown lean clay with sand
ASB12794	32 00	72 05	12 1	48	31	CL	Brown lean clay with sand
ASB12794	36 00	97 67	19 6	77	51	CH	Brown fat clay
ASB12794	40 00	88 65	11 3	48	31	CL	Brown lean clay
ASB12794	44 00	86 93	12 2	57	39	CH	Brown fat clay
ASB12794	48 00	86 71	19 4	88	67	CH	Brown fat clay
SAB12894	4 00	54 39	7 5	31	14	CL	Brown sandy lean clay
SAB12894	8 00	56 11	6 8	34	18	CL	Brown sandy lean clay
SAB12894	12 00	44 80	9 2	33	17	SC	Brown clayey sand
SAB12894	16 00	42 14	9 6	37	23	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB12894	20 00	57 44	12 0	37	22	CL	Brown sandy lean clay
SAB12894	24 00	51 40	11.9	36	20	CL	Brown sandy lean clay
SAB12894	28.00	51 36	12.4	35	19	CL	Brown sandy lean clay
SAB12894	32 00	64 28	14 7	39	25	CL	Brown sandy lean clay
SAB12894	36 50	89 41	20 8	50	31	CH	Brown fat clay
SAB12894	40 00	63 01	17 5	44	24	CL	Brown sandy lean clay
SAB12894	44 00	29 82	13.0	47	23	SC	Brown clayey sand
SAB12894	48 00	7 61	4 5	NA	NA	SP-SM	Brown sand with silt
BRB12994	4 00	49 45	8 3	34	16	SC	Brown clayey sand
BRB12994	8 00	52 67	11 5	32	16	CL	Brown sandy lean clay
BRB12994	12 00	37 67	13 0	51	30	SC	Brown clayey sand
BRB12994	16 00	39 73	9 1	41	26	SC	Brown clayey sand
BRB12994	20 00	62 02	9 2	37	22	CL	Brown sandy lean clay
BRB12994	24 00	47 16	10 0	44	20	SC	Brown clayey sand
BRB12994	28.00	24 88	5 6	41	24	SC	Brown clayey sand
BRB12994	32 00	32 03	4 2	27	9	SC	Brown clayey sand
BRB12994	36.00	50 76	10 3	45	31	CL	Brown sandy lean clay
BRB12994	40.00	77.48	18 7	46	25	CL	Brown lean clay with sand
BRB12994	44 00	49 90	19.5	28	8	SC	Brown clayey sand
BRB12994	48.00	54.29	26 3	48	30	CL	Brown sandy lean clay
BRB13094	4 00	28 19	5 6	26	5	SC-SM	Brown silty clayey sand
BRB13094	8.00	58.72	7.4	33	14	CL	Brown sandy lean clay
BRB13094	12.00	36 96	6 2	41	23	SC	Brown clayey sand
BRB13094	16 00	44 23	11.0	48	25	SC	Brown clayey sand
BRB13094	20 00	39 83	9 7	48	30	SC	Brown clayey sand
BRB13094	24 00	53 29	11 2	42	27	CL	Brown sandy lean clay
BRB13094	28.00	81.28	10 4	50	34	CH	Brown fat clay with sand
BRB13094	32.00	62 33	12.3	50	33	CH	Brown sandy fat clay
BRB13094	36 00	64.80	11 1	53	37	CH	Brown sandy fat clay
BRB13094	40 00	87.48	20 7	71	48	CH	Brown fat clay
BRB13094	44 00	88 09	11 9	55	38	CH	Brown fat clay
SAB13194	4 00	48 53	8 6	34	15	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
SAB13194	8 00	76 01	7 8	34	14	CL	Brown lean clay with sand
SAB13194	12 00	59 01	6 2	27	11	CL	Brown sandy lean clay
SAB13194	16 00	62 24	8 7	38	21	CL	Brown sandy lean clay
SAB13194	20 00	64 77	9 4	41	21	CL	Brown sandy lean clay
SAB13194	24 00	68 10	9 8	38	19	CL	Brown sandy lean clay
SAB13194	28 00	63 11	10 4	42	22	CL	Brown sandy lean clay
SAB13194	30 00	54 85	8 3	40	21	CL	Brown sandy lean clay
SAB13194	36 00	57 69	9 9	44	25	CL	Brown sandy lean clay
SAB13194	37 00	97 11	15 7	50	32	CH	Brown fat clay
SAB13194	40 00	77 73	16 5	68	46	CH	Brown fat clay with sand
SAB13194	44 00	84 72	17 6	77	56	CH	Brown fat clay with sand
SAB13194	48 00	85 98	14 2	64	47	CH	Brown fat clay
ASB13294	4 00	54 09	8 6	33	15	CL	Brown sandy lean clay
ASB13294	8 00	60 12	9 1	34	12	CL	Brown sandy lean clay
ASB13294	12 00	48 56	9 9	48	28	SC	Brown clayey sand
ASB13294	16 00	56 18	7 1	38	23	CL	Brown sandy lean clay
ASB13294	20 00	39 92	8 1	53	36	SC	Brown clayey sand with gravel
ASB13294	24 00	46 20	10 6	59	37	SC	Brown clayey sand with gravel
ASB13294	28 00	80 19	15 3	45	29	CL	Brown lean clay with sand
ASB13294	32 00	69 63	17 4	62	42	CH	Brown sandy fat clay
ASB13294	36 00	84 74	19 1	75	52	CH	Brown fat clay with sand
ASB13294	40 00	68 88	13 3	51	32	CH	Brown sandy fat clay
ASB13294	44 00	73 58	14 0	54	36	CH	Brown fat clay with sand
ASB13294	48 00	84 87	17 6	76	51	CH	Brown fat clay with sand
ASB13394	4 00	65 36	8 7	32	16	CL	Brown sandy lean clay
ASB13394	8.00	58 14	7 8	33	17	CL	Brown sandy lean clay
ASB13394	12 00	50 01	6 9	28	13	CL	Brown sandy lean clay
ASB13394	16 00	50 50	8 2	33	19	CL	Brown sandy lean clay
ASB13394	20 00	35 23	4 6	30	15	SC	Brown clayey sand with gravel
ASB13394	24 00	64 61	6 8	41	25	CL	Brown sandy lean clay
ASB13394	28 00	58 54	7 0	38	23	CL	Brown sandy lean clay
ASB13394	32 00	41 11	8 0	53	37	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
ASB13394	36 00	61 52	11 1	58	41	CH	Brown sandy fat clay
ASB13394	40 00	79 07	15 2	55	36	CH	Brown fat clay with sand
ASB13394	44 00	78 99	15 8	55	34	CH	Brown fat clay with sand
ASB13394	48 00	93 00	19 6	40	19	CL	Brown lean clay
BRB13494	4 00	63 11	6 7	30	9	CL	Brown sandy lean clay
BRB13494	8 00	61 48	6 9	31	12	CL	Brown sandy lean clay
BRB13494	12 00	37 61	6 3	34	17	SC	Brown clayey sand
BRB13494	16 00	31 31	5 8	33	17	SC	Brown clayey sand
BRB13494	20 00	39 79	9 3	32	14	SC	Brown clayey sand
BRB13494	24 00	51 87	11 8	34	15	CL	Brown sandy lean clay
BRB13494	28.00	41 86	11 0	32	14	SC	Brown clayey sand
BRB13494	32 00	38.17	10 4	35	17	SC	Brown clayey sand
BRB13494	36 00	46 35	13 8	30	10	SC	Brown clayey sand
BRB13494	40 00	52 76	14 6	38	20	CL	Brown sandy lean clay
BRB13494	44 00	83 25	19 8	49	29	CL	Brown lean clay with sand
BRB13494	48.00	80 72	22 2	49	28	CL	Brown lean clay with sand
BRB13494	50.00	68 87	26 2	47	26	CL	Brown sandy lean clay
BRB13594	4 00	34.83	6 0	36	17	SC	Brown clayey sand
BRB13594	8 00	50.01	5 8	28	12	CL	Brown sandy lean clay
BRB13594	12 00	50.95	7 3	35	16	CL	Brown sandy lean clay
BRB13594	16.00	51 14	7 4	37	20	CL	Brown sandy lean clay
BRB13594	20 00	48 06	8 1	43	25	SC	Brown clayey sand
BRB13594	24 00	54 00	9 4	48	31	CL	Brown sandy lean clay
BRB13594	28 00	59 96	8 3	39	20	CL	Brown sandy lean clay
BRB13594	32 00	59 79	12 1	54	31	CH	Brown sandy fat clay
BRB13594	36.00	61.48	NA	NA	NA	CH	Brown sandy fat clay
BRB13594	40 00	19 87	7 2	46	24	SC	Brown clayey sand
BRB13594	42 00	34 77	14 0	48	30	SC	Brown clayey sand
BRB13694	4 00	32 90	5 1	48	30	SC	Brown clayey sand
BRB13694	8 00	52.38	5 7	32	16	CL	Brown sandy lean clay
BRB13694	12 00	67 27	6 9	32	15	CL	Brown sandy lean clay
BRB13694	16 00	65.17	8 3	39	23	CL	Brown sandy lean clay

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
BRB13694	20 00	51 51	10 2	41	26	CL	Brown sandy lean clay
BRB13694	24 00	53 20	9 1	33	20	CL	Brown sandy lean clay
BRB13694	28 00	65 67	9 1	43	28	CL	Brown sandy lean clay
BRB13694	32 00	91 81	12 3	44	24	CL	Brown lean clay
BRB13694	36 00	86 98	16 9	58	37	CH	Brown fat clay
BRB13694	40 00	98 44	18 3	68	46	CH	Brown fat clay
BRB13694	44 00	96 86	19 6	69	47	CH	Brown fat clay
BRB13694	48 00	97 48	20 8	77	56	CH	Brown fat clay
BRB13794	4 00	41 85	6 8	30	11	SC	Brown clayey sand
BRB13794	8 00	51 82	5 3	31	15	CL	Brown sandy lean clay
BRB13794	12 00	51 90	6 7	30	14	CL	Brown sandy lean clay
BRB13794	16 00	47 29	9 2	39	22	SC	Brown clayey sand
BRB13794	20 00	49 33	8 9	40	20	SC	Brown clayey sand
BRB13794	24 00	63 14	12 6	48	28	CL	Brown sandy lean clay
BRB13794	28 00	96 02	20 7	82	55	CH	Brown fat clay
BRB13794	32 00	86 34	20 0	77	52	CH	Brown fat clay
BRB13794	36 00	94 42	15 3	61	41	CH	Brown fat clay
BRB13794	40 00	97 38	8 2	58	38	CH	Brown fat clay
BRB13794	44 00	95 12	13 7	59	42	CH	Brown fat clay
BRB13794	48 00	96 57	14 9	58	38	CH	Brown fat clay
BRB13894	4 00	52 81	8 7	34	15	CL	Brown sandy lean clay
BRB13894	8 00	66 23	6 9	31	11	CL	Brown sandy lean clay
BRB13894	12 00	40 29	7 0	33	16	SC	Brown clayey sand
BRB13894	16 00	44 22	6 9	36	18	SC	Brown clayey sand
BRB13894	20 00	46 64	7 4	30	11	SC	Brown clayey sand
BRB13894	24 00	39 71	7 2	33	16	SC	Brown clayey sand
BRB13894	28 00	53 46	11 2	37	21	CL	Brown sandy lean clay
BRB13894	32 00	52 54	10 9	41	26	CL	Brown sandy lean clay
BRB13894	36 00	93 72	21 6	53	31	CH	Brown fat clay
BRB13894	40 00	77 81	21 3	50	30	CH	Brown fat clay with sand
BRB13894	44 00	17 41	7 4	41	22	SC	Brown clayey sand
BRB13894	48 00	24 39	10 2	46	27	SC	Brown clayey sand

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No. 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
WEB13994	4 00	24 77	4 3	30	12	SC	Brown clayey sand
WEB13994	8 00	22 38	3 8	NA	NA	SM	Brown silty sand
WEB13994	12.00	40 83	4 8	25	8	SC	Brown clayey sand
WEB13994	16 00	49 93	10 2	38	20	SC	Brown clayey sand
WEB13994	20 00	58 84	10 9	36	17	CL	Brown sandy lean clay
WEB13994	24 00	63 51	12 6	39	22	CL	Brown sandy lean clay
WEB13994	28.00	64 98	15 2	37	20	CL	Brown sandy lean clay
WEB13994	32 00	36 79	12 0	40	19	SC	Brown clayey sand with gravel
WEB13994	36 00	89 95	15 9	50	28	CH	Brown fat clay
WEB13994	40 00	93 77	19 4	57	38	CH	Brown fat clay
WEB13994	44.00	96.96	17 8	57	39	CH	Brown fat clay
WEB13994	48 00	91 88	18.0	54	36	CH	Brown fat clay
BRB14094	4 00	27 95	5 7	33	17	SC	Brown clayey sand
BRB14094	8 00	23 17	4 0	29	14	SC	Brown clayey sand
BRB14094	12 00	40 84	9 8	35	15	SC	Brown clayey sand
BRB14094	16 00	32 10	5 6	29	20	SC	Brown clayey sand
BRB14094	20 00	60 96	30 1	69	29	MH	Brown sandy elas silt
BRB14094	22.00	37.72	27 1	61	27	SM	Brown silty sand
BRB14094	24 00	78 68	29 5	82	53	CH	Brown fat clay with sand
BRB14094	28 00	86 52	31 9	95	61	CH	Brown fat clay
BRB14094	32 00	85 88	32 9	101	71	CH	Brown fat clay
BRB14094	36 00	81 14	31.7	100	69	CH	Brown fat clay with sand
BRB14094	40 00	81 05	21 1	77	55	CH	Brown fat clay with sand
BRB14094	44 00	75 23	20 5	64	44	CH	Brown fat clay with sand
BRB14094	48 00	79 45	20.3	78	55	CH	Brown fat clay with sand
BRB14194	4.00	41.33	5 5	30	9	SC	Brown clayey sand
BRB14194	8.00	46 13	5 4	30	11	SC	Brown clayey sand
BRB14194	12.00	62.50	9 0	31	13	CL	Brown sandy lean clay
BRB14194	16 00	47 40	7 9	37	20	SC	Brown clayey sand
BRB14194	20 00	44.35	6 7	32	14	SC	Brown clayey sand
BRB14194	24 00	45 45	7 2	35	19	SC	Brown clayey sand
BRB14194	28 00	67 00	21 9	61	31	CH	Brown sandy fat clay

Table 4.5 (continued)

Boring Number	Sample Depth (feet)	Percent Passed No 200* (%)	Moisture Content# (%)	Liquid Limit# (%)	Plasticity Index# (%)	USCS*	USCS Description*
BRB14194	32 00	59 70	17 2	60	40	CH	Brown sandy fat clay
BRB14194	36 00	63 68	15 2	59	45	CH	Brown sandy fat clay
BRB14194	40 00	56 80	17 3	37	21	CL	Brown sandy lean clay
BRB14194	44 00	82 54	18 2	59	41	CH	Brown fat clay with sand
BRB14194	48 00	71 19	17 3	51	35	CH	Brown fat clay with sand
BRB14294	4 00	49 89	6 7	35	17	SC	Brown clayey sand
BRB14294	8 00	56 66	8 5	37	20	CL	Brown sandy lean clay
BRB14294	12 00	70 74	10 7	55	28	CH	Brown fat clay with sand
BRB14294	16 00	67 27	11 1	36	20	CL	Brown sandy lean clay
BRB14294	20 00	53 04	11 1	41	23	CL	Brown sandy lean clay
BRB14294	24 00	56 02	13 7	48	28	CL	Brown sandy lean clay
BRB14294	27 50	74 97	18 1	49	23	CL	Brown lean clay with sand
BRB14294	32 00	58 63	16 9	48	22	CL	Brown sandy lean clay
BRB14294	36 00	53 83	17 9	51	29	CH	Brown sandy fat clay
BRB14294	40 00	48 86	18 4	52	27	SC	Brown clayey sand
BRB14294	44 00	38 40	13 8	40	20	SC	Brown clayey sand
BRB14294	48 00	48 90	18 3	40	21	SC	Brown clayey sand
BRB14294	50 00	46 64	27 3	55	31	SC	Brown clayey sand

% Percent
ASTM American Society for Testing and Materials
NA Not analyzed
USCS Unified Soil Classification System

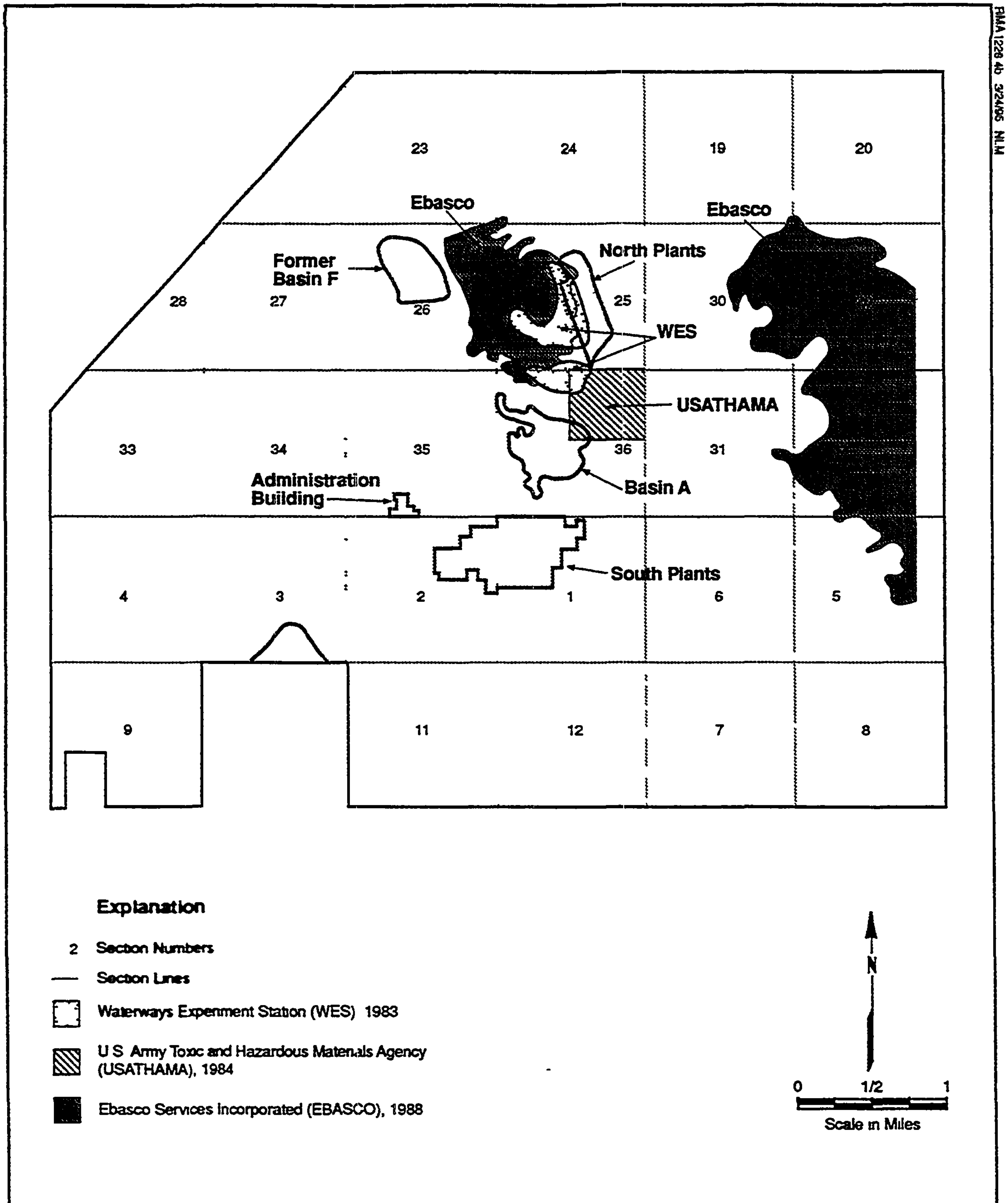
* ASTM D 422
\# ASTM D 4318

Table 4.6: Compaction, Permeability, Shrink, and Swell Results

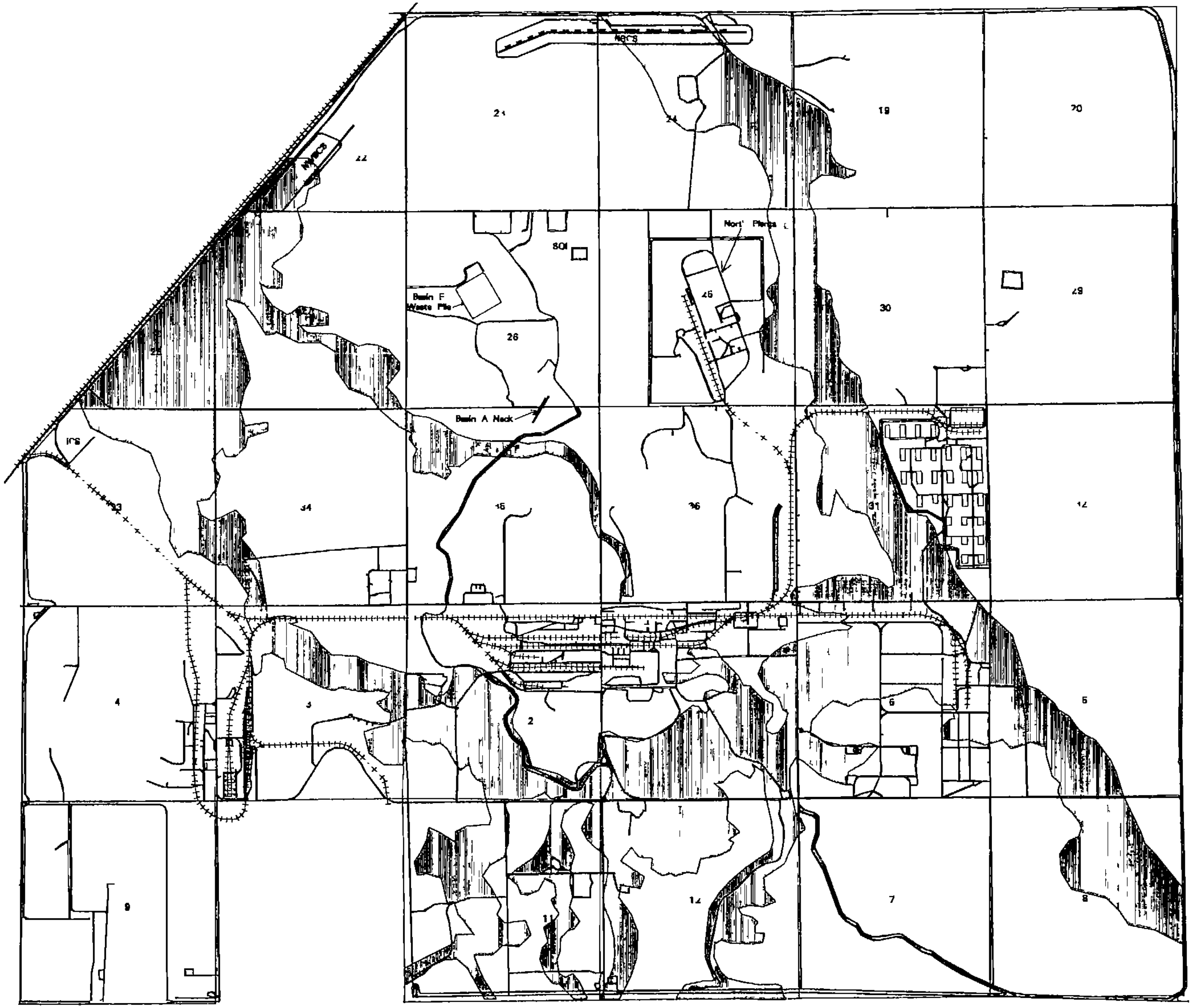
Boring Number	Sample Depth (feet)	Optimum Moisture Content[a] (%)	Maximum Dry Density[b] (pcf)	Permeability at 90 percent[c] (cm/s)	Permeability at 95 percent[c] (cm/s)	Shrinkage[d] (%)	Swell Pressure[e] (psf)	Organic Content[f] (%)
WEB11494	4 00	18 4	102 2	1 31 x 10^{6}	1 54 x 10^{6}	14 4	35 3	3 4
ASB11594	8 00	15 0	109 7	2 14 x 10^{7}	5 42 x 10^{7}	42 0	67 5	2 2
ASB11694	4 00	17 1	105 8	5 11 x 10^{7}	7 81 x 10^{7}	13 6	35 8	3 3
SAB11794	12 00	12 5	117 4	1 66 x 10^{7}	7 92 x 10^{8}	42 1	117 4	1 3
ASB11894	8 00	14 0	112 4	6 29 x 10^{8}	3 58 x 10^{8}	12 9	26 2	2 5
ASB11994	8 00	15 2	109 6	7 20 x 10^{8}	1 11 x 10^{8}	16 3	41 2	1 6
ASB12094	8 00	15 1	111 3	2 54 x 10^{8}	1 10 x 10^{7}	12 8	40 6	1 8
SAB12194	8 00	15 3	111 8	8 37 x 10^{8}	4 47 x 10^{-8}	13 2	43 1	1 9
SAB12294	20 00	17 0	110 2	5 28 x 10^{7}	3 03 x 10^{7}	11 6	88 1	1 6
SAB12394	8 00	18 7	104 0	1 76 x 10^{6}	1 38 x 10^{8}	14 2	79 4	2 0
ASB12494	4 00	17 8	105 9	2 80 x 10^{6}	1 67 x 10^{8}	14 5	50 2	2 2
ASB12594	8 00	14 4	114 7	1 08 x 10^{7}	7 64 x 10^{8}	14 8	113 8	1 9
SAB12694	16 00	15 3	113 9	6 77 x 10^{-6}	5 00 x 10^{6}	13 7	136 2	1 7
ASB12794	4 00	15 5	111 8	3 70 x 10^{-8}	1 54 x 10^{8}	14 8	27 8	2 9
SAB12894	16 00	14 1	115 1	5 47 x 10^{8}	2 61 x 10^{8}	13 0	30 7	1 6
BRB12994	4 00	13 5	115 8	6 09 x 10^{6}	8.16 x 10^{6}	14 2	50 5	1 9
BRB13094	24 00	16 4	113 2	1 70 x 10^{7}	1 34 x 10^{7}	41 8	23 1	1 8
SAB13194	12 00	14 2	114 7	1 98 x 10^{5}	2 39 x 10^{5}	13 2	38 3	1 3
ASB13294	8 00	15 8	110 5	3 89 x 10^{7}	4 96 x 10^{7}	14 6	161 6	1 5
ASB13394	4 00	15.3	110 2	7 18 x 10^{8}	4 01 x 10^{8}	18 4	27 8	2 2
BRB13494	4 00	17 2	103 9	3 66 x 10^{8}	2 08 x 10^{8}	23 3	35 7	4 5
BRB13594	12 00	14 2	114 9	1 43 x 10^{7}	1 16 x 10^{7}	16 6	63 5	1 4
BRB13694	16 00	15 1	111 0	4 74 x 10^{8}	2 55 x 10^{8}	12 4	56 2	1 9
BRB13794	8 00	12 3	117 6	8 05 x 10^{8}	2 30 x 10^{8}	15 1	46 7	1 3
BRB13894	12 00	14 6	112 7	8 24 x 10^{-8}	3 96 x 10^{-8}	17 1	29 3	1 5
WEB13994	20 00	16 0	110 7	5 46 x 10^{8}	4 51 x 10^{-8}	13 5	312 1	1 9
BRB14094	16 00	13 2	115 7	1 17 x 10^{7}	8 02 x 10^{-8}	13 0	27 8	1 3
BRB14194	4 00	13 8	114 2	4 42 x 10^{-8}	3 42 x 10^{8}	15 2	58 8	8 8
BRB14294	20 00	17 6	106 1	2 73 x 10^{8}	1 38 x 10^{-8}	15 8	20 8	2 0

%	Percent
ASTM	American Society for Testing and Materials
pcf	Pounds per cubic foot
cm/s	Centimeters per second
psf	Pounds per square foot

a	ASTM D 2216
b	ASTM D 698
c	EM 1110-2-19096
d	ASTM D 427
e	ASTM D 4546
f	ASTM D 2974



Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	Figure 4 1 Proposed Landfill Locations from Previous Landfill Siting Studies



Explanation

100-Year Floodplain

Road

Railroad

Section line

12 Section number

NBCS North Boundary Containment System

NWBCS Northwest Boundary Containment System

ICS Irondale Containment System

SQI Submerged Quench Incinerator

1000 0 2000 4000 FEET

Scale 1 36 000
One inch represents 3 000 feet

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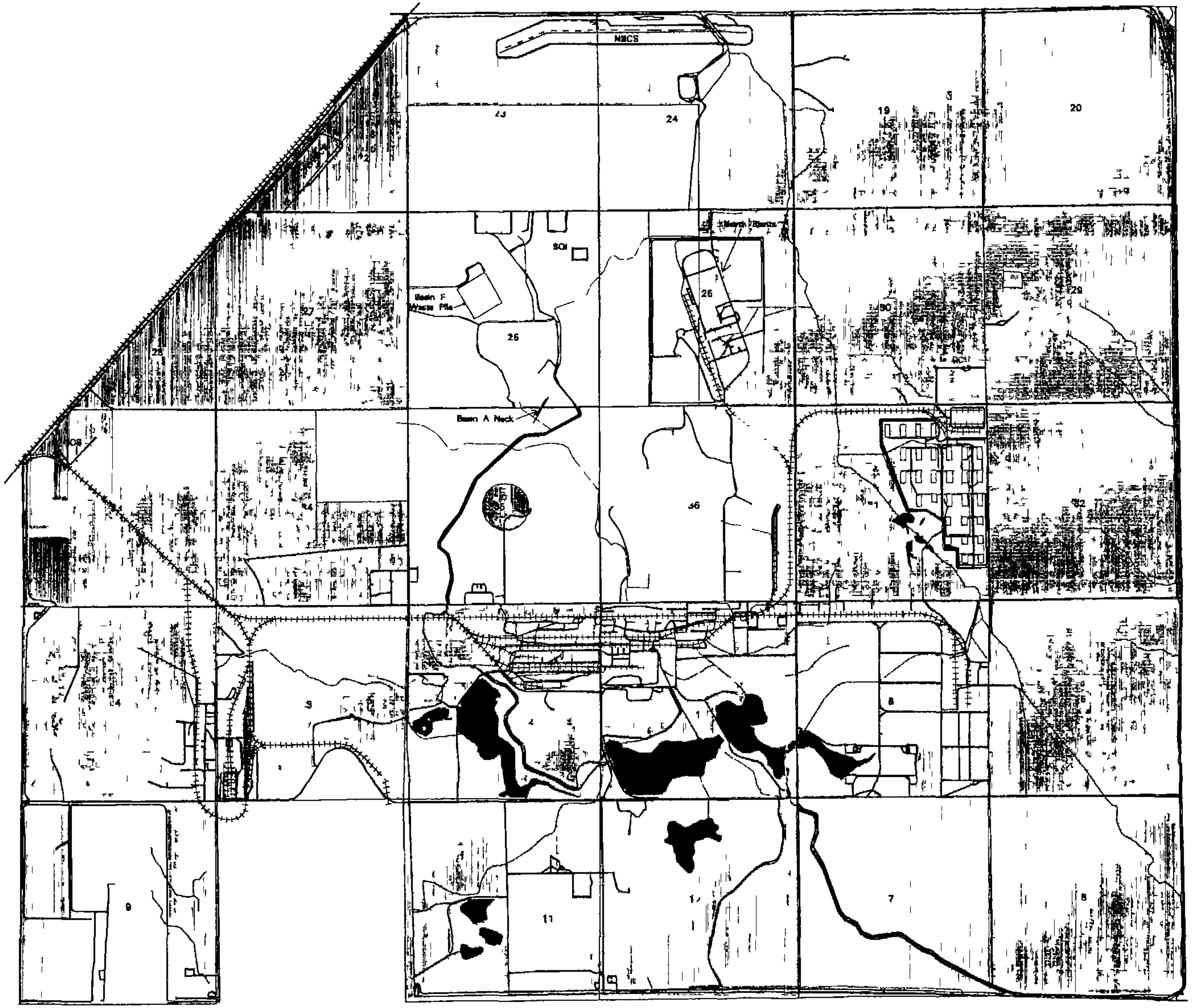
Prepared by
Harding Lawson Associates

Figure 4 2

100-Year Floodplain Map

(U.S. Army Corps of Engineers, 1983)



Explanation

- United States Fish and Wildlife Service (USFWS) approved landfill sites
- Surface Water
- Stream
- Road
- Railroad
- Section line
- 12 Section number
- NBCS North Boundary Containment System
- NWBCS Northwest Boundary Containment System
- ICS Irondale Containment System
- SQI Submerged Quench Incinerator

1000 0 2000 4000 FEET

Scale 1 36 000
One inch represents 3 000 feet

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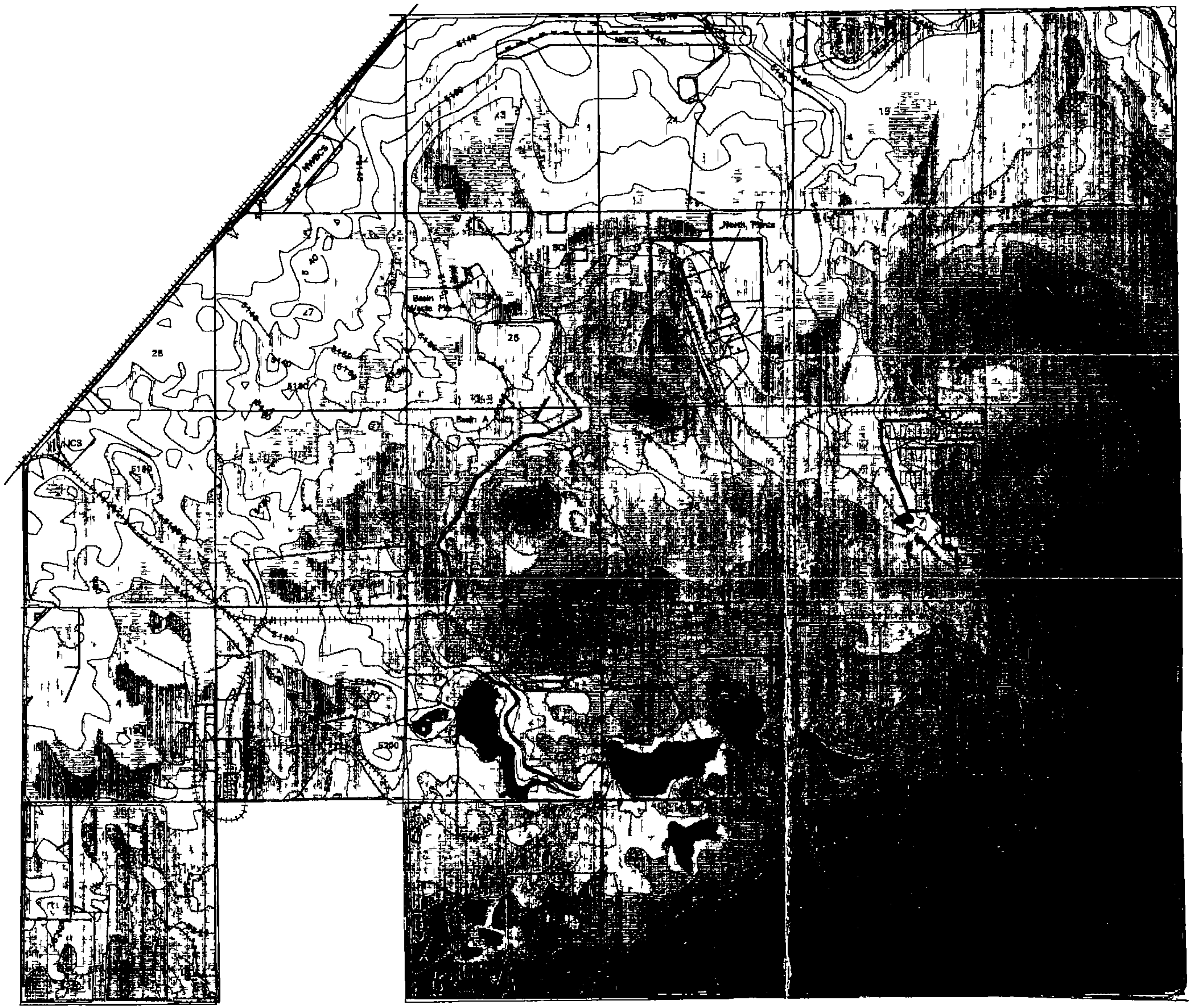
Figure 4 3

United States Fish and Wildlife Service Approved Hazardous Waste Landfill Sites (USFWS 1994)



Explanation

5110 feet

5340 feet

10-foot contour interval

Surface Water

Stream

Road

Railroad

Section line

12 Section number

NBCS North Boundary Containment System

NWBCS Northwest Boundary Containment System

ICS Irondale Containment System

SQI Submerged Quench Incinerator

PMRMA Program Manager Rocky Mountain Arsenal

1000 0 2000 4000 FEET

Scale 1 36 000

One inch represents 3,000 feet

Prepared for
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Prepared by
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Figure 4 4

Onpost Topographic Elevation Contour Map

(PMRMA, 1988)

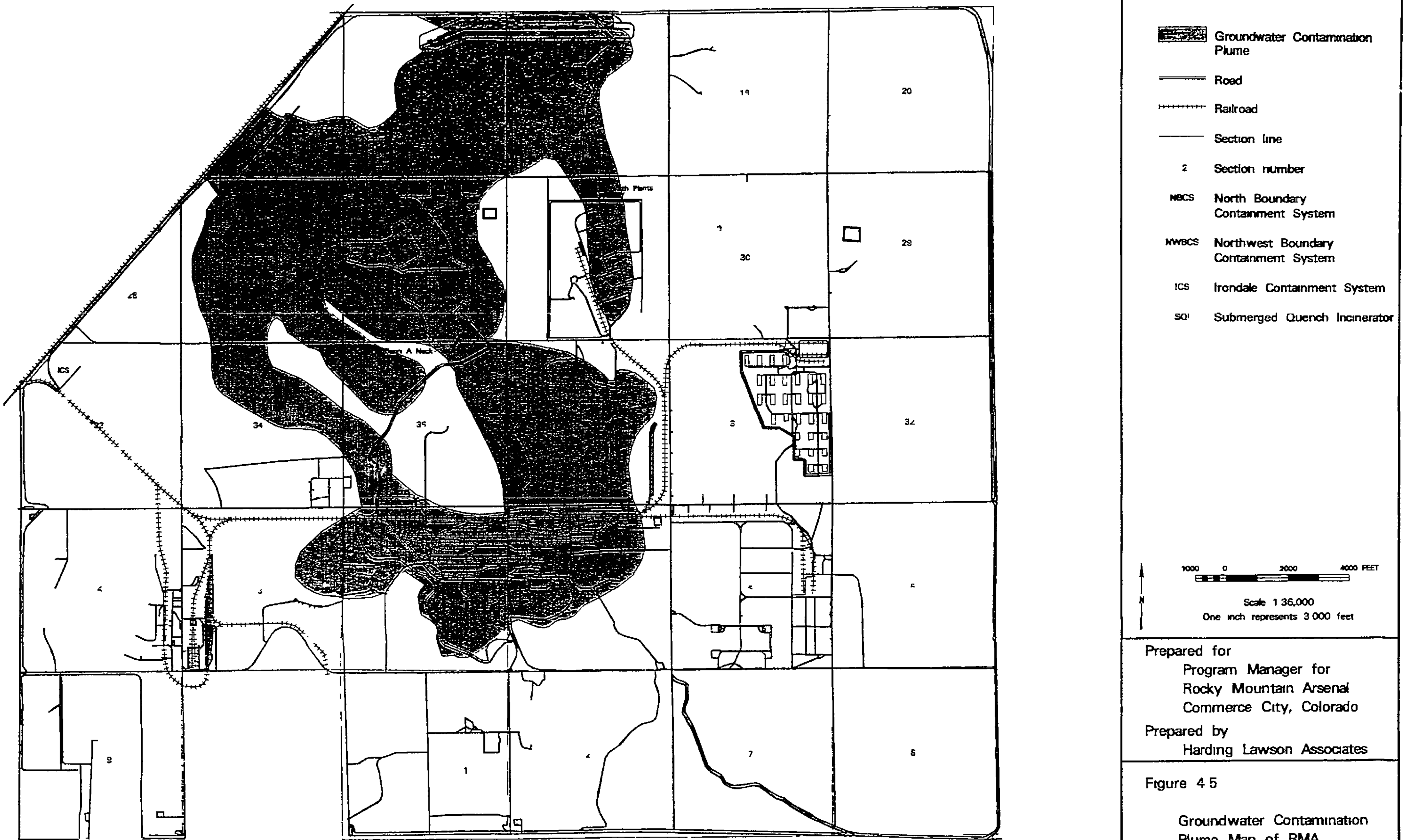

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Figure 4 5

Groundwater Contamination Plume Map of RMA

(EBASCO, 1994)

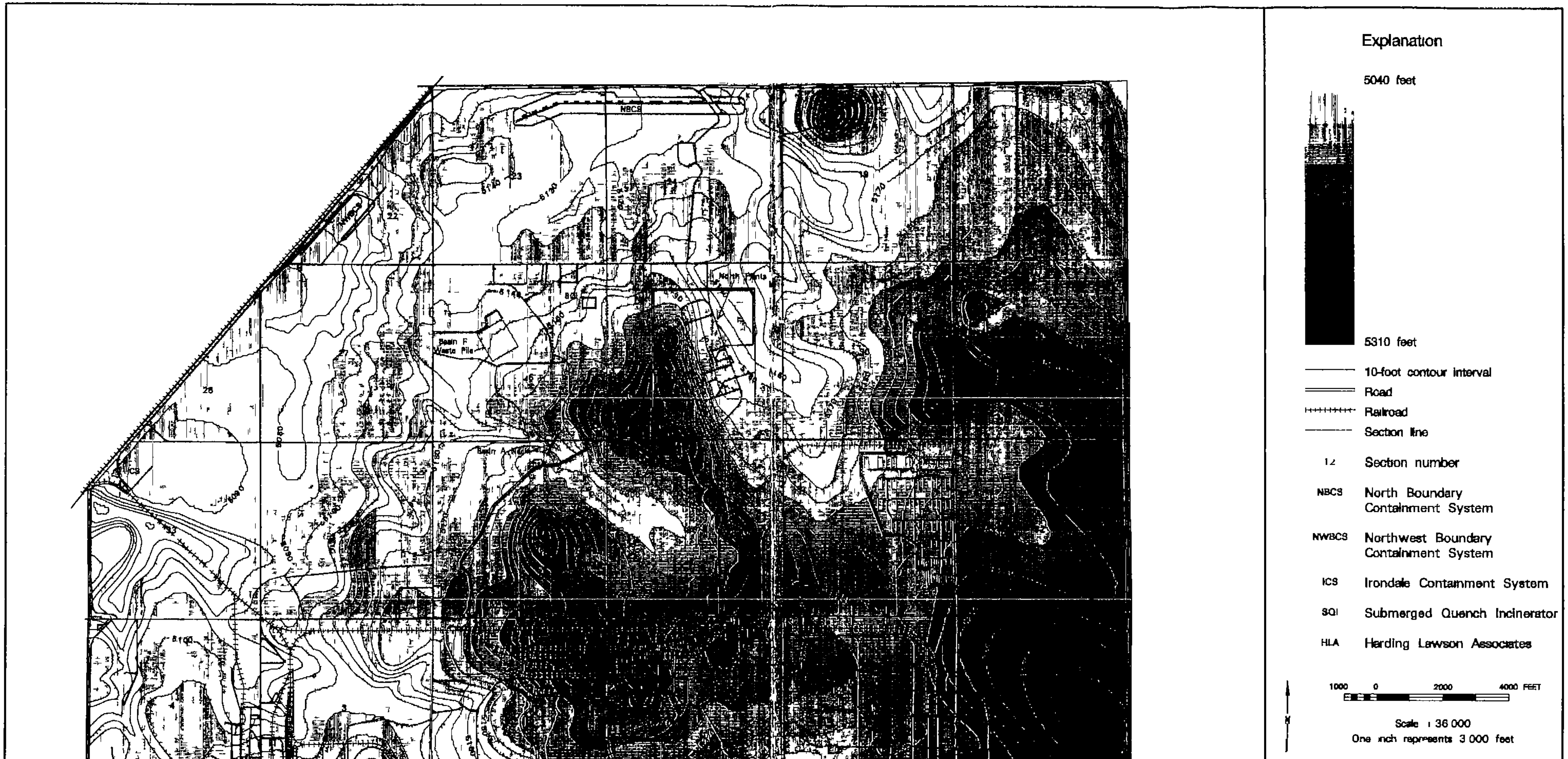

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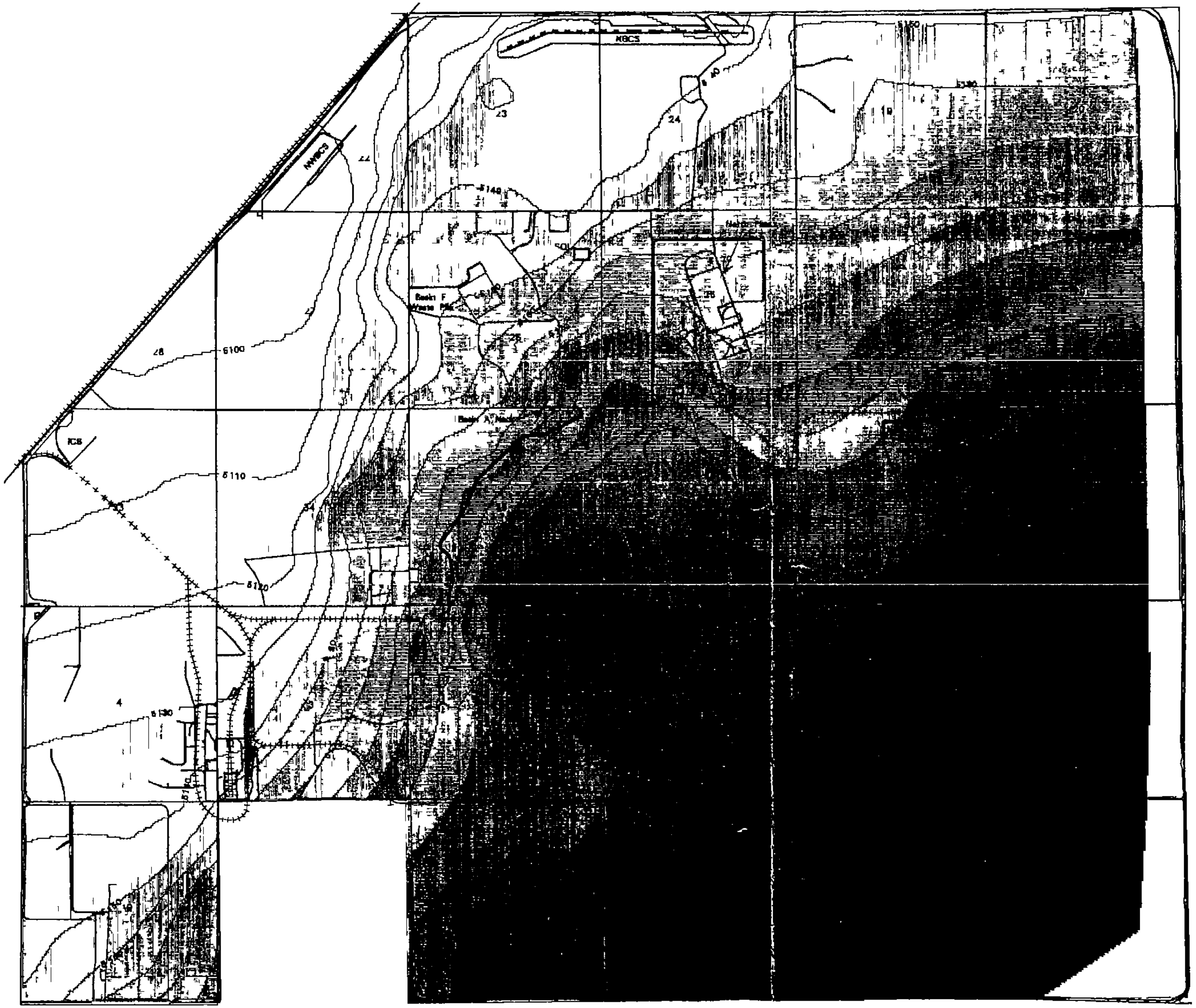
Figure 4 7

Onpost Bedrock
Elevation Contour Map
(HLA, 1992)



Explanation

5090 feet

5300 feet

10-foot contour interval

Road

Railroad

Section line

12 Section number

NBCS North Boundary Containment System

NWBCS Northwest Boundary Containment System

ICS Irondale Containment System

SQI Submerged Quench Incinerator

HLA Harding Lawson Associates

Scale 1 36,000

One inch represents 3,000 feet

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Figure 4 8

Onpost Winter 1991 Water-level Elevation Contour Map (HLA, 1992)

Explanation

0 feet

90 feet

10-foot contour interval

Road

Railroad

Section line

12 Section number

NBCS North Boundary Containment System

NWBCS Northwest Boundary Containment System

ICS Irondale Containment System

SQI Submerged Quench Incinerator

1000 0 2000 4000 FEET

Scale 1 36 000
One inch represents 3 000 feet

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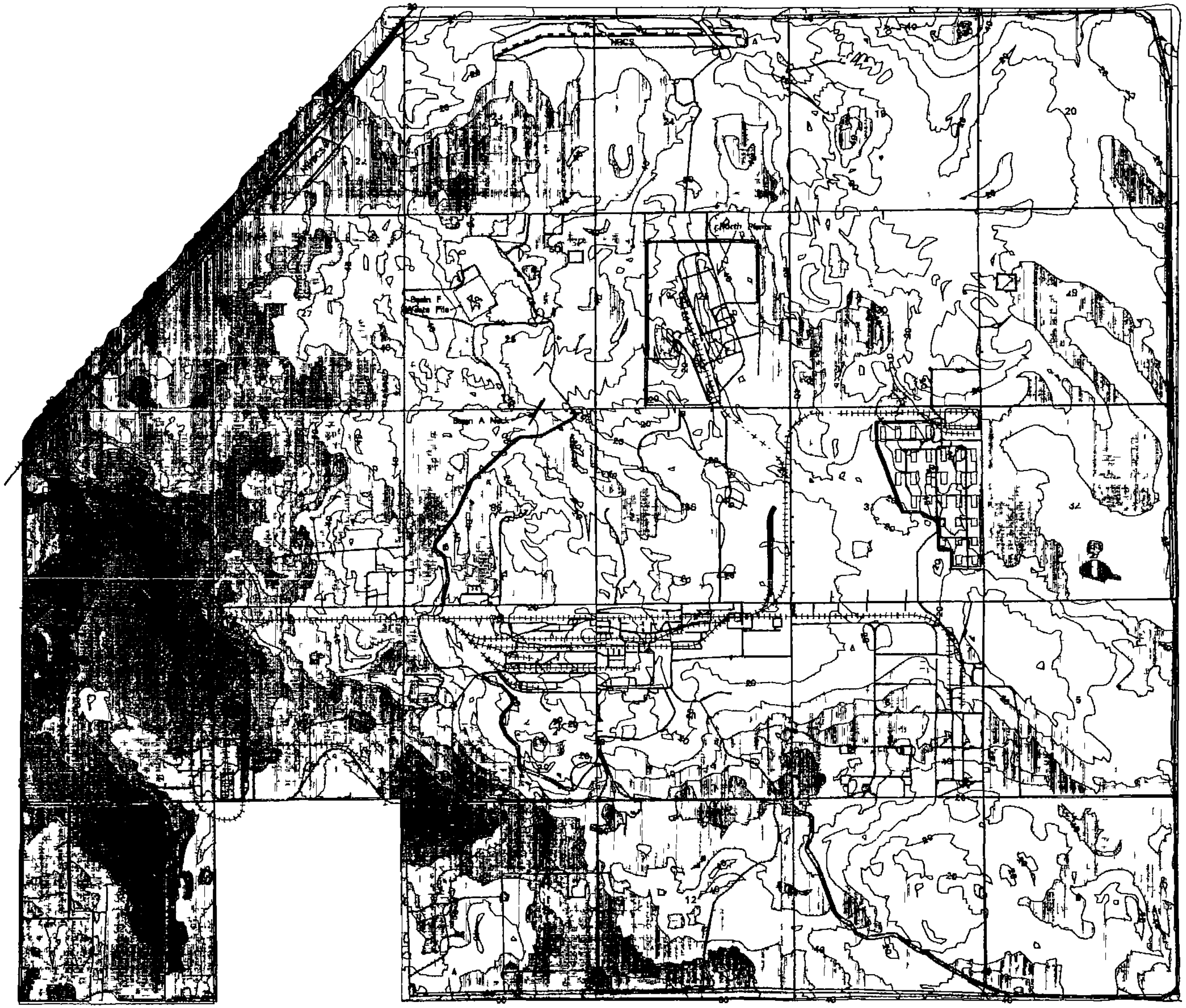
Figure 4 9

Onpost Approximate Depth to Groundwater Contour Map



Explanation

0 feet

140 feet

10-foot contour interval

Road

Railroad

Section line

12 Section number

NBCS North Boundary Containment System

NWBCS Northwest Boundary Containment System

ICS Irondale Containment System

SQI Submerged Quench Incinerator

1000 0 2000 4000 FEET

Scale 1 36 000
One inch represents 3,000 feet

Prepared for
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Prepared by
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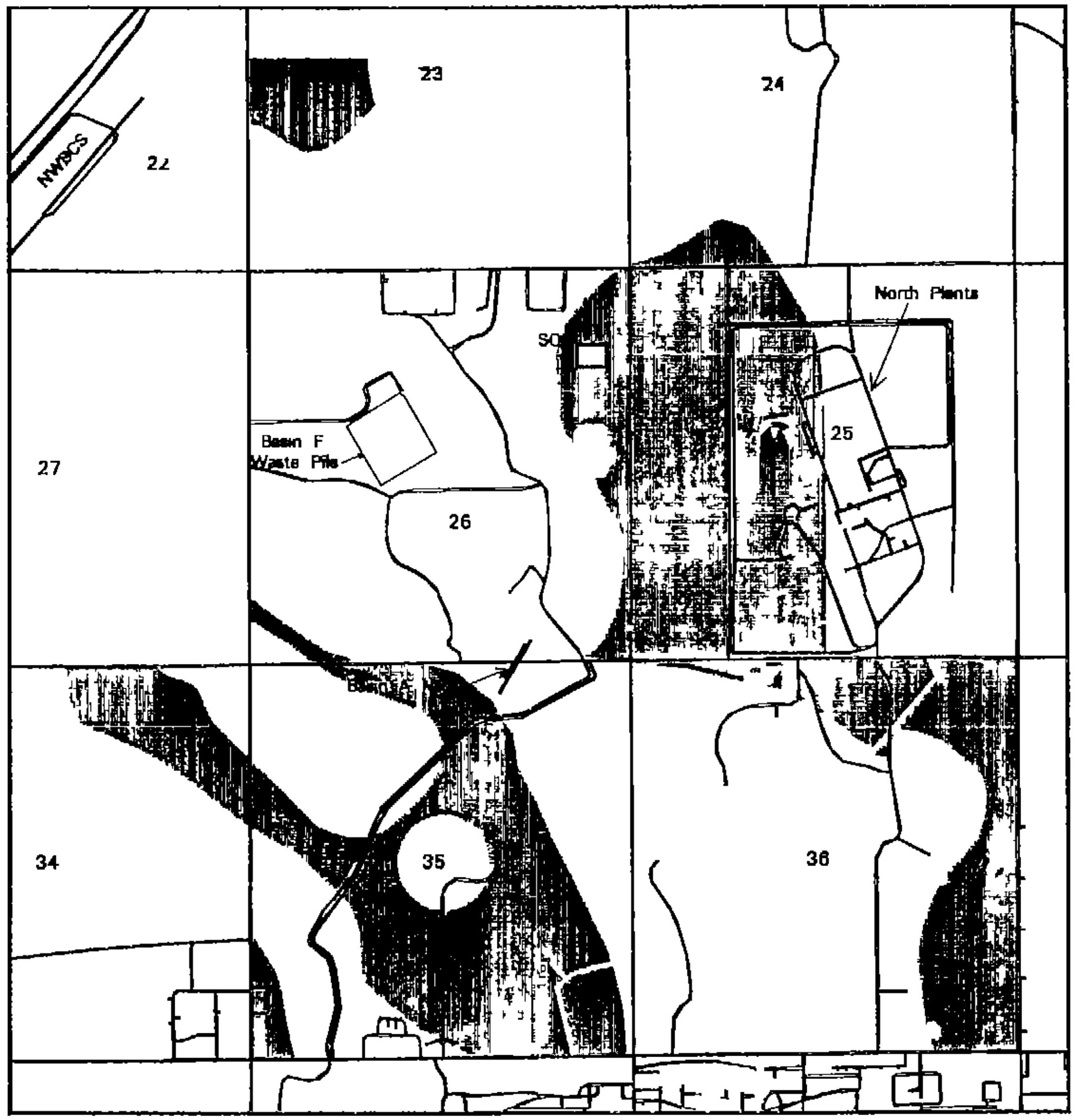
Figure 4.10

Onpost Approximate Depth to Bedrock Contour Map

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize
Depth to groundwater (in feet)

10 to 70 feet	Not suitable
70 to 90 feet	Suitable

Minimize
Depth to bedrock (in feet)

0 to 10 feet	Suitable
10 to 80 feet	Not Suitable

Note Secondary landfill siting criteria includes unsaturated alluvium

	Suitable areas based on primary landfill siting criteria
	Suitable areas based on secondary landfill siting criteria
	Road
12	Section number
NWBCS	Northwest Boundary Containment System
SQI	Submerged Quench Incinerator

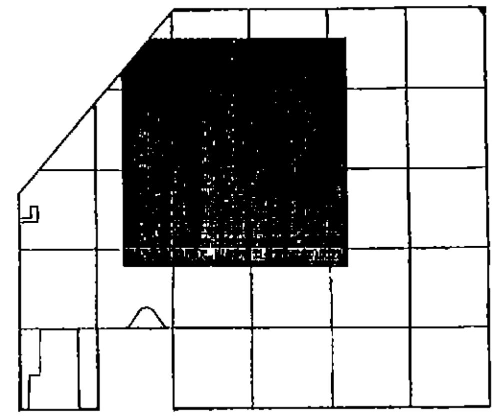
Total suitable acres based on primary and secondary landfill siting criteria 1

Maximum contiguous suitable acres 1

1000 0 2000 4000 FEET

Scale 1 30 000
One inch represents 2,500 feet

Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands sensitive habitats, 100-year floodplain organic groundwater contamination plumes, and human health exceedance areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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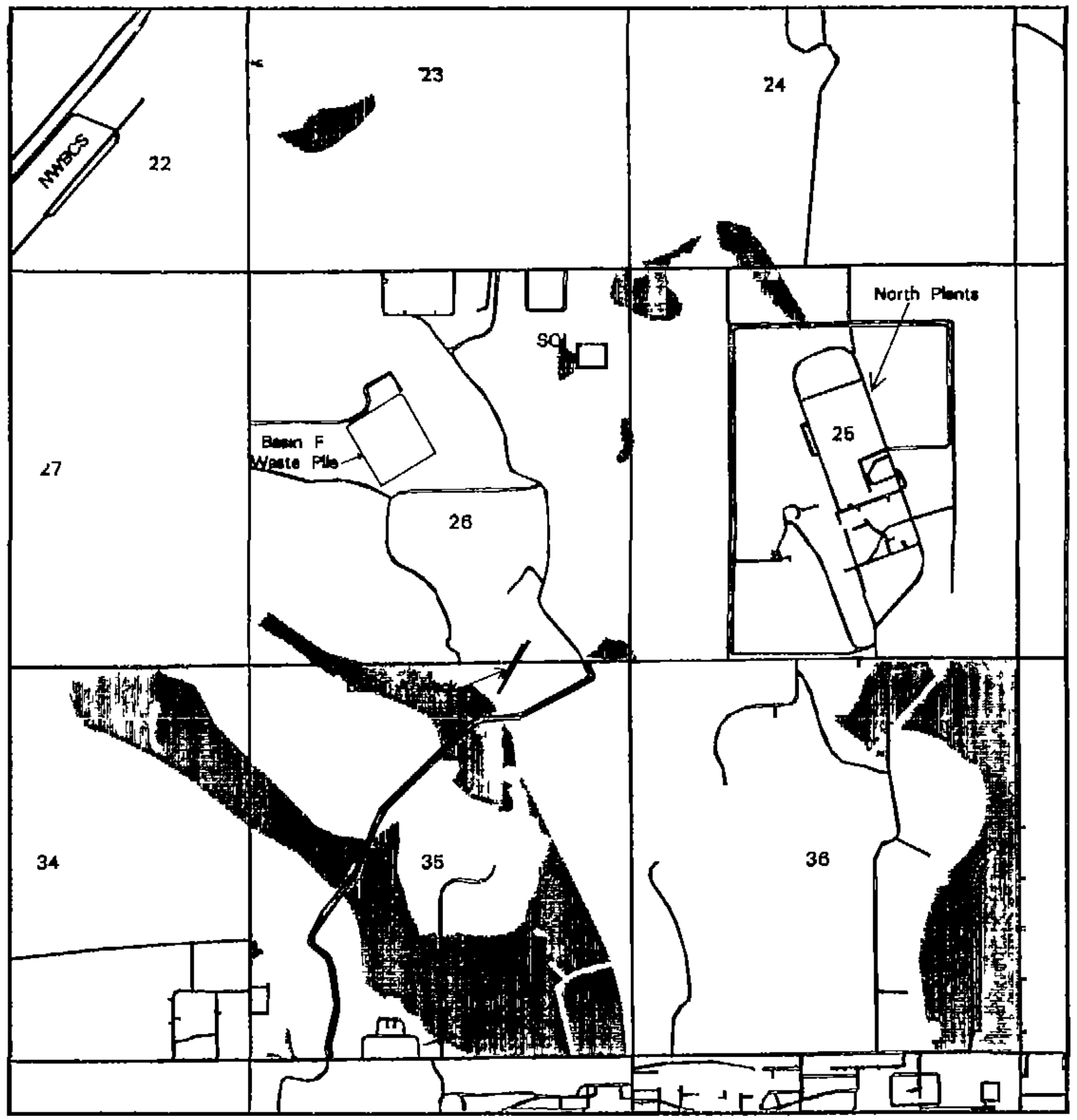
Figure 4 11 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 70 feet, and Depth to Bedrock Less Than or Equal to 10 feet

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize
Depth to groundwater (in feet)

10 to 40 feet	Not suitable
40 to 90 fee	Suitable

Minimize
Depth to bedrock (in feet)

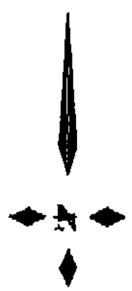
0 to 40 feet	Suitable
40 to 80 feet	Not Suitable

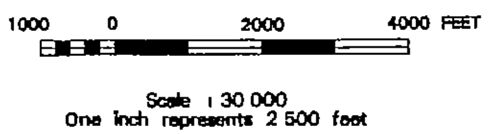
Note Secondary landfill siting criteria includes unsaturated alluvium

	Suitable areas based on primary landfill siting criteria
	Suitable areas based on secondary landfill siting criteria
	Road
12	Section number
NWBCS	Northwest Boundary Containment System
SQI	Submerged Quench Incinerator

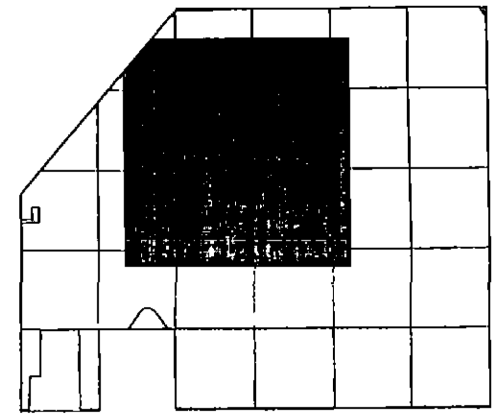
Total suitable acres based on primary and secondary landfill siting criteria 469

Maximum contiguous suitable acres 371





Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands sensitive habitats 100-year floodplain organic groundwater contamination plumes, and human health exceedance areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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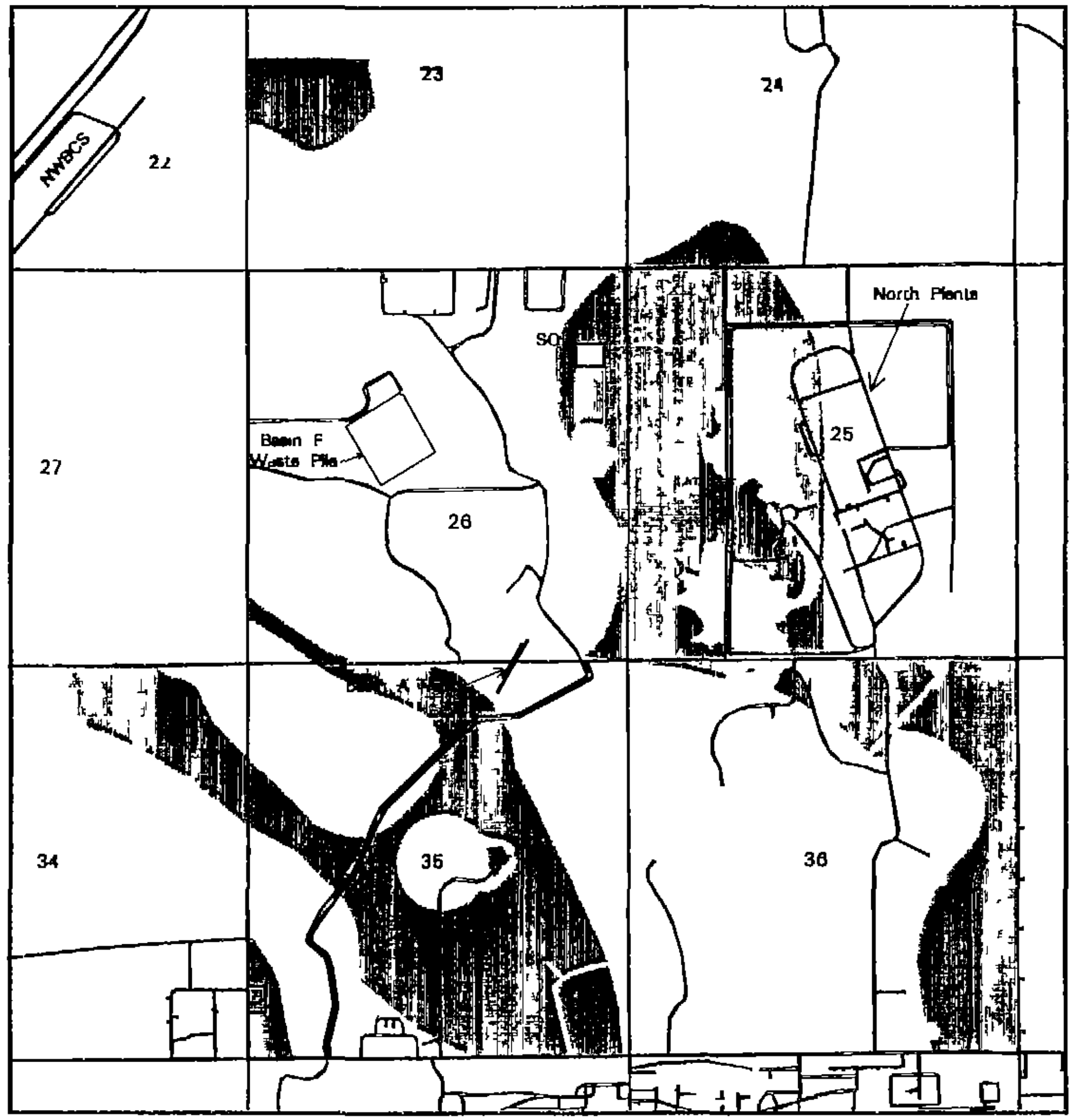
Figure 4 12 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 40 feet, and Depth to Bedrock Less Than or Equal to 40 feet

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize
Depth to groundwater (in feet)

10 to 60 feet	Not suitable
60 to 90 feet	Suitable

Minimize
Depth to bedrock (in feet)

0 to 20 feet	Suitable
20 to 80 feet	Not Suitable

Note Secondary landfill siting criteria includes unsaturated alluvium

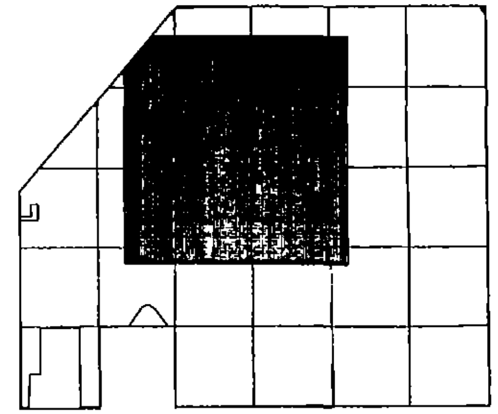
	Suitable areas based on primary landfill siting criteria
	Suitable areas based on secondary landfill siting criteria
	Road
17	Section number
NWBCS	Northwest Boundary Containment System
SQI	Submerged Quench Incinerator

Total suitable acres based on primary and secondary landfill siting criteria 81

Maximum contiguous suitable acres 76

Scale 1 30 000
One inch represents 2 500 feet

Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands, sensitive habitats 100-year floodplain organic groundwater contamination plumes, and human health exceedance areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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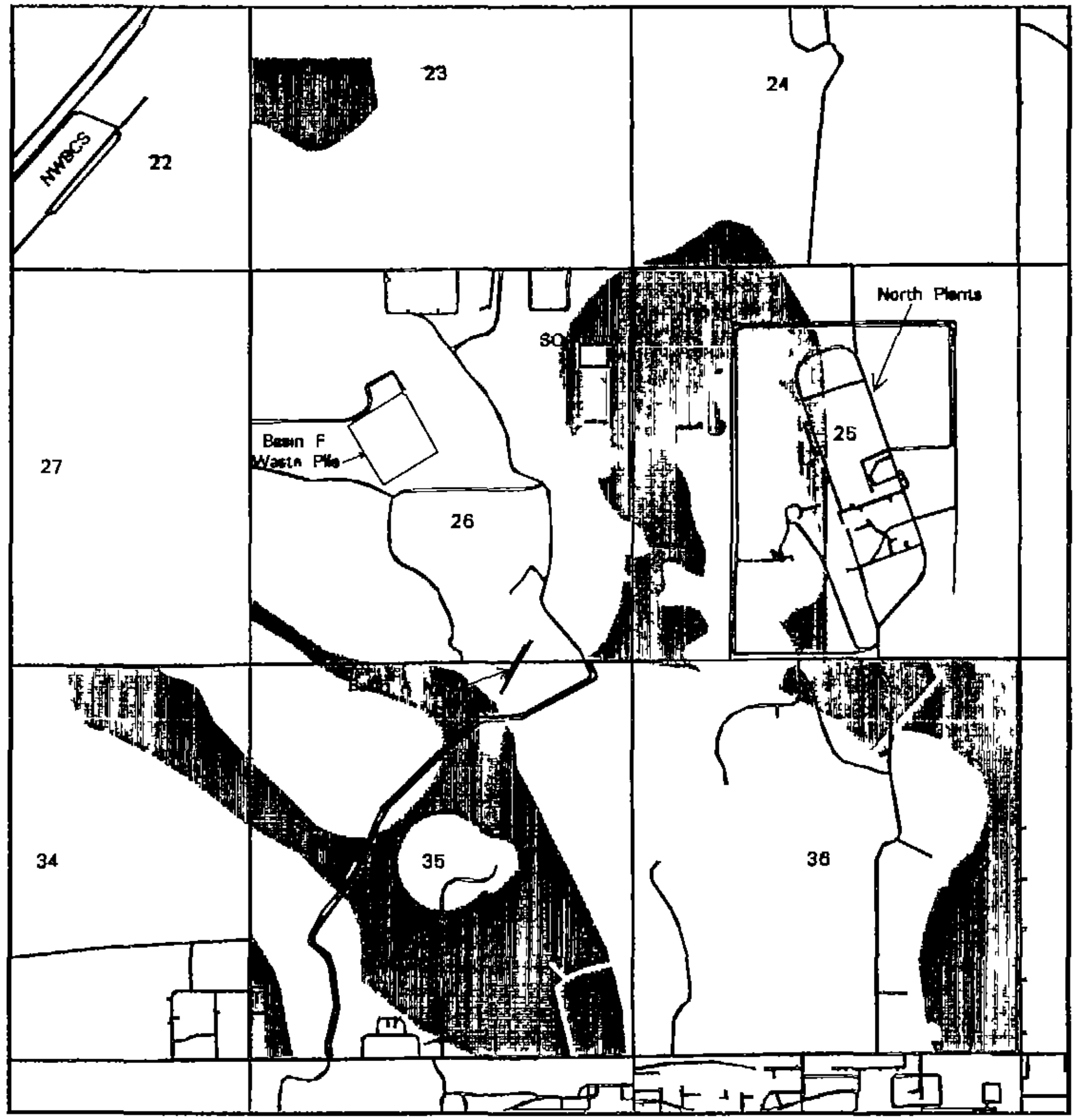
Figure 4 13 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 60 feet, and Depth to Bedrock Less Than or Equal to 20 feet

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize Depth to groundwater (in feet)	
10 to 60 feet	Not suitable
60 to 90 feet	Suitable

Minimize Depth to bedrock (in feet)	
0 to 40 feet	Suitable
40 to 80 feet	Not Suitable

Note Secondary landfill siting criteria includes unsaturated alluvium

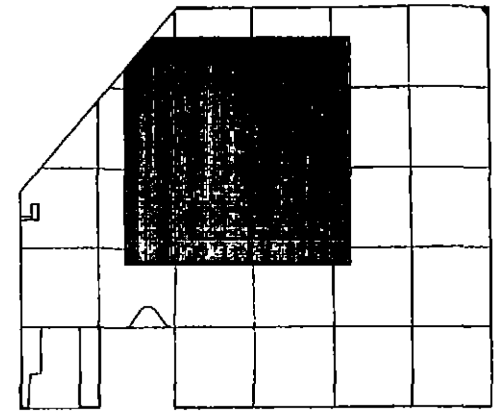
	Suitable areas based on primary landfill siting criteria
	Suitable areas based on secondary landfill siting criteria
	Road
12	Section number
NWBCS	Northwest Boundary Containment System
SQI	Submerged Quench Incinerator

Total suitable acres based on primary and secondary landfill siting criteria 147

Maximum contiguous suitable acres 138

Scale 1 30 000
One inch represents 2 500 feet

Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands sensitive habitats 100-year floodplain organic groundwater contamination plumes, and human health exceedence areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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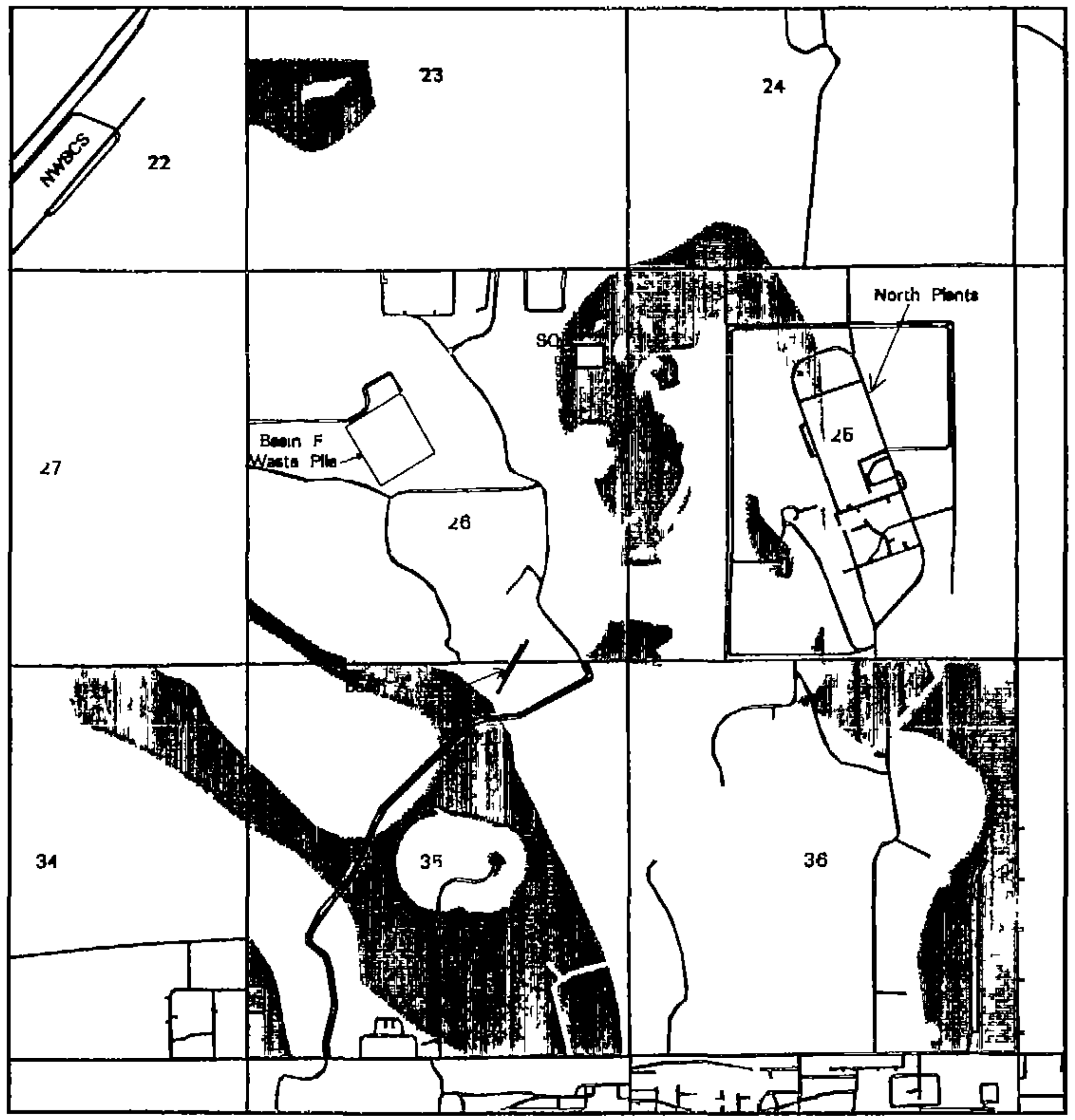
Figure 4 14 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 60 feet, and Depth to Bedrock Less Than or Equal to 40 feet

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize
Depth to groundwater (in feet)

10 to 50 feet	Not suitable
50 to 90 feet	Suitable

Minimize
Depth to bedrock (in feet)

0 to 30 feet	Suitable
30 to 80 feet	Not Suitable

Note Secondary landfill siting criteria includes unsaturated alluvium

Suitable areas based on primary landfill siting criteria

Suitable areas based on secondary landfill siting criteria

Road

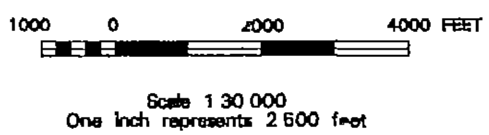
12 Section number

NWBCS Northwest Boundary Containment System

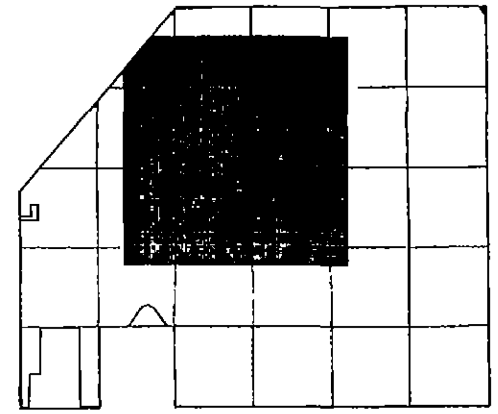
SQI Submerged Quench Incinerator

Total suitable acres based on primary and secondary landfill siting criteria 233

Maximum contiguous suitable acres 217



Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands sensitive habitats 100-year floodplain organic groundwater contamination plumes, and human health exceedance areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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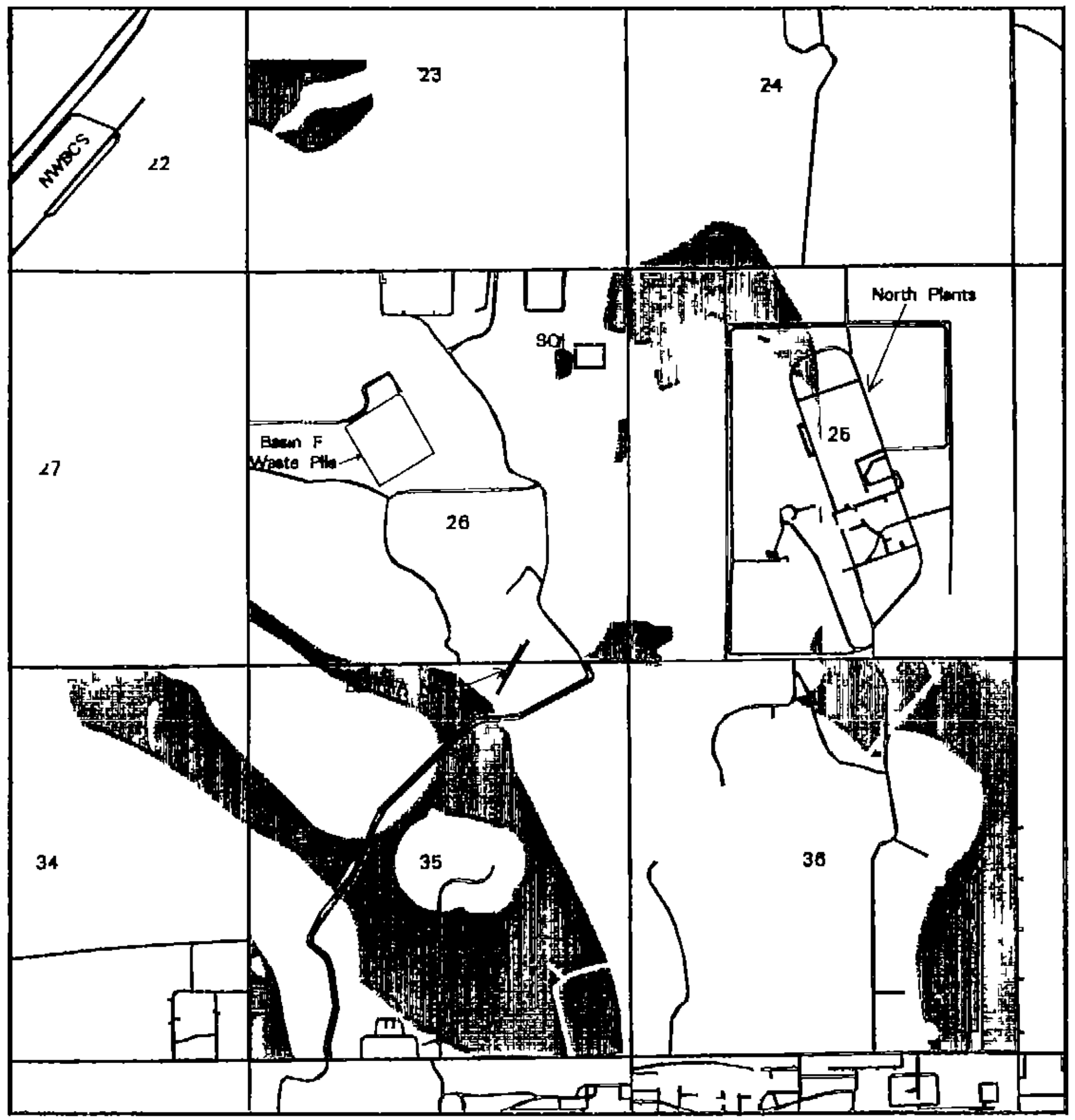
Figure 4 15 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 50 feet, and Depth to Bedrock Less Than or Equal to 30 feet

Potential Landfill Areas



Secondary Landfill Siting Criteria

The values listed below were used to determine siting potential based on depth to groundwater depth to bedrock and depth to saturated alluvium

Maximize
Depth to groundwater (in feet)

10 to 50 feet	Not suitable
50 to 90 feet	Suitable

Minimize
Depth to bedrock (in feet)

0 to 40 feet	Suitable
40 to 80 feet	Not Suitable

Note Secondary landfill siting criteria includes unsaturated alluvium

	Suitable areas based on primary landfill siting criteria
	Suitable areas based on secondary landfill siting criteria
	Road
12	Section number
NWBCS	Northwest Boundary Containment System
SQI	Submerged Quench Incinerator

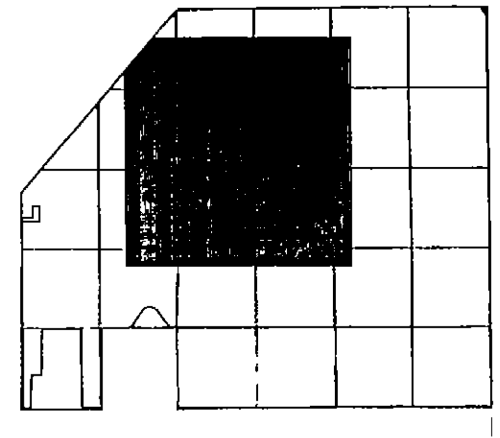
Total suitable acres based on primary and secondary landfill siting criteria: 325

Maximum contiguous suitable acres 299

1000 0 2000 4000 FEET

Scale 1:30 000
One inch represents 2 500 feet

Area shown in figure



Rocky Mountain Arsenal

Note
The "Suitable Areas" identified in this figure are the result of a spatial analysis peformed to eliminate those areas at RMA deemed "unsuitable" with respect to the primary and secondary landfill siting criteria. The primary landfill siting criteria include avoidance of wetlands sensitive habitats 100-year floodplain organic groundwater contamination plumes, and human health exceedance areas as listed in Table 4 2 The secondary landfill siting criteria are identified in the box titled secondary landfill siting criteria.

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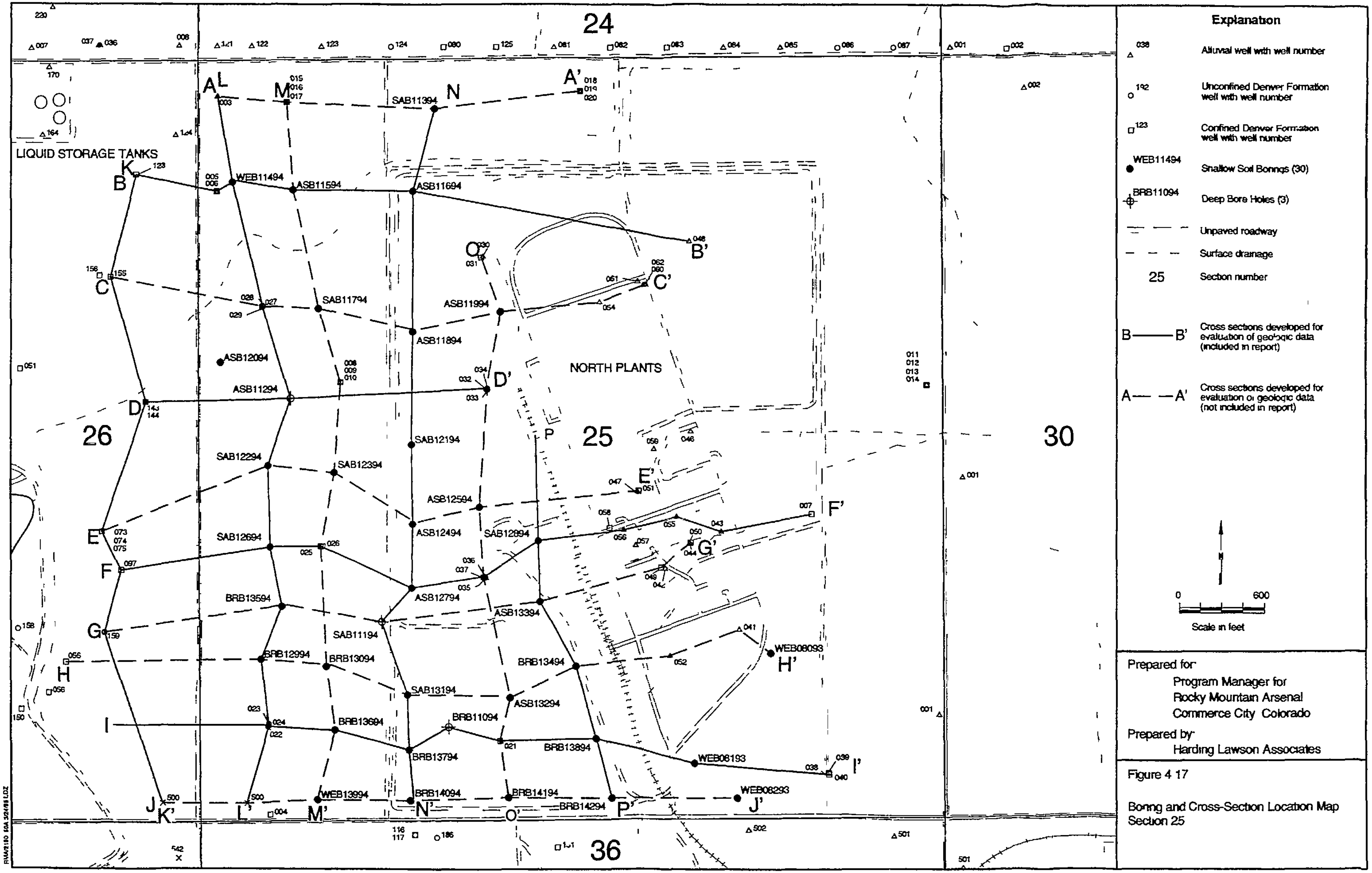
Figure 4 16 - Applied Selection Criteria - Depth to Groundwater Greater Than or Equal to 50 feet, and Depth to Bedrock Less Than or Equal to 40 feet



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Commerce City Colorado

Prepared by:
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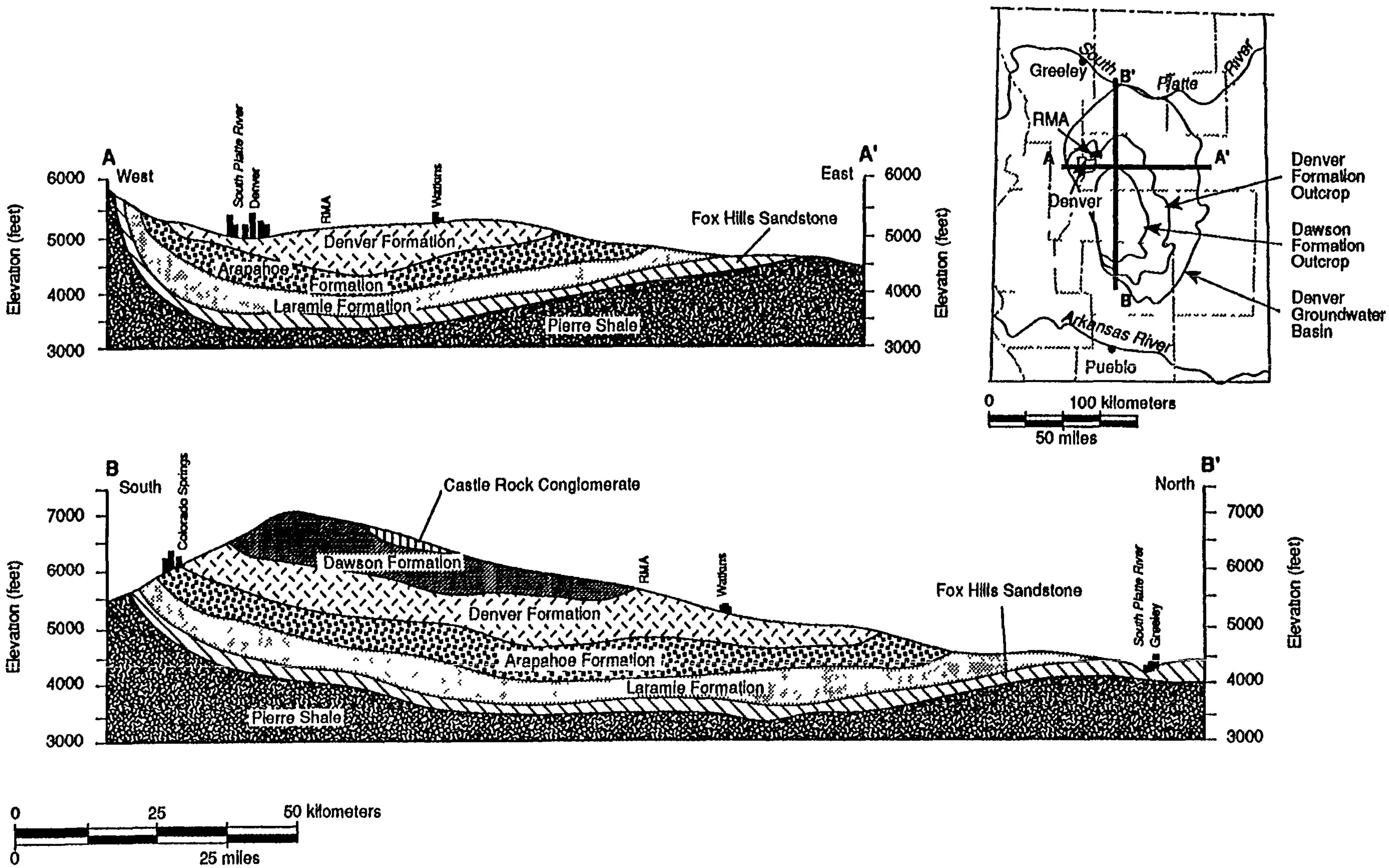
Figure 4 17

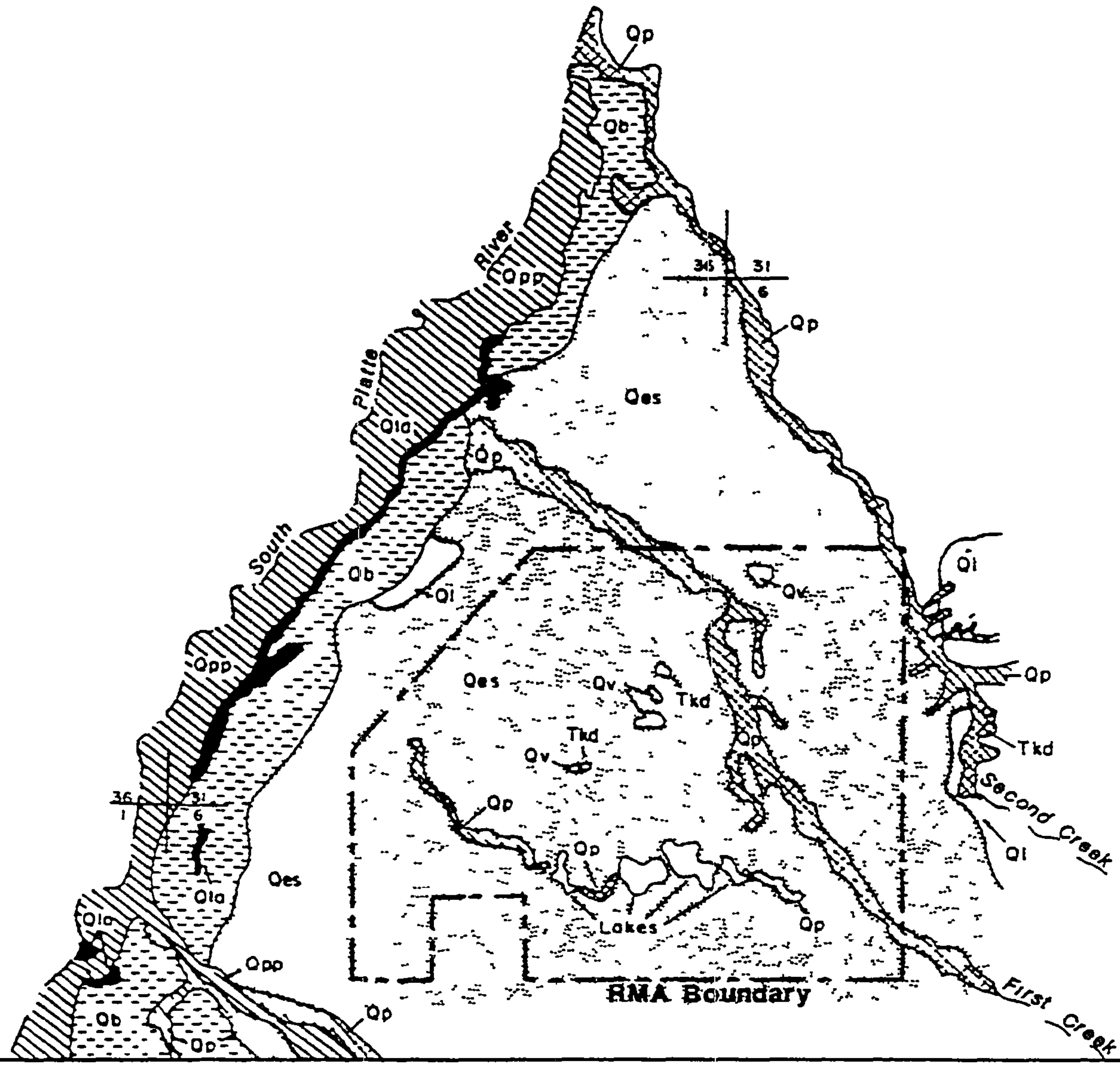
Boring and Cross-Section Location Map
Section 25



Source Robson and Romero, 1981

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by· Harding Lawson Associates	Figure 4 18 Upper Stratigraphic Sections of the Denver Basin

RMA 1037.1 3/24/95 NLM



EXPLANATION

Qpp	Post Piney Creek Alluvium (Quaternary)
Qp	Piney Creek Alluvium (Quaternary)
Qes	Eolian Sand (Quaternary)
Ql	Loess (Quaternary)
Qb	Broadway Alluvium (Quaternary)
Qla	Louviers Alluvium (Quaternary)
Qv	Verdos Alluvium (Quaternary)
Tkd	Denver Formation (Upper Cretaceous & Tertiary)

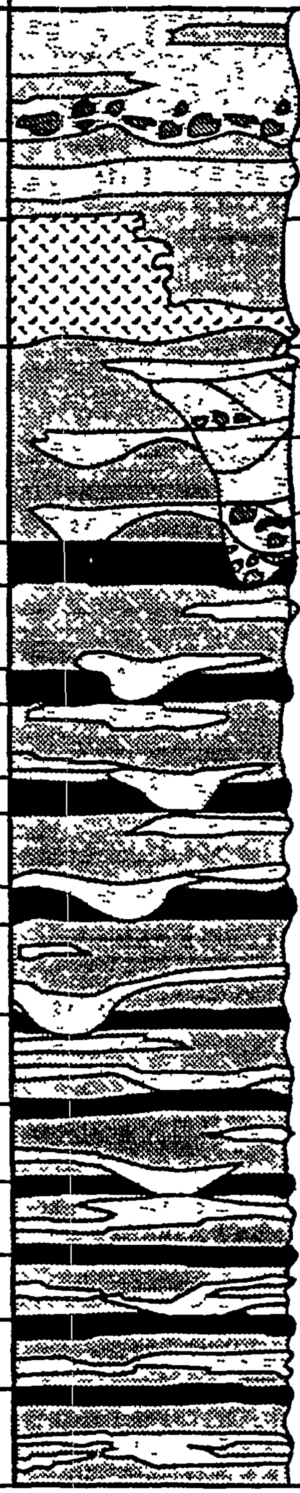
Source Lindvall 1980

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
Harding Lawson Associates

Figure 4 19

Surficial Geologic Map of the Rocky Mountain Arsenal Area

System	Zone and Thickness		Lithologic Description
Quaternary	Alluvium	0 - 120	Gravel, silty sand, sandy silt, and clay, laterally variable
Cretaceous - Tertiary Denver Formation	B	0 - 25' (0 - 19')	B Sand, sandstone, and claystone
	Volcaniclastic	0 - 50'	Volcaniclastic material and laterally equivalent claystone and sandstone
	A	0 75'	A Upper (AU) (0 - 13'); A Middle (AM) (0 - 20'); A Lower (AL) (0 - 20'); A Sand (0 - 46'); Sandstone, claystone, and lignite
	Lignite A	0 - 11'	
	IU	0 - 40' (0 - 36')	
	Lignite B	0 - 12'	
	1	0 - 60' (0 - 54')	
	Lignite C	0 - 13'	
	2	0 - 55' (0 - 41')	
	Lignite D	0 - 13'	
	3	0 - 45' (0 - 33')	Volcaniclastic material and laterally equivalent claystone and sandstone
	4	0 - 50' (0 - 36')	
	5	0 - 25' (0 - 19')	
	6	0 - 30' (0 - 23')	
	7	0 - 30' (0 - 20')	
	8	0 - 40' (0 - 27')	
	9	0 - 20' (0 - 6')	



Source Environmental Science and Engineering 1988

Note Thickness not to scale, net sandstone thickness shown in parentheses

RMA 1080 4 3/24/95 NLM

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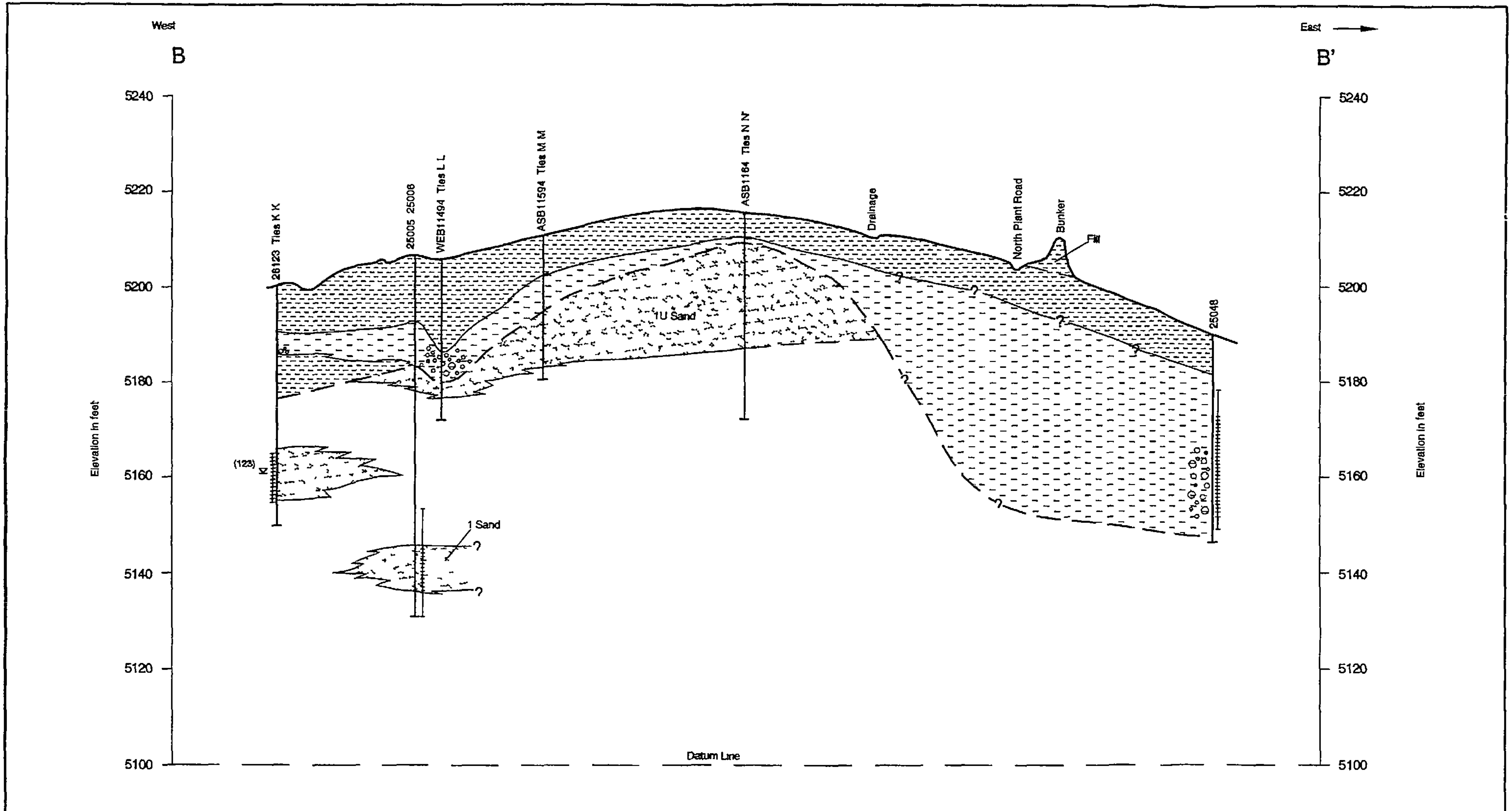
Figure 4 20

Denver Formation Stratigraphic Column



EXPLANATION

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand, clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite, and sandstone (see note)

Top of weathered bedrock

Note:
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite, and claystone is unknown.

SAB11194 Boring identification

29025 Monitoring well(s) identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

20
0
0
400
Scale in feet
Vertical exaggeration = 20x

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Figure 4.21

Geologic Cross Section B-B

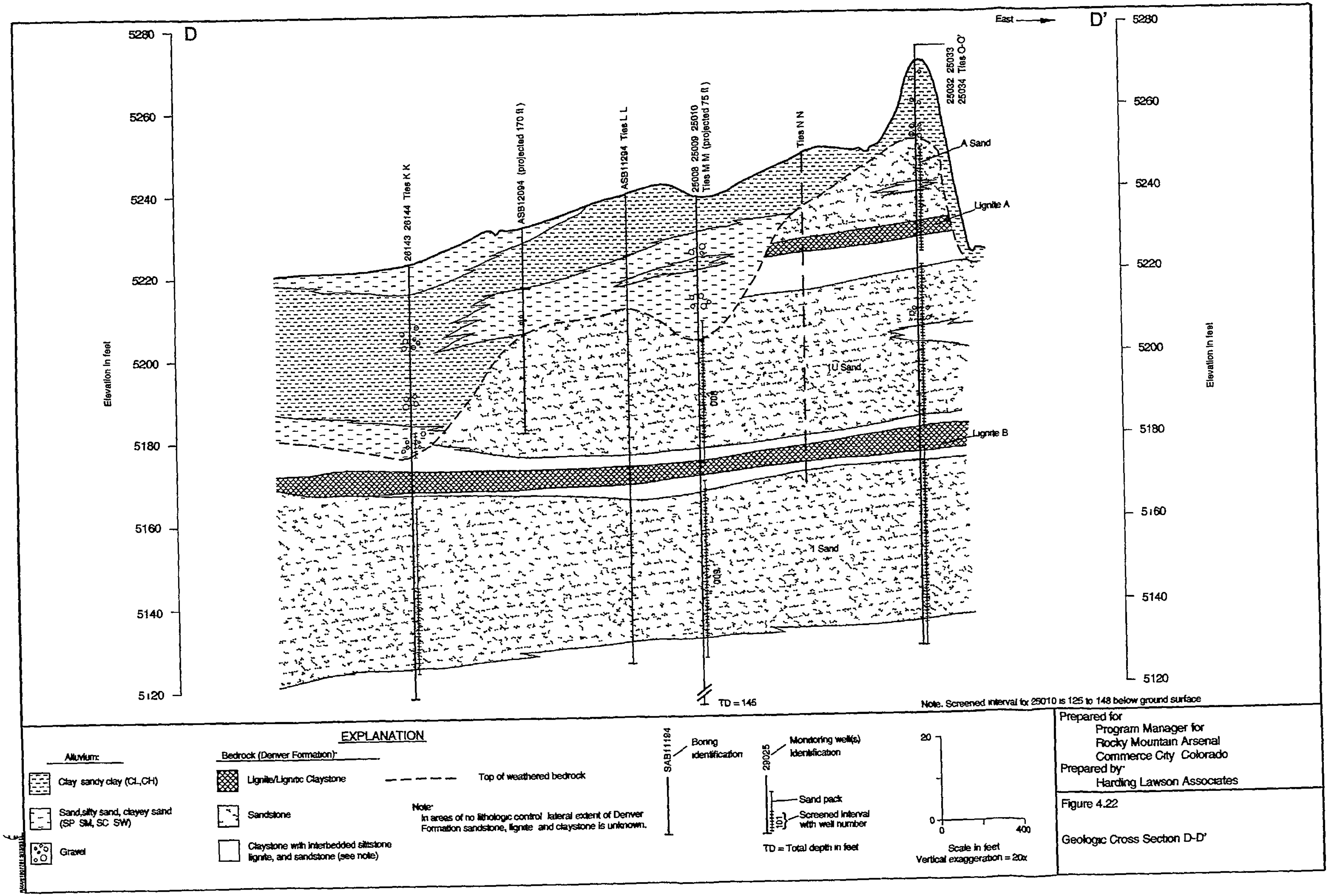

Figure 4.22

Geologic Cross Section D-D'

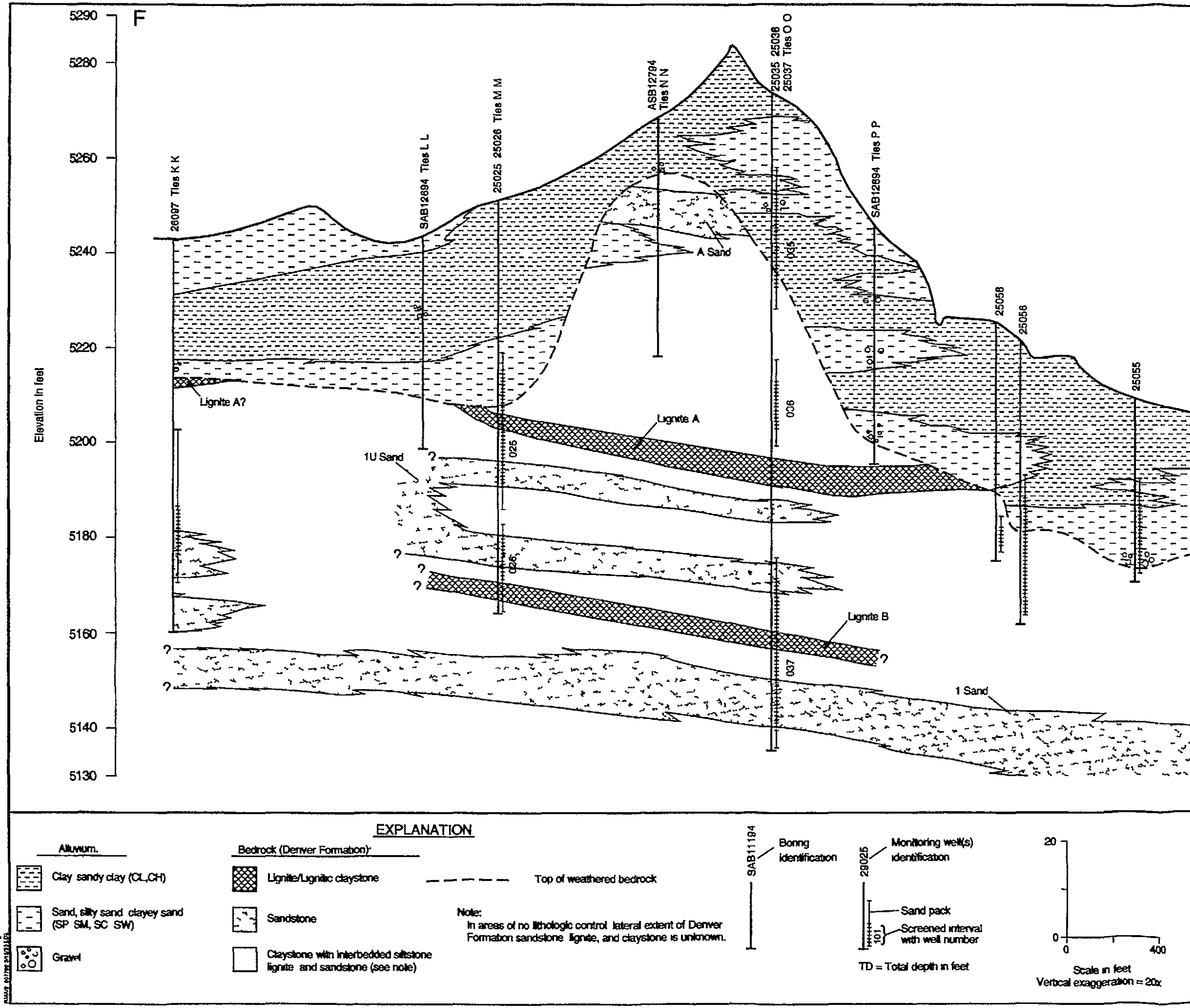

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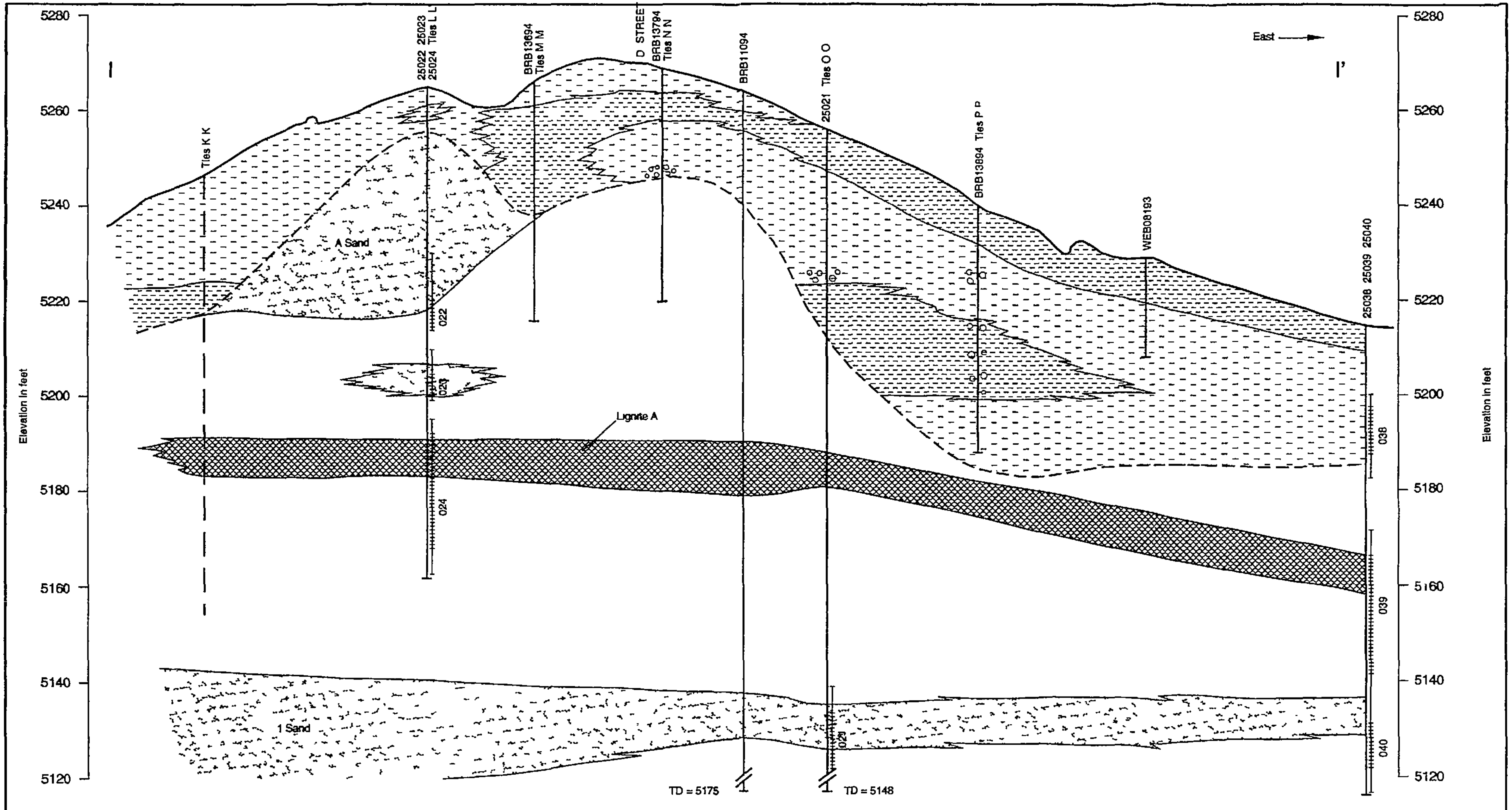
Figure 4.23

Geologic Cross Section F F'



EXPLANATION

Alluvium:

- Clay sandy clay (CL,CH)
- Sand, silty sand, clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation):

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite, and sandstone (see note)

Top of weathered bedrock

Note:
In areas of no lithologic control lateral extent of Denver Formation sandstone, lignite and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

Screened interval with well number (101)

TD = Total depth in feet

20
0
0
400
Scale in feet
Vertical exaggeration = 20x

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Figure 4.24

Geologic Cross Section I I'

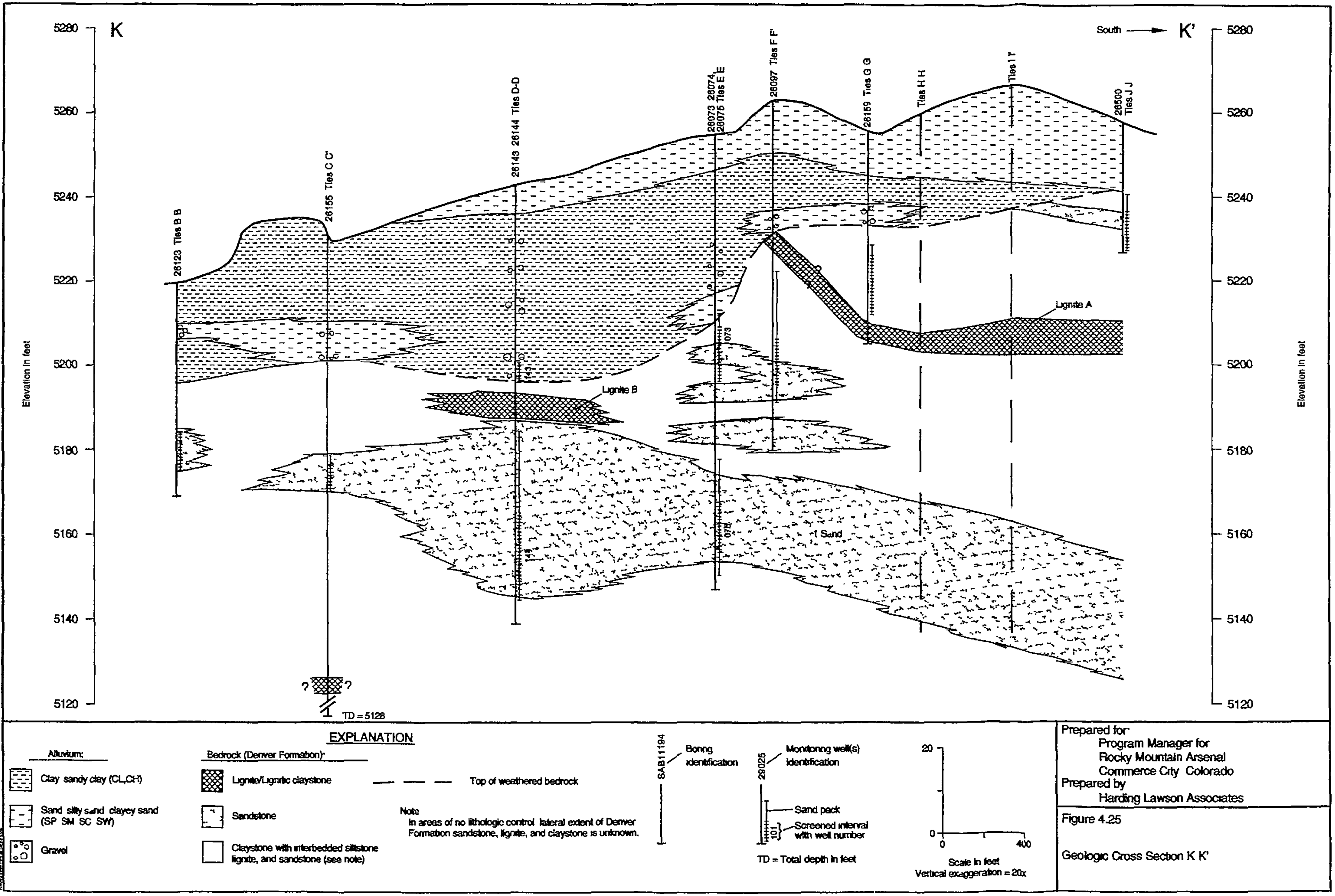
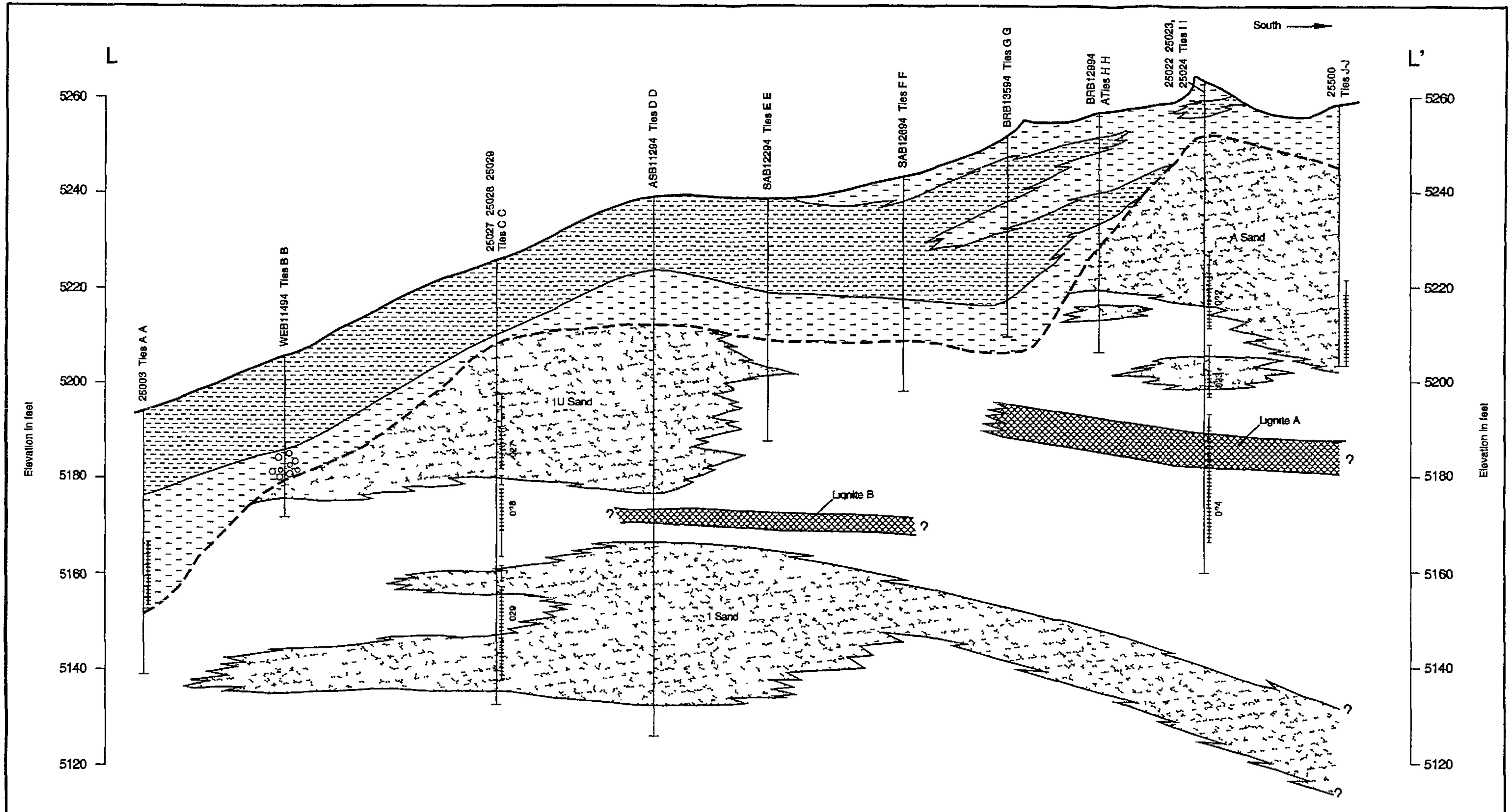


Figure 4.25

Geologic Cross Section K K'



EXPLANATION

Alluvium:

- Clay sandy clay (CL,CH)
- Sand, silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite, and sandstone (see note)

Top of weathered bedrock

Note: In areas of no lithologic control lateral extent of Denver Formation sandstone lignite, and claystone is unknown

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

Scale in feet: 0–400 (horizontal); 0–20 (vertical)

Vertical exaggeration = 20x

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Figure 4.26

Geologic Cross Section L-L

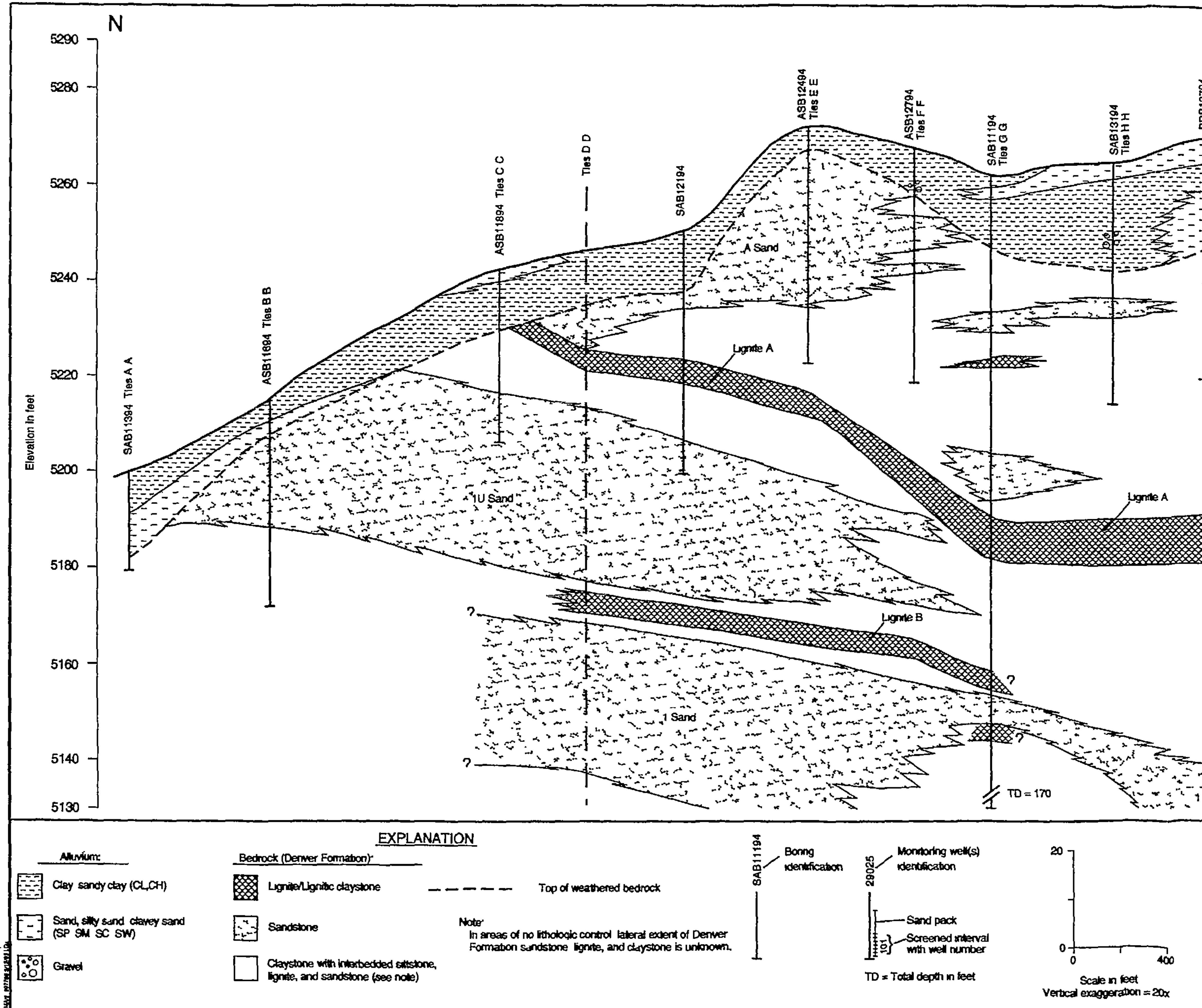

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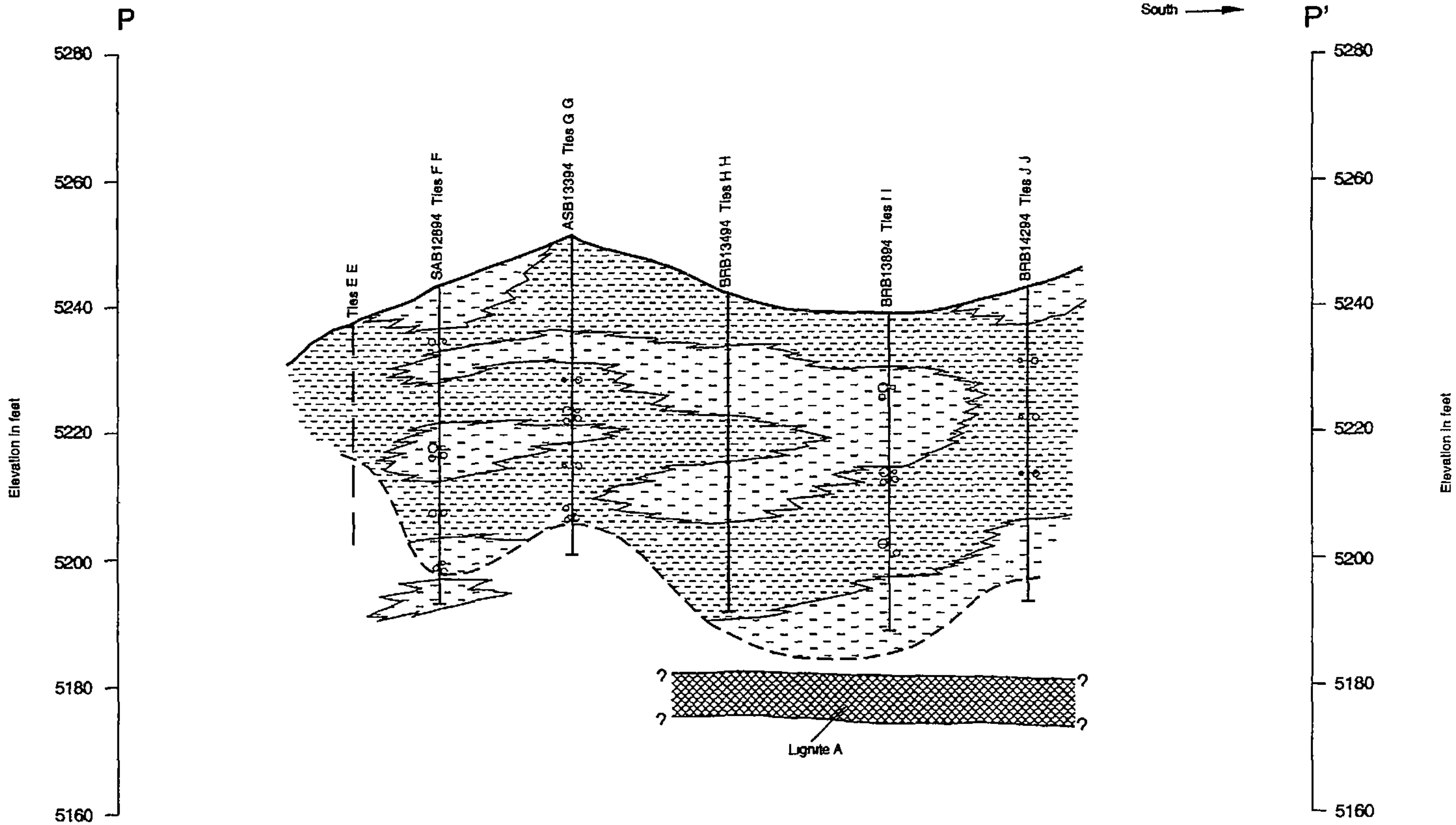
Figure 4.27

Geologic Cross Section N-N'



EXPLANATION

Alluvium:

- Clay sandy clay (CL,CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)*

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite, and sandstone (see note)

— — — Top of weathered bedrock

Note*
In areas of no lithologic control lateral extent of Denver Formation sandstone lignite, and claystone is unknown.

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

20
0
0 40
Scale in feet
Vertical exaggeration = 20x

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Figure 4.28

Geologic Cross Section P P'

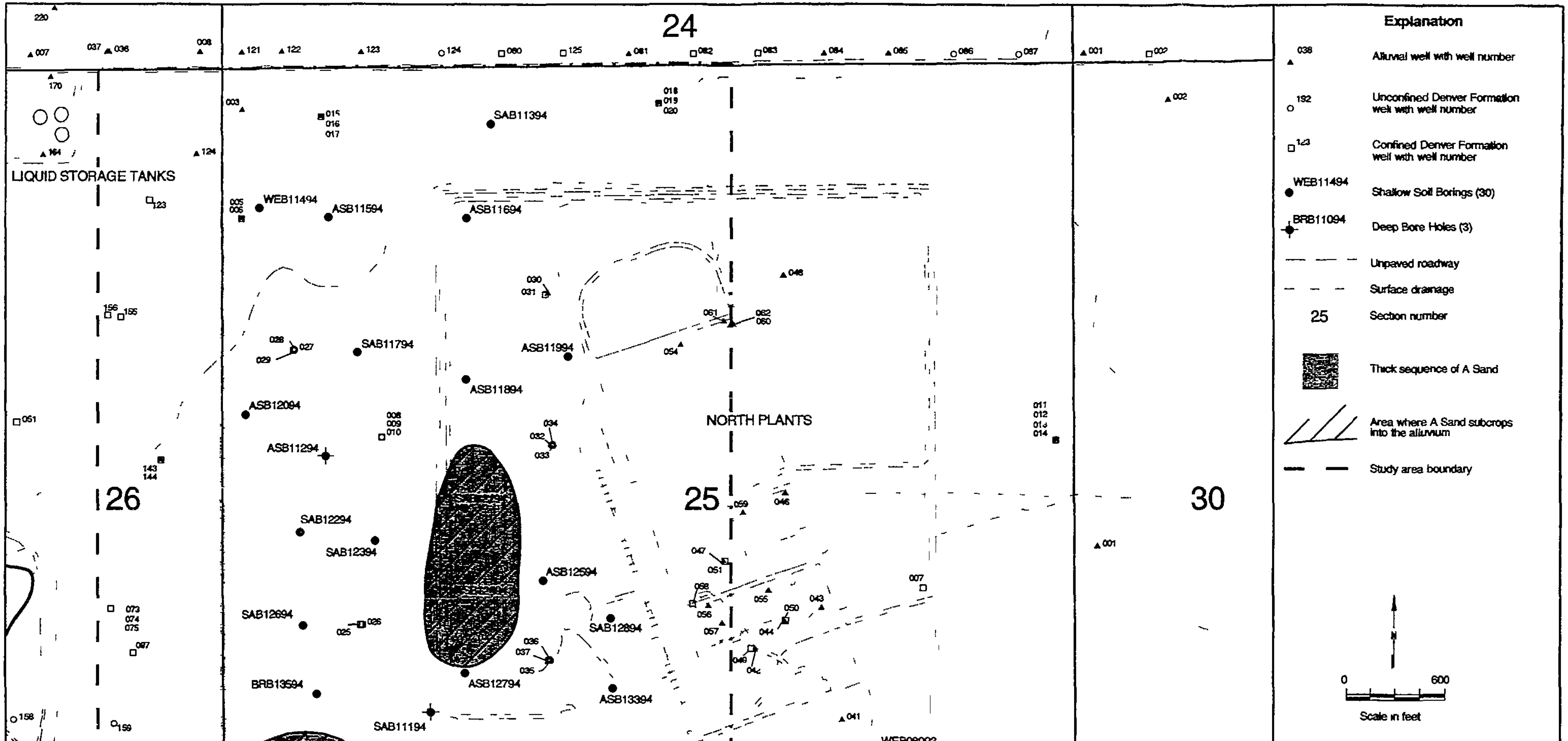

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Figure 4.29

A Sand Extent and Subcrop Map

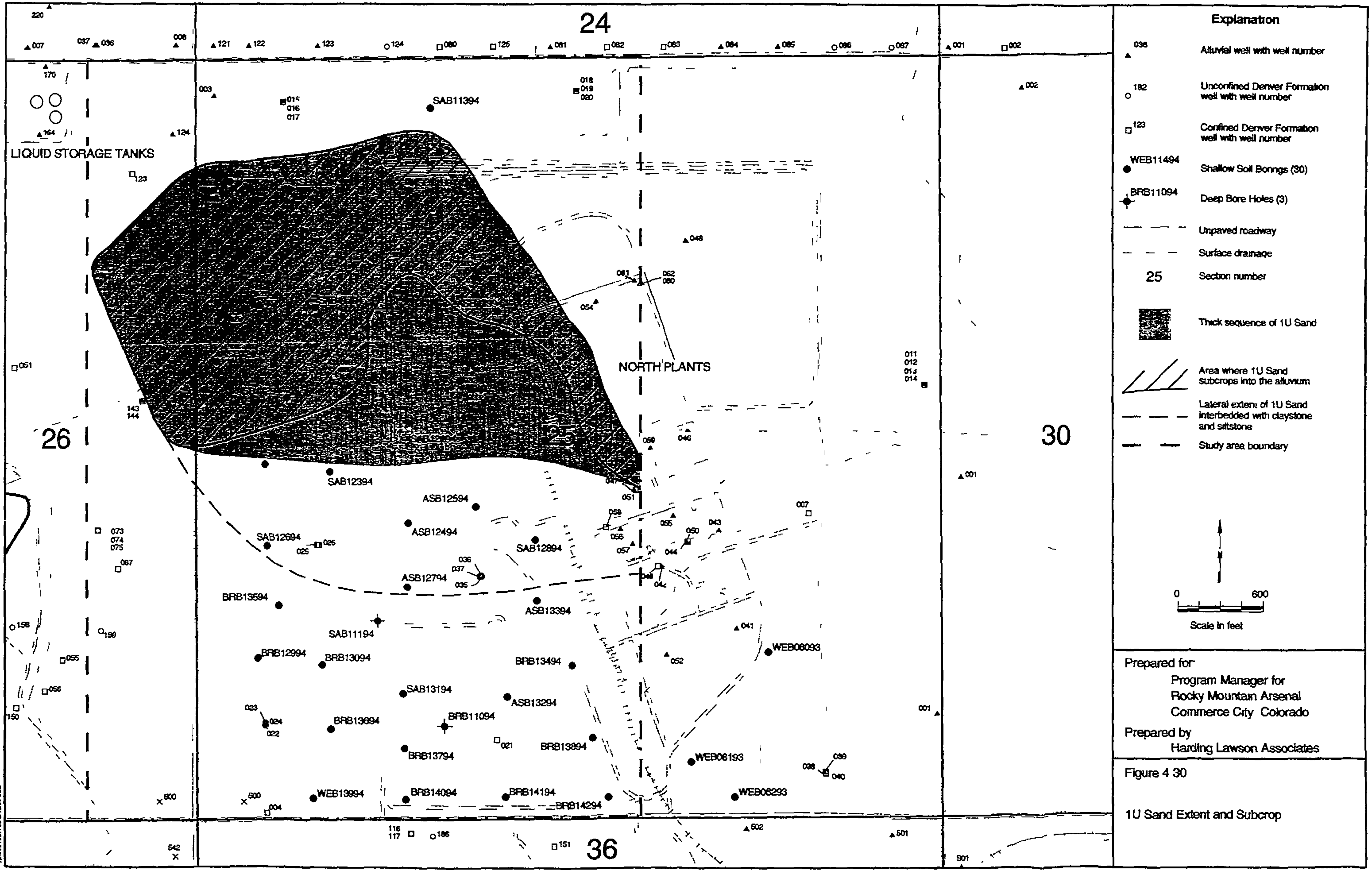

Figure 4 30

1U Sand Extent and Subcrop

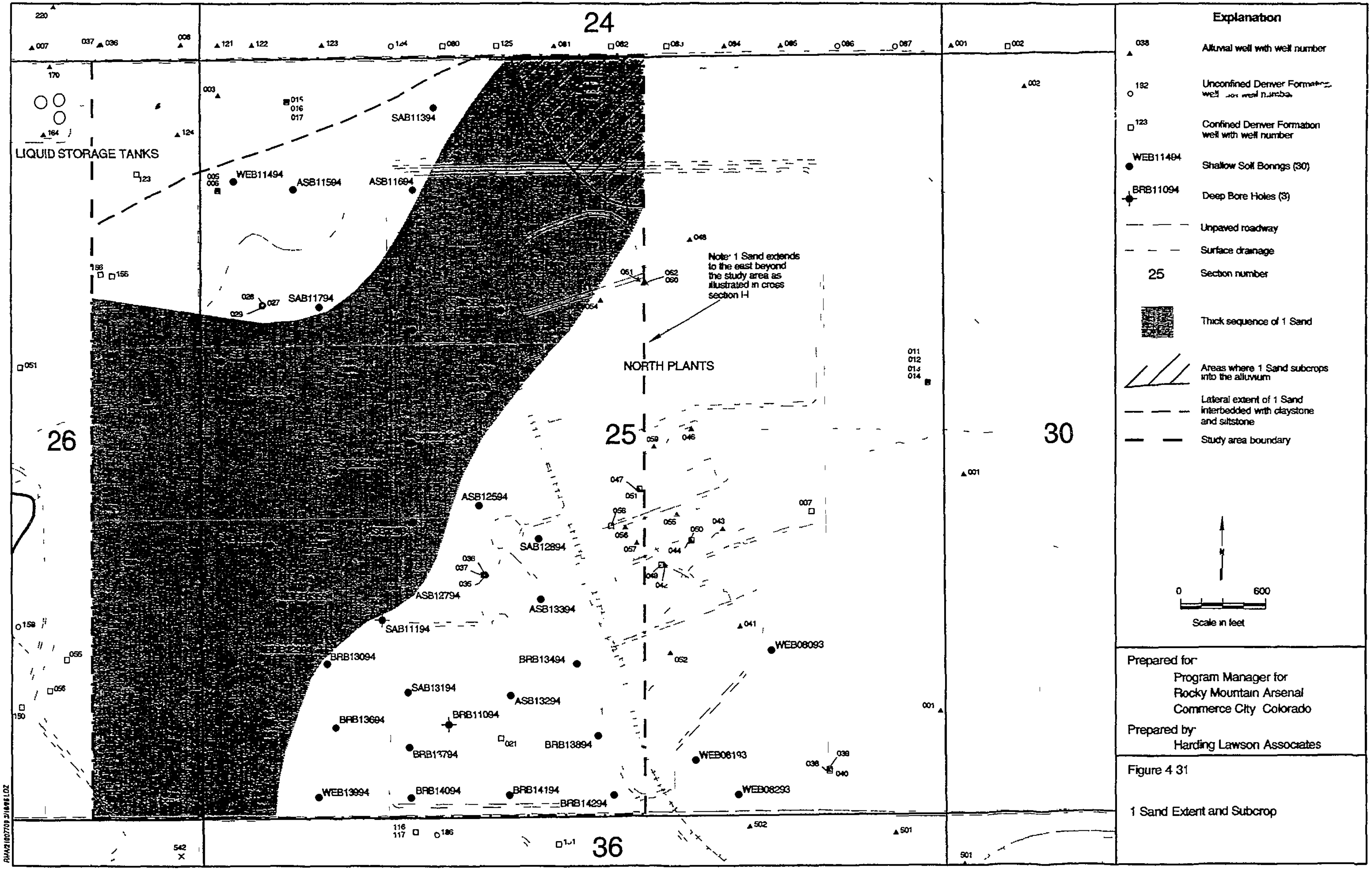

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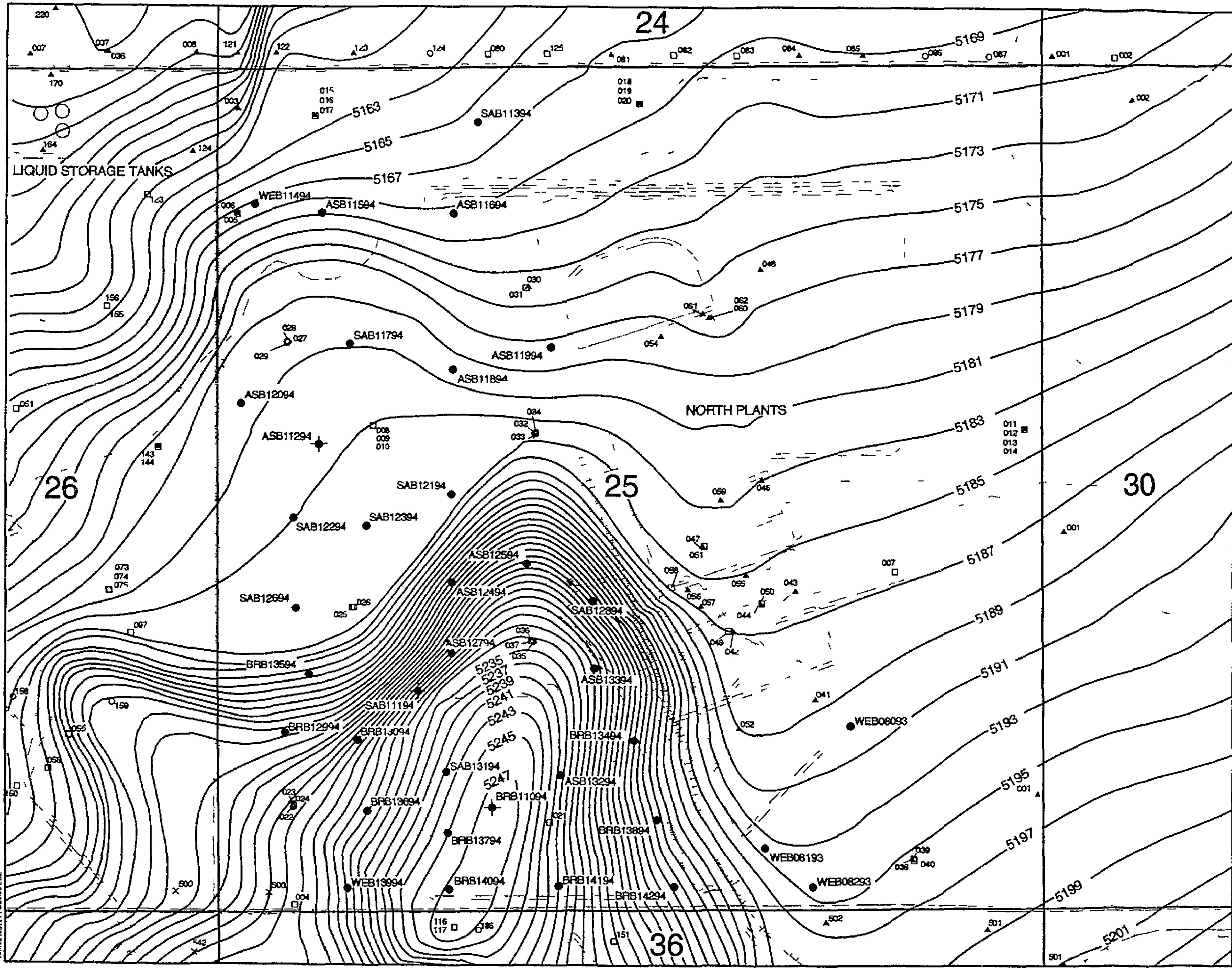
Figure 4 31

1 Sand Extent and Subcrop



Explanation

038 Alluvial well with well number

192 Unconfined Denver Formation well with well number

123 Confined Denver Formation well with well number

WEB11494 Shallow Soil Borings (30)

BRB11094 Deep Bore Holes (3)

Unpaved roadway

Surface drainage

25 Section number

N

0 600

Scale in feet

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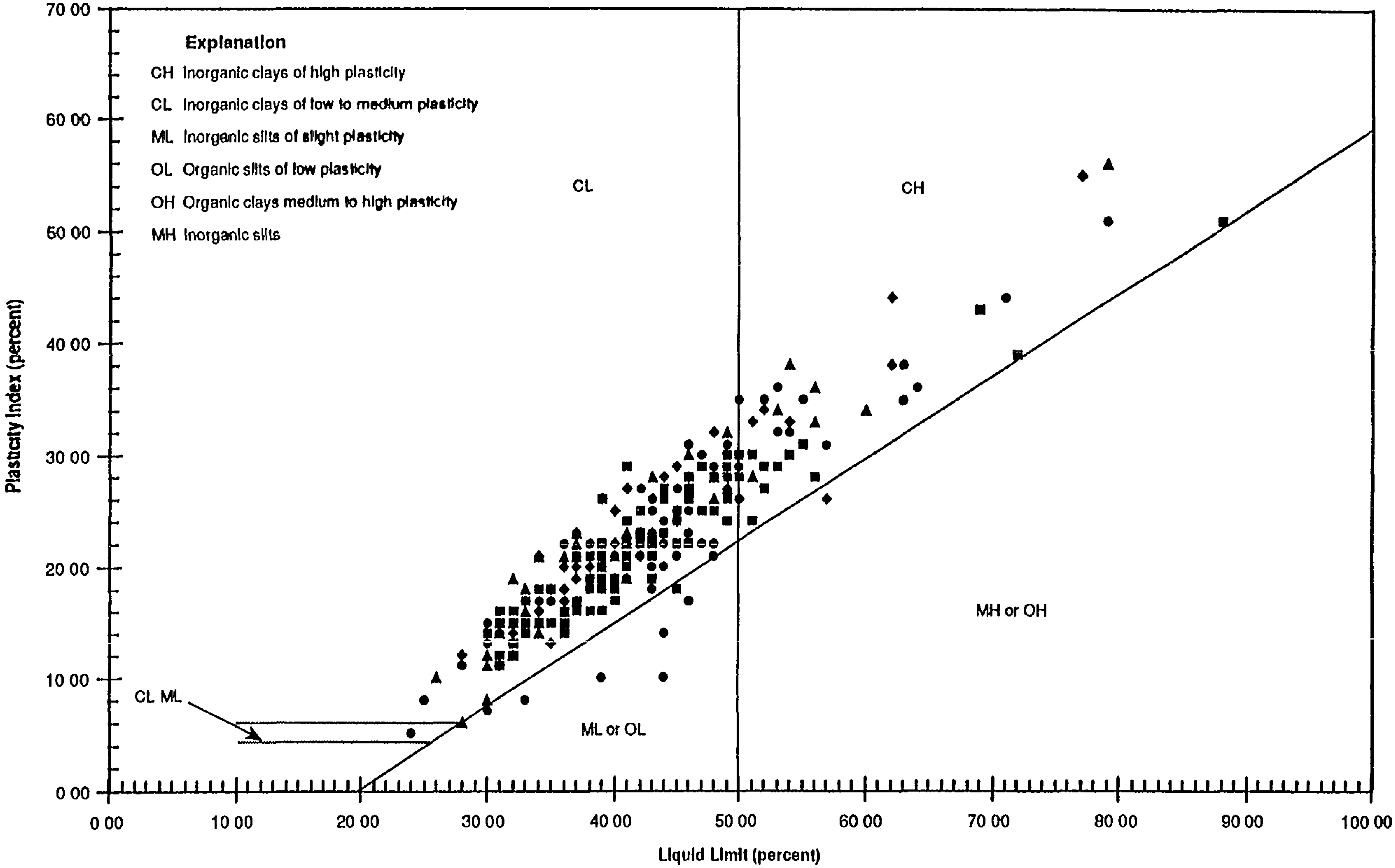
Figure 4 32

Water-Level Contours



RMAG 1049.B 3/17/94 NLM

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5.0 SITE FEASIBILITY STUDY

This section presents the results of the Site Feasibility Study (FS) The primary objectives of the Site FS were to identify an appropriate landfill site within the area identified in the Area FS and to provide information on conceptual landfill models, design elements, construction costs, and schedules The Site FS links the data from the Material and Area Feasibility Studies to evaluate the site-specific requirements of an onpost landfill that will use onpost soils for the soil component of caps and liners, have sufficient capacity to dispose of anticipated waste volumes, and meet applicable federal, state, and local regulatory requirements

The study included a review and evaluation of the following criteria

- Waste types, volumes, and generation rates
- Regulatory criteria
- Specific site considerations and limitations
- Conceptual landfill design alternatives
- Evaluation and screening of alternatives
- Facility layout
- Material quantities and availability
- Construction cost estimates and schedules
- Operations and maintenance requirements

5.1 Waste Data

Waste data is a critical component of any landfill design. The amount of waste requiring disposal dictates the size of the landfill needed The type of waste impacts placement, compaction, and cover criteria. The rate at which the waste is generated effects operation and maintenance criteria and construction phasing The following section discusses

- Projected waste types that may be disposed of at an onsite hazardous waste landfill

- Estimated waste volumes
- Possible waste generation rates

The data presented are based on information obtained in the Proposed Final Detailed Analysis of Alternatives (DAA) (Ebasco, 1994) as summarized by RUST Environment and Infrastructure (RUST E&I, 1994)

5.1.1 Projected Waste Types and Characteristics

Based on information in the DAA, the potentially contaminated materials at the RMA that may be landfilled can be classified into three waste types hazardous and toxic materials, unexploded ordnance (UXO), and surety-contaminated materials The two major waste forms within these waste types include contaminated soils and building debris

The actual waste volumes generated for landfilling will be dependant on the selected remedial action alternative The alternatives define differing methods of treatment, storage, and disposal for contaminated material Contaminated materials that may be landfilled can be categorized as follows

- Contaminated soil
- Soil and debris treated by caustic washing
- Soil treated by thermal desorption
- Structural debris

The contaminated soil consists of excavated soil that is untreated. However, it is estimated that only a small portion of the soil will contain listed or characteristic hazardous waste Metallic debris and soil from UXO clearance operations are included in the contaminated soil category The second category includes soil and structural debris that has been treated by caustic washing to address agent contamination. The third category consists of soil treated by thermal desorption to remove organic contamination. The final category includes untreated debris from the demolition of structures

5.1.2 Projected Waste and Landfill Volumes

Table 5.1 summarizes the estimated volume of material to be landfilled for five different remedial alternatives presented in the DAA. It is estimated that between 440,000 cubic yards (CY) and 4,400,000 CY of waste materials will require landfilling depending on the selected remedial action alternative The preferred sitewide alternative in the DAA, Landfill/Caps Scenario, requires a waste volume of 2,300,000 CY

For the purposes of this report, the minimum and maximum waste volumes shown in Table 5 1 were increased to 1,000,000 CY and 6,000,000 CY to account for future adjustments in waste volumes Based on this projected minimum and maximum waste volume, three conceptual landfill models were developed to account for different waste volumes and to provide a total landfill capacity that accounts for the operational and intermittent cover materials that must be placed over the waste Conceptual Model 2 is the preferred sitewide alternative and meets the waste volume requirements of 2,300,000 CY The three models are as follows

Conceptual Model No	Total Landfill Volume (CY)	Waste Volume (CY)
1	1,200,000	1,000,000
2	2,760,000	2,300,000
3	7,200,000	6,000,000

For conceptual design purposes, the total landfill volumes presented above include a 20 percent volume increase over the needed waste volume to account for operational and intermittent waste cover material

5.1.3 Waste Generation Rates and Schedule

Waste generation rates at RMA will primarily be dependant on which of the five remedial action alternatives is selected and the duration of the remedial action. For this study, generation rates were estimated based on a schedule of 260 landfill operating days per year (5 operating days per week for 52 weeks) Additionally, two generation rates are estimated for each alternative in the DAA based on the development of remediation time frames with and without funding limitations The funding limitation case assumes an annual funding limitation of $100 million for overall remediation activities, which lengthens the remediation period and decreases the generation rates The remediation time frame includes landfill design, construction, and final closure Table 5.2 presents the estimated waste generation rates for five different remedial alternatives presented in the DAA

Waste generation rates have been estimated to be in the range of 98,000 CY to 1,100,000 CY of material per year without considering a funding limit Assuming the $100 million annual funding limit, waste generation rates are estimated to be in the range of 37,000 CY to 280,000 CY of material per year

5.2 Regulatory Criteria

Section 4 2 of this report describes the regulatory criteria that apply to siting a landfill in Colorado A detailed review of all possible current requirements, such as a review of applicable or relevant and appropriate requirements (ARARs) under CERCLA and the Superfund Amendments and Reauthorization Act of 1986 (SARA) was not conducted as part of the current scope of work. The criteria listed in Section 4 2 will likely form the basis for siting a facility under a variety of regulatory scenarios, such as a permitted facility under RCRA, a corrective action management unit (CAMU) under RCRA, or as an interim response action (IRA) under CERCLA. The specific regulatory criteria can be more fully developed once the regulatory framework for siting the facility is better defined.

5.3 Site-specific Considerations and Limitations

Following development of the range of landfill volume (1,000,000 CY, 2,300,000 CY, 6,000,000 CY), the landfill conceptual models were further developed by reviewing and evaluating site conditions and characteristics that could impact the construction of a hazardous waste landfill. Existing site data was reviewed to identify specific limitations and considerations that may need to be addressed in

- The development of design alternatives
- The specific placement of the landfill within the preferred area

- Final design

5.3.1 Climate, Topography, and Surface Hydrology

The site's climate is semiarid with an average annual precipitation of 15 inches The majority of the yearly precipitation typically occurs between the months of March and August. The agricultural growing season is defined as the period between the last frost and the first frost, which averages about 150 days, however, soil temperatures are high enough to sustain plant growth for about 250 days of most years Therefore, selection of the vegetative cover for the final cover system at final design should take this into consideration to establish the necessary erosion protection year round

The ground surface in the vicinity of the preferred siting area generally ranges in elevation from about 5,280 feet above MSL to 5,225 feet above MSL and slopes towards the northwest. Figure 4.4 illustrates the onpost topography at RMA. In general, the area is a treeless plain. As illustrated in the 100-year floodplain map of RMA (Figure 4 2), there are no major drainage channels across the preferred landfill site First Creek is a well-defined channel crossing the RMA to the east of the study area.

The footprints for the three conceptual models should be placed such that run-on to the landfill will be minimized and runoff can be effectively managed As described in Sections 4.2 and illustrated in Figure 4 2, the site is not within the 100-year floodplain. Drainage can be designed to comply with regulations without any significant problems for any of the three proposed landfill volumes There is sufficient area for ditches and other drainage facilities, existing slopes are acceptable or can be amended without excessive amounts of cut and fill, and there is a receiving ditch north of the footprint areas

Run-on to the landfill can be prevented by constructing ditches and/or berms A landfill perimeter berm could serve this purpose

A more detailed description of the topography, and surface hydrology is included in Section 4 2.1 of this report.

5.3.2 Soil and Bedrock

The preferred landfill area is underlain by unconsolidated Quaternary alluvium and the Denver Formation The alluvial soils encountered in the preferred landfill siting area generally consist of the following two types of material (1) clay and sandy clay and (2) sand, silty sand and clayey sand with occasional gravel

The depth to weathered bedrock (Denver Formation) in general follows the surface topography in the study area and ranges from approximately 5 feet to 60 feet. The areas where depth to bedrock is shallowest correspond with areas of high topographic elevation The Denver Formation generally consists of three strata claystone with interbedded siltstone, lignite, and sandstone; sandstone, and lignite/lignitic claystone The alluvium is generally underlain by claystone; however, there are areas in the vicinity of the landfill siting area where Denver Formation channel sand units (sandstone) are in contact with the alluvium Geologic cross sections are presented in Figures 4.21 through 4.28 A more detailed description of the geological and geotechnical study is included in Section 4 4 2 1 of this report

Bedrock channel sands subcrop into the alluvium in three locations in the preferred landfill area, as was noted in Section 4 0 (see Figures 4 29 4.30, and 4 31) Although there are no regulatory siting criteria that require avoiding sand units, siting the landfill such that the base of the landfill were placed above or into the subcrop sands could be a preferential pathway for leachate migration away from the facility If possible, the specific siting should place the base of the landfill into claystone If it is not possible to avoid the sand subcrop areas, the following alternatives are available

- Apply appropriate landfill design technology to minimize the potential impacts associated with these features

- Include wet/dry sand subcrop monitoring points in the facility's monitoring program because the saturated sand units could provide preferential migration pathways

5.3.3 Groundwater

As described in Section 4 4 2.3, there are two groundwater flow systems (the unconfined flow system and the confined flow system) in the preferred landfill area. The unconfined flow system is the primary flow system of concern because it is the first groundwater system encountered beneath the site The unconfined flow system occurs at depths ranging from 20 to 70 feet below ground surface (bgs) The groundwater flow direction in the unconfined flow system is generally to the northwest. A groundwater surface contour map for the preferred area is presented in Figure 4 32 Figure 4 9 presents a contour map showing the depth to groundwater over the preferred area.

Hydrogeologic siting considerations at the preferred landfill site include maximizing the depth to groundwater and evaluating groundwater flow conditions with regard to the long-term groundwater monitoring At the preferred landfill location (western half of Section 25), the depth to groundwater is greatest in the center of the area (Figure 4 32) For long-term groundwater monitoring of the landfill, it is preferable to place the landfill away from areas where groundwater mounds occur because groundwater flows radially from these areas and monitoring for potential leakage is difficult. A groundwater mound exists that straddles the boundary between Sections 25 and 36 (Figure 4 32) For these two reasons, siting the landfill within the central portion of western Section 25 is preferred

5.3.4 Geologic Hazards

The location of the preferred landfill siting area was selected where no geologic hazards such as active faults, unstable areas, or poor foundation conditions are known to exist. Additional study may be required as a component of subsequent engineering design.

5.3.5 Environmentally Sensitive Areas

The location of the preferred landfill siting area was selected to avoid wetlands, floodplains, sites of historical significance, sensitive wildlife habitats, or other environmental sensitive areas

5.3.6 Slope Stability Considerations

Proposed preliminary excavation plans should be developed such that the landfill bottom will be located in or near a competent bedrock formation (Denver Formation) consisting of either shale, sandstone, lignite, or claystone Slope failure within these formations is unlikely, considering the slope geometry and proposed final elevations

5.3.7 Settlement Considerations

The field and laboratory data indicate the alluvial soils are generally medium dense/stiff to very dense/stiff. Assuming landfill geometry consisting of a 30-foot excavation and a 35-foot fill above grade, the net maximum additional surcharge on the subsurface soils will be on the order of 600 pounds per square foot (psf). This magnitude of surcharge may result in settlements on the order of 1/2 inch This estimate should be checked during final design.

5.4 Conceptual Design Alternatives

The conceptual design parameters of a hazardous waste landfill are intended to

- Provide waste containment by separating the waste from the environment
- Prevent contaminant migration by encapsulating the waste
- Confirm facility performance by planning, scheduling, and implementing a periodic site monitoring program

The primary features of a hazardous waste landfill containment system are a liner system and cover (cap) system that completely enclose the waste Containment system components and alternatives are discussed in detail in sections below and are as follows

- Liner Systems
- Leachate Collection and Removal Systems
- Gas Management Systems
- Final Cover Systems
- Performance and Environmental Monitoring System

5.4.1 Liner Systems

Liner systems include multiple layers consisting of a combination of geomembranes/flexible membrane liners (FML), compacted clay liners (CL) or geosynthetic clay liners (GCL), and granular soil or geosynthetic drainage layers The liner system is designed to minimize the release of hazardous waste or hazardous waste constituents to the environment.

Six liner systems were evaluated using EPA's Hydrologic Evaluation of Landfill Performance (HELP) Model, as shown below:

Landfill Liner System Alternatives

Layer (Top to Bottom)	Liner System No. 1	Liner System No. 2	Liner System No. 3	Liner System No. 4	Liner System No 5	Liner System No. 6
1 Geomembrane	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE
2 Barrier	GCL	CL	GCL	GCL	CL	CL
3 Drainage	Geonet	Geonet	Geonet	Geonet	Geonet	Geonet
4 Geomembrane	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE
5 Barrier	GCL	GCL	CL	CL	CL	CL
6 Geomembrane	N.A.	N.A.	N.A	40-mil HDPE	N.A.	40-mil HDPE

HDPE High-density polyethylene
CL 3 feet of compacted clay
GCL Geosynthetic clay liner
N.A Not applicable

Cross sections of each liner system are presented in Figure 5 1 The purpose of the tertiary geomembrane included with Liner System Nos 4 and 6 is to provide a moisture barrier between the moisture-conditioned compacted clay liner and the drier in situ soils The results of the evaluation are presented in detail in Section 5.5.1 1

5.4.2 Leachate Collection and Removal System

Leachate collection and removal will be an integral part of the overall containment system to prevent contaminant migration. The system design will be of sufficient capacity and drainage capabilities to effectively and efficiently manage leachate generated by the landfill

The leachate collection and removal system (LCRS) will be designed so the maximum head pressure on the liner immediately beneath the system will be 12 inches A 12-inch layer of clean sand with a 200-foot maximum drainage length and 2 percent slope was assumed for liner evaluation with EPA's HELP Model as described in Section 5 5 1.1

A leak detection system (secondary leachate collection and removal system), similar to the LCRS will be constructed between the primary and secondary composite liner systems. It will be designed to intercept, collect, and remove any leachate that passes through the primary liner system Therefore, it will serve both as a monitoring system for performance of the primary liner system and a mechanism for removal of leachate The volume of leachate removed from this system can be measured and recorded to evaluate whether leakage through the primary liner exceeds the Action Leakage Rate (ALR)

5.4.3 Gas Management System

The generation of gases from the landfilling of RMA waste is expected to be minimal The wastes will be primarily soils and structural debris with little or no putrescible or decomposable waste material It possible that volatile organic compounds (VOC) could be released by the contaminated soils

Gases generated may be managed using a passive venting system consisting of a granular soil layer and a grid array of collection pipes that will vent gases through the final cover system Gas vents can be monitored for gas quantity and constituents, and can be fitted with VOC control devices, if necessary

5.4.4 Final Cover Systems

Cover (cap) systems include multiple layers, each selected to serve a specific function Layers include an erosion control layer, a water balance/infiltration soil layer, a drainage layer, and a barrier layer Materials that may be used for these layers include geomembranes/FML, compacted clay liners or GCL, and granular soil or geosynthetic drainage layers The cover system is designed to provide a physical barrier for containment of waste and have a low permeability The cover system is intended to minimize percolation of water into the waste, thereby reducing the amount of leachate generated

There are a variety of natural and synthetic materials that may be combined in the design of a cover system Four conceptual cover systems were evaluated using EPA's HELP Model, as shown below

Landfill Cover System Alternatives

Layer	Cover System No. 1	Cover System No. 2	Cover System No. 3	Cover System No 4
1 Erosion Control	Sandy Loam & Gravel	Sandy Loam & Gravel	Sandy Loam & Gravel	Sandy Loam & Gravel
2 Water Balance	Loam	Loam	Loam	Loam
3 Drainage	Geonet	Geonet	Geonet	Geonet
4 Geomembrane	60-mil HDPE	60-mil HDPE	60-mil HDPE	60-mil HDPE
5 Barrier	CL	GCL	CL	GCL

HDPE High-density polyethylene
CL 3 feet of compacted clay

Cross sections of each cover system are presented in Figure 5 2 The results of the evaluation are presented in detail in Section 5 5 1 2

The erosion control layer evaluated was 8 inches thick and will include 50 percent gravel mixed with the sandy loam. This layer will be seeded to produce a protective vegetative cover The water balance layer evaluated was 52 inches thick and will include a 6- to 12-inch thick animal exclusion barrier near the top of the layer. The animal intrusion barrier will consist of rocks or aggregates large enough to prohibit burrowing animals from damaging the underlying liner system A geotextile filter fabric will be installed between the water balance and the drainage layers. The drainage layer will be geonet or gravel The drainage layer material will be selected to provide adequate removal of water. The barrier layer will be a composite of HDPE, and, either 3 feet of compacted clay or a GCL.

5.4.5 Performance and Environmental Monitoring

Monitoring systems will be used to periodically confirm facility performance This will include the monitoring observation wells around the facility, monitoring leachate collection and leak detection systems, monitoring the gas management system, and inspecting the physical plant features. Performance monitoring will be incorporated into the landfill operation and maintenance plan, as described in Section 5.9

Environmental monitoring will be performed as part of the facility performance monitoring A groundwater sampling and analysis plan will be used to establish background groundwater quality Subsequent groundwater monitoring will be compared statistically to background values to identify any significant changes

5.5 Evaluation and Screening of Alternatives

This section presents an evaluation and screening of the conceptual liner and final cover alternatives developed in Section 5 3 Two forms of evaluation are utilized First, an effectiveness evaluation is performed using the HELP Model Second, a cost evaluation is conducted by estimating the unit cost on a square foot basis for each liner and final cover alternative

The final evaluation performed in this section evaluates the overall performance of the selected liner and final cover

5.5.1 Effectiveness Evaluation

The objective of the evaluation and screening of landfill technology alternatives was to develop an appropriate range of waste management options to protect human health and the environment and analyze them in detail with respect to specific site conditions

EPA's HELP Model (Version 3), was used to assess the comparative effectiveness of various cover and liner systems and evaluate waste isolation. The model was also used to predict potential leachate production from a landfill using the best cover and liner design under both "most likely" and "worst-case" scenarios The HELP Model is a quasi-two-dimensional water balance model that predicts the movement of water across, into, through, and out of landfills (EPA, 1994) Version 3 of the model accepts various weather, soil, and landfill design data and uses solution techniques that calculate a water balance The model accounts for components such as surface storage, snowmelt, runoff, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners

The following sections describe the HELP Model effectiveness evaluations for the landfill liner and final cover

5.5.1.1 Landfill Liner System Effectiveness Evaluation

The HELP Model was used to evaluate the comparative effectiveness of six liner alternatives, which consisted of various configurations of double, or composite, liner systems using geomembranes, geonet, or sand drainage layers, and compacted clay or geosynthetic clay barrier layers The six alternatives are shown in Figure 5 1 To approximate conditions within a landfill, HELP Model simulations of the liners consisted of adding additional water on top of the liners until approximately 12 inches of head was built up on the upper drainage layer (leachate collection system) This was done to compare the effectiveness of the liners under maximum head conditions, not to predict actual values of leachate generated by the landfill Thus, the conditions used in this analysis are not expected to exist during the operating, closure, or post-closure care periods of the landfill life.

To generate a consistent amount of hydraulic head in the upper layer (leachate collection system) of each conceptual design, 100 years of synthetic precipitation data were generated by inputting a consistent monthly average value for precipitation. Through iterative simulations, it was concluded that a monthly average of 3 inches (an annual average of 36 inches) was needed to generate a long-term average of approximately 11.8 inches of head in the leachate collection system Evapotranspiration was significantly reduced by setting the evaporative depth to 0 1 inches and the leaf area index to 0 This was done to promote infiltration. All other weather parameters were set consistent with the simulations of the caps

Table 5 3 presents the HELP Model input parameters for the various liner alternatives The liners were configured such that the top layer represents the leachate collection system, which is underlain by an upper liner consisting of 60-mil HDPE. Below these layers is a leak detection system consisting of a sand or geonet drainage layer, which overlies the composite bottom liner system Default HELP Model properties were used for all layers. Initial moisture contents were calculated by the HELP Model

Two simulations were run for each alternative, a most likely case and a worst-case scenario The assumptions used for these scenarios were the same as for the cover simulations, consisting of good installation of geomembranes for the most likely case and poor installation for the worst-case scenario Table 5 4 presents the results of the simulations for the various liner alternatives in terms of the amount of leachate that may pass through the liner system. For the most likely case, all liners performed approximately the same Even with 1 foot of head in the leachate collection system continuously for 100 years, only 2 5 x 10^{-6} in/yr of leachate is predicted to leak through the liners For the worst-case scenarios, leachate infiltration is predicted to range from 0.04 to 0.5 in/yr. Under this scenario, the conceptual liner designs that included geosynthetic clay as the base layer (Liner System Nos 1 and 2) performed better than those with compacted clay or a tertiary geomembrane liner as the base

The similarity of results for conceptual designs under the most likely case indicates that final screening of the conceptual liner designs should consider cost and constructability, rather than potential performance

5.5.1.2 Landfill Cover Effectiveness Evaluation

The HELP Model was used to assess the comparative effectiveness of four cover systems The four alternatives are shown in Figure 5.2 and include various configurations of geomembrane and compacted clay or geosynthetic clay barriers and sand or geonet drainage layers Key input parameters in the HELP Model water balance approach include those associated with precipitation, evapotranspiration, and runoff The performance of each system was simulated using 100 years of weather data synthetically generated by the HELP Model using default Denver data as input. A review of the weather data generated by the HELP Model versus actual Denver data (from Stapleton Airport) from 1905 to 1993 indicates that both the mean and maximum annual precipitation are greater for the synthetic data than the actual data, resulting in a conservative analysis with respect to precipitation

Important parameters associated with evapotranspiration include evaporative zone depth, temperature, solar radiation, length of growing season, and leaf area index. One hundred years of synthetic temperature and solar radiation data were generated using default values for Denver It was assumed that "fair" grass would be maintained on all the cover systems, therefore the Denver default values of evaporative zone depth (28 inches) and leaf area index (2.0) were used Default data for the length of growing season for Denver were used.

The Soil Conservation Service (SCS) curve number, which controls the runoff calculation, was calculated with the HELP Model assuming a sandy loam surface soil with a fair stand of grass, a surface slope of 5 percent, and a slope length of 1000 feet. The final calculated value was 67 6, which limits the overall runoff and indicates significant infiltration.

Table 5 5 presents the HELP Model input parameters for the various cover systems Model default soil property data were used for all layers Each cover consisted of 8 inches of surface soil (sandy loam) underlain by 52 inches of soil (loam) to provide water storage and frost protection. These surface layers overlie either a sand or geonet drainage layer, which sits above a 60-mil HDPE geomembrane The bottom layer of each cover is a compacted clay or geosynthetic clay barrier layer Initial moisture content of each layer was calculated by the HELP Model

Two simulations were performed for each of the cover systems a "most likely" case and a "worst-case" scenario The HELP Model allows for variations in the number of defects a geomembrane liner may contain. This is the key assumption in evaluating each of the cover systems, as they all contain a 60-mil HDPE layer as the primary component. Both simulations assumed that the geomembrane liner contained one pinhole per acre as a manufacturing defect. The most likely scenario assumes that installation of the geomembrane portion of the cover is "good," with three construction defects per acre and good contact between the geomembrane and the underlying soil (better contact means less potential drainage) The worst-case scenario assumes poor construction, with ten construction defects per acre and no contact between the geomembrane and the underlying soil

Table 5 6 presents results of the simulations for the cover systems As shown on the table, all the systems were predicted to perform well for the most likely scenario, with virtually no water (9 6 x 10^{7} to 7.2 x 10^{-6} in/yr) infiltrating through any of the alternatives Landfill Cover System No 4 performed the best at limiting infiltration for the most likely scenario For the worst-case scenario, a wider range of infiltration was predicted, ranging from 0 005 in/yr for Cover System No 4 to

1 119 in/yr for Cover System No 1 A review of the worst-case results indicates that the sand drainage layer is predicted to perform better than the geonet drainage layer (Cover System No 3 versus No 1 and No 4 versus No 2) and the geosynthetic clay barrier performed better than the compacted clay Cover System No 4, which contained both a sand drainage layer above the geomembrane and a geosynthetic clay barrier below the geomembrane, performed the best in the worst-case scenario

In conclusion, the calculated infiltration results for all the cover systems evaluated are similar and very low The similarity of results for the alternatives under the most likely case indicates that final screening of the cover systems should consider cost and constructability, rather than potential performance

5.5.2 Cost Evaluation of Landfill Liner and Cover Systems

A unit cost was estimated for each liner system and cover system by estimating unit costs for each system component, and adding them together Tables 5 7 and 5 8 present the unit cost estimates for each liner system and cover system, respectively

As was noted in the previous sections, the liner and covers systems generally performed equally well and should be selected on the basis of cost and constructability The constructability of each component will also be reflected in the overall unit cost (i e., the more difficult/labor intensive it is to install, the higher the unit cost).

The total unit cost estimate for the liner systems ranged from \$3.00 to \$6 40 per square foot. Liner System No 1, which included a GCL instead of a compacted clay liner, was the most cost-effective

The total unit cost estimate for cover systems ranged from \$3 60 to \$4 55 per square foot. Similarly, the cover system that utilized the GCL was more cost-effective The sand drainage layer performed better than the geonet for relatively the same cost, therefore, Cover System No 4 was more cost effective and efficient.

5.5.3 Overall Landfill Performance Evaluation

The analysis of potential effectiveness of the cover and liner systems indicates that, in general, the various alternatives should perform in similar fashion. Two subsequent HELP Model simulations were performed using Cover System No 4 and Liner System No 1, both of which were the most cost-effective and predicted to perform well under worst-case conditions, to estimate the potential long-term leachate production from the landfill The waste portion of the landfill was assumed to be 65 feet thick and was simulated using default characteristics for municipal refuse (HELP Model default number 19, which allows for channeling and dead zones) The simulations were performed using the same weather parameters as the cap screening simulations The most likely and worst-case scenarios were simulated as before

Results of the simulations are presented in Table 5 9 As shown in the table, extremely small rates of potential release are predicted for both the most likely ($2\ 6 \times 10^{7}$ in/yr) and worst-case ($1\ 6 \times 10^{-3}$ in/yr) scenarios

An evaluation was performed to assess whether leachate produced at these extremely small rates could potentially move through the vadose zone beneath the landfill to the water table To estimate advective travel times of unsaturated flow produced by the leachate predicted from the HELP Model, the methodology incorporated into EPA's RITZ Model (EPA, 1988) was used The equation for advective water movement in the unsaturated zone is

$$V_a = V_d/\theta$$

$$\theta = \theta_s[V_d/k_s]^{1/(2b+3)}$$

where

V_a = Advective water velocity

V_d = Infiltration or recharge rate

θ = Long-term soil water content at recharge rate V_d on a volume basis

θ_s = Saturated water content of the soil on a volume basis

k_s = Saturated hydraulic conductivity of the soil

b = Clapp and Hornberger, 1978, soil constant

General soil data collected during Task 93-03 were reviewed to estimated parameters representative of the vadose zone beneath the landfill The following parameters were used

θ_s = 0 40 (average value for clay/silt material)

k_s = ranges from 4 25 ft/day to 42 5 ft/day

b = 7 75 (Clapp and Hornberger, 1978, silty clay loam)

V_d = 0.00165 in/yr, or 3.77×10^{-7} ft/day (worst-case)

Using these parameters, potential travel times through the vadose zone are estimated at $8\ 29 \times 10^{-4}$ ft/yr to $9\ 37 \times 10^{-4}$ ft/yr, depending on saturated hydraulic conductivity At these rates, it would take from 1000 to 1200 years for soil water in the vadose zone to move downward one foot. The landfill configurations being evaluated contain at least 10 feet of vadose zone between the base of the liner and the water table

5.6 Evaluation of Facility Layout and Material Quantities

This section presents an evaluation of a conceptual facility layout and material quantities based on the three conceptual landfill volume requirements described in Section 5 1.2 and the site-specific considerations and limitations presented in Section 5.3

5.6.1 Conceptual Facility Layout

The size of the landfill facility will depend on the remedial alternative selected and the corresponding volume of waste generated for that alternative The landfill footprints for the three proposed conceptual models are shown in Figures 5 3, 5 4, and 5 5 The landfill footprint in this discussion is the maximum lateral extent of waste, which nearly coincides with the top of the landfill's interior, below-grade slope The dimensions of each footprint are as follows

Conceptual Model No	Dimensions (feet)	Acres	Total Landfill Volume (CY)	Waste Volume (CY)
1	900 x 900	19	1,200,000	1,000,000
2	1200 x 1300	36	2,760,000	2,300,000
3	1650 x 2300	87	7,200,000	6,000,000

The excavation depth for each landfill scenario was assumed to be an average of 30 feet below the existing ground surface, with a maximum liner thickness of 5 feet, including the leachate collection and removal system Cross sections showing the approximate limits of excavations for each scenario are presented in Figures 5 6 through 5 9 Conceptual Models 1 and 2 are similar in that the base of each is placed within the alluvium and both footprints avoid areas of sand subcrops Conceptual Model 3 is a much larger footprint and the base of excavation is within the weathered Denver Formation. As illustrated in Figures 5 6 through 5 9, Conceptual Model 3 is cut into both the A sand and the IU sand Although avoidance of the subcropping sand units is preferable, it is only possible with the smaller two configurations

Excavation sideslopes were assumed to be 3 horizontal to 1 vertical (3H 1V) to calculate airspace volumes below grade A sideslope of 6H 1V and a 35-foot average waste height at the top of the sideslope was used to calculate the airspace above grade A containment dike, averaging approximately 5 feet above grade, will be initially constructed around the excavation perimeter A series of similar dikes will be constructed in a stair-step fashion as the landfilling operations proceed above grade Typical plan views of the excavation and final cover are presented on Plates 5.1 through 5 6 Plate 5 7 illustrates the depth of excavation and depth to groundwater for the three conceptual models The survey data used in these plates are based on the 1983 horizontal datum and 1988 vertical datum In all three scenarios, the depth to groundwater beneath the base of excavation is no less than 10 feet.

As is shown on Plates 5 2, 5 4, and 5 6, the 6H 1V portion of the final cover exceeds the recommended maximum top slope of 5 percent presented in EPA's Technical Guidance Document Final Covers on Hazardous Waste Landfills and Surface Impoundments (EPA, 1989) The guidance does allow for alternative designs provided that the alternative design fulfills the applicable regulatory requirement. The purpose of maintaining a final covers slope below 5 percent is to control erosion. The allowable erosion control rate listed in the guidance is less than 2 tons/acre/year. Thus, to proceed with final design using a 6H 1V sideslope, an appropriate erosion control demonstration would be required

5.6.2 Evaluation of Slope Stability and Slippage

The slope stability evaluation described below indicates that the planned landfill can be constructed at the site if a final geotechnical investigation is performed and the recommendations contained therein are addressed in the final landfill design. The final investigation should refine and expand upon the testing and analyses presented in this report, and consider in its analyses any changes from these conceptual models

Since slope failure within the Denver Formation is not considered likely, the critical area for analysis are with the thickest alluvium deposits Boring SAB12894 was selected for the subsurface profile analysis This boring consists of 45-foot-thick interbedded strata of sandy lean clays and clayey sands Standard Penetration Test (SPT) blow counts ranged from 6 per foot to 20 per foot for these soils, which are underlain by sandstone with blow counts greater than 50 per foot.

Published information about relationships between SPT blow counts and soil strength parameters (cohesion and angle of internal friction) were used to obtain theoretical values and compare them with the limited laboratory strength test data and select input parameters for stability analyses Because of the generally dry condition of the alluvial soils, the field blow count values may indicate higher soil strengths than can be expected under wet or saturated conditions; therefore, the soil strength parameters were conservatively interpreted The following soil parameters were selected in the slope stability analyses performed using the subsurface profile from Boring SAB12894:

Depth Interval (feet)	Cohesion (psf)	Friction Angle (Degrees)
0 to 8	500	10
8 to 26	1,500	15
26 to 45	1,000	15
Below 45	4,000	35

The conceptual design cross section consists of 3.1 cutslopes (horizontal to vertical), with the maximum landfill bottom approximately 60 to 70 feet below existing grade However, the typical average excavation depth is anticipated to be approximately 30 feet. A 5-foot-high (average) soil berm will be constructed at the top of the cutslopes Upon closure, the top of the landfill sideslope will average about 35 feet above existing grade

The cutslope cross section with the 5-foot berm in place was analyzed for stability This is a short-term condition and will occur before any waste is placed in the landfill In addition, a maximum flood elevation (to the top of the 5-foot berm) was assumed for this condition to represent flood stage The long-term condition (i.e , with the waste and cap in place) is expected to have safety factors comparable to or higher than those computed for the short-term conditions

The following factors of safety were obtained for the three conditions analyzed. Because of the small difference in computed values, they are shown in two decimal places Typically, the computed factors of safety are shown in one decimal place

Condition	Factor of Safety
Short-term without flood	2 86
Short-term with flood	2 83

These safety factors are greater than 1 5, which is commonly considered as the lowest acceptable safety factor for static conditions The landfill cross section analyzed therefore has adequate factors of safety for anticipated conditions

The cover and liner systems can be designed to avoid potential slippage along component interfaces Material such as textured geomembranes and geonet with geotextile bonded to both sides can be specified for use, if required These materials can provide friction factors in excess of 14 degrees (25 percent or 4H 1V) at all interfaces Slopes that are too steep to provide an adequate factor of safety against slippage can be constructed with proper design (i.e , use of an anchor trench)

5.7 Material Quantities and Availability of Onpost Materials

Material quantities were estimated for soils and landfill liner and cover system components The soil quantities include volume estimates for low permeability soils and structural fill soils Surface areas were calculated for the liner and cover systems Estimated quantities of soils required for landfill construction were then compared to estimated volumes of onpost materials

5.7.1 Material Quantities

Soil requirements will depend on the selected liner and cover systems developed during the design phase of the project To provide a conservative estimate of soil requirements, it is assumed that

- A 30-inch compacted clay liner will be incorporated in the final cover
- 12 inches of structural fill will be placed to achieve a suitable subgrade under the final cover
- A 12-inch protective soil layer will be placed over the LCRS
- The primary and secondary barrier layers in the liner will use 36 inches of clay
- The liner system will be underlain by a 12-inch structural fill (prepared subgrade)

Table 5 10 presents the estimated soil material requirements for each conceptual landfill model based on the above assumptions

The surface area to be lined was calculated for each conceptual landfill model assuming an excavation depth of 30 feet with sideslopes of 3H.1V The surface area that will require final cover was calculated assuming a waste height of 35 feet above grade and sideslopes of 6H 1V The estimated liner and cover surface areas are presented below

Estimated Liner and Cover Surface Areas

Conceptual Model No.	Liner Area (square feet)	Cover Area (square feet)
1	850,000	850,000
2	1,600,000	1,600,000
3	3,900,000	3,900,000

5.7.2 Availability of Onpost Materials for Landfill Construction

Ninety-eight soil borings were drilled as part of the FS Soils Support Program (HLA, 1995a) to identify potential borrow sources for low permeability and/or structural soils For the purpose of landfill liner/cap construction, low permeability soils are those that can be compacted at a specified density and moisture content to achieve a hydraulic conductivity of equal to or less than 1×10^{-7} cm/s The results of the materials feasibility study, presented in Section 3.0, indicate that soil from the two identified onpost borrow areas tested can be used to construct clay liners or caps that achieve hydraulic conductivity requirements of less than 1×10^{7} cm/s

In the FS Soils Support Report (HLA, 1995a), a total of four potential low permeability onpost soil borrow areas and two onpost structural soil borrow areas were identified The soil borrow areas and estimated volumes are presented below

Onpost Soil Borrow Areas and Estimated Soil Volumes

Area	Low Permeability Soil (cubic yards)	Structural Fill (cubic yards)	Location
Area 1	1,247,000	--	Southern half of Section 24
Area 2*	768,000	--	SE corner of Section 25 and NE corner of Section 36

Area	Low Permeability Soil (cubic yards)	Structural Fill (cubic yards)	Location
Area 3	5,454,000	--	Northern half and SE quarter of Section 29
Area 4	4,999,000	--	SW and NE quarter of Section 20
Area 5	--	8,889,000	Section 34
Storage Area	--	180,000	NE Section 31

* Area 2 is not recommended as a borrow area because of the limited volume of low permeability soil available and because the site is located in the biota exceedance area The biota exceedance area includes the top 2 inches of soil

Based on the above estimates, approximately 11,700,000 CY of low permeability soil have been identified along with 9,069,000 CY of structural fill. Additional low permeability and structural fill soils may be available from excavation of the landfill

The approximate amount of material available from each of the conceptual landfill model excavations is as follows

Conceptual Model Number	Estimated Total Excavation (CY)	Estimated Percent Low Permeability Soil % (CY)	Estimated Percent Structured Fill % (CY)
1	860,000	75 (645,000)	25 (215,000)
2	1,380,000	60 (828,000)	40 (552,000)
3	2,850,000	50 (1,425,000)	50 (1,425,000)

Based on this analysis, it appears that sufficient onpost soil from borrow areas and the landfill excavation exists to meet the construction requirements for even the largest landfill (Conceptual Model 3) Additional low permeability soil and structural fill will be required for implementing the landfill/caps remedial alternative According to the estimates provided in the Proposed Final DAA (Ebasco, 1994) and updated by RUST, E&I (1995), approximately 2,500,000 CY of low permeability soil and 13,000,000 CY of structural fill will be required to implement the preferred remedy (landfill/caps) To meet the volume of structural fill required, expansion of the proposed borrow areas identified in the FS Soils Support Report may be required (HLA, 1995a) Further soil testing will be required to expand the proposed borrow areas

5.8 Cost Estimates and Construction Schedule

This section presents preliminary cost estimates for construction and annual operation and maintenance for the three conceptual landfill models evaluated for this site feasibility study A conceptual construction schedule was also prepared for the initial phase of landfill cell construction.

5.8.1 Construction Cost

The preliminary construction cost estimates were prepared to be accurate within the typical feasibility study range (plus 50 percent to a minus 30 percent) Table 5 11 presents a construction cost summary for each landfill model The table presents costs associated with the various elements of landfill construction. Estimated costs listed in this table reflect current present value costs to construct or install the listed items Appendix H details the estimated quantities, unit rates, and assumptions used in developing Table 5 11 Based on the total estimated costs show in Table 5 11, the estimated construction cost per cubic yard of waste disposal capacity is approximately

Conceptual Model 1 $12 50 per cubic yard

Conceptual Model 2 $10 00 per cubic yard

Conceptual Model 3 $9 00 per cubic yard

Actual landfill airspace may be constructed in a phased sequence corresponding to the estimated annual waste generation rates described in Table 5 2, in which case, landfill space would only be constructed on an annual basis, as needed If this approach is implemented, the total cost of landfill construction would increase over the estimates shown in Table 5 11 The increase would occur as a result of inflation, multiple contractor mobilization/demobilization charges, and possible increases in unit cost because of reduced volumes of materials purchased or placed at one time In addition, landfill capping cannot occur until the landfill has been filled to cap subgrade

The following discussion presents a construction sequence that reflects how construction might proceed

Initial Construction

Construct or install maintenance building, office building, access roads, perimeter security fence, parking, leachate management system, groundwater monitoring wells

Perform initial excavation (two years capacity) and construct first portions of drainage, sumps, header pipe, pumps, prepare subgrade, place liner and protective cover, construct storm-water control system, and commence waste placement.

Operational Years

Construct additional portions of drainage, sumps, header pipe, pumps, excavate soil, prepare subgrade, place liner and protective cover, construct storm-water diversion berm, and place cover on waste as cell fills

Construct cover system over areas of the landfill that are filled to capacity

Last Year

Construct remaining portions of drainage, sumps, header pipe, pumps, prepare subgrade, place liner and protective cover, construct storm-water diversion berm, and place cover on waste as cell fills

Construct remaining portion of cover system over closed landfill

5.8.2 Annual Operation and Maintenance Costs

Table 5 12 presents a summary of estimated operation and maintenance (O&M) costs for each of the landfill conceptual models under both restricted and unrestricted funding scenarios The detailed annual O&M estimate is presented in Appendix H The O&M estimates were prepared at an FS level (plus 50 percent to minus 30 percent)

Major assumptions made in preparing the O&M estimate include

1 Major heavy equipment is purchased for O&M functions and has a six-year replacement life and $0 salvage value at six years

2 Leachate and contaminated storm water is generated at a rate of 100,000 gallons per acre of open cell and is disposed at DuPont's Chambers Works in Deep Water, New Jersey

3 A 3 percent rate of inflation will occur for all labor, equipment purchase, and equipment O&M

4 The daily waste volume that must be handled is equal to the landfill volume divided by the landfill life in years, divided by 250 operating days per year. Waste inflow is uniform throughout the life of the landfill

5 The landfill life is obtained from information in the DAA that is summarized in Table 5 2

6 Borrow soil requirements for operational cover equal 20 percent of the waste volume and will be obtained from cell excavation stockpiled adjacent to the landfill

7 The CERCLA Wastewater Treatment Facility will treat water from decontamination procedures

8 Unit costs for equipment O&M include fuel, tires, trucks, and routine maintenance.

9 Groundwater monitoring costs equal $10,000 per well per year

The lowest estimated O&M costs, $7 per CY, occur for Conceptual Model 3 with unrestricted funding The highest estimated O&M costs, $18 per CY, occur for Conceptual Model 1 with restricted funding

Estimated labor costs are typically the largest component of the total estimated O&M cost over the life of the landfill However, leachate disposal costs are significant and, in the case of Conceptual Model 3, exceed labor costs

As described in the assumptions listed above, leachate is projected to be generated in portions of the landfill that have not received final cover at a rate of 100,000 gallons per acre per year This assumption is based on actual leachate production rates for 1994 at the Highway 36 Hazardous Waste Disposal Facility Leachate disposal was assumed to take place at an offsite facility. Based on the estimated volume of leachate that will be generated and the cost of disposal, onsite treatment and disposal may be more economical and should be evaluated further

5.8.3 Construction Schedule

Figure 5.10 presents a conceptual construction schedule for cell development of an approximate 200,000 CY module that could be applied to any of the three conceptual landfill models. The schedule can be refined to be more exact once the size, operating life, and projected daily waste volumes are selected

5.9 Operation and Maintenance Plans

Operation plans should be developed for the landfill facility to help assure that operations will conform to regulatory requirements and be consistent with the engineering design of the facility These plans will provide for safe operation but, in case of accidents, the plans will include contingency plans and emergency procedures Maintenance plans should also be developed so that the facility can be properly maintained during its operating life and throughout the post-closure The specific plans that must be developed and their content and approach will depend on the final determination of applicable regulatory requirements

5.9.1 Operation Plans

A comprehensive site operating plan should be prepared for the facility Major components of the plan will include the following elements

- Construction and construction quality control (CQC) requirements
- Daily operations
- Periodic operational activities
- Specific plans

The construction and CQC section will discuss the type of future construction required throughout the life of the landfill facility This will help guide the operator from the initial construction through the completion of construction and eventual closure of the facility Specific discussion will focus on the need to monitor waste generation and the progress of the remedial alternative Monitoring the waste generation rate is needed to predict the final quantity of waste to be received at the landfill, and when that final waste will be placed into the landfill Guidance will be provided for implementing partial closure of areas of the landfill that reach final grade, and for final closure following placement of the last quantity of waste to be received

The daily operations section of the plan will discuss accepting waste and inspection procedures, placing waste, containing or covering waste, and any other activities that are part of the daily operating routine Periodic activities will be discussed in the site operating plan including inspection, monitoring, and maintenance functions These will be developed to be specifically applicable to this landfill facility

Specific plans that should be developed are discussed in the following sections These plans are related to regulatory criteria for the operation and maintenance of a hazardous waste land disposal facility Such plans are normally prepared prior to the startup of waste management activities, and are subject to change at any time throughout the active life of the facility Changes may be made in these plans to reflect the availability of new construction materials or waste management techniques, changed conditions or operating practices at the facility, or for similar reasons

5.9.2 General Waste Analysis

Before disposing of any hazardous waste in the landfill, a representative sample of the waste stream should be obtained for chemical and physical analysis This analysis provides information necessary to properly store or dispose of the waste and is be performed on each waste stream that is to be accepted at the landfill The analysis is repeated when necessary to assure that the analysis is accurate and up-to-date Periodically, a further confirmatory sample of the waste stream being brought into the facility will be analyzed to determine its continuing conformance with the results of previous analyses

The waste analysis plan for the onpost landfill at RMA should account for the extensive sampling and site characterization that has already taken place, and minimize the amount of new sampling and analysis required prior to waste receipt.

5.9.3 Security Plan

A security plan should be developed to prevent unknowing entry and minimize the possibility of unauthorized entry of persons or livestock onto the active portion of the facility This plan will include provisions for a barrier system (e g , a security fence in good repair) and a means to control entry, such as a lockable security gate Signs will be posted at the entrance and at periodic intervals along the security fence to warn individuals about the potential danger associated with trespassing and forbidding unauthorized access to the facility The security plan should take into account the overall security system for RMA.

5.9.4 Inspection Plan

A written inspection plan should be developed to contain all the inspection requirements necessary to periodically evaluate the condition of the facility and identify need for repairs, replacement, or restoration. The inspection plan will detail the specific inspection procedures and frequency of inspecting all parts of the facility The plan will also provide for a recordkeeping system that includes an inspection form to be prepared for each inspection activity The inspection form will provide for recording adverse conditions discovered as a result of the inspection and a method of initiating appropriate followup to assure the necessary action is taken.

5.9.5 Personnel Training

A written personnel training plan should be prepared for the facility This plan will discuss, on a position-by-position basis, the training requirements for all personnel engaged in the management, operation, and maintenance of this landfill facility The plan will describe the necessary levels of pre-employment training as well as any periodic or ongoing training required for specific categories of employees Records of the personnel training program will be maintained to demonstrate compliance with these requirements

5.9.6 Preparedness and Prevention Plan

This plan will relate to the existing the RMA Contingency Plan and will focus on operations and procedures to minimize the possibility of a fire, explosion, or any unplanned sudden or non-sudden release of hazardous waste or hazardous waste constituents to the environment. This plan would provide specific information regarding equipment such as internal communications, alarm systems, external communications, fire extinguishers, spill containment, and fire control systems The plan would establish testing and maintenance requirements for related equipment. All personnel in the operations area of the facility will have access to communications, response, and alarm systems Arrangements will be made with local authorities to provide standby or backup support in case the emergency is of such magnitude that outside help is required

5.9.7 Contingency Plan and Emergency Procedures

A site-specific contingency plan will be developed as an appendix to the overall RMA Contingency Plan to minimize hazards to human health or the environment from fires, explosions, or any unplanned sudden or non-sudden release of hazardous waste or hazardous waste constituents This plan is a supplement to the Preparedness and Prevention Plan, and provides for emergency action in the event that an emergency exists in spite of efforts to prevent it. The contingency plan will contain emergency procedures to be followed in the event of any one of a number of potential emergencies that could occur at the facility The training plan described above will include provisions for training in both preparedness and prevention, and in emergency response

5.9.8 Manifest System, Recordkeeping, and Reporting

It is not anticipated that a manifest system for waste shipment will be required for this facility since it will not receive any hazardous waste from offsite sources

A full set of operating records should be routinely prepared and maintained at the landfill facility These records should be maintained at the facility until closure The records should describe the quantity and type of waste received, the date of receipt, and the location of specific wastes stored in the landfill The records should also contain results of waste analyses, inspection results, the details of any incident requiring implementing the contingency plan, all monitoring, testing, and analytical data, and other records that are either pertinent to the facility operation or are required by federal, state, or local regulations

Reports of landfill operation should be prepared to comply with current federal or state regulations

5.9.9 Maintenance Plan

A facility maintenance plan should be prepared that requires the repair or replacement of any aspect of the landfill facility that becomes unserviceable during the operating life of the facility or during post-closure If any mechanical equipment is incorporated into the operation of the facility, such as emergency response equipment or dedicated pumps in groundwater monitoring wells, the manufacturer's recommended maintenance procedures will be obtained and incorporated into the maintenance plan. The plan would require that the specified maintenance be performed in accordance with the manufacturer's recommendations The maintenance plan should be related to the inspection plan discussed above because inspection activities may identify the need for certain maintenance operations Maintenance activity that requires repair or replacement of material or equipment will be entered into the operating record of the facility This record will enable the operator of the facility to identify maintenance activities that occur at an above average frequency This in turn could identify a need to employ different material or equipment.

5.9.10 Closure and Postclosure Care Plans

A closure plan and a postclosure care plan may be required for the landfill facility These plans will incorporate certain operation and maintenance activities These activities will become part of the overall maintenance plan at the time of landfill closure

5.10 Site Feasibility Summary and Conclusions

This section provides a summary and conclusions of the Site Feasibility Study with respect to the construction of a hazardous waste landfill at this site.

Regulatory Criteria

Regulatory criteria that apply to siting a landfill in Colorado were described in Section 4 2 and will likely form the basis for siting a facility under the various regulatory scenarios RCRA as a permitted facility, RCRA as a CAMU, or an IRA under CERCLA.

Site-Specific Considerations and Limitations

Site-specific considerations and limitations were reviewed to evaluate the potential impact on construction of a hazardous waste landfill. Site-specific climate, topography, and surface hydrology should not impact landfill construction. Based on the sand channel subcrop maps developed as part of the Area FS, areas exist in the vicinity of the landfill siting area where Denver Formation channel sand units are in contact with the alluvium The subcropping sand units should be avoided if possible The hydrogeologic site considerations include maximizing the depth to groundwater and placing the landfill away from areas where groundwater flows radially The depth to groundwater is greatest at the center of the preferred site A groundwater mound exists between Sections 25 and 36 (Figure 4 32) Siting the landfill within the central portion of western Section 25 is preferred No geologic hazard or environmentally sensitive area considerations were noted in this study, but additional study may be required for siting and design. Slope failure within competent bedrock of shale, sandstone, lignite, or claystone is unlikely considering the proposed landfill geometry The settlement resulting from a 30-foot excavation and 35-foot fill above grade may be on the order of one-half inch and should not impact construction or O&M of the landfill This estimate should be reevaluated during design.

Conceptual Landfill Design Alternatives

Conceptual design alternatives were developed for liner systems, leachate collection and removal systems, gas management systems, final cover systems, and performance of an environmental monitoring system Six liner system alternatives were developed A leachate collection and removal system consisting of 12 inches of sand with a 200-foot drainage length and 2 percent slope was proposed Gas generation from landfilling of RMA waste is expected to be minimal Gases generated

5.10.1 Summary

The Site FS included a review and evaluation of waste types, volumes, and generation rates, regulatory criteria, site considerations and limitations, conceptual landfill design alternatives, evaluation and screening of the alternatives, facility layouts, material quantities and onsite availability, construction cost estimates and schedules, and operation and maintenance requirements Three conceptual landfill models were evaluated for this Site FS to account for the potential variation of waste volumes to be generated based on the selected remedial action alternative The siting of the proposed landfill footprints was based on site-specific considerations and limitations including topographic, geologic, and hydrogeologic conditions

5.10.2 Conclusions

The objective of this Site FS was to evaluate whether a RCRA Subtitle C hazardous waste landfill of sufficient capacity could constructed at the preferred site that would meet applicable federal, state, and local regulatory requirements The site-specific requirements were reviewed and evaluated in a logical sequence

Waste Data

Review and evaluation of the waste data yielded the following conclusions

- Contaminated materials that may be landfilled can be categorized as contaminated soil, soil and debris treated by caustic washing, soil treated by thermal desorption, and structural debris

- The landfill waste volume depends on the selected remedial action alternative For purposes of this report, waste volumes of 1,000,000 CY, 2,300,000 CY (the preferred sitewide alternative in the DAA), and 6,000,000 CY were used to account for projected minimum and maximum waste volumes

- The total landfill volumes used for three conceptual models included a 20 percent volume increase over the needed waste volume to account for operational cover (1,200,000 CY, 2,760,000 CY, and 7,200,000 CY, respectively)

- Waste generation rates were estimated to be in the range of 98,000 CY to 1,100,000 CY of material per year without a funding limit, and 37,000 to 280,000 CY of material per year assuming $100 million annual funding limit.

may be managed using a passive venting system consisting of a granular soil layer and grid array of collection pipes that will vent gases through the final cover system Four final cover systems alternatives were developed Environmental monitoring will be performed as part of the facility performance monitoring

Conceptual liner and final cover alternatives were evaluated for effectiveness using the HELP model and evaluated for cost by estimating the unit cost on a square foot basis Using the HELP Model to simulate the most likely construction quality scenario, all liners performed about equally For the worst-case scenarios, leachate infiltration is predicted to range from 0 04 to 0.5 inches per year (in/yr) The conceptual liner designs that included geosynthetic clay as the base layer (Liner System Nos 1 and 2) performed better than those with compacted clay or a tertiary geomembrane liner as the base The final screening of the conceptual liner designs should consider cost and constructability rather than potential performance because performance results for conceptual liner designs are so similar

The calculated infiltration results for all the final cover systems evaluated are similar and very low All the systems are predicted to perform well for the most likely scenario, with very limited water infiltrating through the cover For the worst-case scenario, infiltration ranged from 0 005 in/yr to 1 119 in/yr Cover System No 4 performed the best in worst-case scenario The similarity of performance results for the cover alternatives indicates that final screening of the cover systems should consider cost and constructability rather than potential performance

The total unit cost estimate for the liner systems ranged from $3 00 to $6 40 per square foot. Liner System No 1, which included a GCL instead of a compacted clay liner was the most cost-effective The total unit cost estimate for the cover systems ranged from $3 60 to $4 55 per square foot. Similarly, the cover system that uses the GCL was more cost-effective The sand drainage layer performed better than the geonet for relatively the same cost, therefore, Cover System No 4 was more cost-effective and efficient

Evaluation and Screening of Alternatives

The overall landfill performance was evaluated using the HELP Model to assess the potential effectiveness of the cover and liner systems Cover System No 4 and Liner System No 1, both of which were the most cost-effective and predicted to perform well under worst-case conditions, were used to estimate the long-term leachate production from the landfill. Extremely small rates of potential release are predicted for both the most likely (2 6 x 10^{7} in/yr) and worst-case (1.6 x 10^{-3} in/yr) scenarios EPA's RITZ Model was used to estimate advective travel times of unsaturated flow produced by the leachate predicted from the HELP Model Potential travel times through the vadose zone are estimated at 8 29 x 10^{-4} feet per year (ft/yr) to 9.37 x 10^{-4} ft/yr, depending on the saturated hydraulic conductivity The landfill configurations being evaluated contain at least 10 feet of vadose zone between the base of the liner and the water table At the estimated rates, it would take from 1000 to 1200 years for soil water in the vadose zone to move downward 1 foot

Facility Layout

Conceptual facility layouts and material quantities were based on the three conceptual landfill volume requirements (1,200,000 CY, 2,760,000 CY, and 7,200,000 CY) and the site-specific considerations and limitations The areas of each footprint are as follows 19 acres (1,200,000 CY), 35 acres (2,750,000 CY), and 87 acres (7,200,000 CY) The excavation depth for each landfill scenario was assumed to be an average of 30 feet below the existing ground surface, with a maximum liner thickness of 5 feet. Conceptual Models 1 and 2 are placed within alluvium and both footprints avoid sand subcrops The base of Conceptual Model 3 is much larger than Models 1 and 2 and is placed within the weathered Denver Formation. Conceptual Model 3 is cut into subcropping sand Units A and 1U Although avoidance of the subcropping sand units is preferable, it is only possible with Conceptual Models 1 and 2 The excavation sideslopes were assumed to be 3H.1V to calculate airspace volumes below grade A sideslope of 6H 1V was used to calculate the airspace above grade

To proceed with final design using a 6H 1V sideslope, an appropriate erosion control demonstration would be required

The slope stability evaluation indicated that the planned landfill can be constructed at the site if a final geotechnical investigation is performed and the recommendations contained therein are addressed in the final landfill design. The final investigation should refine and expand upon the testing and analyses presented in this report, and consider in its analyses any changes from these conceptual models

Material Quantities and Availability

Material quantities were estimated for low-permeability soils and structural fill soils used in landfill liner and cover system components The quantities of soils required for landfill construction were then compared to estimated volumes of onpost materials Conceptual Models 1, 2, and 3 required 270,000 CY, 510,000 CY, and 1,235,000 CY of clay soil, respectively, and 296,000 CY, 640,000 CY, and 1,635,000 CY of structural fill soil, respectively

The surface area to be lined was calculated for each conceptual landfill model assuming an excavation depth of 30 feet with sideslopes of 3H 1V The surface area for final cover was calculated assuming a waste height of 35 feet above grade and sideslopes of 6H 1V Based on these assumptions, the estimated surface area to be lined and the surface area to be covered are approximately the same Both the liner and cover areas for Conceptual Model 1 are 850,000 square feet, for Conceptual Model 2, both areas are 1,600,000 square feet, and for Conceptual Model 3, both the liner and cover areas are 3,900,000 square feet.

Approximately 11,700,000 CY of low-permeability soil and 9,069,000 CY of structural fill soil have been identified at RMA during borrow area investigations Additional low-permeability soil and structural fill soil may be available from the landfill excavation. Based on the estimated volumes of onpost soil from borrow area and the landfill excavation, it appears that sufficient onpost soil exists to meet the construction requirements for even the largest landfill (Conceptual Model 3)

Construction Cost Estimates and Schedules

Cost estimates for construction and annual operation and maintenance for the three conceptual landfill models were prepared to be accurate within plus 50 percent to a minus 30 percent. Based on the total estimated costs (shown in Table 5.11), the estimated construction cost per cubic yard of waste disposal capacity for Conceptual Models 1, 2, and 3 are $12.50 per CY, $10.00 per CY, and $9 00 per CY, respectively The estimated total construction cost for Conceptual Models 1, 2, and 3 are $12,500,000, $22,500,00, and $52,500,000, respectively If landfill space is constructed on an annual basis as needed, then landfill construction costs would increase from the estimates presented

Annual O&M costs were prepared at a plus 50 percent to minus 30 percent range Estimates of yearly O&M costs were made for each conceptual model using both restricted and unrestricted funding The landfill life and average yearly O&M costs for restricted funding for Conceptual Models 1, 2, and 3 are 12 years and $1,487,000/yr, 10 years and $2,440,000/yr, and 16 years and $3,109,000/yr, respectively The landfill life and average yearly O&M costs for the unrestricted funding scenario for Conceptual Models 1, 2, and 3 are 4.5 years and $2,294,000/yr, 2 5 years and $5,820,000/yr, and 9 years and $4,460,000/yr, respectively

The lowest O&M costs, $7 per CY, occur for Conceptual Model 3 with unrestricted funding The highest O&M costs, $18 per CY occur for Conceptual Model 1 with restricted funding

A conceptual construction schedule for cell development of an approximate 200,000 CY module that could be applied to any of the three conceptual landfill models was prepared (Figure 5 10). The 200,000 CY module would take approximately 34 weeks to prepare

Operation and Maintenance Plans

A comprehensive site operating plan should be prepared for the facility and should include the following elements

- Construction and CQC requirements
- Daily operations
- Periodic operational activities
- Specific plans

Additional necessary plans include waste analysis, security, inspection, personnel training, preparedness and prevention, contingency and emergency procedures, manifest system, recordkeeping and reporting, maintenance, and closure and postclosure care

Based on the results of the Site FS presented in this report, it is feasible to construct a RCRA Subtitle C hazardous waste landfill of sufficient capacity at the preferred site that would meet the applicable federal, state, and local regulatory requirements

Table 5.1: Waste Volume Estimates Rocky Mountain Arsenal Site Feasibility Study

Estimated Waste Volume by Type	Remedial Action Alternative				
	Caps/Covers	Landfill/Caps	Landfill	Consolidation/Caps/Treatment/Landfill	Caps/Treatment/Landfill
Contaminated Soil	260 000	2,100 000	3,600,000	880,000	3,100,000
Treated Soil/Debris Caustic Washing	4,000	5,000	7,000	5,000	7,000
Treated Soil Thermal Desorption	0	0	0	160,000	1,100,000
Structural Debris Landfilled	180,000	180,000	180,000	180,000	180,000
Total Volume Landfilled	440,000	2,300,000	3,800,000	1,200,000	4,400,000

All amounts are in cubic yards

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Table 5.2: Waste Generation Rate Estimates Rocky Mountain Arsenal Site Feasibility Study

Estimated Waste Volume by Type	Remedial Action Alternative				
	Caps/Covers	Landfill/Caps	Landfill	Consolidation/Caps/ Treatment/Landfill	Caps/Treatment/Landfill
Total Volume Landfilled (CY)	440,000	2,300,000	3,800,000	1,200,000	4,400,000
No Funding Limit Scenario					
Remediation Time/Landfill Operations	7 years/4.5 years	6 years/2.5 years	7 years/3.5 years	9 years/6 years	14 years/9 years
Annual Generation Rate (CY/year)	98,000	920,000	1,100,000	200,000	490,000
Daily Generation Rate (CY/day)	400	3,500	4,200	800	1,900
Funding Limit Scenario*					
Remediation Time/Landfill Operation with Restriction*	17 years/12 years	16 years/10 years	22 years/16.5 years	17 years/13 years	28 years/16 years
Annual Generation Rate (CY/year)*	37,000	230,000	230,000	92,000	280,000
Daily Generation Rate (CY/day)*	100	900	900	400	1,100

CY Cubic yards

* Based on $100 million annual funding limit for overall RMA remediation activities

Table 5.3: Liner System Effectiveness Evaluation
HELP Model Input Parameters

Layer Number	HELP Model Layer Type	Layer Thickness (inches)	HELP Model Default Material Type	Porosity	Field Capacity	Wilting Point	Drainage Length (feet)	Drainage Slope (%)
Liner System 1								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	0 25	17 (geosynthetic clay)	0 75	0 747	0 4		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	3 (barrier)	0 25	17 (geosynthetic clay)	0 75	0 747	0 4		
Liner System 2								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	3 (barrier)	0 25	17 (geosynthetic clay)	0 75	0 747	0 4		
Liner System 3								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	0 25	17 (geosynthetic clay)	0 75	0 747	0 4		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
Liner System 4								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	0 25	17 (geosynthetic clay)	0 75	0 747	0 4		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	1 (vert perm)	36	16 (compacted clay)	0 427	0 418	0 367		
7	4 (geomembrane)	0 04	35 (HDPE)	0	0	0		

Table 5.3 (continued)

Layer Number	HELP Model Layer Type	Layer Thickness (inches)	HELP Model Default Material Type	Porosity	Field Capacity	Wilting Point	Drainage Length (feet)	Drainage Slope (%)
Liner System 5								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
Liner System 6								
1	2 (drainage)	12	1 (clean sand)	0 417	0 045	0 018	200	2
2	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
3	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
4	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
5	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
6	3 (barrier)	36	16 (compacted clay)	0 427	0 418	0 367		
7	4 (geomembrane)	0 04	35 (HDPE)	0	0	0		

HDPE High density polyethylene
HELP Hydrologic Evaluation of Landfill Performance
Vert Perm Vertical permeability
% Percent

Table 5.4: Landfill Liner Effectiveness Evaluation
HELP Model Results

Liners	Estimated average annual leachate passing through liner with approximately 1 foot of head on top					
	Most Likely (inches/yr)	Worst-Case (inches/yr)	Most Likely (ft^3/yr)	Worst-Case (ft^3/yr)	Most Likely (gallons/yr)	Worst-Case (gallons/yr)
System						
1	2 5 x 10^{6}	0 04	0 397	5,973	2 97	44,678
2	2 5 x 10^{6}	0 04	0 397	5,972	2 97	44,671
3	2 5 x 10^{6}	0 51	0 398	82,073	2 98	613,906
4	2 5 x 10^{6}	0 51	0 398	82,073	2 98	613,906
5	2 5 x 10^{6}	0 51	0 398	81,015	2 98	605,992
6	2 5 x 10^{6}	0 51	0 398	81,012	2 98	605,970

Most likely case assumes one pinhole per acre (manufacturing defect), three construction defects per acre, and good geomembrane contact

Worst-case assumes one pinhole per acre, ten constructions defects per acre, and worst-case geomembrane contact

Volume estimates (ft^3/yr and gallons/yr) were calculated assuming 44 acres as the landfill area

ft^3 Cubic feet
yr Year

Table 5.5: Final Landfill Cover Effectiveness Evaluation
HELP Model Input Parameters

Layer Number	HELP Model Layer Type	Layer Thickness (inches)	HELP Model Default Material Type	Porosity	Field Capacity	Wilting Point	Drainage Length (feet)	Drainage Slope (%)
Cover System 1								
1	1 (vert perm)	8	6 (sandy loam)	0 453	0 19	0 085		
2	1 (vert perm)	52	8 (loam)	0 463	0 232	0 116		
3	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
4	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
5	3 (barrier)	30	16 (compacted clay)	0 427	0 418	0 367		
Cover System 2								
1	1 (vert perm)	8	6 (sandy loam)	0 453	0 19	0 085		
2	1 (vert perm)	52	8 (loam)	0 463	0 232	0 116		
3	2 (drainage)	0 2	20 (Geonet)	0 85	0 01	0 005	200	2
4	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
5	3 (barrier)	0 25	17 (geosynthetic clay)	0 427	0 418	0 367		
Cover System 3								
1	1 (vert perm)	8	6 (sandy loam)	0 453	0 19	0 085		
2	1 (vert perm)	52	8 (loam)	0 463	0 232	0 116		
3	2 (drainage)	12	21 (gravel)	0 85	0 01	0 005	200	2
4	4 (geomembrane)	0 06	35 (HDPE)	0	0	0		
5	3 (barrier)	30	16 (compacted clay)	0 427	0 418	0 367		

Table 5.5 (continued)

Layer Number	HELP Model Layer Type	Layer Thickness (inches)	HELP Model Default Material Type	Porosity	Field Capacity	Wilting Point	Drainage Length (feet)	Drainage Slope (%)
Cover System 4								
1	1 (vert. perm.)	8	6 (sandy loam)	0.453	0.19	0.085		
2	1 (vert. perm.)	52	8 (loam)	0.463	0.232	0.116		
3	2 (drainage)	12	21 (gravel)	0.85	0.01	0.005	200	2
4	4 (geomembrane)	0.06	35 (HDPE)	0	0	0		
5	3 (barrier)	0.25	17 (geosynthetic clay)	0.427	0.418	0.367		

HDPE High density polyethylene
HELP Hydrologic Evaluation of Landfill Performance
Vert. Vertical
Perm. Permeability
% Percent

Table 5.6: Landfill Final Cover Effectiveness Evaluation
HELP Model Results

	Estimated Average Annual Cover Infiltration from 100 Years of Denver Weather					
Covers	Most Likely (inches/yr)	Worst-Case (inches/yr)	Most Likely (ft^3/yr)	Worst-Case (ft^3/yr)	Most Likely (gallons/yr)	Worst-Case (gallons/yr)
System						
1	7 3 x 10^{-6}	1 12	1 161	178,651	8 68	1,336,310
2	2 8 x 10^{-6}	0 04	0 439	5,650	3 28	42,262
3	4.2 x 10^{-6}	0 08	0 664	12,836	4 97	96,013
4	9 6 x 10^{-7}	0 005	0 154	743	1 15	5,558

Most likely case assumes one pinhole per acre (manufacturing defect), three construction defects per acre, and good geomembrane contact.

Worst-case assumes one pinhole per acre, ten constructions defects per acre, and worst-case geomembrane contact.

Volume estimates (ft^3/yr and gallons/yr) were calculated assuming 44 acres as the landfill area

ft^3 Cubic feet
yr Year

Table 5.7: Cost Evaluation of Landfill Liner Systems

Liner Component	Estimated Unit Cost $/ft²*	Unit Cost Reference
Liner System No. 1. Double Composite Liner With GCLs		
LCRS	0.50	GNRA
60-mil HDPE Primary Geomembrane	0.45	Polyflex
Geosynthetic Clay Liner	0.55	CETCO
Geonet	0.50	GNRA
60-mil HDPE Secondary Geomembrane	0 45	Polyflex
Geosynthetic Clay Liner	0.55	CETCO
Net unit cost	3.00	
Liner System No 2: Double Composite Liner with GCL and GCL		
LCRS	0.50	GNRA
60-mil HDPE Primary Geomembrane	0 45	Polyflex
3-foot-thick compacted clay/amended soil	1.80	GNRA
Geotextile	0.50	
Geonet	0.50	GNRA
60-mil HDPE Secondary Geomembrane	0 45	Polyflex
Geosynthetic Clay Liner	0.55	CETCO
Net Unit Cost	4.75	
Liner System No. 3: Double Composite Liner with GCL and GCL		
LCRS	0 50	GNRA
60-mil HDPE Primary Geomembrane	0 45	Polyflex
Geosynthetic Clay Liner	0 55	CETCO
Geonet	0.50	GNRA
60-mil HDPE Secondary Geomembrane	0 45	Polyflex
3-foot-thick compacted clay/amended soil	1 80	GNRA
Net Unit Cost	4.25	
Liner System No 4 Double Composite Liner with GCL and GCL with Tertiary FML		
LCRS	0 50	GNRA
60-mil HDPE Primary Geomembrane	0.45	Polyflex
Geosynthetic Clay Liner	0 55	CETCO
Geonet	0 50	GNRA
60-mil HDPE Secondary Geomembrane	0.45	Polyflex
3-foot-thick compacted clay/amended soil	1.80	GNRA
40-mil HDPE Tertiary Liner	0 40	
Net Unit Cost	4 65	

Table 5.7 (continued)

Liner Component	Estimated Unit Cost $/ft²*	Unit Cost Reference
Liner System No. 5: Double Composite Liner with CCLs		
LCRS	0 50	GNRA
60-mil HDPE Primary Geomembrane	0.45	Polyflex
3-foot-thick compacted clay/amended soil	1.80	GNRA
Geotextile	0 50	
Geonet	0 50	GNRA
60-mil HDPE Secondary Geomembrane	0 45	Polyflex
3-foot-thick compacted clay/amended soil	1 80	GNRA
Net Unit Cost	6.00	
Liner System No 6: Double Composite Liner with CCLs and Tertiary FML		
LCRS	0 50	GNRA
60-mil HDPE Primary Geomembrane	0 45	Polyflex
3-foot-thick compacted clay/amended soil	1.80	GNRA
Geotextile	0 50	
Geonet	0 50	GNRA
60-mil HDPE Secondary Geomembrane	0 45	Polyflex
3-foot-thick compacted clay/amended soil	1 80	GNRA
40-mil HDPE Tertiary Liner	0 40	
Net Unit Cost	6 40	

All costs are in 1995 dollars

CETCO Geosynthetic liner manufacturer
FML Flexible membrane liner
GCL Geosynthetic clay liner
GNRA G N Richardson and Associates
HDPE High-density polyethylene
LCRS Leachate collection and recovery system
Polyflex Geomembrane manufacturer

* Liner price does not include cost of 1-foot-thick prepared subgrade

Table 5.8: Cost Evaluation of Landfill Cover Systems

Cover Component		Unit Cost $/ft²*	Unit Cost Reference
Cover System No. 1			
6-foot Erosion Control Layer		1.60	GNRA
Geotextile		0 50	
Geonet		0 50	GNRA
60-mil HDPE		0 45	Polyflex
2 5-foot compaced clay/amended soil		1 50	GNRA
	Net unit cost	4 55	
Cover System No. 2			
6-foot Erosion Control Layer		1 60	GNRA
Geotextile		0.50	
Geonet		0.50	GNRA
60-mil HDPE		0 45	Polyflex
Geosynthetic Clay Liner		0 55	CETCO
	Net Unit Cost	3 60	
Cover System No. 3			
6-foot Erosion Control Layer		1 60	GNRA
Geotextile		0 50	
1-foot Sand Capillary/Drainage Layer		0 50	GNRA
60-mil HDPE		0 45	Polyflex
2 5-foot compaced clay/amended soil		1 50	GNRA
	Net Unit Cost	4 55	
Cover System No. 4			
6-foot Erosion Control Layer		1 60	GNRA
Geotextile		0 50	
1-foot Sand Capillary/Drainage Layer		0 50	GNRA
60-mil HDPE		0 45	Polyflex
Geosynthetic Clay Liner		0.55	CETCO
	Net Unit Cost	3.60	

All costs are 1995 dollars

CETCO	Geosynthetic liner manufacturer
GNRA	G N Richardson & Associates
HDPE	High-density polyethylene
Polyflex	Geomembrane manufacturer

* Cap price does not include cost of structural fill for grading

Table 5.9: Overall Landfill Cover and Liner Evaluation Potential Leachate Release

System	Estmate Average Annual Leachate Passing Through Liner Most Likely (inches/yr)	Worst-Case (inches/yr)	Most Likely (ft^3/yr)	Worst-Case (ft^3/yr)	Most Likely (gallons/yr)	Worst-Case (gallons/yr)
Cover System No 4 Liner System No 1	$2\ 6 \times 10^{-7}$	$1\ 6 \times 10^{-3}$	0 06	260	0.3	2000

ft^3 Cubic feet
yr Year

Table 5.10: Estimated Soil Material Requirements for Conceptual Landfill Models

Soil Use	Depth (inches)	Acceptable Soil Type	Estimated Volume Required (CY) Conceptual Model No 1	Conceptual Model No 2	Conceptual Model No 3
Cover					
Vegetative layer	8	Sandy loam	21,000	40,000	100,000
Water storage/frost protection	52	Loam	140,000	260,000	630,000
Barrier	30	Clay	80,000	150,000	365,000
Subgrade	12	Structural fill	32,000	60,000	145,000
Liner					
Protective layer	12	Structural fill	32,000	60,000	145,000
Primary barrier	36	Clay	95,000	180,000	435,000
Secondary barrier	36	Clay	95,000	180,000	435,000
Subgrade	12	Structural fill	32,000	60,000	145,000
Operational Cover		Structural fill	200,000	460,000	1,200,000
Total Liner and Cover					
Sandy loam		NA	21,000	40,000	100,000
Loam		NA	140,000	260,000	630,000
Clay		NA	270,000	510,000	1,235,000
Structural fill		NA	296,000	640,000	1,635,000

CY Cubic yard
NA Not applicable

Table 5.11: Summary of Estimated Construction Cost

Item Description	Conceptual Model 1	Conceptual Model 2	Conceptual Model 3
Support Construction			
Drainage	$8,000	$13,000	$20,000
Storm-water Detention	$50,000	$100,000	$150,000
Fencing	$57,000	$77,000	$113,00
Maintenance Building	$150,000	$150,000	$150,000
Office/Decontamination Building	$30,000	$30,000	$30,000
Roads	$40,000	$40,000	$40,000
Parking	$2,000	$2,000	$2,000
Leachate Management System	$200,000	$400,000	$800,000
Groundwater Monitoring System	$120,000	$156,000	$240,000
Cell Construction			
Excavation	$1,892,000	$3,036,000	$6,270,000
Sumps, Header Pipe, and Pumps	$62,000	$68,000	$75,000
Subgrade Prep	$22,000	$42,000	$101,000
Liner System	$4,038,000	$7,600,000	$18,525,000
Protective Cover	$228,000	$427,000	$1,039,000
Embankment	$287,000	$426,000	$686,000
Cover Vent System	$855,000	$1,602,000	$3,897,000
Cover System	$3,868,000	$7,280,000	$17,745,000
Mobilization/Demobilization	$233,000	$433,000	$1,041,000
Construction QA/QC	$350,000	$650,000	$5,561,000
Total	**$12,500,000**	**$22,500,000**	**$52,500,000**

QA/QC Quality assurance/quality control

Table 5.12: Operation & Maintenance Cost Summary Table

Conceptual Model	Landfill Life in Years	Funding	Yearly O&M Costs Minimum	Yearly O&M Costs Maximum	Yearly O&M Costs Average	Total O&M Cost Per Cubic Yard
1	12	Restricted	$1,150,000	$2,374,000	$1,487,000	$18
1	4 5	Unrestricted	$2,035,000	$2,991,000	$2,294,000	$11
2	10	Restricted	$1,994,000	$3,442,000	$2,440,000	$11
2	2 5	Unrestricted	$4,979,000	$7,429,000	$5,820,000	$8
3	16	Restricted	$2,364,000	$4,436,000	$3,109,000	$8
3	9	Unrestricted	$3,695,000	$6,159,000	$4,460,000	$7

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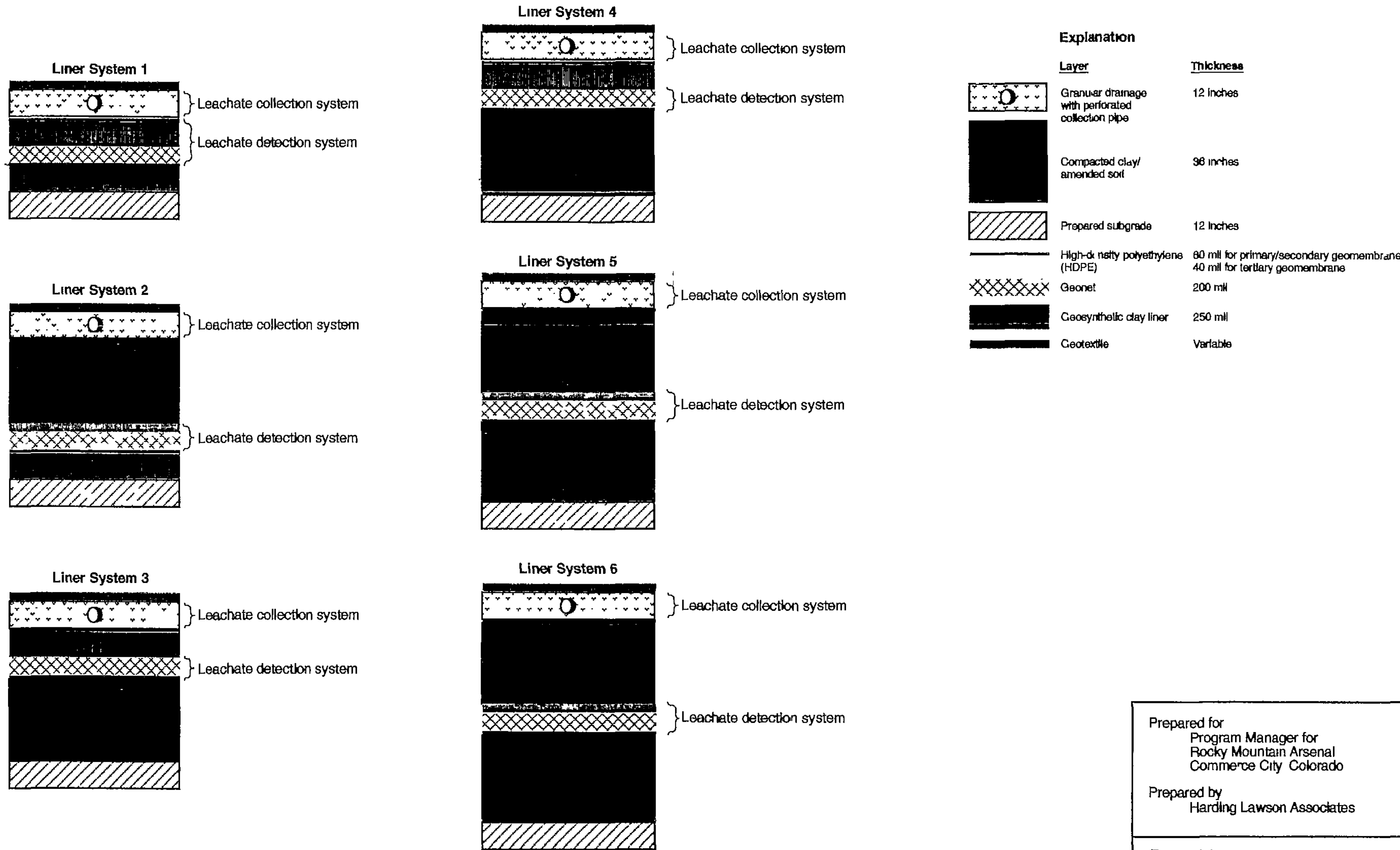

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Figure 5 1

Liner System Alternatives

RMA 1245 4/8/95 NLM

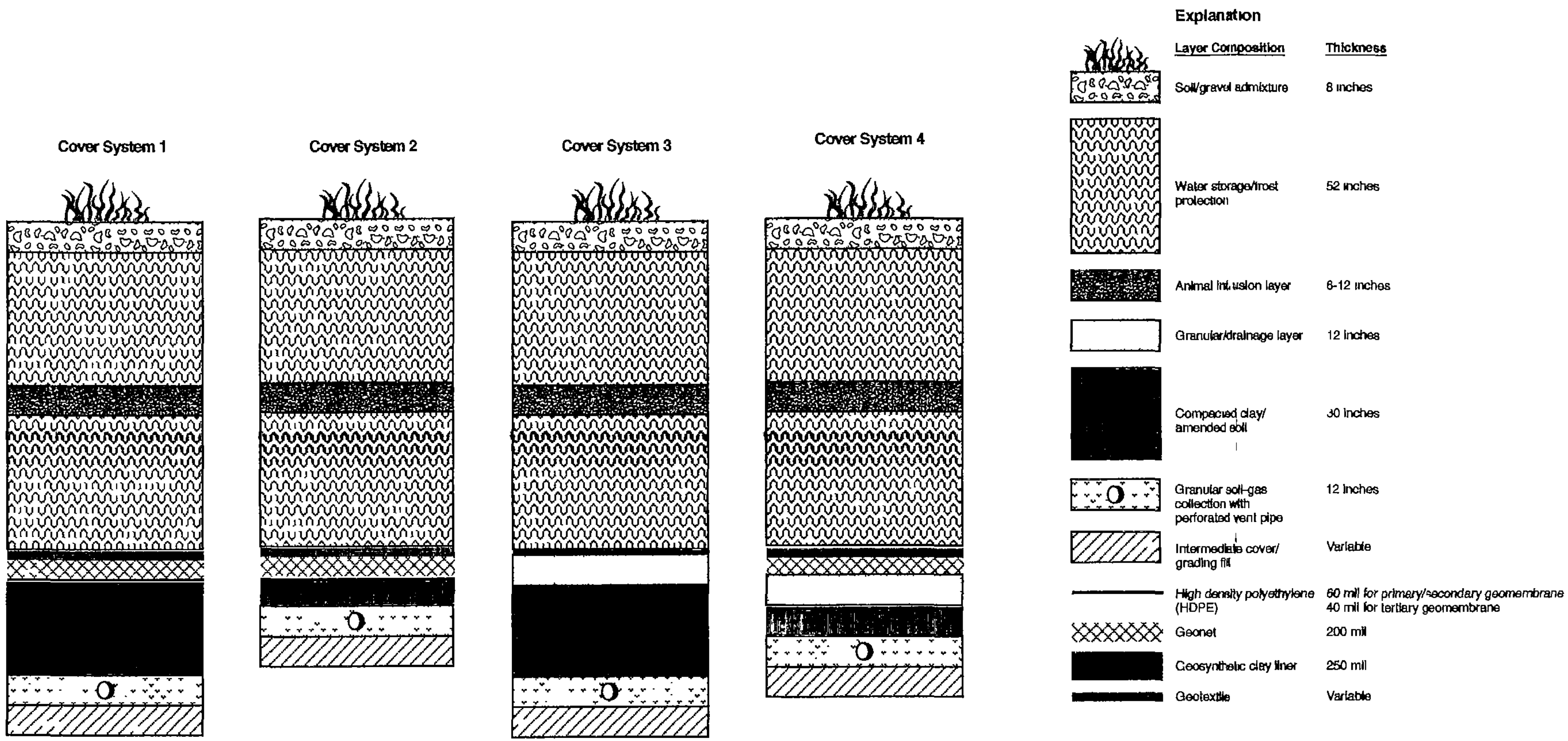

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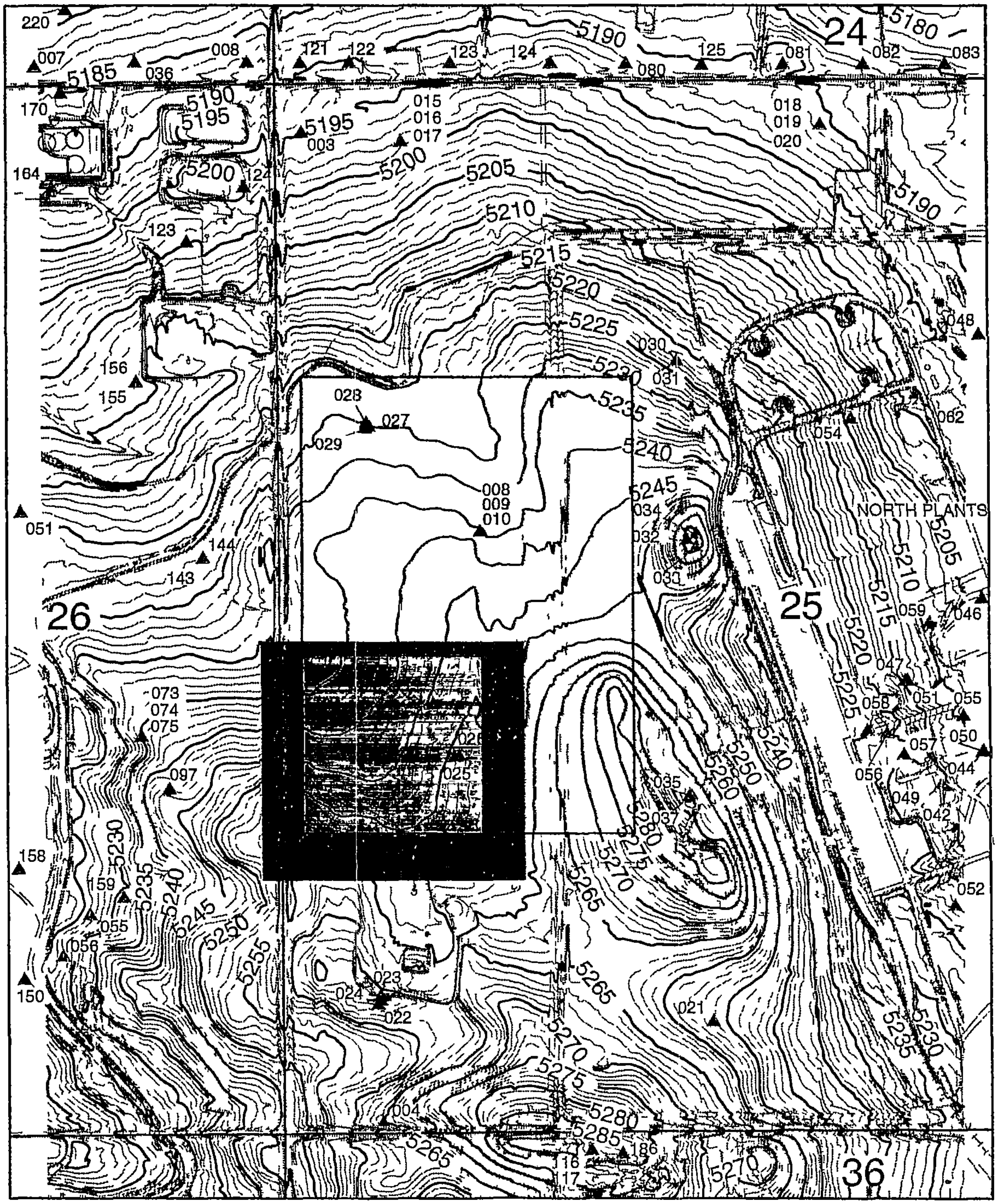
Figure 5 2

Cover System Alternatives

RMA/21907754 5/4/95 LDZ



Explanation

Approximate Waste Footprint for Conceptual Model 1
Area = 900 ft x 900 ft
Waste to be landfilled = 1 0 million cubic yards

Approximate Waste Footprint for Conceptual Model 2
Area = 1200 ft x 1300 ft
Waste to be landfilled = 2 3 million cubic yards

Approximate Waste Footprint for Conceptual Model 3
Area = 1650 ft x 2300 ft
Waste to be landfilled = 6 0 million cubic yards

038 Monitoring well

Surface Topography (1-foot contour interval)

Unpaved roadway

Surface drainage

25 Section number

N

0 400 800
Scale in feet

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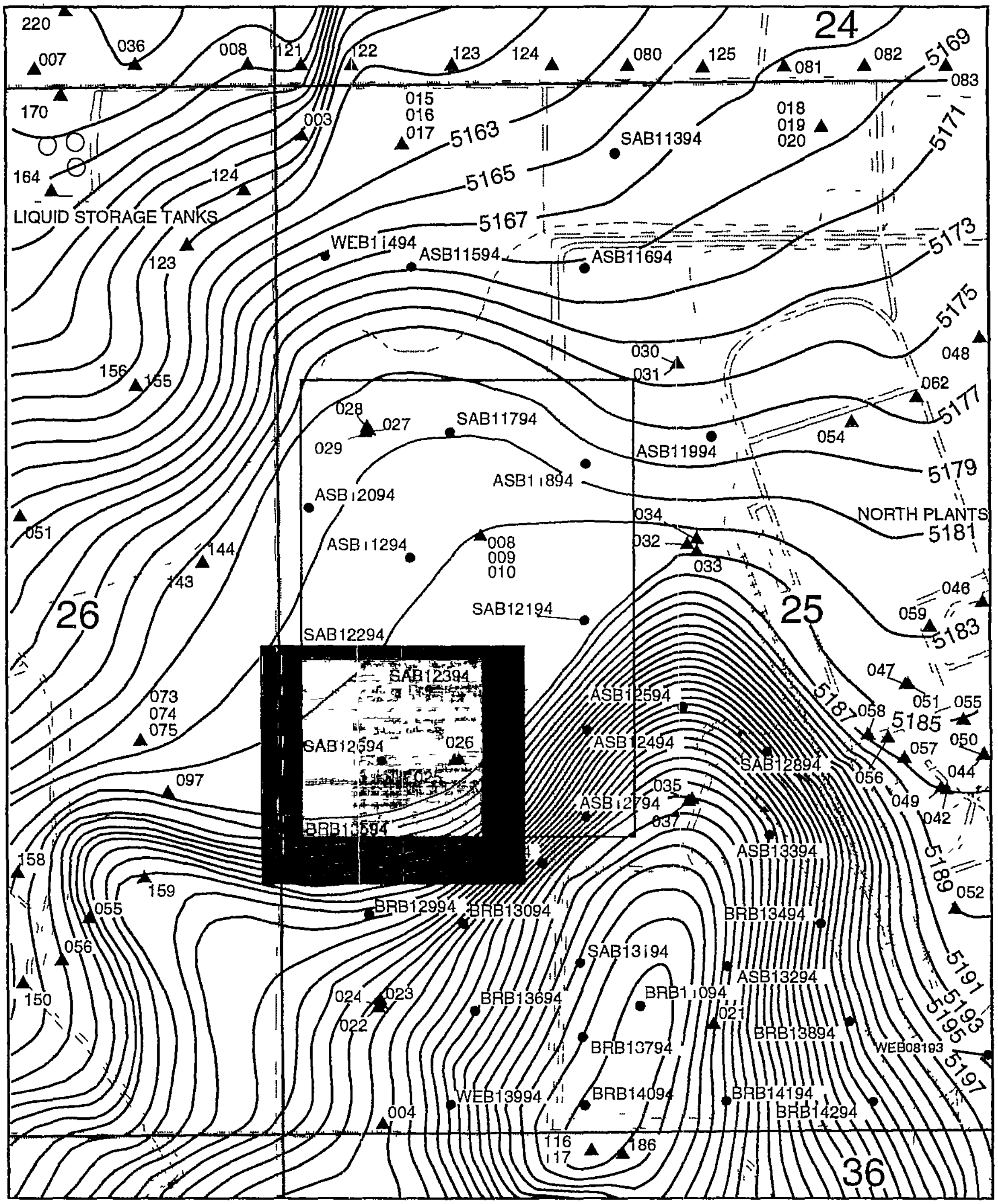
Figure 5 3

Conceptual Landfill Footprints and Surface Topography



Explanation

Approximate Waste Footprint for Conceptual Model 1	038 Water-level monitoring well location
Approximate Waste Footprint for Conceptual Model 2	BRB11094 Borehole location
Approximate Waste Footprint for Conceptual Model 3	Water-level elevation (2-foot contour interval)
	Unpaved roadway
	Surface drainage
	25 Section number

N

0 400 800
Scale in feet

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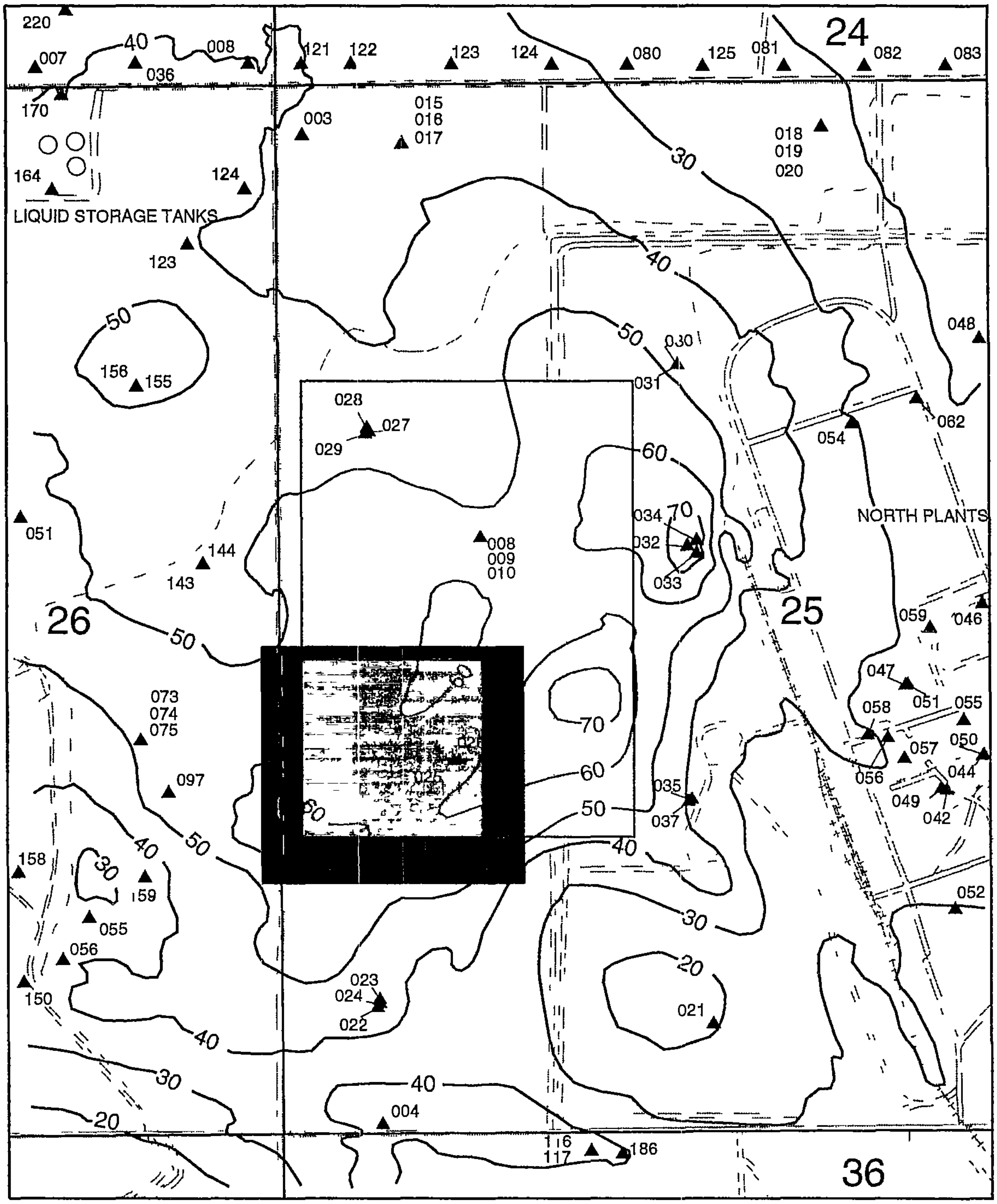
Figure 5 4

Conceptual Landfill Footprints and Groundwater Elevation Map



Explanation

	Approximate Waste Footprint for Conceptual Model 1
	Approximate Waste Footprint for Conceptual Model 2
	Approximate Waste Footprint for Conceptual Model 3
▲038	Monitoring well
	Depth to groundwater (10-foot contour interval)
	Unpaved roadway
	Surface drainage
25	Section number

N

0 400 800
Scale in feet

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Figure 5 5

Conceptual Landfill Footprints and Depth to Groundwater

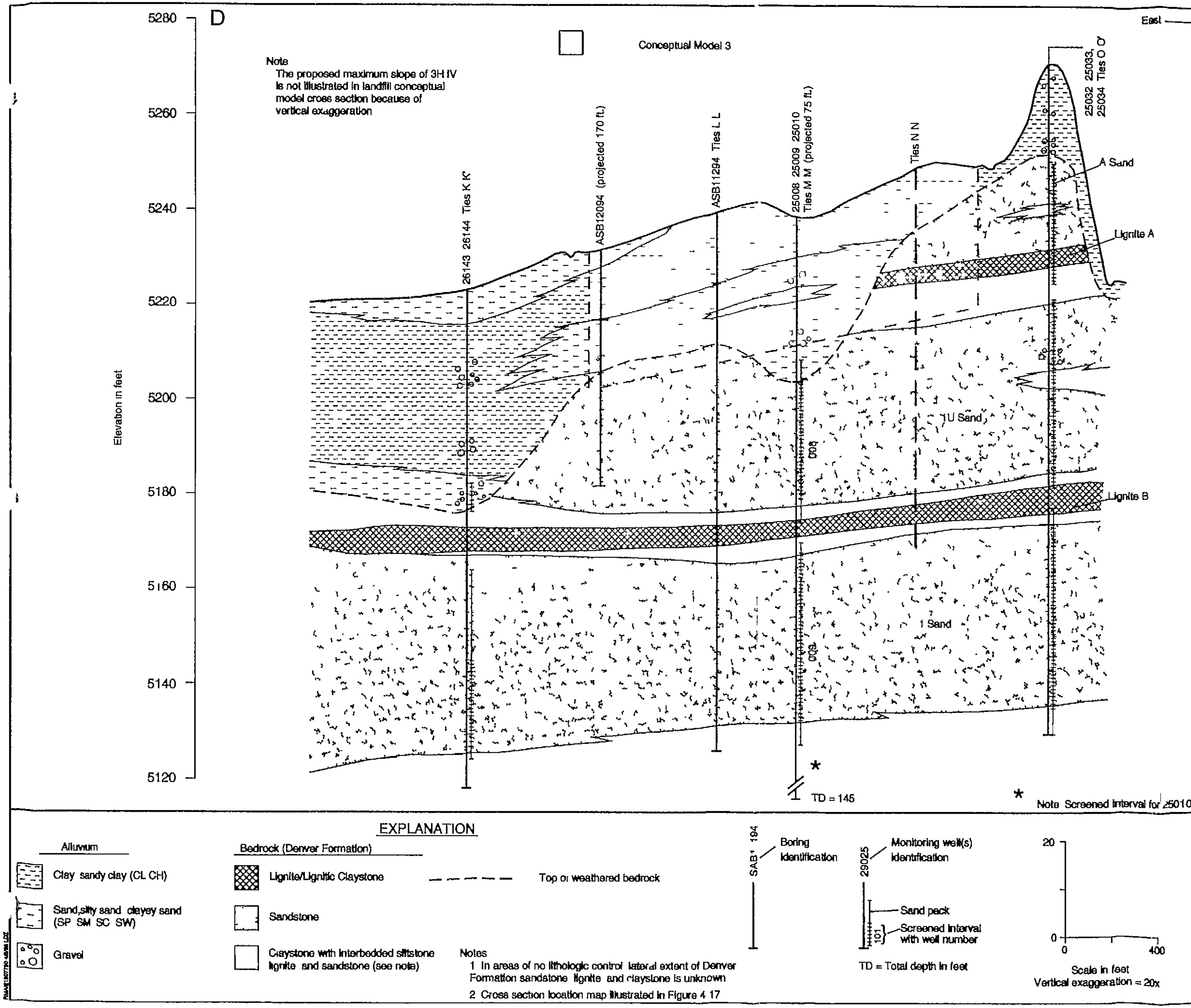

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Figure 5 6

Conceptual Model 3 through Geologic Cross Section D-D'

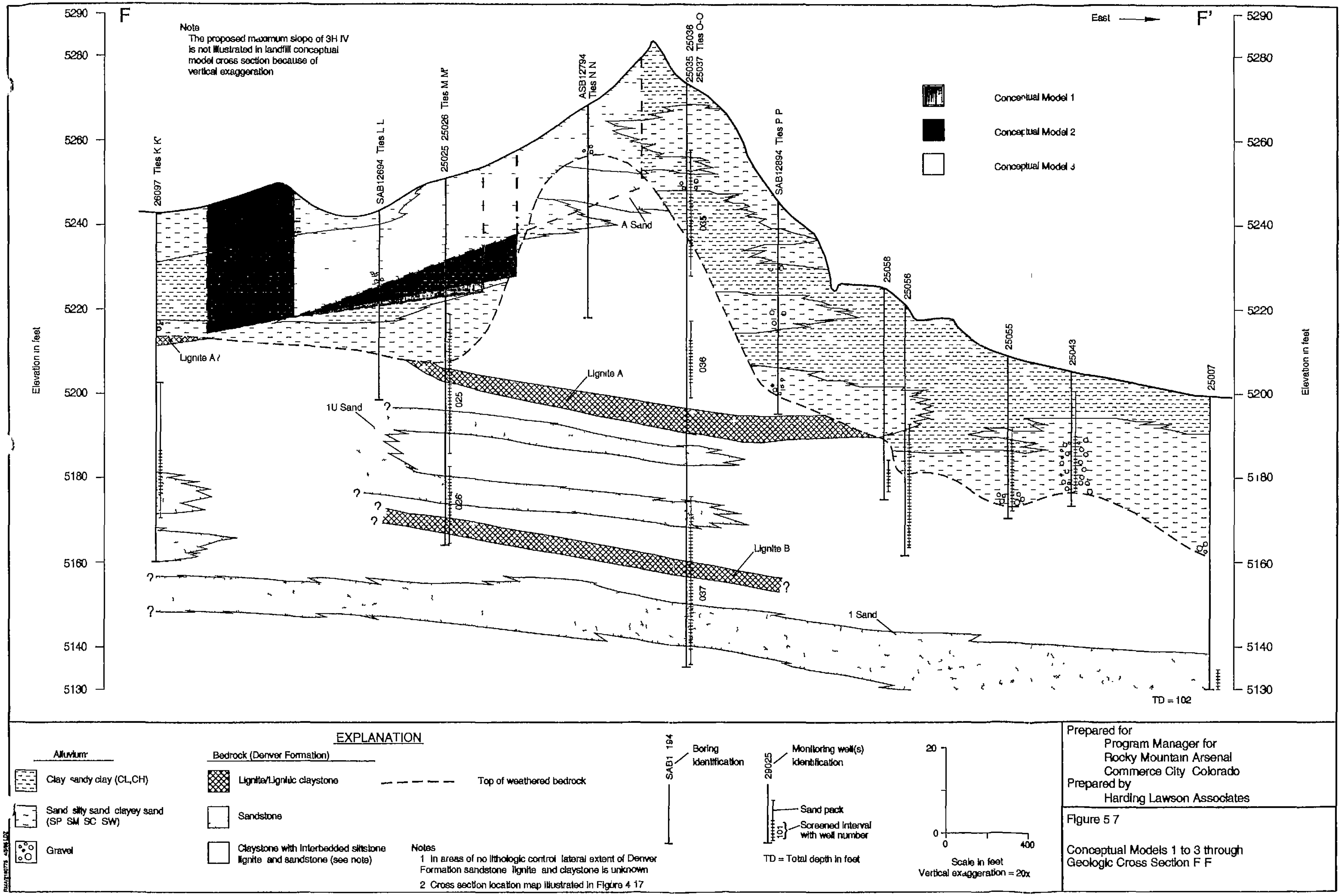

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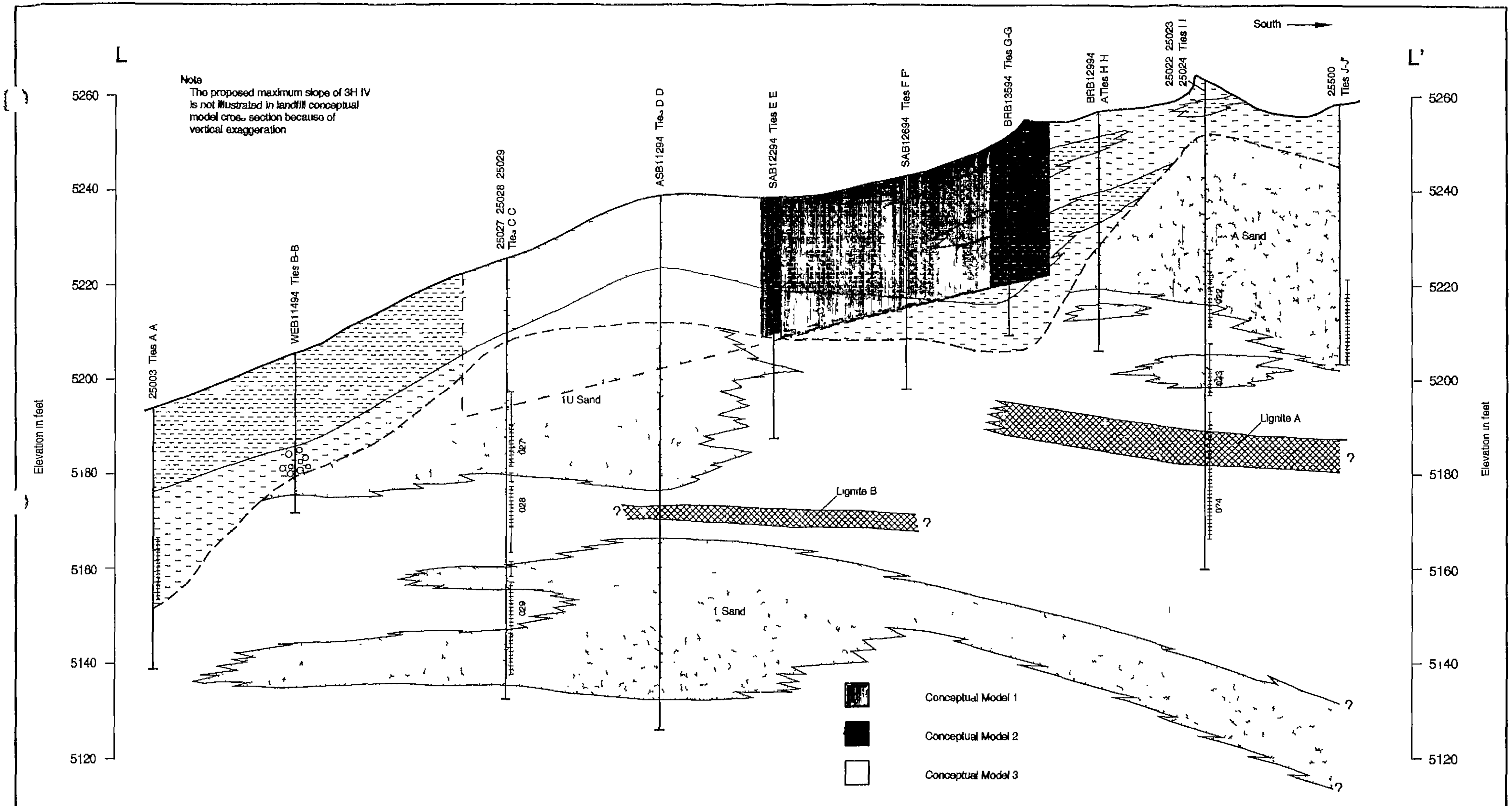
Figure 5 7

Conceptual Models 1 to 3 through Geologic Cross Section F F



EXPLANATION

Alluvium

- Clay sandy clay (CL CH)
- Sand silty sand clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone lignite, and sandstone (see note)

Top of weathered bedrock

SAB11194 Boring Identification

29025 Monitoring well(s) Identification

Sand pack

101 Screened interval with well number

TD = Total depth in feet

Scale in feet (0–400; vertical 0–20)
Vertical exaggeration = 20x

Notes
1 In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown
2. Cross section location map illustrated in Figure 4 17

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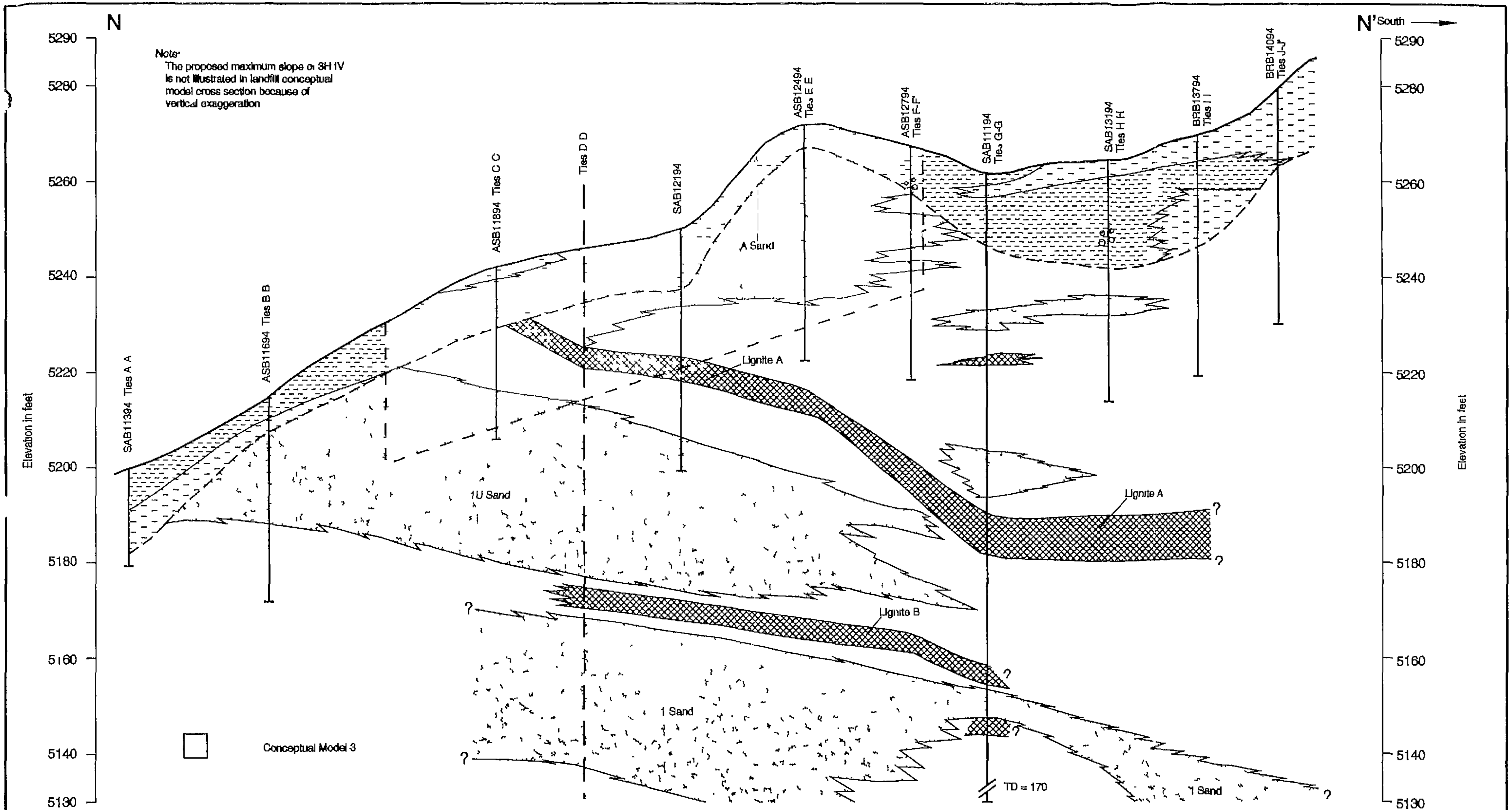
Figure 5 8

Conceptual Models 1 to 3 through Geologic Cross Section L L



EXPLANATION

Alluvium

- Clay sandy clay (CL CH)
- Sand silty sand, clayey sand (SP SM SC SW)
- Gravel

Bedrock (Denver Formation)

- Lignite/Lignitic claystone
- Sandstone
- Claystone with interbedded siltstone, lignite and sandstone (see note)

— — — — Top of weathered bedrock

SAB11194 — Boring identification

29025 — Monitoring well(s) identification

Sand pack

101 — Screened interval with well number

TD = Total depth in feet

Scale in feet: 0 – 400 (horizontal), 0 – 20 (vertical)
Vertical exaggeration = 20x

Notes
1 In areas of no lithologic control lateral extent of Denver Formation sandstone lignite and claystone is unknown
2 Cross section location map illustrated in Figure 4 17

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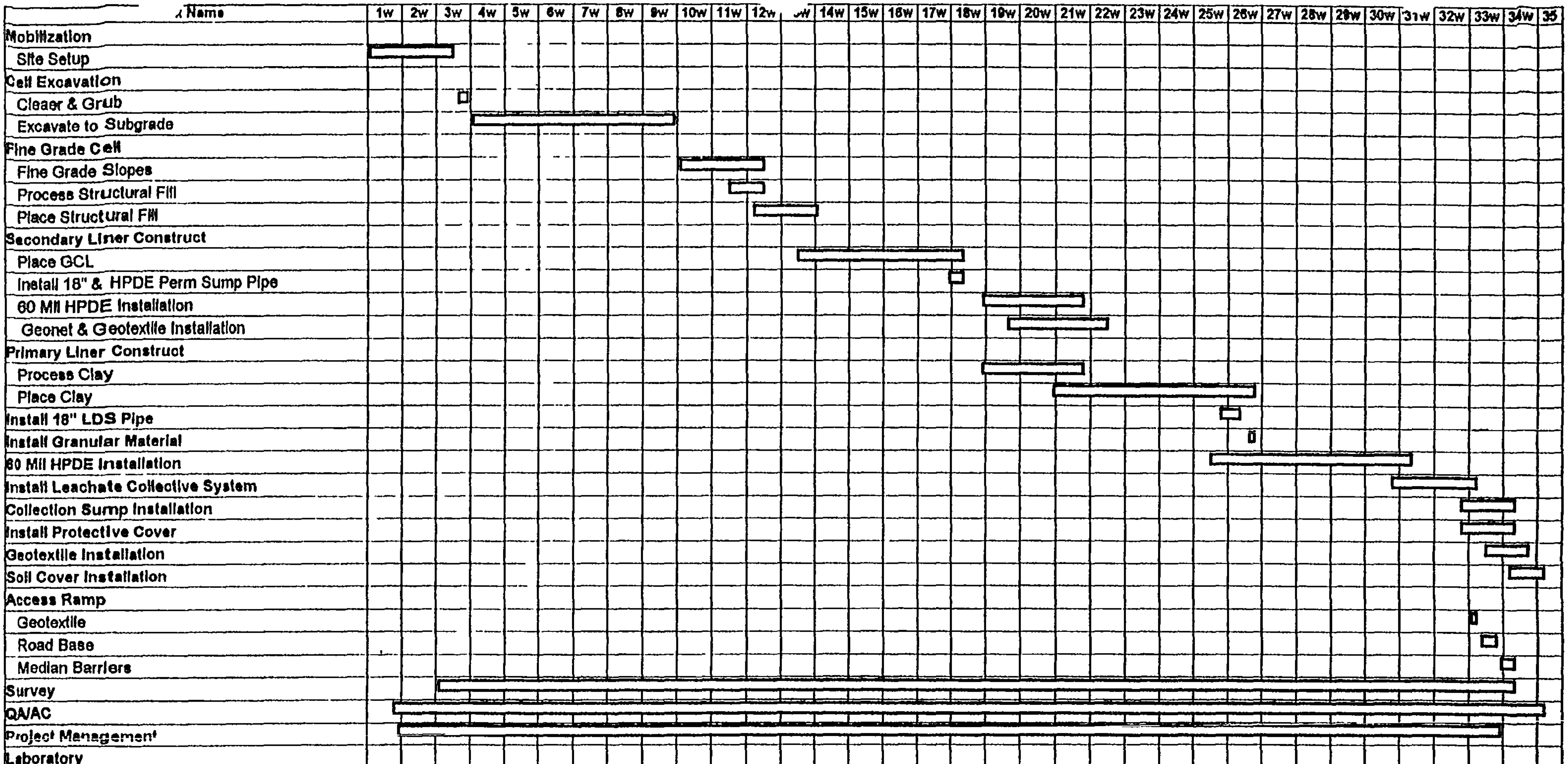
Figure 5 9

Conceptual Model 3 through Geologic Cross Section N N'



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Program Manager Rocky Mountain Arsenal

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Figure 5.10

Typical Estimated Hazardous Waste Cell Construction Schedule for an approximately 200,000 Cubic Yard Module

6.0 CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions and recommendations based on the Material FS, Area FS, and Site FS results The Material FS evaluated whether onsite soils are suitable for use as landfill liners and capping material based on field and laboratory tests The Area FS identified an area within RMA suitable for siting a landfill based on current regulatory and institutional criteria After an area was identified, adequate geologic and geotechnical data was collected to characterize the site and evaluate the feasibility of constructing a landfill in the existing foundation materials The Site FS identified an appropriate site within the area identified in the Area FS and provided information on the overall footprint of the landfill (based on 3 different waste volumes)

6.1 Conclusions

The Material FS objectives were met The field and laboratory test results confirm that onpost soils can be used to construct caps and liners that meet regulatory-required hydraulic conductivity The construction methods employed to construct the two test fills identified the approximate lift thickness, moisture content, density, and compactive effort necessary to achieve the required permeability

The Area FS objectives were met. Landfill siting criteria and policies were used to screen RMA and identify an area suitable for potentially siting a hazardous waste landfill in the western half of Section 25 Three deep borings and thirty shallow borings were drilled and lithologically logged to characterize the geology of the area identified The three deep borings were also geophysically logged to help understand the geology across the area Three-hundred thirty-five samples were analyzed for particle size and Atterberg limits Sixty-five percent of the samples were classified as clay, and thirty percent as clayey sand Remolded permeability tests were performed on a clay soil sample from each of the 30 shallow boreholes Approximately half of the permeability tests achieved vertical permeability values less than 1×10^{-7} cm/s The results of the geologic and geotechnical characterization suggest that approximately half the soil in the identified area could potentially be used as material for construction of caps or liner Geologic and geotechnical results indicate that the area is conducive to construction of a hazardous waste landfill with primarily clay and claystone underlying the site

The Site FS objectives were met. Appropriate landfill sites within the area identified in the Area FS were evaluated and conceptual landfill models, design elements, construction costs, operation and maintenance costs, and schedules information was developed and evaluated For the purposes of this report, waste volumes of 1,000,000 CY, 2,300,000 CY (the preferred sitewide alternative in the DAA), and 6,000,000 CY were used to account for projected minimum and maximum waste volumes The total landfill volumes used for the three conceptual models included a 20 percent volume increase over the needed waste volume to account for operational cover (1,200,000 CY, 2,760,000 CY, and 7,200,000 CY, respectively) Waste generation rates were estimated to be in the range of 98,000 CY to 1,100,000 CY of material per year without a funding limit, and 37,000 to 280,000 CY of material per year assuming a $100,000,000 annual funding limit Climate, topography, and surface hydrology should not impact landfill construction Subcropping Denver Formation sand units in contact with the alluvium should be avoided if possible Maximizing the depth to groundwater and placing the landfill away from areas where groundwater flows radially is preferred Therefore, siting the landfill within the central portion of western Section 25 is preferred No geologic hazard or environmentally sensitive area considerations were noted in this study, but additional study may be required for siting and design Slope stability and settlement from excavation should not impact construction or O&M of the landfill

Conceptual design alternatives were developed for liner systems, leachate collection and removal systems, gas management systems, final cover systems, and performance of an environmental monitoring system Six liner system alternatives were developed Four final cover systems were developed Environmental monitoring will be performed as part of the facility performance monitoring Conceptual liner and final cover alternatives were evaluated for effectiveness using EPA's HELP

Model, and evaluated for cost by estimating the unit cost on a square foot basis Using the HELP Model to simulate the most likely construction quality scenario, all liners performed about equally Liner System Nos 1 and 2 (use geosynthetic clay liner) performed better than the other liner systems The final screening of the conceptual liner designs should consider cost and constructability rather than potential performance because performance results for conceptual liner designs are so similar

The calculated infiltration results for all the final cover systems evaluated are similar and very low Cover System No 4 performed the best. The similarity of performance results for the cover alternatives indicates that final screening of the cover systems should consider cost and constructability rather than potential performance

The total unit cost estimate for the liner systems ranged from $3 00 to $6 40 per square foot The total cost estimate for the cover systems ranged from $3 60 to $4 55 per square foot. Liner System No 1 was the most cost-effective Cover System No 4 was the most cost-effective

The overall landfill performance was evaluated using the HELP Model to evaluate the potential effectiveness of the cover and liner systems Cover System No 4 and Liner System No 1 were used to estimate the long-term leachate production from the landfill Extremely small rates of potential release are predicted for both the most likely (2 6 x 10^{7} in/yr) and worst-case (1 6 x 10^{3} in/yr) scenarios EPA's RITZ Model was used to estimate advective travel times of unsaturated flow produced by the leachate predicted from the HELP Model Potential travel times through the vadose zone are estimated at 8 20 x 10^{-4} ft/yr to 9 37 x 10^{-4} ft/yr, depending on the saturated hydraulic conductivity At the estimated rates, it would take from 1000 to 1200 years for soil water in the vadose zone to move downward 1 foot

The conceptual facility layouts and material quantities were based on the three conceptual landfill volume requirements and an excavation depth of 30 feet below the existing ground surface The areas for each footprint are 19 acres (1,200,000 CY), 36 acres (2,760,000 CY), and 87 acres (7,200,000 CY) Conceptual Models 1 and 2 are placed within alluvium and both footprints avoid sand subcrops The base of Conceptual Model 3 is within the weathered Denver Formation and is cut into subcropping sand units

Material quantities were estimated for low-permeability soils and structural fill soils used in landfill liner and cover system components The quantities of soils required for landfill construction were then compared to the estimated volumes of onpost materials The surface area to be lined and surface area for final cover were calculated using the waste depth, height, excavation, and above grade sideslopes Based on the estimated volumes of onpost soil from borrow areas and landfill excavation, it appears that sufficient onpost soil exists to meet the construction requirements for even the largest landfill layout, Conceptual Model 3

Cost estimates for construction and annual O&M for the three conceptual landfill models were prepared to be accurate within a plus 50 percent to minus 30 percent range The estimated construction cost per cubic yard of waste disposal capacity for Conceptual Models 1, 2, and 3 are $12 50 per CY, $10 00 per CY, and $9.00 per CY, respectively The estimated total construction cost for Conceptual Models 1, 2, and 3 are $12,500,000, $22,500,000, and $52,500,000, respectively

Annual O&M costs were prepared at a plus 50 percent to minus 30 percent range The average yearly O&M costs for the restricted funding scenarios for Conceptual Models 1, 2, and 3 are $1,487,000/yr, $2,440,000/yr, and $3,181,000/yr, respectively The average yearly O&M costs for the unrestricted funding scenarios for Conceptual Models 1, 2, and 3 are $2,294,000/yr, $5,820,000/yr, and $4,460,000/yr, respectively Additionally, the lowest average O&M costs per cubic yard are associated with the largest landfill (Conceptual Model 3) at $7 per cubic yard

A conceptual construction schedule was developed for construction of an approximately 200,000 CY module Based on the estimated schedule, construction would take approximately 34 weeks

O&M plans should be prepared for the facility and should include construction and CQC requirements, daily operations, periodic operational activities, and specific plans

In conclusion, based on the evaluation performed in the Site FS, it is feasible to construct a RCRA Subtitle C hazardous waste landfill of sufficient capacity at the preferred site using onsite borrow materials that would meet the applicable federal, state, and local regulatory requirements

6.2 Recommendations

Material FS recommendations include the following

- Perform additional geotechnical testing of borrow materials concurrent with construction to assess actual specifications for cap and liner construction

Area FS recommendations include the following

- Perform a detailed hydrogeologic study to evaluate groundwater flow velocities and vertical gradients in the potential landfill area identified

Site FS recommendations include the following

- Based on completion of a hydrogeologic study in the potential landfill area, and a decision by PMRMA to pursue construction of an onsite hazardous waste landfill, a formal Subtitle C Landfill siting report should be prepared The report should rely on the information provided in this Site FS report Minimal, if any, field investigation will be required Once the ROD for the onpost operable unit is decided upon, and if the final remedy includes a landfill, a formal landfill siting report should be prepared for submittal
- Perform necessary additional geological and geotechnical drilling and testing within the landfill site concurrent with construction to prepare landfill siting report.

7.0 ACRONYMS

AHPA	Archeological and Historical Preservation Act
ALR	Action leakage rate
ARAR	Applicable or relevant and appropriate requirement
Army	U S Department of the Army
ASTM	American Society for Testing and Materials
bcy	Bank cubic yard
BEMA	Bald Eagle Management Area
bgs	Below ground surface
CCR	Code of Colorado Regulations
CEC	Cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CL	Clay liners
cm/s	Centimeters per second
CME	Central Mine Equipment
CMP	Comprehensive Monitoring Program
COC	Chain of custody
COE	U S Army Corps of Engineers
Colog	Colog, Inc
COR	Contracting Officer's Representative
CQC	Construction quality control
CRS	Colorado Revised Statute
CY	Cubic yard
DAA	Detailed Analysis of Alternatives
DSA	Development and Screening of Alternatives
Ebasco	Ebasco Services, Inc

EPA	U S Environmental Protection Agency
ESA	Endangered Species Act
ESE	Environmental Science and Engineering, Inc
FFA	Federal Facilities Agreement
FML	Flexible membrane liners
FS	Feasibility study
GCL	Geosynthetic clay liners
GIS	Geographic Information System
GMP	Groundwater Monitoring Program
HLA	Harding Lawson Associates
ID	Inside diameter
IRA	Interim response action
K	Hydraulic conductivity
K1	Time-weighted average value of Stage 1 hydraulic conductivity
K2	Time-weighted average value of Stage 2 hydraulic conductivity
K_H	Horizontal hydraulic conductivity
K_v	Vertical hydraulic conductivity
LCRS	Leachate collection and removal system
ml	Milliliter
meq/g	Milliequivalent per gram
MKE	Morrison-Knudsen Environmental Services, Inc (formerly Morrison-Knudsen Engineers, Inc)
NCP	National Contingency Plan
NHPA	National Historic Preservation Act
O&M	Operation and maintenance
OD	Outside diameter
OU	Operable unit
pcf	Pounds per cubic foot

PI	Plasticity Index
PID	Photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal
PPE	Personal protective equipment
PRG	Preliminary remediation goal
psf	Pounds per square foot
psi	Pounds per square inch
PVC	Polyvinyl chloride
QC	Quality control
RAO	Remedial action objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial investigation
RMA	Rocky Mountain Arsenal
ROD	Record of Decision
RPO	Representative process option
RUST E&I	Rust Environment and Infrastructure
SARA	Superfund Amendments and Reauthorization Act of 1986
SCS	Soil Conservation Service
SIA	Stapleton International Airport
SM	Site Manager
SPT	Standard Penetration Test
TEG	Temperature effect gauge
USC	United States Code
USCS	Unified Soil Classification System
USFWS	U S Fish and Wildlife Service
UXO	Unexploded ordnance
VOC	Volatile organic compound

Walsh	J P Walsh and Associates, Inc
WES	Waterways Experiment Station
°F	Degrees Fahrenheit

8.0 BIBLIOGRAPHY

Arthur D Little 1979 *Hydrogeologic description of Rocky Mountain Arsenal groundwater module, fourth interim report, installation, restoration, simulation and cost benefit analysis* Prepared for Geraghty and Miller RIC No 81295R16

Bopp, and others 1979 *Hydrogeology and water quality of Basin A neck area, Rocky Mountain Arsenal, Denver, Colorado, draft report* U S Army Engineer Waterways Experiment Station, C E Vicksburg, Miss

Boutwell, G P 1992 *The STEI two-stage borehole field permeability test* Presented at Containment Alignment and Subtitle D, sponsored by Geotechnical Committee Houston Branch, American Society of Civil Engineers, March 12

Broughton, J , W Miller, and G Mitchell 1979 *Geology and groundwater definition, Basin A area, Rocky Mountain Arsenal, Denver, Colorado* U.S Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 81266R27

Colorado Climate Center 1994 *Public access meteorological data base* Fort Collins, Colo

Devoto, R.H 1968 *Quaternary history of the Rocky Mountain Arsenal and environs, Adams County, Colorado* Quarterly of the Colorado School of Mines RIC No 84291R01

Earth Technology Corporation. 1981 *Hydraulic conductivity and the Unified Soils Classification System at Rocky Mountain Arsenal, Denver, Colorado* Project Number 82-169 Prepared for the U S Army Toxic and Hazardous Materials Agency and Computer Sciences Corporation Long Beach, Calif RIC No 81352R135

Ebasco Services, Inc 1988a *Final report, task number 27, hazardous waste land disposal facility assessment report*

——— 1988b *Hazardous waste land disposal facility assessment* Rocky Mountain Arsenal, September

——— 1989a *Final remedial investigation, north central study area* Prepared for the Program Manager for Rocky Mountain Arsenal, July

——— 1989b *Final water remedial investigation report, vol III version 3 3* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 89186R01, July

——— 1994 *Proposed final detailed analysis of alternatives* Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colo, December

Ebasco Services, Inc , and others 1991 *Draft final remedial investigation summary report, version 2 3* Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colo RIC No 91137R01, May

Ebasco Services, Inc , R.L Stollar & Associates, Inc , Munter/ESE, Inc , and Harding Lawson Associates 1989a *Proposed final water remedial investigation report (version 3 2), vols I, II, III,* June

Emmons, S F , and others 1896 *Geology of the Denver Basin in Colorado* U S Geological Survey Monographs Vol 27

Environmental Science and Engineering, Inc , Harding Lawson Associates, and Applied Environmental, Inc 1988 *Offpost operable unit remedial investigation and chemical specific applicable or relevant and appropriate requirements, final report, Version 3 1* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 89173R01, December

Evans, D M 1965 *Denver area earthquakes and the Rocky Mountain Arsenal disposal well* Mountain Geologist V 3, no 1, pp 23-36 RIC No 81356R32

Hansen, W R , and E J Crosby 1982 *Environmental geology of the front range urban corridor and vicinity, Colorado* USGS Professional Paper No 1230

Harding Lawson Associates 1989 *Regional ground-water flow modeling at the Rocky Mountain Arsenal, Denver, Colorado* Draft final report, Version 2 1

——— 1992a *Groundwater monitoring program final annual groundwater monitoring report for 1991* Prepared for the Program Manager for Rocky Mountain Arsenal, Commerce City, Colorado RIC No 92272R01, September

——— 1992b *Results of treatability studies for groundwater containment and/or control and subsurface drains final report* Volume I of IV, September 18

——— 1994a *Final geophysical assessment report, Rocky Mountain Arsenal, Commerce City, Colorado*, February

——— 1994b *Final fourth year reevaluation report for complex disposal trenches interim response action, Rocky Mountain Arsenal, Commerce City, Colorado*, September

——— 1994c *Final work plan for material and area feasibility studies, soils support program, Rocky Mountain Arsenal, Commerce City, Colorado*, November

——— 1995a *Final feasibility study soils support program report, Rocky Mountain Arsenal, Commerce City, Colorado*, January

——— 1995b *Groundwater monitoring program final annual groundwater monitoring report for 1993 Rocky Mountain Arsenal, Commerce City, Colorado*, March.

Harding Lawson Associates and Environmental Science and Engineering, Inc , 1992 *Offpost operable unit remedial investigation final addendum* Prepared for the Program Manager for Rocky Mountain Arsenal. RIC No 92156R01, March.

Howard Needles Tammen & Bergendoff 1981 *Chemical waste treatment/solidification disposal facility plan* Prepared for Highway 36 Land Development Co , Adams County, Colorado, April

Hynes, J L., and C J Sutton. 1980 *Hazardous wastes in Colorado A preliminary evaluation of generation and geologic criteria for disposal* Prepared by the Colorado Department of Health and Colorado Geological Survey Department of Natural Resources

Kirkham, R J , and W P Rogers 1981 *Earthquake potential in Colorado* Colorado Geological Survey, Bulletin 43

Lindvall, R M 1980 *Geological map of the Commerce City quadrangle, Adams and Denver Counties, Colorado* U S Geological Survey Map CQ-1541

——— 1983 *Geological map of the Sable quadrangle, Adams and Denver Counties, Colorado* U S Geological Survey Map MF-1180

May, J H 1982 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado report 1, hydrogeological definition* U S. Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 82295R01, July

May, J H , J D Crabtree, R W Hunt, and M L Murphy 1983 *Hydrogeology of Basin A/South Plants area, Rocky Mountain Arsenal, Denver, Colorado, phase I* U S Army Corps of Engineers Waterways Experiment Station Vicksburg, Miss RIC No 83299R01

——— 1983 *Hydrogeology of Basin A/South Plants area, Rocky Mountain Arsenal, Denver, Colorado, phase I* Final Report. Geotechnical Laboratory, U S Army Engineer Waterways Experiment Station, September

Miller, C H , and others 1979 *Preliminary magnetic, seismic, and petrographic investigation of a possible igneous dike at the Rocky Mountain Arsenal* Denver, Colorado U.S Geological Survey, Open File Report 79-1685

Morrison-Knudsen Engineers, Inc 1987 *Preliminary recharge estimates for RMA regional flow model, final version*

——— 1988 *Geology of the Rocky Mountain Arsenal, Adams County, Colorado* Prepared for Holme, Roberts, and Owens Denver, Colo

Morrison-Knudsen Environmental Services, Inc 1994 White paper evaluation of the Denver Formation at Rocky Mountain Arsenal, April

Pacific Western Technologies 1993 *Groundwater monitoring program final annual groundwater monitoring report for 1992* Prepared for the Program Manager for Rocky Mountain Arsenal RIC No 94230R02, August

Rauch, R 1994 U S Fish and Wildlife Service, Rocky Mountain Arsenal, Commerce City, Colorado Letter to Charles Sharmann, Program Manager for Rocky Mountain Arsenal, September 22

Richardson, G N 1995 Review of Repository Alternatives Letter to Harding Lawson Associates, February 9

Robson, S G 1987 *Bedrock aquifers in the Denver Basin, Colorado - A quantitative water-resources appraisal* U S Geological Survey Professional Paper 1257, p 73

Robson, S G , and J C Romero 1981 *Geologic structure, hydrology, and water quality of the Denver Aquifer in the Denver Basin, Colorado* Prepared for the U S Geological Survey and the Colorado Division of Water Resources RIC No 82350M02

Rust Environment and Infrastructure 1994 Landfill Quantity, Borrow Materials, and Landfill Generation Rate Summary Letter to Harding Lawson Associates, December 22

Sampson, J , T Babor, and C Prentiss 1974 *Soil survey of Adams County, Colorado* CSU, USDA. RIC No 81266R54

Shepherd, W D 1982 Letter to Commander of RMA from J H Knaus, Shell Oil Col, including data from aquifer tests dated May 5, 1982

Spaine, P A , D W Thompson, and J H Dildane 1984 *Regional groundwater study of Rocky Mountain Arsenal, Denver, Colorado Report 2 contamination distribution* U S Army Corps of Engineers Waterways Experiment Station, Environmental Laboratory Vicksburg, Miss

Stollar, R L , and F Van der Leeden 1981 *Evaluation of the hydrogeological system and contaminant migration patterns, Rocky Mountain Arsenal final report* Geraghty and Miller, Inc Prepared for the U S Army Toxic and Hazardous Materials Agency Denver, Colorado RIC No 81293R05

Trimble and Machette 1979 *Geologic map of the greater Denver area, front range urban corridor, Colorado* U S Geological Survey Map I-856-H

U S Army Corps of Engineers 1983 *Evaluation of the existing and future flood potential on the Rocky Mountain Arsenal, Denver, Colorado* Omaha, Nebr RIC No 84066R01

U S Army Toxic and Hazardous Materials Agency 1984 *Decontamination assessment for land and facilities at Rocky Mountain Arsenal* Draft Final Report RIC No 84034R01

——— 1983 *Selection of a contamination control strategy for Rocky Mountain Arsenal* Final Report RIC No 83326R01

U S Environmental Protection Agency 1988 *Guidance for conducting remedial investigations and feasibility studies under CERCLA*, Interim Final October

——— 1994 *The hydrologic evaluation of landfill performance (HELP) model, engineering documentation for version 3* September EPA/600/R-94/168b

——— 1988 *Interactive simulation of the fate of hazardous chemicals during land treatment of oily wastes RITZ user's guide* January EPA/600/8-88/001

Vispi, M A. 1978 *Report of findings, RMA pumping tests, USAEWES report* U S Army Corps of Engineers Waterways Experiment Station. Vicksburg, Miss RIC No 81266R70

Waterways Experiment Station (Crabtree, J D , and Thompson, D W) 1983 *Proposed hazardous waste landfill siting and suitability, Rocky Mountain Arsenal, Denver, Colorado* Prepared for the U S Army Toxic and Hazardous Materials Agency November

Weimer, R 1973 *A guide to uppermost cretaceous stratigraphy, central front range, Colorado* Department of Geology, Colorado School of Mines, Golden, Colo RIC No 81266R59

Appendix A

TESTFILL CONSTRUCTION SPECIFICATIONS

TABLE OF CONTENTS

SECTION 01: SUMMARY OF WORK

PART 1 GENERAL

1.01 PROJECT DESCRIPTION

A. Work of the Contract comprises construction of two (2) test fills at Rocky Mountain Arsenal, Commerce City, Colorado. Work includes, but is not limited to:

1A. Stripping and stockpiling 12 inches topsoil from the two designated borrow areas shown in Figure 2.

1B. Stripping and stockpiling 4 inches topsoil from the test fill area, and processing area.

2. Excavating approximately 500 cubic yards (yd^3) of clay from each of two (2) designated borrow areas (total of 1000 yd^3).

3. Transporting clay to soil processing area

4. Processing clay to meet moisture content and clod size specifications

5 Grading Test Fill area to a smooth, uniform surface.

6. Wetting the subgrade and placing a working layer of clay at base of each test fill.

7. Constructing the three-foot thick test fills in six (6) six-inch lifts, allowing for testing by the Engineer during construction.

8 Preparing necessary test fill surfaces and assisting with field testing, e.g , blading smooth surface for nuclear gauge, pushing Shelby tubes, excavating small test pits to check lift bonding.

9 Regrading and placing stockpiled topsoil over completed test fill, processing, and borrow areas

10 Seeding and mulching all disturbed areas.

B The Subcontractor shall furnish all labor and equipment to perform the Work outlined above The following shall be provided to the Subcontractors:

a. The Owner shall provide approved onpost borrow sources for all soil for compacted soil test fills

b The Contractor shall provide onpost water source at the Fire Station, corner of D Street and 7th Avenue, 1 1/8 miles south of test fills.

c The Contractor shall provide soil testing during processing and placement of test fill soil.

d. The Owner shall provide native grass hay mulch.

1 02 FORM OF SPECIFICATIONS

A. Term "provide" or "provided" shall mean "furnish and install in-place," except as noted.

B These Specifications are intended to be used in conjunction with the accompanying Test Fill Design Plans, hereinafter referred to as "Drawings."

C Definitions:

1. Contract - Contract documents signed by HLA and Subcontractor

2. Contractor - Harding Lawson Associates

3. Engineer - HLA's resident project engineer or designated representative

4 Subcontractor - Earthwork construction company

5 Owner - Program Manager for Rocky Mountain Arsenal

6. Work - All site work related to this project that is to be performed by the Subcontractor

D Any reference to standards of any society, institute, association or governmental agency shall be the edition in effect as of the date of this Specification, unless stated otherwise

1.03 CONTRACTS

A. Perform work as agreed to in Contract with Contractor.

1 04 WORK BY OTHERS

A. Work on project which will be performed by others during period of contract, but that is excluded from contract, is as follows

1. Construction management services.

2. Construction material testing.

3. Surveying services

4 Health and safety monitoring.

5 Owner and regulatory liaison.

1 05 SCHEDULE

A Coordinate construction schedule and operations with Engineer.

1.06 SUBCONTRACTOR'S USE OF PREMISES

A Confine construction operations to within designated work areas unless otherwise authorized by Owner. A fenced parking lot and equipment laydown area are shown in Figure 2. Some parking is also available at the test fill site.

B. Keep driveways and roads clear and available to Owner at all times. Do not use these areas for parking or storage of materials. Schedule deliveries with Engineer to minimize space and time requirements for storage and handling of materials and equipment onsite

C Subcontractor shall, at all times, conduct operations to assure least inconvenience to Owner, Contractor, other subcontractors, onpost personnel, and operations of facility.

D Do not perform any work within protected area boundaries.

E. Coordinate hours of operation with Engineer.

1.07 OWNER - FURNISHED ITEMS

A. Owner will furnish site laydown and parking facilities.

B. Owner will furnish access to construction water at the Fire Station, corner of D Street and 7th Avenue, 1 1/8 miles south of test fills.

C Owner will furnish native grass hay mulch (located in Section 29 of RMA; see Figure 2).

1 08 CONTRACTOR RESPONSIBILITIES

A. Provide construction management services.

B. Arrange for soil testing as specified in Specifications.

C. Arrange for necessary surveying.

D Coordinate construction activities with Owner.

E. Monitor site conditions for health and safety

1.09 SUBCONTRACTOR'S RESPONSIBILITIES

The Subcontractor shall furnish all labor and equipment required to perform the Work, including, but not limited to:

A. Handle material at site, including receiving, unloading, and storage in accordance with Contractor's requirements and manufacturer's recommendations

B Install materials as required by Specifications.

C. Repair or replace materials damaged by Subcontractor.

D. Arrange for replacement of damaged, defective, or missing items or materials

- END OF SECTION -

SECTION 02. GENERAL REQUIREMENTS

PART 1 GENERAL

1.01 SUMMARY

A. Two test fills shall be constructed to verify the suitability of two different local materials for use as impermeable clay liner and to verify/determine the construction procedures (i.e., moisture content range and compaction effort) required to achieve a compacted in-place permeability less than or equal to 1 x 10^{-7} centimeters per second (cm/sec).

B. This Specification and other Contract Documents cover the furnishing of all labor, materials, equipment, superintendence, and services necessary to construct the test fills

C. Cooperation. The Subcontractor shall cooperate with all other parties engaged in project-related activities to the greatest extent possible. Disputes or problems should be referred to the Contractor for resolution.

D Construction Water. The quality of construction water used to accomplish construction work is crucial due to the nature of the facilities being constructed. Subcontractor shall use construction water provided by Owner, which is a good quality water from an onpost source

E. Inspection All inspection, testing, and documentation procedures shall be the responsibility of the Contractor. As described in other Specification sections, Subcontractor shall assist as necessary in facilitating testing procedures

- END OF SECTION -

SECTION 03: HEALTH AND SAFETY REQUIREMENTS

PART 1 GENERAL

1.01 SUMMARY

A. SITE BACKGROUND

Rocky Mountain Arsenal (RMA) occupies approximately 27 square miles in southern Adams County, Colorado, approximately 9 miles northeast of downtown Denver (Figure 1) RMA was established by the Army in 1942 to produce chemical and incendiary munitions for World War II.

During operations at RMA, the U.S. Department of the Army's (Army's) day-to-day activities generated miscellaneous solid waste, as well as potentially contaminated tools, equipment, unwanted containers, rejected incendiaries, empty munitions casings, demilitarized munitions, explosives, burster charges, rocket propellant, rocket motors, wastes from the Mustard Plant, and wastes from the production of nerve agent (GB). These materials were decontaminated with caustic or other decontaminants and transported to burning pits to assure complete decontamination by incineration. Following World War II, the production of munitions decreased, and the Army leased selected portions of RMA to private industry.

From 1942 until 1957, chemical agents were manufactured at RMA. Levinstein mustard (H) was produced in the South Plants manufacturing area from 1942 until 1950 This area was also used to fill shells with the chemical agent phosgene or incendiary mixtures, including napalm and white phosphorous. During this period, obsolete World War II munitions were destroyed by detonation or incineration on RMA.

Section 36 was the primary area for waste disposal at RMA in the 1940s and 1950s. Potentially contaminated solid waste including metal were incinerated in pits and trenches located east and north of Basin A. The chemical nerve agent isopropylmethyl fluorophosphonate (Sarin or GB) was produced in the North Plants manufacturing area from 1953 until 1957. Munitions filling with this nerve agent continued at RMA until 1969. From 1970 to 1984, Army activities focused primarily on the demilitarization of chemical warfare materials.

In 1947, portions of RMA were leased to private industry. Early lessees included Colorado Fuel and Iron Corporation (CF&I) and Julius Hyman and Company (Hyman). CF&I produced chlorine and chlorinated benzenes and attempted to manufacture dichlorodiphenyltrichloroethane (DDT). Hyman produced several pesticides during this period. In 1950, Hyman added to its lease a number of facilities formerly operated by CF&I. In 1952, Shell Oil Company (Shell) acquired Hyman and operated it as a wholly owned subsidiary until 1954, when Hyman was integrated into the Shell corporate structure and Shell succeeded Hyman as the named lessee. From 1952 until 1982, Hyman and/or Shell produced a variety of herbicides and pesticides in the South Plants manufacturing complex.

Between 1942 and 1982, a variety of the contaminants associated with the industrial activities onsite were released to the environment at RMA. Chemical waste effluents were discharged into lined and unlined evaporation basins, and solid wastes were buried or disposed on the surface. Wastewater, raw materials, and end products were leaked and accidentally spilled within the manufacturing complexes, storage areas, and transportation routes on RMA. Chemical products that were not manufactured to specification were commonly discharged into shallow trenches. Munitions were demilitarized and disposed in trenches and on the surface. The sites that are believed to have been the primary groundwater contamination source areas at RMA are the manufacturing complexes, the wastewater storage and evaporation basins (Basins A, C, D, E, and F), areas of solid waste disposal, and the rail classification yard.

In the early 1950s, the detrimental effects of chemical contamination on the local environment became evident. By 1951, high waterfowl mortality was suspected of being linked to the insecticide contamination of three artificial lakes on RMA (Armitage, 1951; Goodall, 1951). In 1954 and 1955, severe crop loss was reported by farmers northwest of RMA using well water for irrigation (U.S. Department of Health, Education, and Welfare, 1965). Two contaminants, diisopropylmethylphosphonate (DIMP), a manufacturing byproduct of the nerve agent GB, and dicyclopentadiene (DCPD), a chemical used to produce insecticides, were detected in offpost surface water in 1974 (R. L. Stollar and Associates, Inc. [Stollar], and others, 1991). Groundwater contaminated with dibromochloropropane (DBCP) and other compounds has been detected in samples from offpost since 1978 (Environmental Science and Engineering [ESE], 1987).

B NATURE AND EXTENT OF CONTAMINATION

Releases of a variety of contaminants to the environment at RMA have resulted in contamination of environmental media both onpost and offpost (ESE and others, 1988; HLA and ESE, 1992; Ebasco Services, Inc. [Ebasco], and others, 1991) Soil and groundwater contamination have occurred at several locations onpost. Soil contamination is in some cases fairly localized, whereas in other cases it has resulted in broader contamination as soil contaminants entered the groundwater.

The distance that a groundwater contaminant plume extends from its source area depends on numerous factors, including the contaminants' behavior in the environment, the amount and time of the release, and other factors, as noted below. Groundwater contaminant plumes at RMA may extend only a few hundred feet from their sources or may extend miles, as is the case for DIMP. Generally, the occurrence and migration of contaminants in groundwater at RMA is complicated by the following factors

- Many contaminant sources, some areally separated, some overlapping
- A variety of release scenarios, including single or repeated spills, continuous or intermittent leaks, discharges to ditches or basins, leaching from trenches, and leaching from or direct contact of groundwater with buried transport lines
- Many contaminants
- Spatial variabilities in aquifer properties
- Complex interactions between water-bearing zones
- Historical changes in the distribution and quantity of groundwater recharge

C. The areas of the RMA in which the work will be performed are considered clean (nonhazardous) and no special safety measures are anticipated to be necessary beyond standard construction protective gear such as hard hats, steel-toed boots, and safety glasses or goggles.

D. However, because of the nature of the site, construction activities at the RMA could, if unexpected conditions are encountered, potentially place Subcontractor's personnel in situations where additional personal protective equipment (PPE) or other safety measures may be necessary.

E. Therefore, all Subcontractor's personnel doing work on the site shall be 40-hour trained per Occupational Safety and Health Administration (OSHA) Safety and Health Standards (29 Code of Federal Regulations [CFR] 1910) and general construction standards (29 CFR 1926).

1.02 PAYMENT

A. Subcontractor shall assume that all work shall be performed under OSHA Hazardous Waste Site "Level D" conditions, (i.e., the work is "clean" and only standard construction protective gear is necessary) Therefore, the Subcontractor shall make no allowance in time or cost in the bid for working under "Level C" or more strict conditions If results of real-time monitoring by Contractor indicates a need for additional health and safety precautions and/or protective equipment, Contractor and Subcontractor shall agree upon fair compensation for work performed under the altered circumstances.

B See also paragraph 1 06 A.

1 03 OPERATIONS AND EQUIPMENT SAFETY

A. Contractor shall be responsible for initiating, maintaining, and supervising safety precautions and programs in connection with Work. Subcontractor shall take necessary precautions for safety of employees on Project site as directed by Contractor.

B Both the Contractor and Subcontractor's duties and responsibilities for safety in connection with Work shall continue until such time as Work is complete and Contractor has issued notice to Subcontractor that Work is complete.

1 04 HEALTH AND SAFETY

A. Contractor shall prepare a site-specific Health and Safety Plan and be responsible for implementation and enforcement of health and safety requirements, and Subcontractor shall conform with this Plan, take necessary precautions, and provide protection for the following:

1. Subcontractor personnel working on or visiting Project site

2. Work and materials or equipment to be incorporated in Work area.

B Read, sign, and follow the Contractor's Health and Safety Plan.

C Hold a safety meeting prior to starting Work each day. Inform Contractor of time and location prior to meeting. Provide attendance roster to Contractor.

1.05 CONTRACTOR'S RESPONSIBILITIES

A. If Contractor determines that Subcontractor's activities do not comply with requirements of this Specification or the site-specific health and safety plan developed by the Contractor for the Subcontractor, Contractor may direct its and/or Subcontractors employees to leave Project site or implement additional safeguards for Owner's or Contractor's protection.

B. If Contractor observes situations that appear to have potential for immediate and serious injury to persons, Contractor may warn persons who appear to be affected by such situations.

1.06 DECONTAMINATION

A. Owner requires that all construction equipment be run through an onpost decontamination station. Subcontractor shall allow 1/2 hour per piece of equipment for this procedure for bidding purposes. However, payment shall be made by actual time and materials used.

- END OF SECTION -

SECTION 04: PROJECT MEETINGS

PART 1 GENERAL

1.01 SUMMARY

A. Engineer will schedule a preconstruction meeting, weekly progress meetings, and any specially called meetings throughout progress of work. Engineer will be responsible to.

1. Prepare agenda for preconstruction meeting.
2. Notify Owner and Subcontractor of location and time.
3 Make physical arrangements for meetings
4 Preside at meetings.
5. Record minutes; include significant proceedings and decisions
6. Reproduce and distribute copies of minutes to meeting participants and other parties affected by decisions made at meeting.

B Representatives of Subcontractor attending meeting shall be authorized and qualified to act on Subcontractor's behalf.

C. Payment: Consider work specified in this section incidental and include payment as part of lump sum price in Bid Schedule

1.02 PRECONSTRUCTION MEETING

A. Purpose of meeting:

1 Review principal features of Work.
2. Environmental protection.
3 Safety requirements
4 Progress schedules.
5. Payment.
6. Address Subcontractor's questions regarding contract and Work.

1.03 WEEKLY PROGRESS MEETINGS

A. Minimum of once per week, or as requested by Engineer.

B Attendance

1 Owner and/or Owner's representative.
2. Subcontractor's superintendent.

3 Engineer

4 Other Subcontractors as appropriate.

- END OF SECTION -

SECTION 05: CONSTRUCTION STAKING AND SURVEYING

PART 1 GENERAL

1.01 SUMMARY

A. Vertical and horizontal control staking information will be provided by Contractor at no expense to Subcontractor. Stakes will be located (by the Contractor) to set the horizontal boundaries of the test fills, and processing areas.

1. Contractor shall be responsible for reviewing and following all initial construction staking. Any restaking shall be approved by the Engineer.

2. Contractor shall be responsible for maintaining, restaking as necessary, and removing survey control stakes.

B. Payment: Consider Work specified in this section incidental (except items specifically noted as being provided by Contractor) and include cost as part of appropriate fixed prices in Bid Schedule.

1.02 CONSTRUCTION LINE AND GRADE

A. Contractor shall bear sole responsibility for correct transfer of construction lines and grades from primary vertical and horizontal control stakes and for correct alignment and grade of completed Work based on lines and grades shown on Drawings and described in these Specifications.

B Contractor shall transfer line and grade for construction from control stakes to Work utilizing the following procedures:

1. Provide qualified technician during course of construction.

2. Check line and grade as Work progresses.

C. Contractor shall

1. Review all initial construction staking.

2. Verify accuracy of line and grade by checking between stakes

3. Place stakes during test fill placement as needed to maintain specified lift thickness.

4 Assure that all elements of test fill, including subgrade, working layer, and completed lifts, slope as specified in these Specifications and on Figure 3.

5 Be responsible for protection and preservation of stakes during construction and at completion of construction.

6. Be responsible for removal of all stakes used for construction.

7. Arrange operations to avoid interference with documentation of final lines and grades.

- END OF SECTION -

SECTION 06: PROTECTION OF ENVIRONMENT

PART 1 GENERAL

1.01 SUMMARY

A. Subcontractor, in executing Work, shall maintain work areas free from environmental pollution that would be in violation of federal, state, or local regulations.

B. Subcontractor shall maintain sediment runoff within the project boundaries. Subcontractor shall take appropriate action to prevent sediment runoff beyond the designated work areas, into drainageways, or into restricted area boundaries. No significant work of this nature is anticipated.

C. Payment: Consider Work specified in this section incidental and include payment as part of lump sum price specified in Bid Schedule.

1.02 PROTECTION OF WATERWAYS

A. Observe rules and regulations of the State of Colorado and agencies of U S. government prohibiting pollution of any lakes, streams, rivers, or wetlands by dumping of refuse or debris therein.

B Divert flows, including stormwater and flows created by construction activity, to sumps, sediment traps, silt fencing, or other controls approved by Engineer to prevent excessive silting of waterways.

1.03 EROSION AND SEDIMENT CONTROL

A. Apply appropriate soil conservation measures to protect project area and adjacent lands Measures may include, but are not limited to, mulching, fabric mat, straw or hay bales, filter barriers, and sediment traps Adjust sediment control measures in field to meet conditions encountered.

B Provide erosion control measures before commencing work on project site as directed by Engineer Engineer shall direct, inspect, and approve of erosion control measures before commencing Work.

1 Maintain erosion control measures during course of construction.

2 Remove erosion control measures upon establishment of permanent, surface stabilization or as directed by Engineer.

1.04 PROTECTION OF AIR QUALITY

A. Minimize air pollution by requiring use of properly operating combustion emission control devices on construction vehicles and equipment, and encouraging shutdown of motorized equipment not actually in use.

B Trash burning is not permitted on construction site.

1.05 FUELING AND VEHICLE/EQUIPMENT LEAKAGE

A. Do not fuel or perform maintenance on equipment while within the Work area boundaries without the Engineer's permission. These activities may be performed in the test fill parking area or the designated staging/parking area. Fueling must be performed carefully to prevent spillage. Spillage or leakage of fuel, oil, or vehicle fluid must be cleaned up immediately to the satisfaction of the Engineer.

1 06 NOISE CONTROL

A. Conduct operations to cause the least annoyance to personnel and wildlife in vicinity of work, and comply with applicable local ordinances.

B. Equip equipment with mechanical devices necessary and reasonable to minimize noise and dust.

C Route vehicles carrying soil or other material over those streets that will cause the least annoyance to humans and animals, as directed by the Owner or Engineer, and do not operate on RMA roads between hours of 7.00 p.m. and 6:00 a.m., or on Saturdays, Sundays, or legal holidays, unless otherwise approved by Owner or Engineer.

1.07 DUST CONTROL

A. Due to proximity of project to sensitive onpost operations and habitats, take special care in minimizing dust generation on temporary access roadways, Owner's existing roads, and roads used for construction operation. Subcontractor shall be responsible for the control of dust by watering within the construction project area and areas utilized by Subcontractor to perform the Work. Speed limits will be followed on Owner's existing roads to minimize dust generation.

B Comply with local environmental regulations for dust control, and also with directions of Engineer and Owner If Subcontractor's dust control measures are considered inadequate by Engineer or Owner, Contractor will require Subcontractor to improve dust control measures at no cost to Contractor.

1.08 PROTECTION OF WILDLIFE

A. Due to proximity of the project to sensitive wildlife habitats, the Subcontractor shall take special care to minimize impact to these habitats. Hauling equipment will be required to stay on designated traffic routes and yield right-of-way to all wildlife. Vehicles and equipment shall proceed slowly when wildlife is present.

B No photography or harassment of wildlife is permitted.

- END OF SECTION -

SECTION 07: MATERIAL AND EQUIPMENT

PART 1 GENERAL

1.01 SUMMARY

A. Material and equipment incorporated into Work shall:

1. Conform to applicable Specifications and standards.

2. Comply with size, make, type, and quality specified or as specifically approved by Engineer.

B. Do not use material or equipment for purpose other than that for which it is designated or specified.

C. Payment Consider Work specified in this section incidental and include cost as part of lump sum prices in Bid Schedule.

1.02 SUBSTITUTIONS

A. Substitutions.

1. Subcontractor's requests for changes in equipment from those required by Contract Documents are considered "requests for substitutions" and subject to Subcontractor's representations and review provisions of Contract Documents when one of the following conditions are satisfied:

   a. Where request directly related to or "equal" clause or other language of same effect in Specifications.

   b. Where required equipment cannot be provided within Contract Time, but not as a result of Subcontractor's failure to pursue work promptly or coordinate various activities properly.

2. Subcontractor's Options.

   a. Compatibility of Options. Where more than one choice available as options for Subcontractor's selection of equipment, select option compatible with other equipment and materials already selected.

   b. Standards, Codes, and Regulations: Where compliance with imposed standard, code or regulation required, select from among products that comply with requirements of those standards, codes, and regulations.

   c. "Or Equal": For equipment specified by naming one or more equipment manufacturer and "or equal," subcontractor shall submit request for substitution for equipment or manufacturer not specifically named.

   d. Two or More Manufacturers: For equipment specified by naming several manufacturers, select one of manufacturers named. Do not provide or offer to provide unnamed manufacturer or equipment.

e. Single Manufacturer· For equipment specified by naming only one manufacturer and followed by words indicating no substitution, there is no option.

B Conditions that are not substitutions:

1. Requirements for substitutions do not apply to Subcontractor options on materials and equipment provided for in Specifications.

2 Revisions to Contract Documents, where requested by Owner or Contractor, are "changes," not "substitutions."

3. Subcontractor's determination of and compliance with governing regulations and orders issued by governing authorities do not constitute substitutions or basis for Change Orders, except as provided for in Contract Documents

1.03 TRANSPORTATION AND HANDLING

A. Arrange deliveries of equipment with Engineer and in accordance with construction schedule; coordinate to avoid conflict with Work and conditions at site.

B. Provide equipment and personnel to handle materials and equipment by methods recommended by manufacturer to prevent soiling or damage to materials or equipment, or packaging

C. Handling:

1. Handle material at Site, including receiving, unloading, and storage, in accordance with Contractor's requirements and manufacturer's recommendations. The Owner-designated staging area shown on Figure 2 or the area adjacent to the test fills shall be used for such activities.

2 Install materials as required by Specifications.

1 04 STORAGE, PROTECTION, AND MAINTENANCE

A. The designated onsite storage and staging area is shown on Figure 2. Equipment and vehicles may be stored overnight in this fenced area with Engineer's permission. No overnight parking of personal vehicles is allowed.

B Subcontractor assumes full responsibility for security and/or damage due to improper storage of materials.

C. Maintenance·

1. Repair or replace materials damaged by Subcontractor.

- END OF SECTION -

SECTION 08. SITE PREPARATION AND CLOSURE

PART 1 GENERAL

1.01 SUMMARY

A. Section includes

1. Requirements for topsoil removal and stockpiling, and protection of wells and utilities.

2. Installation of sediment and erosion control measures as necessary

3. Regrading and topsoil placement upon completion of work.

4. Temporary roads.

B Payment: Payment for items in this section is included under Bid Items A2, B1, and E1

1 02 DEFINITIONS

A. Utilities: For purposes of this section, existing gas mains, water mains, steam lines, electric lines and conduits, telephone and other communication lines and conduits, sewer pipe, cable television, other utilities, and appurtenances.

B Topsoil. For purposes of this section, the upper 12 inches of soil available from borrow areas to be disturbed during construction, or the upper 4 inches of soil available from the test fill/processing areas.

C Sediment and Erosion Control Measures: As described in Section 06 paragraph 1.03.

1.03 PROJECT/SITE CONDITIONS

A. Notification

1 Owner will identify all utilities/wells and notify Contractor, who will notify Subcontractor. No utilities are currently known to exist within the Work areas. Subcontractor bears sole responsibility for damage caused to any identified utilities or wells, or any associated damages and claims caused as a result of Subcontractor damaging such utilities or wells.

B. Protection:

1. Protect existing utilities against damage.

2. Locate existing underground utilities by hand excavation. When Work requires Subcontractor to be near or to cross known utilities, the Subcontractor shall carefully uncover, support and protect these utilities and shall not cut, damage, or otherwise disturb them without prior authorization from the Engineer.

3. If uncharted utilities are encountered during excavation, notify Engineer and wait for instructions before proceeding.

a Repair damage to utilities encountered when Work is continued without notifying Engineer or his designated representative. This work shall be done at no expense to Contractor

4. Preserve and protect groundwater monitoring wells. Damaged or destroyed monitoring wells shall be replaced at Subcontractor's expense.

PART 2 EXECUTION

2 01 PERFORMANCE

A. Site Preparation:

1 Establish sediment controls prior to disturbing project areas.

2. Cut or remove growth of tall weeds and grass greater than 6 inches high from areas to be stripped. Remove debris and boulders, within project area.

3 Strip topsoil within limits of borrow areas, processing areas, and test fill area Stripping shall not extend beyond limits of designated areas.

4 Maintain bench marks, control monuments, and monitoring wells Re-establish if disturbed, damaged or destroyed, at no cost to Contractor

B Topsoil Handling:

1 Stockpile topsoil in neat piles adjacent to each project area. Topsoil shall be kept separate from other excavated materials

C Regrading

1 The borrow areas shall be regraded and smoothed out after excavation is completed. Finished contours shall be gently sloping and blended to meet existing topography

2 The test fill and immediately surrounding area shall also be regraded and blended with existing topography. For bidding purposes, assume 1 day with a dozer to regrade test fill area.

D Topsoil Placement

1 Stockpiled topsoil shall be used to cover the completed test fills, processing areas, and disturbed borrow areas upon completion of activities in these areas The topsoil shall

a. Be placed and lightly compacted so as not to impede infiltration and subsequent plant growth.

b Be spread over the borrow areas upon completing placement of excess test fill area soil and regrading.

c. Be placed to a minimum of 1-foot thickness in all areas receiving topsoil.

E. Temporary Roads:

1. The Subcontractor shall be responsible for constructing any temporary roads that he may require in the execution of his Work. Any ditches that are filled to provide access to borrow areas or test fill area must be cleaned out and restored to original condition upon completion of Work.

- END OF SECTION -

SECTION 09· EXCAVATION, STOCKPILING, AND PROCESSING

PART 1 GENERAL

1.01 SUMMARY

A. Section includes.

1. Excavating soil from designated borrow areas and test fill area; grading and preparation of test fill area.
2. Transporting borrow soil to processing areas.
3. Stockpiling/spreading soil as required to achieve adequate independent sources for topsoil, working layer soil, and test fill soil.
4. Processing test fill soil as needed to reduce clod size, adjust moisture content, and remove rocks.

B Payment· Payment for items in this section is included under Bid Items B2, B3, B4, C1, and C2.

1.02 PROJECT/SITE CONDITIONS

A. Locate identified existing utilities; underground utilities shall be located by hand excavation. No utilities are known to exist within the project areas

B. If uncharted utilities are encountered during excavation, notify Engineer and wait for instructions before proceeding.

C. Protect, support, and maintain monitoring wells, conduits, wires, pipes, or other features and utilities that are to remain onsite in accordance with requirements of Contractor and Owner.

D Notify Engineer if any unidentified wells or piezometers, potentially hazardous material, or other unexpected items are encountered during this work, and wait for instructions before proceeding.

E. The material borrow source for each test fill is a designated borrow area, as shown on the Drawings, Figure 2 The Engineer shall determine what borrow material is appropriate for the test fills

PART 2 EXECUTION

2.01 PREPARATION

A. Contractor shall identify to the Subcontractor acceptable independent stockpile/processing locations for topsoil, working layer material, and test fill material Areas designated for processing are shown on the Drawings, Figure 3, and shall be stripped of topsoil prior to placement of borrowed materials

B. Install, prior to construction, silt fencing or other controls approved by Contractor in areas where sediment from this construction or operations may impact wetlands, drainageways, or other sensitive areas. No or minimal activity of this type is anticipated to be done by the Subcontractor

2 02 EXCAVATION, TEST FILL AREA PREPARATION, AND STOCKPILING

A. Excavate approximately 500 yd^3 of soil from each borrow area, as directed by the Engineer, and transport soil to processing area. Borrow soil from Borrow Area A shall be taken from 1 to 4 feet in depth; borrow soil from Borrow Area B shall be taken from 4 to 7 feet in depth. Shallow soil in Borrow Area B shall be moved to the side prior to borrowing, then replaced upon completion of borrow activities.

B. Grade the test fill area to within ± 0.2 feet of the proposed grades Proposed grades are approximately 4 inches below existing grades. Subgrade shall slope at 2 percent in the direction shown on Drawings, Figure 3. Each test fill area will be approximately 40 feet wide by 100 feet long, as shown on the Drawings, Figure 3

C. The subgrade shall be compacted with 12 passes of a wedge-foot compactor, imparting a maximum of 50,000 lbs of load, or to the satisfaction of the Engineer.

D The Engineer will inspect the exposed subgrade for soft areas or other poor subgrade conditions Proofrolling is required to identify any soft areas that may require additional excavation and backfilling. After the Engineer is satisfied with the overall condition of the subgrade, the subgrade shall be scarified and recompacted uniformly with a smooth-drum roller

E Maintain subgrade free of erosion and desiccation cracks. If necessary, rework and/or restore to be free of erosion and desiccation cracks prior to test fill construction

F Stockpile/process earthen material per category· topsoil, working layer soil, test fill soil, or other if directed by Engineer.

G Stockpile/process for proper drainage and control sediment runoff with erosion control measures as necessary

H. Notify Contractor immediately if potentially hazardous conditions or materials are encountered during construction (i e., buried drums, etc.)

2 03 PROCESSING

As part of the test fill construction, the Subcontractor will be required to adjust moisture content, reduce clod size, and remove rocks from the borrow soil prior to placement of the soil in the test fills The Engineer will evaluate the Subcontractor's methods for:

A. Moisture Conditioning. The Subcontractor shall be required to provide all necessary personnel and equipment to successfully achieve the required moisture contents as specified. The Subcontractor shall be responsible for discing, aerating, tilling, wetting, covering, or otherwise controlling the moisture content in the test fill materials using a method approved by the Engineer It is anticipated that the moisture content of the soil will need to be increased by approximately 4 to 6 percent prior to construction.

B. Clod Reduction. The Subcontractor shall be responsible for providing the necessary personnel and equipment for reduction of clod size as necessary to meet Specifications and achieve proper remolding of soil for compaction.

C Soil for the two test fills shall be stockpiled in two separate designated areas. The processing areas are designed to be large enough to process all test fill soil at one time using a depth of 1 foot. All soil processing shall be performed in the designated processing areas. The only exception is that addition of up to 2 percent moisture is allowable during placement and compaction of the test fill This exception is intended to be used only if the material dries during or between placement of lifts.

D Soil shall be blended and cured for an appropriate amount of time to allow added moisture to distribute evenly throughout processed soil. For bidding purposes, assume it will take an estimated 3 days to complete material processing. Additional curing time beyond 3 days will be paid at the unit rate quoted by the Subcontractor in the Bid Schedule. The processed soil should be kept moist during the curing process.

E. The moisture content in the processed soil immediately prior to test fill construction shall be no lower than 0.5 percent above the low end of the target moisture content range, and no higher than 1 percent above the high end of the target moisture content range.

F Processing of soil shall be done using an approximate soil thickness of 1 foot.

- END OF SECTION -

SECTION 10 WORKING LAYER

PART 1 GENERAL

1.01 SUMMARY

A. Section includes

1. Wetting of subgrade prior to working layer placement.

2. Placement of clay working layer to obtain the desired test fill subbase characteristics and elevations.

3. Requirements of completed working layer grades, prior to test fill placement.

B. Subcontractor will provide all equipment, labor and supplies required to perform the work in accordance with the contract.

C. Contractor will provide visual inspection and construction testing.

D. Payment. Payment for items in this section is included under Bid Item D1

1.02 REFERENCES

A. American Society for Testing and Materials (ASTM)

1. ASTM D422-63. Standard Test Method for Particle-size Analysis of Soil

2. ASTM D2487-92: Standard Classification of Soil for Engineering Purposes (Unified Soil Classification System [USCS]).

3. ASTM D2922-91: Standard Test Methods for Density of Soil and Soil-Aggregate in-Place by Nuclear Methods (Shallow Depth)

4. ASTM D3017-88. Standard Test Method for Water Content of Soil and Rock in-Place by Nuclear Methods (Shallow Depth)

5. ASTM D4318-84: Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soil.

B. Section 11, 2.01A.

PART 2 PRODUCTS

2.01 WORKING LAYER

A. Onsite cohesive soil to be used for the working layer shall be substantially free of organics and other deleterious materials, and shall be approved by the Engineer Onsite cohesive soil is anticipated to typically consist of CL and SC soil per USCS

B. Subcontractor shall modify working layer material (if required) to assure it meets Specification requirements. Modifications include but are not limited to, the following:

1. Removal of rocks greater than 6 inches in any dimension.

2. Removal of deleterious or unsuitable materials such as large roots, organic soil, and as otherwise determined unsuitable by the Engineer.

PART 3 EXECUTION

3.01 PLACEMENT

A. Immediately prior to placement of working layer, the subgrade shall be gently wetted by sprinkling or spraying until the soil moisture reaches a depth of at least 1 foot.

B Place working layer in accordance with the following:

1. Approximate loose lift thickness: 9 inches.

2. Soil compaction: Density not specified, as required to achieve 6-inch compacted lift thickness.

C Control lift thickness using laser-guided equipment, construction staking, manual measurement, or other method acceptable to the Engineer to assure Specification requirements are met

D Care must be used in placing the working layer over the prepared subgrade to avoid excessive tearing-up of the subgrade. A minimum of 6 inches of soil shall be maintained between the equipment and the subgrade.

E. Contractor shall examine surfaces to receive test fill material to determine existence of any unsuitable materials, including materials significantly above or below optimum moisture content. Suitable moisture content shall be obtained prior to placement of the test fill The working layer surface shall be roughened prior to placement of first test fill lift.

- END OF SECTION -

SECTION 11: CLAY TEST FILL

PART 1 GENERAL

1.01 SUMMARY

A. Section includes:

1. Requirements for placement and compaction of clay test fill, and test fill maintenance.

2. Completion of test fill with testing assistance.

B The Subcontractor will provide all equipment, labor, and supplies required to perform the Work in accordance with the Drawings and Specifications.

C. The Contractor will provide testing during construction.

D Unsuitable materials include topsoil, peat, roots, organic soils, and materials containing slag, cinders, foundry sand, debris, rubble or frozen soils, and material not meeting requirements of Specifications.

E. Payment. Payment for items in this section is included under Bid Items D2 and E2.

1.02 REFERENCES

A. American Society for Testing and Materials (ASTM): (Testing to be performed by the Engineer)

1 ASTM D422-63. Standard Test Method for Particle-size Analysis of Soil.

2 ASTM D1140-54. Standard Test Method for Amount of Material in Soils Finer than the No 200 (75 Micrometer) Sieve.

3 ASTM D2216-90. Standard Test Method for Moisture Content Determination Using Oven-Drying Method.

4 ASTM D2850-87. Standard Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression.

5 ASTM D4767-88. Standard Test Method for Direct Shear Test of Soils Under Consolidated Undrained Conditions.

6 ASTM D5084-90. Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.

7. ASTM D2487-92. Standard Classification of Soil for Engineering Purposes (Unified Soil Classification System).

8. ASTM D2922-91. Standard Test Methods for Density of Soil and Soil-Aggregate in-Place by Nuclear Methods (Shallow Depth).

9. ASTM D3017-88 Standard Test Method for Water Content of Soil and Rock in-Place by Nuclear Methods (Shallow Depth).

10. ASTM D4318-84 Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soil

B The frequency, duration, and schedule for soil testing to be conducted by the Engineer during and after construction is included as Table 1.

1.03 PROJECT/SITE CONDITIONS

A. Do not block or obstruct roads with equipment or excavated materials Maintain soil stockpiles within authorized areas

B. Construction traffic shall yield right-of-way to other onpost vehicles and all wildlife

C. Schedule work in coordinated effort with Engineer and Owner.

D. Contractor and Subcontractor will notify each other immediately if delays are anticipated for any reason.

E. All placement and compaction of test fill soil shall be performed only when the Engineer or his representative is on the project site and is informed by the Contractor of intent to perform such work.

PART 2 PRODUCTS

2 01 SOURCE OF TEST FILL AND WORKING LAYER MATERIAL

A. Subcontractor shall obtain clay test fill and working layer material from the designated borrow areas; the Engineer shall observe and approve these materials prior to transport Test fill and working layer material onsite has been classified by the Engineer based on soil borings as typically CL, CH, and SC soil using the Unified Soil Classification System (USCS)

B Upon request, Subcontractor may obtain copies of pertinent boring logs and material testing results at the Contractor's offices

2 02 TEST FILL MATERIAL

A. Material - (Selected by the Engineer)

1 Soil classified as SC, CL, or CH by USCS.

2 Permeability: 1 x 10^{-7} cm/sec or less by ASTM 5084-90.

3 May contain no more than a negligible amount of organic or other deleterious materials

4 May contain no more than 5 percent gypsum or calcium carbonate, and all gypsum concretions and nodules shall be less than 1 inch in largest diameter.

B. Subcontractor shall modify clay test fill material to assure it meets Specification requirements. Modifications may include, but are not limited to the following.

1. Elimination of soil clods greater than 3 inches in diameter.

2. Removal of rocks larger than 3 inches in any dimension, for all lifts below final lift layer Removal of rocks larger than 1 inch in any dimension within the final lift.

3 Wetting or drying of liner soil to meet moisture requirements

4 Removal of deleterious soil and material not conforming to test fill quality clay requirements

PART 3 EXECUTION

3.01 SUBBASE (WORKING LAYER) EXAMINATION

A. Contractor shall examine surfaces to receive test fill material to determine existence of any unsuitable materials, including materials significantly above or below optimum moisture content. Suitable moisture content shall be obtained prior to placement of the test fill. The working layer surface shall be roughened prior to placement of first test fill lift.

B Unsuitable areas of the working layer shall be corrected prior to clay liner placement. Corrective action may require, but is not limited to: wetting subgrade, drying subgrade by disc harrow, drag harrow, or other means; roughening working layer to promote lift bonding, reworking and recompacting working layer; and removal and replacement of working layer soils.

C. The Subcontractor will be responsible for all costs associated with corrective actions taken to amend the working layer in preparation for test fill placement, at no additional cost to Contractor

D Do not place test fill until working layer has been surveyed, and approved by the Engineer

3.02 PLACEMENT OF TEST FILL

A. Construction of the actual test fill shall begin following placement of the working layer, and after completion of processing and moisture conditioning of the test fill soil. Place clay test fill in accordance with the following:

1 Maximum Loose Lift Thickness. 9 in., includes scarified or roughened depth of previous lift.

2 Maximum Compacted Lift Thickness 6 in. or depth of foot or tooth on compactor used, whichever is less.

3 Minimum Completed Test Fill Thickness 3 0 ft.

4 Maximum Allowable Variation from Design Thickness of Test Fill: 0 ft. to + 0.2 ft.

5. Maximum Rock Size 3 inches in all lifts below final lift. One inch in final lift surface within area designated for Sealed Double-Ring Infiltrometer (SDRI) test.

6. Maximum Soil Clod Size Prior to Compaction: 3 in., or half the lift thickness, whichever is less.

7 Allowable Soil Moisture Content Range· +1 percent to + 4 percent wet of optimum, or as directed by the Engineer.

8 Minimum Soil Compaction. 95 percent of maximum dry density as determined by the Standard Proctor ASTM D698-78.

9. Sideslopes shall be 2H:IV maximum and 3H:IV minimum on the long sides of the test fills. Sideslopes shall be 3H:IV maximum and 4H:IV minimum on the ends of the test fills

B. Material distribution and gradation throughout clay test fill shall be such that material remains free from lenses, pockets, streaks, or sections of material differing substantially in texture or gradation from designated test fill material for which prior source testing has been performed.

C Soil clods larger than specified maximum in any direction shall be broken down to size less than or equal to 3 inches prior to lift compaction.

D Place lifts of clay to form one continuous monolithic layer of material. Assure previous lift is moist and scarify surface of previously placed lifts with disc or other piece of machinery capable of penetrating into previous lift to minimum 1 in. depth to provide proper bonding between subsequent lifts of clay test fill.

E. Bonding successive lifts together shall be accomplished by penetration of the compactor feet or pads through the top lift and into the immediately underlying lift. Compactor feet shall be at least as long as the compacted lift thickness

F Compaction shall be achieved using sheepsfoot roller or similar heavy penetrating foot kneading-type compactors (e.g., CAT 825). Footed rollers towed behind a dozer shall be filled with water to assure sufficient compactive effort is exerted to test fill

G The appropriate number of passes shall be determined by performing density testing during placement and compaction of the lifts.

For the first three lifts, each test fill will be tested by the Engineer for moisture content and density in three locations after the lift has been compacted with each set of two passes of the compactor until at least 95 percent of Standard Proctor compaction has been achieved. The fourth, fifth, and sixth lifts of each test fill shall be compacted using the appropriate number of passes required to achieve a dry density at least 95 percent of Standard Proctor compaction (determined by the testing from the first three lifts)

Final density and moisture content will be verified for each of the top three lifts after the prescribed number of passes has been performed.

A visual lift bonding check using a hand shovel will be performed after each lift. Following completion of the test fill, a backhoe or excavator bucket will be used to check lift bonding of the entire test fill thickness Additionally, three laboratory permeability test samples will be obtained by the Engineer from each test fill after they are completed

For the purposes of these Specifications, a compaction pass is defined as one trip of a single-drum compactor up and back over the complete length of the test fill. If a dual-drum compactor without laterally separated front and rear drums is used, one trip up and back over the test fill would constitute two passes. If a dual-drum compactor that has the drums laterally separated by the operator's cab and differential (such as a CAT 825) is used, one trip up and a staggered trip back to cover the central portion of the roller path shall be considered one pass

H. Uniformly distribute moisture content of clay material prior to and during compaction throughout each lift of material. Clay material determined by Engineer to contain moisture outside specified range shall be adjusted by Subcontractor to provide material within specified range. Adjustment includes, but is not limited to, drying materials containing moisture in excess of specified range and adding water to materials containing moisture less than specified range. No more than 2 percent moisture may be added to the test fill during construction. If the moisture content is less than or equal to 2 percent below the low end of the target moisture content range, the select fill may be sprinkled or sprayed with water and dozed, windrowed, and/or disced to uniformly increase the moisture content. If the moisture content is greater than 2 percent below the target moisture content, the test fill soil shall be removed from the test fill, returned to the stockpile, and conditioned until the proper uniform moisture content is achieved. If the moisture content is greater than 1 percent above the target moisture content, the test fill soil shall be dozed, windrowed, and/or disced to facilitate drying.

I Maintain moisture content of clay test fill materials in previously placed lifts within specified range. Avoid drying and desiccation cracking of materials. Maintenance includes, but is not limited to, wetting surface of previously placed lifts to avoid drying and desiccation cracking of material. Prior to placement and compaction of subsequent lifts of clay material, Engineer will verify that moisture content of scarified material of previously placed lift is within specified limits. Materials determined to possess moisture content outside specified limits shall be adjusted and rechecked before subsequent lift placed.

J Control lift thickness using construction staking, or other method approved prior to construction by the Engineer to assure that requirements of Specifications are met. If grade stakes are utilized by the Subcontractor, Subcontractor should emphasize the removal of damaged stakes to work crew during daily assignments.

K. Minimum clay layer thickness will be verified and documented by Contractor. Rework or remove and replace portions of test fill not meeting Specification requirements

L. Final test fill surface shall slope at approximately 2 percent in the direction shown on the Drawings, Figure 3.

M. Lift bonding will be visually verified by excavating small test pits per the testing schedule.

N Field density and moisture content results from compaction tests shall be checked against compaction Specifications Recompact or rework and retest soil that fails field testing during construction activity Subcontractor shall recompact or rework soil area following a failed test to boundaries of passing test results, at no additional cost to Contractor.

O Precautions to minimize damage to clay test fill due to rainfall shall be taken prior to anticipated rainfall events. Precautions include, but are not limited to, grading surface to promote runoff, back-blading with dozer, sealing surface with smooth drum roller or other means. Precautions shall be augmented by placing pump(s) in the sump or other area(s) likely to collect water, if necessary. Provide, maintain. and operate pumps; coordinate access to site with Contractor or Owner.

P After test fill or a portion thereof is complete, continue to maintain clay surface in moist condition, free of desiccation cracks. Subcontractor shall remove desiccation cracks by scarifying, wetting, and smooth-drum rolling test fill surface, or other method approved by Engineer.

Q. Repair of Penetrations: Repair of small diameter penetrations, such as those caused when taking Shelby tube samples, shall be repaired to the satisfaction of the Engineer.

R. Maintain surficial moisture content during construction by sprinkling water onto clay materials daily, or more often during hot, dry or windy conditions. Completed lifts that are left unprotected and not sprinkled for several hours or overnight must be scarified and brought to proper moisture content prior to placement of additional lifts

S. All test fill surfaces, with extra attention to areas on which SDRI test apparatus is to be placed, shall be smooth-drum rolled upon completion of clay placement to create surface free of irregularities, protrusions, loose soil, and abrupt changes in grade.

T. From completed test fill areas designated for SDRI, remove stones and soil clods greater than 1 inch in any dimension, bones, and other debris. Restore smooth surface after removal. Embedded, non-protruding smooth rocks may remain in place if approved by the Engineer. Engineer must approve of final test fill surface prior to final payment of Subcontractor.

U Place plastic sheeting or other similar material over completed areas designated for SDRI testing. Method of keeping plastic in place shall be approved by the Engineer.

V After test fill completion, topsoil from the adjacent stockpile shall be placed over the test fill, except SDRI areas, to prevent desiccation. (see Section 08)

3 03 FIELD QUALITY CONTROL

A. Notify Engineer when portions of the test fill are ready for testing.

B Provide Contractor with equipment, time, and labor necessary to support the Engineer in the completion of field testing. (Examples. blading off area for pushing Shelby tubes or nuclear gauge testing.)

C. After the test fill work has been completed, SDRI tests will be conducted by the Engineer on the surface of each test fill. The Subcontractor shall provide an equipment operator to assist the Engineer in the installation of the SDRI apparatus. It is anticipated that 30 hours of time for the operator will be required.

D Equipment to be provided by Subcontractor for installation of the SDRIs includes:

- Trencher (Ditch Witch Model 1010 or other machine capable of making a trench no more than 4 to 6 inches wide)
- Grout mixer (not cement mixer)
- Water truck

- Generator
- Small dozer or loader

This equipment will only be required for three days after completion of test fill

- END OF SECTION -

SECTION 12 SEEDING AND MULCHING

PART 1 GENERAL

1.01 SUMMARY

A. Section includes:

1. Seeding/mulching requirements for completed test fill and processing areas.

2. Seeding/mulching requirements for borrow areas.

B. Payment: Payment for items in this section is included under Bid Item E3.

PART 2 PRODUCTS

2 01 MULCH

A. Native grass hay mulch will be provided by Owner. This grass hay mulch is onpost in the southeast portion of Section 29 (See Figure 2 for location).

2.02 SEED

A. Seed shall be provided by Subcontractor to meet the requirements listed in Tables 2 and 3. If Subcontractor has difficulty in obtaining the specified seed mixture, please contact the Engineer or Bruce Hastings of the U.S Fish and Wildlife Service for assistance (303) 289-0232 .

2 03 FERTILIZER

A. No fertilizer is required for this project.

PART 3 EXECUTION

3 01 PREPARATION

A. Topsoil Grading

1 Grade, rake, and roll with roller weighing not more than 100 lbs. per linear foot and not less than 25 lbs. per linear foot.

3 02 SEEDING

A. Sow seed at rates as described in Tables 2 and 3, dividing seed equally and sowing at 90 degree angles to produce uniform broadcast.

B Rake seed into ground and roll with roller, or use other technique approved by the Engineer

C. Do not seed on surface which has been compacted by rain.

D. Do not seed when wind velocity exceeds 6 mph.

3.03 MULCHING

A. Mulch shall be applied immediately after seeding.

B Place mulch at a rate of 2 tons/acre.

C Mulch shall be crimped immediately after application to prevent blowing away.

D. Place mulch loose or open enough to allow some sunlight to penetrate and air to circulate, but thick enough to shade ground, conserve soil moisture, and minimize erosion.

- END OF SECTION -

Table 1. Test Fill Testing Program (Per Test Fill)

Test	Method	Stockpile	Frequency During Construction	Post-Construction
Moisture Content	Oven drying ASTM D2216-90	3 initial; as needed during processing (approx 12); 3 final· estimate 18 Total	3 per lift (18 total)	---
Moisture Content	Nuclear gauge ASTM D3017	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6; estimate 45 total	---
Atterberg Limits	Grab sample ASTM D4318-84	3	---	---
Grain Size (incl. clay content)	Sieve and Hydrometer analysis ASTM D422-63	3	---	---
		3	---	---
Optimum Moisture Content and Max Dry Density	Standard Proctor test (grab samples) ASTM D698-78	3	---	---
In-place Density (% compaction)	Nuclear gauge ASTM D2922	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6; estimate 45 total	---
Lift Thickness (loose)	Manual	---	25-ft intervals down center-line of test fill	---
Lift Thickness (compacted)	Manual	---	25-ft intervals down center-line of test fill	---

Table 1 (continued)

Test	Method	Stockpile	Frequency During Construction	Post-Construction
Final Test Fill Thickness	Survey	---	---	3
Lift Bonding	Visual: Test Pits	---	2 per lift (Manual)	3 (Backhoe)
Laboratory Permeability	Shelby tubes, Flexible Wall Permeameter (falling-head test) ASTM D5084-90	---	---	3
Field Permeability (large-scale)	Sealed double-ring infiltrometer (SDRI)	---	---	1
Field Permeability (small-scale)	2-stage borehole (Boutwell)	---	---	5
Shear Strength	Consolidated undrained ASTM D4767-88	---	---	2
Shear Strength	Unconsolidated undrained ASTM D2850-87	---	---	2

--- Not performed

Table 2. Seed Mixture for Borrow Areas

Scientific Name	Common Name	Variety	Lbs PLS/ Acre
Seed Mix for Native Grass Species			
Bouteloua gracilis	Blue Grama	Hachita	0.9
Pascopyron smithii	Western Wheatgrass	Arriba	6.5
Buchloe dactyloides	Buffalo Grass	Sharp's	12.9
		Total	20.2
Native Forbs or Semi-shrubs (ALL 0.1 lbs. PLS/acre)			
Erysimum asperum	Wallflower		
Gaillardia aristata	Blanket Flower		
Penstemon angustifolia	Narrow-leaf Penstemon		
Linum lewisii	Blue Flax		
Helianthus annuus	Annual Sunflower		
Achillea lanulosa	Yarrow		
Arstemisia ludoviciana	Louisiana Sagewort		
Sphaeralcea coccinea	Scarlet Globemallow		
Artemisia frigida	Fringed Sage		
Dalea purpurea	Purple Prairie-clover		
Oenothera caespitosa	White Tufted Evening Primrose		
Native Shrubs and Trees (Both 0.1 lbs PLS/Acre)			
Ceratoides lanata	Winterfat		
Atriplex canescens	Fourwing Saltbush		

PLS Pure live seed

Table 3. Seed Mixture for Test Fill and Processing Area

Scientific Name	Common Name	Variety	Lbs PLS/ Acre
Seed Mix for Native Grass Species			
Bouteloua gracilis	Blue Grama	Hachita	1.1
Calamovilfa longifolia	Prairie Sandreed	Goshen	0.4
Bouteloua curtipendula	Side-oats Grama	Vaughn	0.6
Sporobolus cryptandrus	Sand Dropseed		0.1
Stipa comata	Needle-and-thread		1.9
Andropogon hallii	Sand Bluestem	Woodward	1.0
Pascopyron smithii	Western Wheatgrass	Arriba	5.0
Oryzopsis hymenoides	Indian Ricegrass	Nezpar	0.8
		Total	10.9
Native Forms or Semi-shrubs (Wildflowers) (All 0.1 lbs PLS/acre)			
Cleome serrulata	Rocky Mountain Bee Plant		
Delphinium virescens	Larkspur		
Liatris punctata	Blazing-star		
Oenothera caespitosa	Stemless Evening-primrose		
Oenothera villosa	Tall Evening-primrose		
Ipomoea leptophylla	Bush Morning Glory		
Gaillardia aristata	Blanket Flower		
Penstemon angustifolia	Narrow-leaf Penstemon		
Linum lewisii	Blue Flax		
Helianthus annuus	Annual Sunflower		
Achillea lanulosa	Yarrow		
Artemisia ludoviciana	Louisiana Sagewort		
Coreopsis tinctoria	Plains Coreopsis		
Sphaeralcea coccinea	Scarlet Globemallow		
Artemisia frigida	Fringed Sage		
Abronia fragrans	Sand Verbena		
Native Shrubs and Trees (All 0.1 lbs PLS/Acre)			
Chrysothamnus nauseosus	Rubber Rabbitbrush		
Atriplex canescens	Fourwing Saltbush		
Artemisia filifolia	Sand Sagebrush		

PLS Pure live seed

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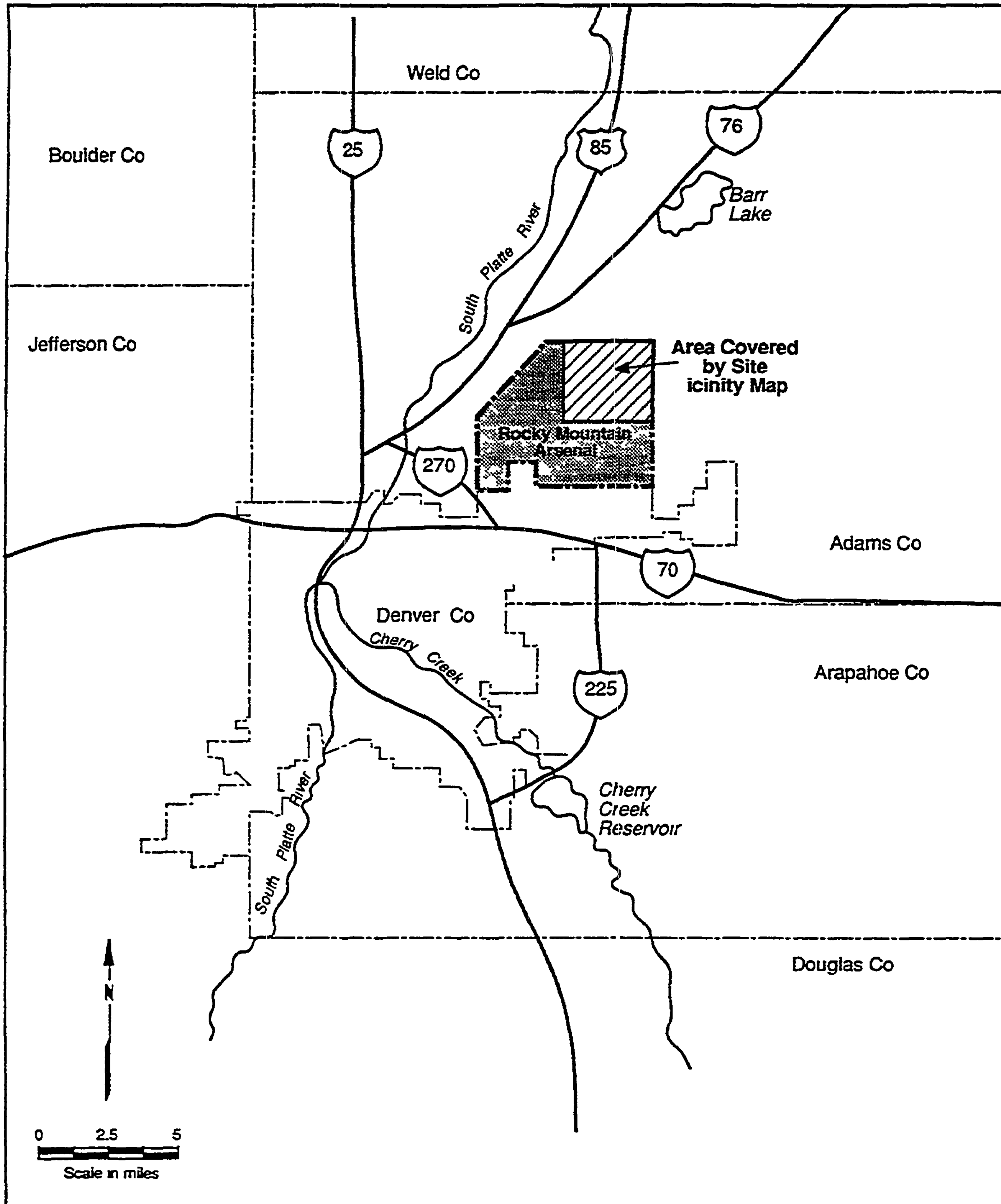


RMA 1232 5 3/7/96 LAM

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure A-1 Site Location Map

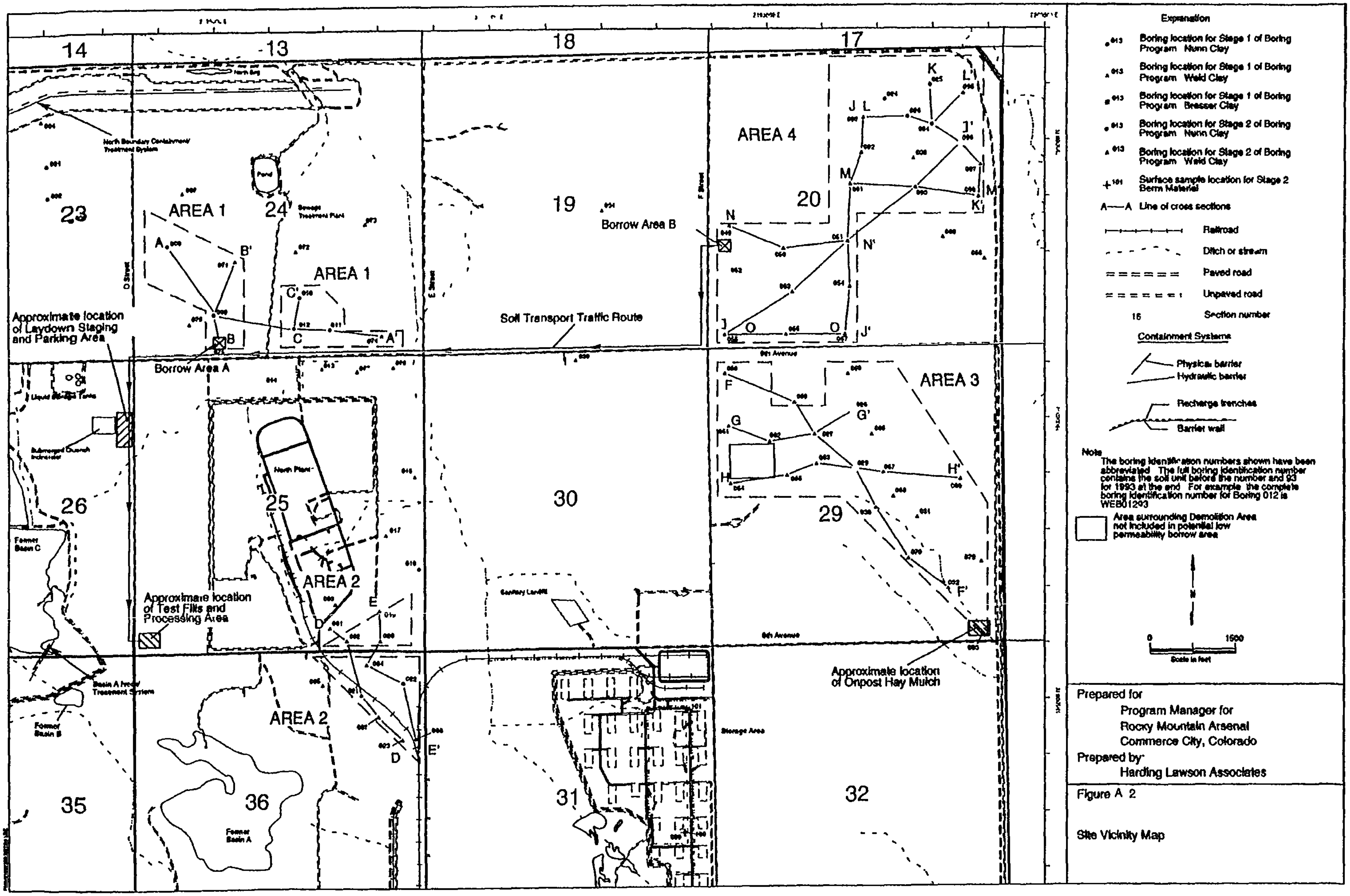
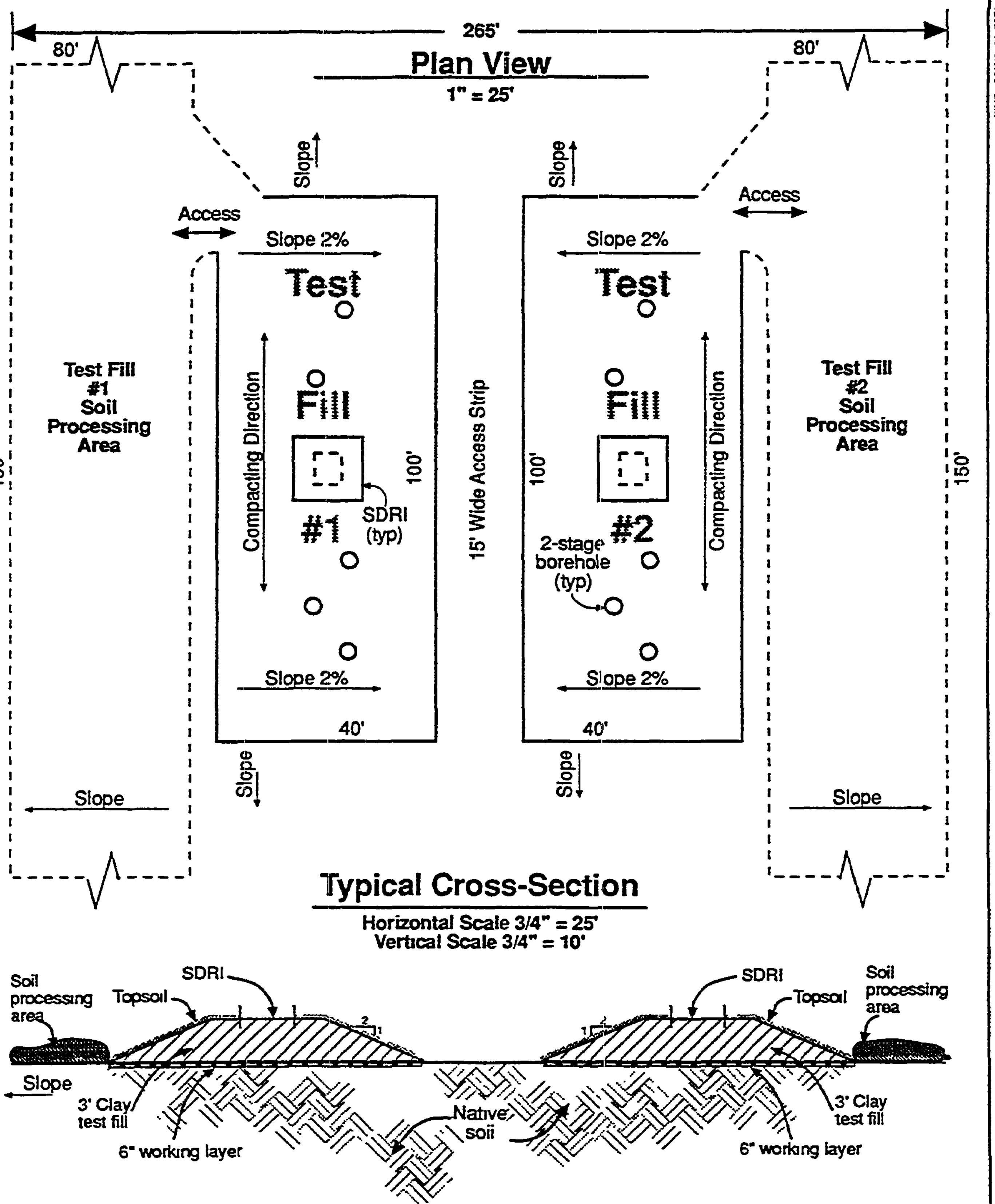


Figure A 2

Site Vicinity Map



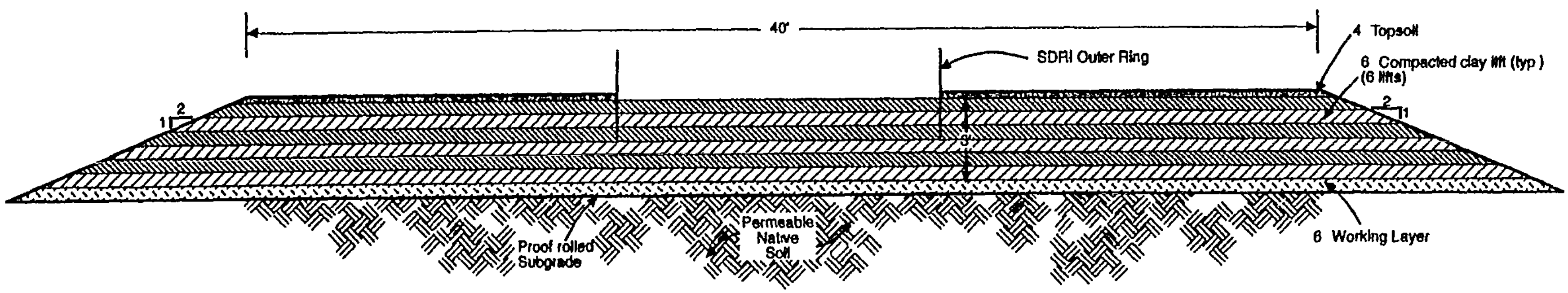
Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure A-3

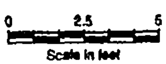
Test Fill Layout

Typical Test Fill Cross Section



1 25" = 5'

Note. Maximum slope shall be 2H:1V on long sides 3H:1V on ends of test fill Minimum slope shall be 3H:1V on long sides and 4H:1V on ends of test fill



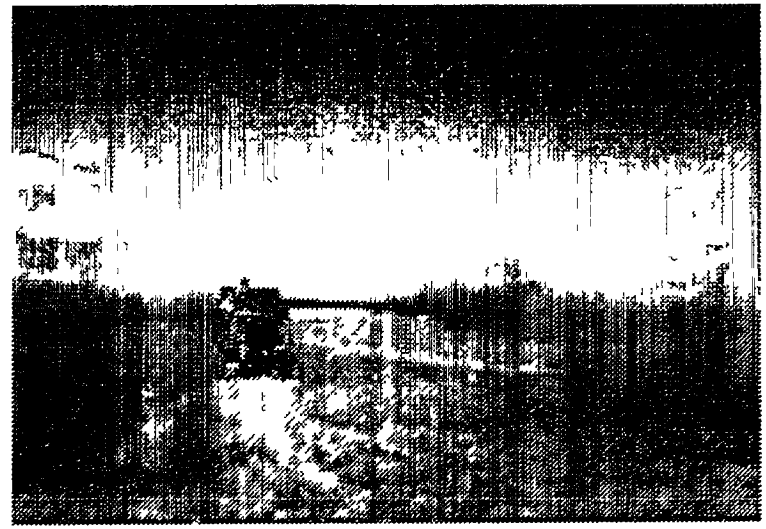
Prepared for Program Manager for Rocky Mountain Arsenal Commerce City Colorado Prepared by Harding Lawson Associates
Figure A 4 Typical Test Fill Cross Section

Appendix B

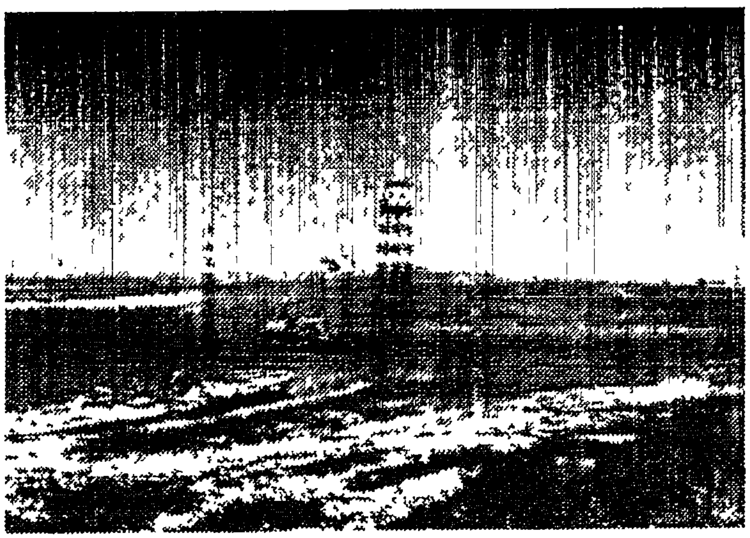
TESTFILL CONSTRUCTION PHOTOGRAPHS

RMA 1241 3/9/85 LAM

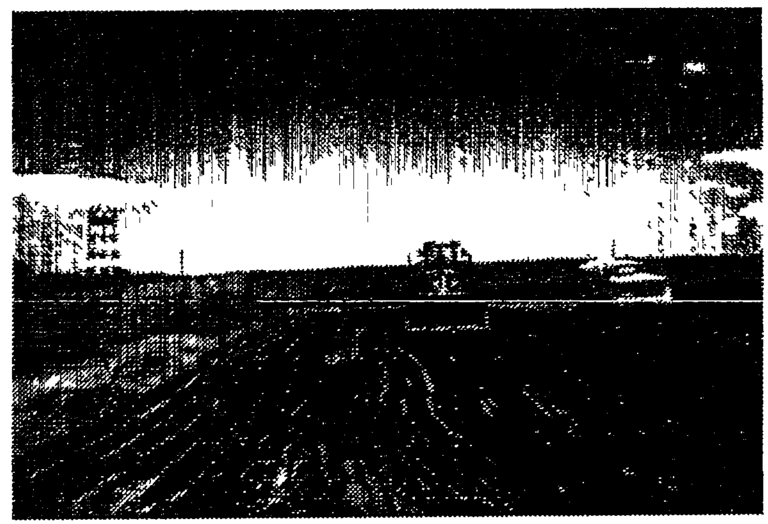
A Excavation of Borrow Pit A in Section 24



B Hay mulching excavation pit after replacing topsoil and reseeding

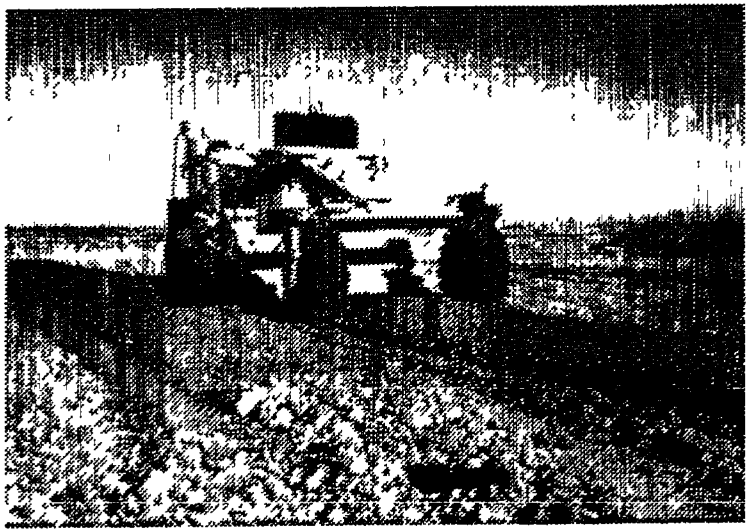


C Stripping and stockpiling topsoil in test fill construction area

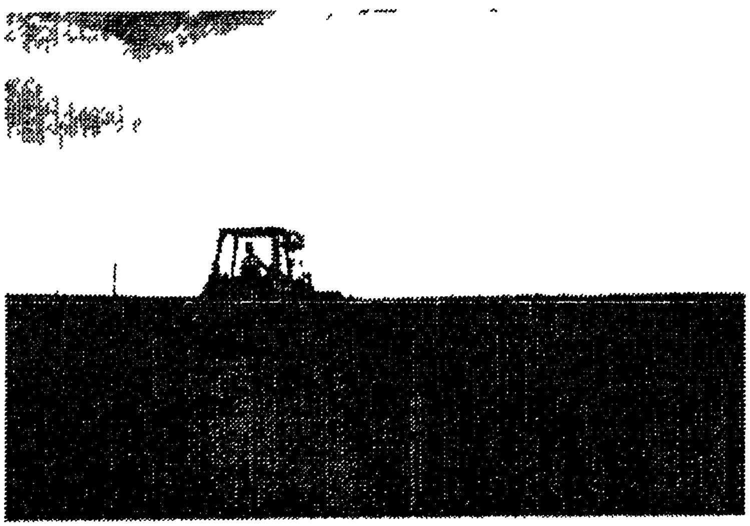


D Scarifying test fill subgrade after wetting and compacting native sandy soil

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure B-1 (1 of 5) Photo Documentation of Test Fill Construction



F Pulvamixer used to reduce clod size, moisture condition, and blend soil

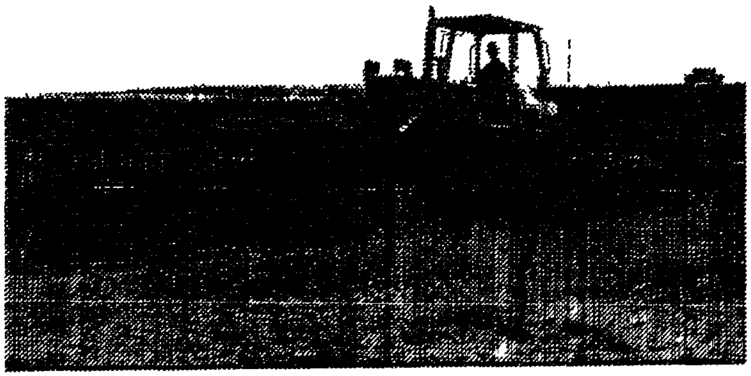


G Scarifying the surface of a lift with the dozer tracks

E Soil processing using a tiller

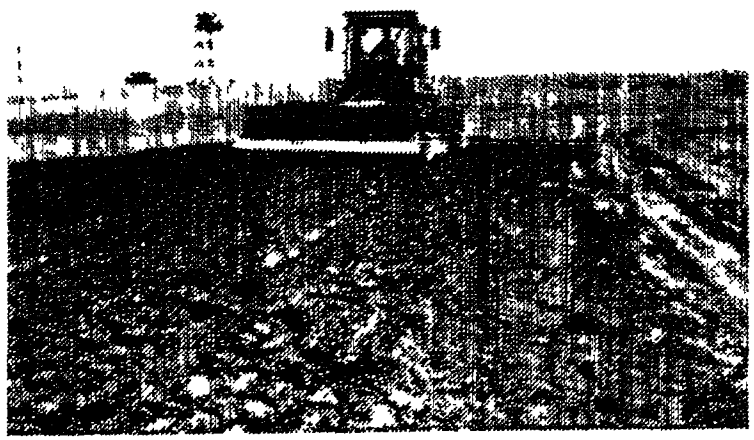
RMA 1241 1 3/9/95 LAM

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure B-1 (2 of 5) Photo Documentation of Test Fill Construction



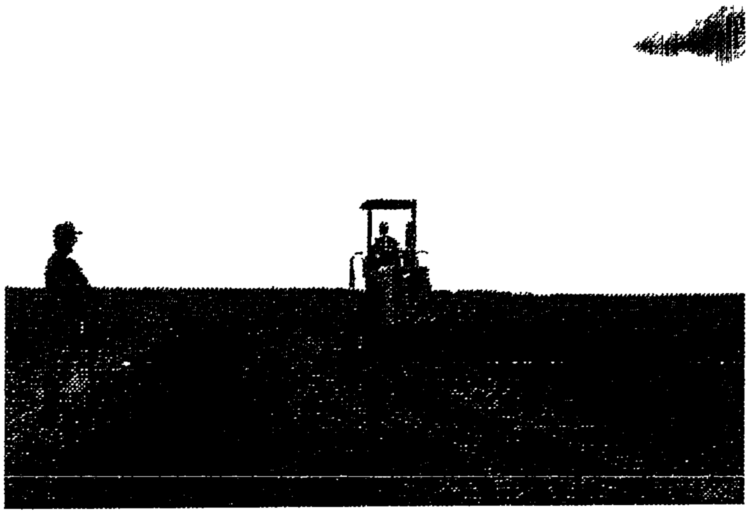
H Spreading a loose lift on the surface of the test fill with a dozer blade at a thickness of 8 - 9 inches

I Blending/moisture conditioning by adding water directly to drum of pulvamixer



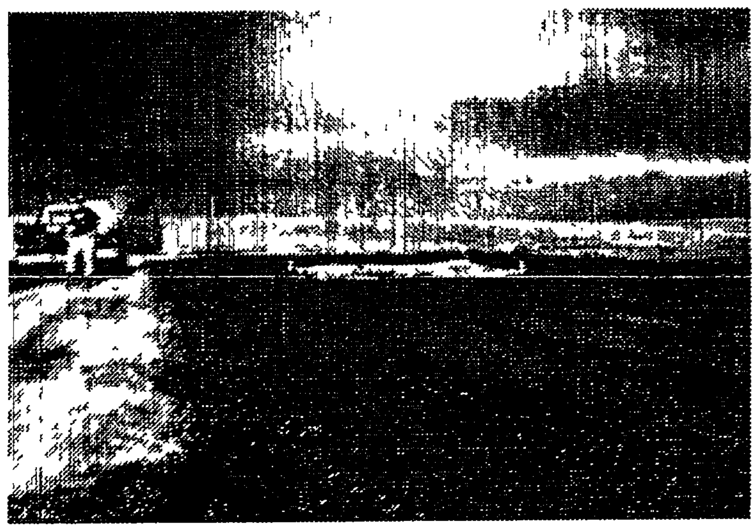
J Compaction of the loose lift with the Caterpillar 815C compactor

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure B-1 (3 of 5) *Photo Documentation of Test Fill Construction*



K. Smooth drum rolling test fill surface

L. Tarp covering test fill lift to prevent dessication



M To prevent desiccation of the test fill, the surface was wetted and topsoil was spread on the test pad except in the 12 x 12 foot area sealed with a tarp for solid double-ring infiltrometer installation

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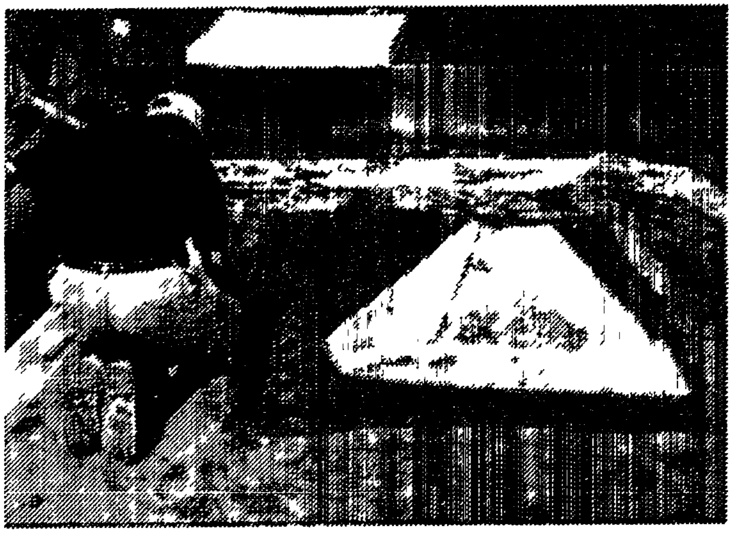
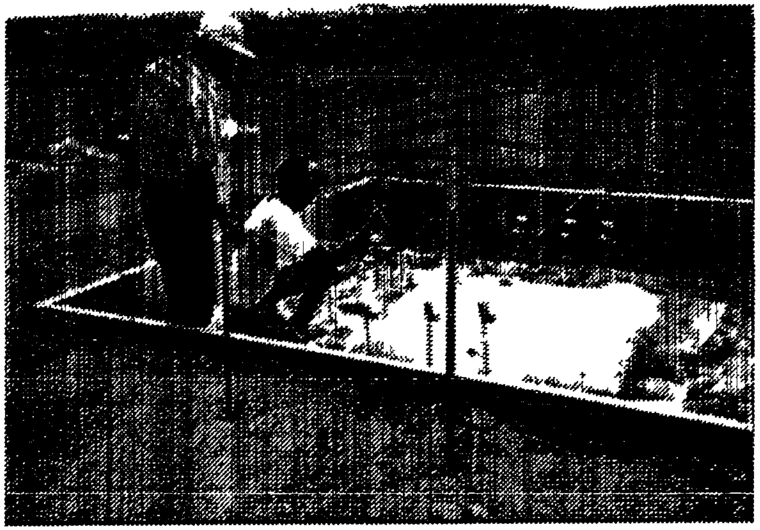
Figure B-1 (4 of 5)

Photo Documentation of Test Fill Construction

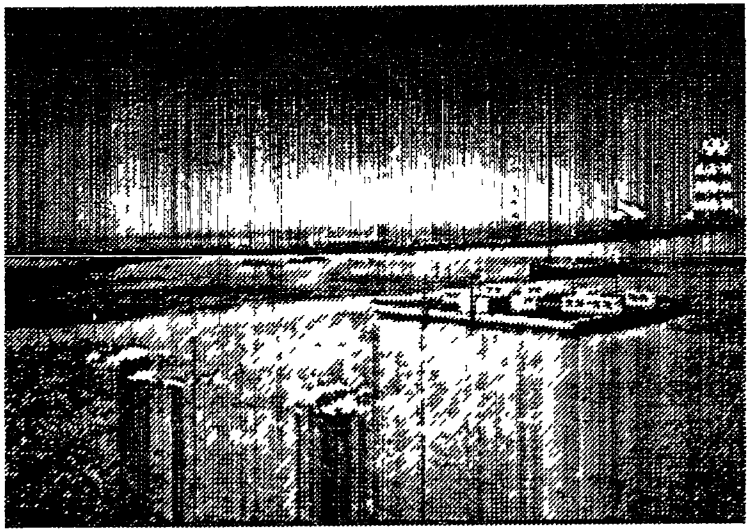
RMA 1241 4 3/8/95 LAM



N Applying grout to the inner SDRI ring installation



O Measuring the distance between the inner ring and the swell measurement guides



P Completed test fill with sealed double-ring infiltrometer and two-stage borehole installation

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure B-1 (5 of 5) Photo Documentation of Test Fill Construction

Appendix C

TESTFILL CONSTRUCTION EQUIPMENT


MODEL	816B			825C		
Flywheel Power	161 kW		216 hp	215 kW		315 hp
Operating Weight	20 035 kg		44 176 lb	32 400 kg		71 420 lb
Engine Model		3306			3406	
Rated Engine RPM		2200			2100	
No Cylinders		6			6	
Displacement	10 5 L		638 in³	14 6 L		893 in³
Speeds						
Forward		4			4	
Reverse		4			4	
Turning Circle with Blade	12 3 m		40 3"	14 2 m		46 6
Fuel Tank Refill Capacity	462 L		122 U S gal	609 L		158 U S gal
TAMPING FOOT WHEELS						
Each Drum Width	978 mm		3 2 5"	1118 mm		3 8
Diameters over feet	1 42 m		4 8	1 69 m		5 6"
over drum	1 03 m		3 4 5	1 29 m		4 3
Feet per Wheel		60			65	
Feet per Row		12			13	
Rows of Feet		5			5	
Foot Length	188 mm		6 6	220 mm		8 7
End Area Per Foot	135 cm²		21 in²	183 cm²		28 4 in²
Width of Two Pass Coverage	4 35 m		14 3	4 88 m		16 0"
GENERAL DIMENSIONS						
Height (top of ROPS)	3 53 m		11 7	3 91 m		12 10"
Height (stripped top)	2 38 m		7 10"	2 98 m		9 8"
Wheel Base	3 35 m		11 0	3 53 m		11 7"
Overall Length with Dozer	6 80 m		22 4	7 68 m		25 2
Width over Drums	3 24 m		10 8"	3 65 m		11 11
Ground Clearance	203 mm		8"	234 mm		9 2"
STRAIGHT BULLDOZER						
Width	3 76 m		12	4 53 m		14 10"
Height	0 80 m		2 10"	1 04 m		3 5"

Operating Weight includes coolant lubricants bulldoze hydraulics ROPS canopy full fuel tank and operator
'Height (stripped top) — without ROPS exhaust, seat back or other easily removed encumbrances
With Compactor feet at 100% penetration

COMPACTION FUNDAMENTALS

The following discussion applies to soil compaction only For information on refuse compaction see Waste Disposal — Section 23 of this book

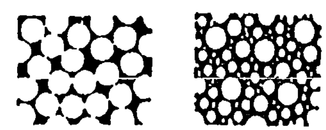
Definition

Compaction is the process of physically densifying or packing the soil resulting in an increase in weight per unit volume. It is generally accepted that the strength of a soil can be increased by densification Three important factors affect compaction

- Material gradation
- Moisture content
- Compactive effort

Material Gradation — refers to the distribution (% by weight) of the different sizes of particles within a given soil sample. A sample is described as well graded if it contains a good, even distribution of particle sizes. If a soil sample is composed of predominantly one size particle, it is said to be poorly graded In terms of compaction, a well graded soil will compact more easily than one that is poorly graded In well graded material the smaller particles tend to fill the empty spaces between the larger particles, leaving fewer voids after compaction

MATERIAL GRADATION

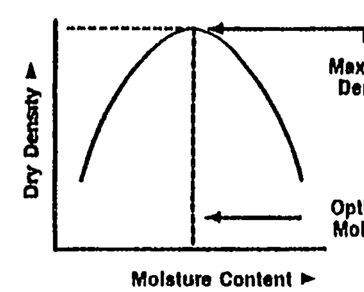


Poorly graded   Well graded

Moisture Content — or the amount of water present in a soil, is very important to compaction Water lubricates soil particles thus helping them slide into the most dense position Water also creates clay particle bonding, giving cohesive materials their sticky qualities.

Experience has shown that it is very difficult, if not impossible, to achieve proper compaction in materials that are too dry or too wet Soil experts have determined that in practically every soil there is an amount of water, called optimum moisture content, at which it is possible to obtain maximum density with a given amount of compactive effort The curve below shows this relationship between dry density and moisture content It is called a compaction curve moisture density curve or Proctor curve

MOISTURE CONTENT



Compactive Effort — refers to the method employed by a compactor to impart energy into the soil to achieve compaction Compactors are designed to use one or a combination of the following types of compactive effort

- Static weight (or pressure)
- Kneading action (or manipulation)
- Impact (or sharp blow)
- Vibration (or shaking)

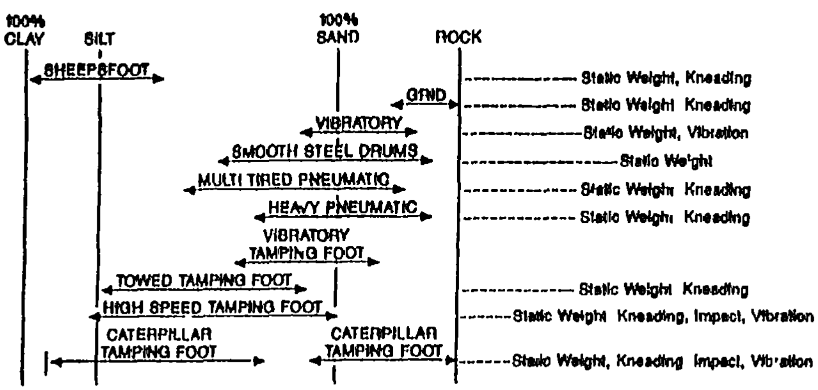
COMPACTOR TYPES

Compaction equipment can be grouped generally into nine different types or classifications
(1) sheepsfoot
(2) grid or mesh
(3) vibratory
(4) smooth steel drum
(5) multi tired pneumatic
(6) heavy pneumatic
(7) towed tamping foot
(8) high speed tamping foot
(9) chopper wheels (see Landfill Compactor section)

Combinations of these types are also available, such as a vibrating smooth steel drum

For ease of comparison, the first eight types of compactors have been placed on the Zones of Application Chart shown below This chart contains a range of material moistures from 100% clay to 100% sand, plus a rock zone Each type has been positioned in what is considered to be its most effective and economical zone of application However, it is not uncommon to find them working out of their zones. Exact positioning of the zones can vary with differing material conditions

COMPACTOR ZONES OF APPLICATION — COMPACTIVE METHOD



COMPACTOR PRODUCTION

Compactor production is expressed in compacted cubic meters (Cm^3) or compacted cubic yards (CCY) per hour Material in its natural or bank state is measured in bank cubic meters or yards (Bm^3 or BCY) When it is removed or placed in a fill, it is measured in loose cubic meters or yards (Lm^3 or LCY)

When the loose material is worked into a compacted state, the relationship of *compacted material* to *bank material* is shown as the shrinkage factor (SF)

$$SF = \frac{\text{Compacted cubic meters } (Cm^3)}{\text{Bank cubic meters } (Bm^3)}$$

$$SF = \frac{\text{Compacted cubic yards (CCY)}}{\text{Bank cubic yards (BCY)}}$$

The construction industry has developed the following formula for use in estimating compactor production. This formula gives the volume of material which a given machine can compact in a 60 minute hour

Metric Method

$$Cm^3 = \frac{W \times S \times L}{P}$$

W = Compacted width per pass, in meters (For Caterpillar Compactors it is recommended that W = Twice the width of one wheel)
S = Average speed, in kilometers per hour
L = Compacted thickness of lift, in millimeters.
P = Number of machine passes to achieve compaction (can only be determined by testing the density of the compacted material on the job).

English Method

$$CCY/Hr = \frac{W \times S \times L \times 16.3}{P}$$

W = Compacted width per pass, in feet (For Caterpillar Compactors it is recommended that W = Twice the width of one wheel)
S = Average speed, in miles per hour
L = Compacted thickness of lift, in inches.
16.3 = Conversion constant, equals 5280 feet ÷ 12 inches ÷ 27 cubic feet
P = Number of machine passes to achieve compaction (can only be determined by testing the density of the compacted material on the job)

Example problem (Metric)

Determine production for an 815B operating under the following conditions

$P = 5$, $S = 10$ km/h, $L = 100$ mm

Refer to 815B in the production table on the next page. Read down the first column until reaching section for 5 passes Within this section in the second column, find the speed closest to 10 km/h Read across this line to the 100 mm compacted lift Read the production figure given.

Answer: 377 Cm^3/h (Since the machine's speed of 10 km/h is slightly faster than the 9.5 of the table, production may be interpolated slightly higher — say 395 Cm^3/h)

• • •

Example problem (English)

Determine production for an 825C operating under the following conditions

P = 4, S = 8 mph L = 6 inches

Refer to the production estimating table below This table contains estimates for the 815B and 825C Compactors using various speeds lift thicknesses and number of passes. These figures were calculated using the formula discussed on this page. The figures represent 100% efficiency W=Twice the width of one wheel

In the 825 portion of this table, read down the first column until reaching the section for four passes. Within this section in the second column, find the line for 8 mph Read across this line to the lift thickness column for 6 inches Read the production figure given

Answer: 1444 CCY/hr

• • •

PRODUCTION TABLE

MODEL AND MACHINE PASSES*	AVERAGE SPEED km/h	mph	COMPACTED LIFT THICKNESS 100 mm m³/h	4 in yd³/hr	150 mm m³/h	6 in yd³/hr	200 mm m³/h	8 in yd³/hr	250 mm m³/h	10 in yd³/hr
815B 3	6.5	4	419	548	628	822	837	1096	—	
	9.5	6	628	822	942	1232	1256	1643	—	
	13.0	8	837	1096	1256	1643	1675	2191	—	
4	6.5	4	314	411	471	616	628	822	—	
	9.5	6	471	616	706	924	942	1232	—	
	13.0	8	628	822	942	1232	1256	1643	—	
6	6.5	4	251	328	377	493	502	657	—	
	9.5	6	377	493	565	739	754	986	—	
	13.0	8	502	657	754	986	1005	1314	—	
8	6.5	4	209	274	314	411	419	548	—	
	9.5	6	314	411	471	616	628	822	—	
	13.0	8	419	548	628	822	837	1096	—	
825C 3	6.5	4	488	642	731	962	975	1283	1219	1604
	9.5	6	713	962	1069	1444	1426	1925	1781	2406
	13.0	8	975	1283	1463	1925	1950	2566	2438	3208
4	6.5	4	366	481	534	722	731	962	914	1203
	9.5	6	534	722	802	1083	1069	1444	1336	1804
	13.0	8	731	962	1097	1444	1463	1925	1828	2406
5	6.5	4	293	385	439	577	585	770	731	962
	9.5	6	428	577	641	866	855	1155	1069	1444
	13.0	8	585	770	878	1155	1170	1540	1463	1925
6	6.5	4	244	321	366	481	488	642	609	802
	9.5	6	356	481	534	722	713	962	891	1203
	13.0	8	488	642	731	962	975	1283	1219	1604

*The number of machine passes required is dependent on soil type moisture content desired compaction and machine weight

RR 250

The RR 250 is a heavy duty single rotor cold in place reclaiming machine that utilizes a cutting mandrel that pulverizes and mixes asphaltic pavement and base materials The machine is utilized for mechanical stabilization of deteriorated road surfaces and for complete reclamation with the addition of asphaltic emulsions or other binding agents. The RR 250 can be equipped with attachments that accurately inject liquid additives directly into the mixing hood Optional rotors can be installed to convert the RR 250 into a soil stabilizer The internally mounted breaker bar aids in material sizing

SS 250

The SS-250 is a heavy duty single rotor soil stabilization machine. The machine cuts, mixes and pulverizes native in place soils or select materials, with or without additives It modifies and stabilizes the soil obtaining a strong base.

Both the RR & SS 250 feature automatic depth control and engine load sensing.

Features.

- Full 2438 mm (8 ft) wide cutting drum delivers maximum production
- Large hood and adjustable rear door enable operator to generate most uniform mix
- Mixing depth down to 457 mm (18 in) on SS-250 and 330 mm (13 in) on RR 250
- Rotor and machine travel direction are the same. Rotor up cuts assuring maximum blending of soil materials and maximum engine and rotor drive life Consistent mixing and blending capability reduces number of passes required to achieve specified mixing Roto- can also be ordered in the down cut mode.
- Interchangeable rotors allow the machine to adapt to the job for best performance.
- Heavy duty mechanical rotor drive is protected with proven shear pin design
- Heavy duty chains on each side of rotor are enclosed in oil and dust tight cases.
- 3 speed hydrostatic transmission provides smooth operation and travel speeds
- 3 usable rotor speeds for matching materials and required gradation
- Automatic depth control
- Engine load sensing.
- Optional Asphalt Spray System available for RR 250
- Optional Water Spray System available for RR 250 and SS 250
- Hydraulically adjusted rear door for gradation control
- Optional rear wheel steering for a 6096 mm (20 ft) turning radius.
- Optional light package for night applications

MODEL	RR 250			SS 250		
Flywheel Power	250 kW		335 hp	250 kW		335 hp
Operating Weight	18 053 kg		39 800 lb	13 517 kg		29 300 lb
Engine Model		3408B			3406B	
Rated Engine RPM		2100			2100	
No Cylinders		6			6	
Bore	137 mm		5 4	137 mm		5 4"
Stroke	165 mm		6 5"	165 mm		6 5
Displacement	14 6 L		893 in³	14 6 L		893 in³
Drive Systems Rotor		3 speed Mechanical			3 speed Mechanical	
Ground		3 speed Hydrostatic			3 speed Hydrostatic	
Operating Dimensions Height	2600 mm		8'6 5	2600 mm		8'6 5
Width	2921 mm		9 7"	2921 mm		9 7
Length	8560 mm		28 1	8560 mm		28 1
Width of Cut	2438 mm		8'0"	2438 mm		8 0
Depth of Cut (Max)	305 mm		12"	457 mm		18
Rotor Speed	Trans	Drive	Speed	Trans	Drive	Speed
	Low	Low	123 rpm	Low	Low	123 rpm
	Low	High	168 rpm	Low	High	168 rpm
	High	Low	284 rpm	High	Low	284 rpm
Minimum Turning Radius: Standard	12 19 m		40 0"	12 19 m		40'0"
with optional rear steer	6 09 m		20'0"	6 09 m		20'0"
Travel Speed (Max)	19 3 km/h		12 mph	19 3 km/h		12 mph
Gross Gradeability (will vary with conditions)		40%			30%	
Standard Tires Front		23 5 x 25-16 ply Lug Type E 2			20 1 x 26 10 PR Lug	
Rear		16 5 x 25-8 ply Lug Type L 2			14 9 x 24 8 PR Lug	
Fuel Capacity	416 L		110 U S gal	416 L		110 U S gal
Cooling System	61 L		16 U S gal	61 L		16 U S gal
Crankcase	34 L		9 U S gal	34 L		9 U S gal

OPTIONAL EQUIPMENT

- Roll Over Protective Structure (ROPS)
- Foot per minute indicator (available in metric)
- Working light package
- Cab with heater and defroster
- Automated Asphalt Metering and Injection System (English or Metric) Includes a foot per minute indicator
- Water spray system with 76 mm (3 in) in line flow meter (English or Metric)
- Rear Wheel Steering for 6 1 m (20 ft) turning radius
- Cab with Air Conditioner

Rotor Options for RR 250 & SS 250

Rotor	Maximum Depth of Work	No of Bits/Tools	Direction of Cut
Quick Change Tool	381 mm 15"	56	Up
Standard Mix Chopper	381 mm 15"	39 RH 39 LH	Up
Standard Mix Straight Tool	406 mm 16	78	Up
Deep Mix Chopper	457 mm 18"	39 RH 39 LH	Down
Deep Mix Straight Tool	483 mm 19	78	Down
RR 250 Reclamation Rotor			
Cone Tool Mildrum	330 mm 13	168 Quick Change Carbide Tipped	Up
Breakaway Holder Rotor	330 mm 13"	168 Carbide Bits	Up

PRODUCTION ESTIMATING

The standard Cat Soil Stabilizer and Reclaimer are capable of cutting and mixing to depths of 15 in* and 13 in respectively In addition, the cutting width of their rotors is 8 feet The following formulas allow you to determine the production in square yards (yd^2/minute or cubic yards (yd^3)/minute

Production in square yards (yd^2) per minute

$$yd^2/min = \frac{\text{FPM of travel speed}}{1\ 125}$$

$$\frac{9\ ft^2/yd^2}{8\ ft\ \text{Cutting width}} = 1\ 125$$ (This is a constant value for an eight foot wide rotor)

Gallons of additive (for units with pump and metering additive system)

$$\frac{GPM}{yd^2/min} = gal/yd^2$$

Or, if required additive amounts are known, you can determine necessary travel speed as shown

$$\frac{GPM}{gal/yd^2} = yd^2/min,\ yd^2/min \times 1\ 125 = ft/min$$

Production in Cubic Yards (yd^3) per minute

$$\frac{\text{FPM of travel speed}}{1\ 125} \times \frac{\text{Cutting or mixing depth in inches}}{36} = \frac{yd^3}{min}$$

Production in Tons per Minute

$$yd^3/min \times \frac{\text{Wt of Material per yd in lbs}}{2000\ lb/ton} = tons/min$$

*Optional 18 in

Abbreviations

FPM = Foot Per Minute
GPM = Gallons Per Minute

WEIGHT OF MATERIALS

Material		lbs/yd^3 (LOOSE)	lbs/yd^3 (IN PLACE)
Clay	— Dry	2500	3100
	— Wet	2800	3500
Clay and Gravel	— Dry	2400	2800
	— Wet	2600	3100
Sand and Gravel	— Dry	2900	3250
	— Wet	3400	3750
Sand	— Dry	2400	2700
	— Damp	2850	3200
	— Wet	3100	3500
Earth	— Dry Packed	2550	3200
	— Wet Excavated	2700	3400
	— Top Soil	1600	2300
	— Loam	2100	2600
Bituminous Concrete	— Windrowed Chunks (25% Voids)	2925	
	— Compacted		3900

STABILIZATION/RECLAMATION PRODUCTION

To eliminate field calculations the following chart lists production in Square Yards per Minute (yd^2/min) and Cubic Yards per Minute (yd^3/min) The information is based on various travel speeds and cutting depths for the Caterpillar RR 250 and SS 250 equipped with a 2438 mm (8 ft) cutting rotor

Travel Speed FPM	6		8		10		12		13		15		16		18	
	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min	yd^2/min	yd^3/min
10	8.9	1.5	8.9	2.0	8.9	2.5	8.9	3.0	8.9	3.2	8.9	3.7	8.9	4.0	8.9	4.5
20	17.8	3.0	17.8	4.0	17.8	4.9	17.8	5.9	17.8	6.4	17.8	7.4	17.8	7.9	17.8	8.9
30	26.7	4.5	26.7	6.0	26.7	7.4	26.7	8.9	26.7	9.6	26.7	11.1	26.7	11.9	26.7	13.4
40	35.6	5.9	35.6	7.9	35.6	9.9	35.6	11.9	35.6	12.8	35.6	14.8	35.6	15.8	35.6	17.8
50	44.5	7.4	44.5	9.9	44.5	12.4	44.5	14.8	44.5	16.0	44.5	18.5	44.5	19.8	44.5	22.3
60	53.4	8.9	53.4	11.9	53.4	14.8	53.4	17.8	53.4	19.3	53.4	22.2	53.4	23.7	53.4	26.7
70	62.3	10.4	62.3	13.8	62.3	17.3	62.3	20.8	62.3	22.5	62.3	25.9	62.3	27.7	62.3	31.2
80	71.2	11.9	71.2	15.8	71.2	19.8	71.2	23.7	71.2	25.7	71.2	29.6	71.2	31.6	71.2	35.6
90	80.1	13.4	80.1	17.8	80.1	22.4	80.1	26.7	80.1	28.9	80.1	33.3	80.1	35.6	80.1	40.1

Appendix D

SDRI AND TSB DATA

SDRI Data Table											
Project Title		Rocky Mountain Arsenal Task 93-03, Soils Feasibility									
Project Number'		21907 207040									
Test Site		RMA Test Fill #1									
					Bag 1		Bag 2				
				Interval	Initial	Final	Initial	Final	Flow	Avg Day	Infiltr
Date On	Date Off	Time On	Time Off	(t)	weight	weight	weight	weight	(Q)	Number	(I)
				sec	gm	gm	gm	gm	ml		cm/sec
8/10/94	8/11/94	13 34	8 00	66360	3759	3578	4222	3750	653	0	4 24E-07
8/11/94	8/12/94	9 58	7 55	79020	3578	3355	3750	3578	395	2	2 15E-07
8/12/94	8/13/94	9 20	8 28	83280	3355	3301	3578	3260	372	3	1 92E-07
8/13/94	8/15/94	9 33	7 45	166320	3301	3046	3260	2974	541	4	1 40E-07
8/15/94	8/16/94	8 22	10 55	95580	3046	3015	2974	2760	245	6	1 10E-07
8/16/94	8/19/94	14 18	7 18	234000	3664	3273	3541	3332	600	8	1 10E-07
8/19/94	8/22/94	7 50	7 40	258600	3273	3273	3332	2928	404	11	6 73E-08
8/22/94	8/26/94	8 45	7 30	341100	3805	2379			1426	14	1 80E-07
8/26/94	9/2/94	7 35	12 15	621600	3900	3242			658	19	4 56E-08
9/2/94	9/28/94	12 20	15 53	2259180	3746	2197			1549	35	2 95E-08
9/28/94	10/13/94	15 56	9 55	1274340	3514	3196			318	56	1 07E-08
10/13/94	11/1/94	9 56	16 20	1664640	3568	3169			399	72	1 03E-08
	Start Water	Start Water	End Water	End Water	Avg Water	Start Water	End Water	Temp.	Est. Flow	% of	
	Reading	Depth	Reading	Depth	Depth	Temp.	Temp	Change	Due to Temp.	Total Flow	
	In	In	In	In	In	F	F	F			
	3	11 5	2 94	11 44	11 47	72	70	2	33 4	8 46	
	2 94	11 44	2 88	11 38	11 41	70	69 5	0 5	8 35	2 24	
	2 88	11 38	2 88	11 38	11 38	69 5	67	2 5	41 75	7 72	
	2 88	11 38	2 88	11 38	11 38	67	67	0	0	0 00	
	2 88	11 38	3 06	11 56	11 47	67	67	0	0	0 00	
	3 06	11 56	2 94	11 44	11 50	67	65 5	1 5	25 05	6 20	
	2 94	11 44	2 65	11 15	11 30	65 5	66	-0 5	-8 35	-0 59	
	2 65	11 15	2 94	11 44	11 30	66	65	1	16 7	2 54	
	2 88	11.38	2 5	11	11 19	65	61	4	66 8	4 31	
	2 5	11	2 82	11 32	11 16	61	52	9	150 3	47 26	
	2 82	11.32	2 5	11	11 16	52	49 5	2 5	41 75	10 46	

Swell data

SDRI Swell Data Table							
Project Title		Rocky Mountain Arsenal Task 93-03, Soils Feasibility					
Project Number		21907 207040					
Test Site		RMA Test Fill #1					
Date	Time	Test Day No	Swell #1	Swell #2	Swell #3	Swell #4	Ave Swell
8/10/94	9:10	0	93 4	98 4	43 7	56	0 00
8/11/94	10:20	1	92.5	97 8	43 4	55 9	0 48
8/12/94	9:37	2	93.2	98 1	43 6	56.2	0 10
8/13/94	9 37	3	93 1	97 9	43 1	55.9	0 38
8/15/94	8 30	5	93	98 3	43 5	55 7	0.25
8/16/94	13 15	6	93 1	93.2	43 3	55 8	1 53
8/19/94	8 00	9	92 7	98.2	43 1	56	0 38
8/22/94	8:50	12	92.9	98 4	43 7	56 5	0 00
8/26/94	7:35	16	91 7	97 5	42.2	55	1.28
9/2/94	7.30	22	93 5	99.2	44.3	56 6	-0 52
9/20/94	13:20	40	93.2	99 8	44.2	56 4	-0 52
9/28/94	1555	48	92.3	98 7	43.5	55	0 50
10/5/94	8 35	55	92.1	98 6	43 6	56 1	0.28
10/7/94	11 05	57	92.4	98 6	43 8	55 7	0.25
10/13/94	10:00	63	92.7	98 5	43 7	55 7	0.23
10/20/94	8 10	70	91 5	98 8	44	55 8	0 35
11/1/94	16.22	81	93.2	99 1	44.9	56 7	-0 60

Tensio data

SDRI Tensiometer Data Table

Project Title: Rocky Mountain Arsenal Task 93-03, Soils Feasibility

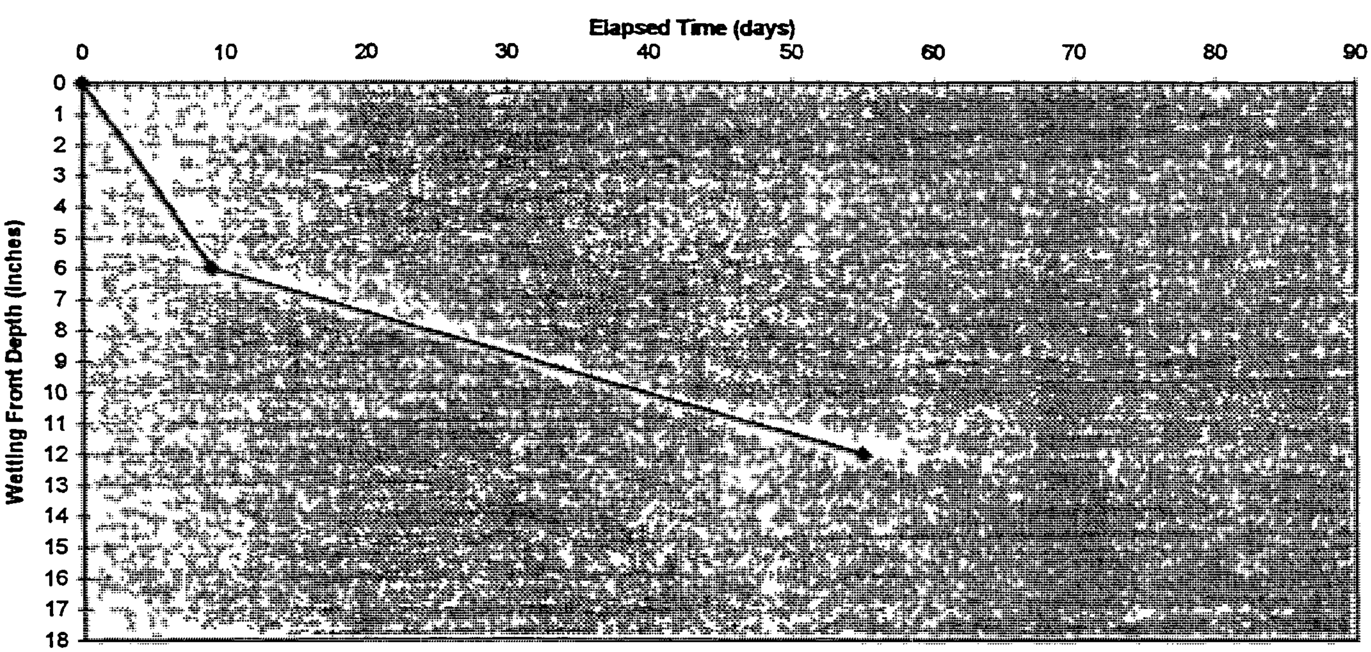
Project Number: 21907 207040

Test Site: RMA Test Fill #1

Note: All readings in Centibars

			Depth 6 inches			Depth 12 inches			Depth 18 inches			Average Readings		
Date	Time	Day No	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
8/10/94	9:10	0	22	28	27	26	22	23	40	20	24	26	24	28
8/11/94	10:20	1	24	36	30	26	23	22	38	18	25	30	24	27
8/12/94	9:37	2	21	34	22	22	26	23	37	16	25	26	24	26
8/13/94	9:37	3	18	29	19	20	26	23	37	17	26	22	23	27
8/15/94	8:30	5	13	19	14	20	25	22	35	17	26	15	22	26
8/16/94	13:15	6	14	14	9	19	24	20	30	14	20	12	21	21
8/19/94	8:00	9	9	11	8	23	22	20	32	17	22	9	22	24
8/22/94	8:50	12	10	7	5	21	18	17	28	11	17	7	19	19
8/26/94	7:30	16	8	6	6	20	18	18	28	16	19	7	19	21
9/2/94	7:30	22	6	4	4	18	14	14	25	16	17	5	15	19
9/6/94	14:30	26	9	4	4	15	11	12	22	14	14	6	13	17
9/12/94	12:00	32	8	4	5	14	11	12	24	14	14	6	12	17
9/16/94	12:35	36	8	4	4	14	11	11	23	14	15	5	12	17
9/20/94	13:30	40	7	1	4	13	10	11	23	15	13	4	11	17
9/23/94	15:20	43	7	2	4	13	10	10	23	14	14	4	11	17
9/28/94	15:55	48	6	2	3	12	10	10	23	15	12	4	11	17
10/5/94	8:35	55	4	2	2	0	10	12	26	17	0	3	7	14
10/7/94	9:45	57	4	2	2	6	9	10	25	13	0	3	8	13
10/13/94	10:00	63	4	1	2	9	8	11	26	18	18	2	9	21
10/20/94	8:10	70	2	2	2	6	8	10	26	20	20	2	8	22
11/1/94	16:22	81	3	2	2	6	9	10	25	19	20	2	8	21

Wetting Front Depth Based on Tensiometer Data



SDRI Hydraulic Conductivity Calculation Table					
Project Title.		Rocky Mountain Arsenal Task 93-03, Soils Feasibility			
Project Number·		21907 207040			
Test Site		RMA Test Fill #1			
Test Day No	Infiltration	Water Depth	Wetting Front	Gradient	Hydraulic Conductivity
	(I)	Depth (H)	Depth (D)	(i)	K
	cm/sec	in	in		cm/sec
0	4.24E-07		0 75	1.00	4.24E-07
2	2.15E-07	11 47	1 75	7.55	2.85E-08
3	1.92E-07	11 41	2	6.71	2.87E-08
4	1 40E-07	11 38	2.75	5 14	2.73E-08
6	1 10E-07	11 38	4	3.85	2.87E-08
8	1 10E-07	11 47	5 5	3.09	3.58E-08
11	6 73E-08	11.50	6.5	2.77	2.43E-08
14	1 80E-07	11.30	6 75	2.67	6.73E-08
19	4.56E-08	11.30	7.5	2.51	1.82E-08
35	2.95E-08	11 19	9 9	2.13	1 39E-08
56	1 07E-08	11 16	11.2	2.00	5 38E-09
72	1 03E-08	11 16	13 5	1 83	5 65E-09

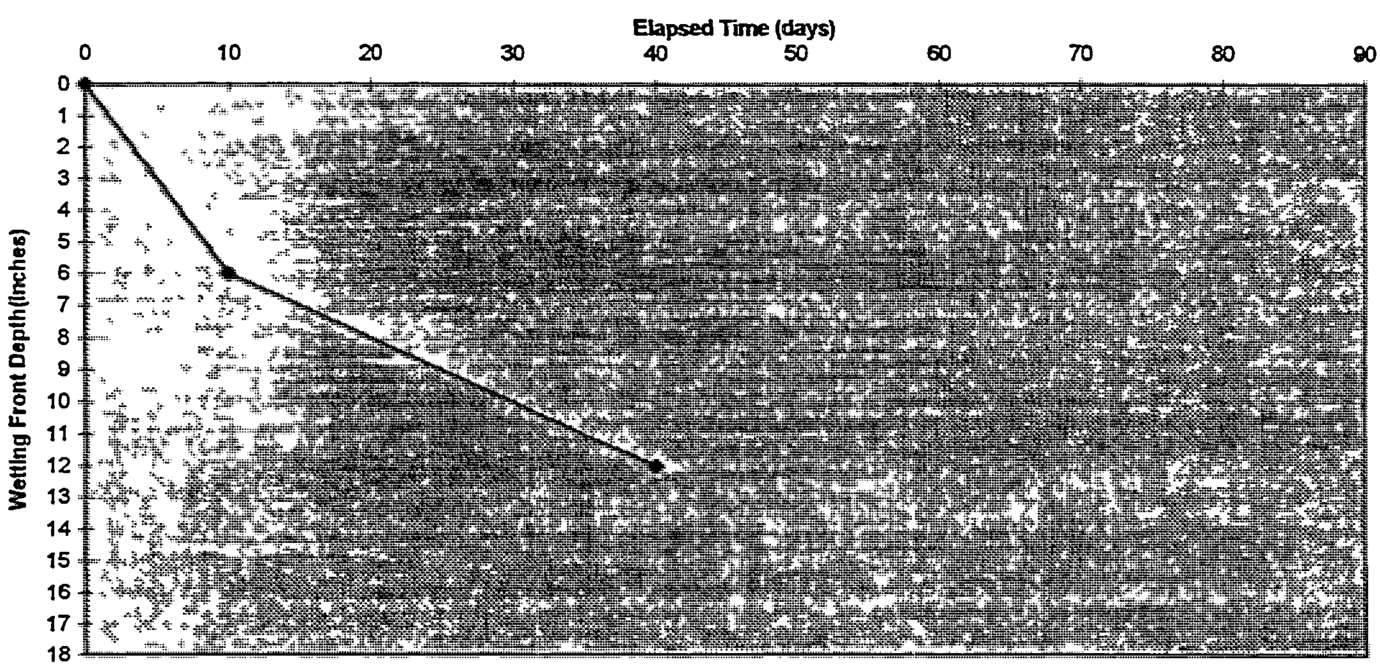
SDRI Data Table											
Project Title		Rocky Mountain Arsenal Task 93-03, Soils Feasibility									
Project Number:		21907 207040									
Test Site.		RMA Test Fill #2									
					Bag 1		Bag 2				
Date On	Date Off	Time On	Time Off	Interval (t) sec	Initial weight gm	Final weight gm	Initial weight gm	Final weight gm	Flow (Q) ml	Avg Day Number	Infiltr (I) cm/sec
8/10/94	8/11/94	13 38	8 00	66120	3600	2701	2528	2874	553	0	3 60E-07
8/11/94	8/12/94	9 52	8 00	79680	2842	2461	3005	2874	512	2	2 77E-07
8/12/94	8/13/94	9 27	8 32	83100	3282	2892	3174	2892	672	3	3 48E-07
8/13/94	8/15/94	9 36	7 48	166320	3800	3228	3741	3269	1044	4	2 70E-07
8/15/94	8/16/94	8 26	11 00	95640	3228	2874	3269	3219	404	6	1 82E-07
8/17/94	8/19/94	9 49	7 23	164040	3282	3037	3696	3446	495	8	1 30E-07
8/19/94	8/22/94	7 55	7 47	258720	3037	2919	3446	3087	477	11	7 94E-08
8/22/94	8/26/94	8 48	7 55	342420	3895	2760			1135	14	1 43E-07
8/26/94	9/2/94	8 00	11 10	616200	3882	3105			777	19	5 43E-08
9/2/94	9/28/94	11 20	16 15	2264100	3804	1689			2115	35	4 02E-08
9/28/94	10/13/94	16 17	10 12	1274100	3528	3096			432	56	1 46E-08
10/13/94	11/1/94	10 16	16 40	1664640	3759	3314			445	72	1 15E-08
	Start Water Reading in	Start Water Depth in	End Water Reading in	End Water Depth in	Avg Water Depth in	Start Water Temp. F	End Water Temp F	Temp. Change F	Est Flow Due to Temp	% of Total Flow	
	2 75	10 25	2 81	11 31	10 78	70	70 5	-0 5	-8 35	-1 63	
	2 81	10 31	2 75	11 25	10 78	70 5	70	0 5	8 35	1 24	
	2 75	10 25	2 75	11 25	10 75	70	67	3	50 1	4 80	
	2 75	10 25	2 75	11 25	10 75	67	68	-1	-16 7	-4 13	
	2 63	10 13	2 5	11	10 57	68	67 5	0 5	8 35	1 69	
	2 5	10	2 38	10 88	10 44	67 5	66	1 5	25 05	5 25	
	2 38	9 88	2 06	10 56	10 22	66	66	0	0	0 00	
	2 06	9 56	3	11 5	10 53	66	66	0	0	0 00	
	3	10 5	2 65	11 15	10 83	66	61	5	83 5	3 95	
	3	10 5	2 94	11 44	10 97	61	53	8	133 6	30 93	
	2 94	10 44	2 5	11	10 72	53	50 5	2 5	41 75	9.38	

SDRI Swell Data Table							
Project Title		Rocky Mountain Arsenal Task 93-03, Soils Feasibility					
Project Number		21907 207040					
Test Site		RMA Test Fill #2					
Date	Time	Test Day No	Swell #1	Swell #2	Swell #3	Swell #4	Ave Swell
8/10/94	10 45	0	53 8	58 5	19 8	8 6	0 00
8/11/94	10 05	1	53 3	57 4	18 1	8 1	0 95
8/12/94	9 55	2	54.2	58	18 7	8 1	0 42
8/13/94	9 50	3	54.9	58 4	19	8 6	-0 05
8/15/94	8 37	5	54.2	58.2	18 7	8 5	0.27
8/19/94	8 15	9	54 4	59.2	19 1	9 1	-0.28
8/22/94	9 00	12	54 3	58 3	19 4	9	-0 07
8/26/94	8 00	16	52.9	58 1	18 3	7.3	1 03
9/2/94	7 30	22	55 4	59 3	20.3	9 2	-0 88
9/20/94	13 50	40	54	58 9	19 7	9	-0.23
9/28/94	16 15	48	54 1	58.2	19 6	8 5	0 07
10/5/94	9 05	55	54	57 7	19.2	8 4	0 35
10/7/94	11 15	57	54.2	57 8	19	8 6	0.27
10/13/94	10 16	63	53 6	58	18.9	8 4	0 45
10/20/94	8 30	70	54 1	58 4	19.5	8.2	0 13
11/1/94	16 40	81	54 6	59 3	19 5	9 4	-0 53

Tensio data

SDRI Tensiometer Data Table														
Project Title.		Rocky Mountain Arsenal Task 93-03, Soils Feasibility												
Project Number		21907 207040												
Test Site		RMA Test Fill #2												
	Note	All readings in Centibars												
			Depth 6 inches			Depth 12 inches			Depth 18 inches			Average Readings		
Date	Time	Day No	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
8/10/94	10:45	0	43	18	46	28	0	38	38	30	35	36	22	34
8/11/94	10:05	1	40	28	49	32	26	42	30	30	32	39	33	31
8/12/94	9 55	2	38	33	42	34	26	40	30	32	30	38	33	31
8/13/94	9 50	3	31	31	38	34	27	40	32	34	30	33	34	32
8/15/94	8 30	5	22	24	24	30	26	37	35	35	33	23	31	34
8/19/94	8 15	9	10	12	11	24	22	34	37	34	37	11	27	36
8/22/94	9 00	12	9	2	7	21	19	30	36	34	38	6	23	36
8/26/94	8 00	16	8	0	4	20	18	30	35	30	38	4	23	34
9/2/94	7 30	22	6	0	0	15	15	23	33	25	35	2	18	31
9/6/94	14 30	26	7	0	2	14	13	18	32	23	35	3	15	30
9/12/94	12:00	32	6	0	4	12	11	14	30	20	34	3	12	28
9/16/94	12.37	36	6	0	1	12	10	10	29	20	33	2	11	27
9/20/94	13 50	40	6	0	1	11	9	5	27	18	32	2	8	26
9/23/94	15:30	43	6	0	0	10	9	4	27	18	32	2	8	26
9/28/94	15 15	48	6	0	2	10	8	4	26	18	32	3	7	25
10/5/94	9:05	55	2	0	0	0	6	0	24	17	26	1	2	22
10/7/94	10.35	57	2	0	0	0	5	0	22	17	24	1	2	21
10/13/94	10 16	63	3	0	0	10	3	2	22	14	22	1	5	19
10/20/94	8:30	70	1	0	0	8	3	3	20	13	32	0	5	22
11/1/94	16 40	81	2	0	0	8	1	1	18	12	32	1	3	21

Wetting Front Depth Based on Tensiometer Data



SDRI Hydraulic Conductivity Calculation Table					
Project Title.		Rocky Mountain Arsenal Task 93-03, Soils Feasibility			
Project Number:		21907 207040			
Test Site		RMA Test Fill #2			
Test Day No	Infiltration	Water Depth	Wetting Front	Gradient	Hydraulic Conductivity
	(I)	Depth (H)	Depth (D)	(i)	K
	cm/sec	in	in		cm/sec
0	3 60E-07		0 5	1.00	3 60E-07
2	2.77E-07	10 78	1	11 78	2.35E-08
3	3 48E-07	10.78	1.5	8 19	4.25E-08
4	2.70E-07	10 75	2.5	5 30	5 10E-08
6	1 82E-07	10 75	3.5	4.07	4 47E-08
8	1 30E-07	10 57	4.5	3.35	3 88E-08
11	7.94E-08	10 44	6.25	2.67	2.97E-08
14	1 43E-07	10.22	7	2.46	5.80E-08
19	5 43E-08	10.53	7 75	2.36	2.30E-08
35	4 02E-08	10 83	11	1.98	2.03E-08
56	1 46E-08	10.97	13 8	1 79	8 13E-09
72	1 15E-08	10 72	17	1 63	7 06E-09

Borehole Permeameter Stage 1 Calculations

Project	RMA 93 03, 21907 207030
Test Location:	RMA, Section 25, Test FM 1
Test Number :	B1A

Test Dimensions and Equations:

(cm)

d = 1 27

D = 10 16

Z = 33 02

R_A = 6 92

b_1 = 58 42

$Z + R_A + b_1$ = 98 36

t_0 = 08/17/94 08 00

K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)

G_1 = 0 043

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/17/94	08 00	0	20 5		118 9		30 5			72 5	22 5	0 93				
08/17/94	08 02	120	9 1	118 9	107 5	30 5	30 5	0 0	107 5	72 5	22 5	0 93	1 11	3 36E-05	0 03	
08/17/94	08 04		22 1	107 5	120 5	30 5	30 5	0 0	120 5	72 7	22 6	0 93	0 89		0 07	Refill
08/17/94	08 06	120	10 6	120 5	109 0	30 5	30 5	0 0	109 0	72 7	22 6	0 93	1 11	3 34E-05	0 10	
08/17/94	08 09		24 8	109 0	123 2	30 5	30 5	0 0	123 2	72 7	22 6	0 93	0 88		0 15	Refill
08/17/94	08 13	240	12 7	123 2	111 1	30 5	30 5	0 0	111 1	72 7	22 6	0 93	1 11	1 72E-05	0 22	
08/17/94	08 15		29 0	111 1	127 4	30 5	30 5	0 0	127 4	72 7	22 6	0 93	0 87		0 25	Refill
08/17/94	08 25	600	8 0	127 4	106 4	30 5	30 4	-0 1	106 5	72 9	22 7	0 93	1 20	1 19E-05	0 42	
08/17/94	08 27		28 9	106 4	127 3	30 4	30 4	0 0	127 3	72 9	22 7	0 93	0 84		0 45	Refill
08/17/94	08 44	1020	4 0	127 3	102 4	30 4	30 4	0 0	102 4	73 2	22 9	0 93	1 24	8 54E-06	0 73	
08/17/94	08 45		29 1	102 4	127 5	30 4	30 4	0 0	127 5	73 2	22 9	0 93	0 80		0 75	Refill
08/17/94	09 06	1260	6 4	127 5	104 8	30 4	30 2	-0 2	105 0	73 4	23 0	0 93	1 21	6 16E-06	1 10	
08/17/94	09 08		29 7	104 8	128 1	30 2	30 2	0 0	128 1	73 4	23 0	0 93	0 82		1 13	Refill
08/17/94	09 36	1680	9 8	128 1	108 2	30 2	30 0	-0 2	108 4	73 9	23 3	0 93	1 18	3 98E-06	1 60	
08/17/94	10 02		27 9	108 2	126 3	30 0	30 0	0 0	126 3	74 1	23 4	0 93	0 86		2 03	Refill
08/17/94	10 37	2100	12 7	126 3	111 1	30 0	29 8	-0 2	111 3	74 3	23 5	0 91	1 13	2 36E-06	2 62	
08/17/94	10 39		28 8	111 1	127 2	29 8	29 8	0 0	127 2	74 3	23 5	0 91	0 87		2 65	Refill
08/17/94	11 38	3540	9 2	127 2	107 6	29 8	29 5	-0 3	107 9	74 7	23 7	0 91	1 18	1 82E-06	3 63	
08/17/94	11 40		29 1	107 6	127 5	29 5	29 5	0 0	127 5	74 7	23 7	0 91	0 84		3 67	Refill
08/17/94	14 37	10620	8 2	127 5	106 6	29 5	29 9	0 4	106 2	75 6	24 2	0 91	1 20	6 74E-07	6 62	
08/17/94	14 38		29 8	106 6	128 2	29 9	29 9	0 0	128 2	75 6	24 2	0 91	0 83		6 63	Refill
08/17/94	16 22	6240	21 6	128 2	120 0	29 9	30 4	0 5	119 5	75 9	24 4	0 91	1 07	4 41E-07	8 37	
08/17/94	16 24		29 8	120 0	128 2	30 4	30 4	0 0	128 2	75 9	24 39	0 91	0 94		8 40	Refill
08/18/94	08 35	58380	13 7	120 0	112 1	30 4	30 3	-0 1	112 2	74 5	23 61	0 91	1 07	4 51E-08	24 58	
08/18/94	08 40		29 4	128 2	127 8	30 4	30 3	-0 1	127 9	74 5	23 61	0 91	1 00		24 67	Refill
08/19/94	07 58	83880	17 1	127 8	115 5	30 3	30 1	-0 2	115 7	73 4	23	0 95	1 10	4 85E-08	47 97	
08/19/94	15 52	28440	14 2	115 5	112 6	30 1	29 7	-0 4	113 0	75 4	24 11	0 91	1 02	3 01E-08	55 87	

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	Test Unit H1 (cm)	Test Unit H2 (cm)	TEG Ro (cm)	TEG Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/19/94	15 55		29 9	112 6	128 3	29 7	29 7	0 0	128 3	75 4	24 11	0 91	0 88		55 92	Refill
08/20/94	09·50	64500	19 7	128 3	118 1	29 7	29 1	-0 6	118 7	70 9	21 61	0 96	1 08	4 98E-08	73 83	
08/20/94	10 30	2400	19 3	118 1	117 7	29 1	29 0	-0 1	117 8	74 3	23 5	0 91	1 00	4 15E-08	74 50	
08/20/94	10 31		29 5	117 7	127 9	29 0	29 0	0 0	127 9	74 3	23 5	0 91	0 92		74 52	Refill
08/21/94	09 32	82860	21 0	127 9	119 4	29 0	29 0	0 0	119 4	71 4	21 89	0 95	1 07	3 39E-08	97 53	
08/22/94	16 09	110220	12 8	119 4	111 2	29 0	29 0	0 0	111 2	74 8	23 78	0 91	1 07	2 53E-08	128 15	
08/22/94	16 11		30 0	111 2	128 4	29 0	29 0	0 0	128 4	74 8	23 78	0 91	0 87		128 18	Refill
08/23/94	11 03	67920	22 7	128 4	121 1	29 0	28 3	-0 7	121 8	74 3	23 5	0 91	1 05	3 04E-08	147 05	
08/23/94	11 04		29 9	121 1	128 3	28 3	28 3	0 0	128 3	74 3	23 5	0 91	0 94		147 07	Refill
08/24/94	09 37	81180	23 4	128 3	121 8	28 3	28 7	0 4	121 4	74 5	23 61	0 91	1 06	2 67E-08	169 62	
08/24/94	09 38		30 0	121 8	128 4	28 7	28 7	0 0	128 4	74 5	23 61	0 91	0 95		169 63	Refill
08/26/94	14 36	190680	15 0	128 4	113 4	28 7	27 6	-1 1	114 5	75 2	24	0 91	1 12	2 35E-08	222 60	
08/26/94	14 37		28 9	113 4	127 3	27 6	27 6	0 0	127 3	75 2	24	0 91	0 89		222 62	Refill
08/27/94	09 52	69300	23 8	127 3	122 2	27 6	27 3	-0 3	122 5	75 4	24 11	0 91	1 04	2 17E-08	241 87	
08/28/94	11 05	90780	17 7	122 2	116 1	27 3	27 8	0 5	115 6	70 6	21 39	0 91	1 06	2 39E-08	267 08	
08/29/94	09 03	79080	12 4	116 1	110 8	27 8	27 9	0 1	110 7	71 2	21 78	0 98	1 05	2 54E-08	289 05	
08/30/94	07 52	82140	7 5	110 8	105 9	27 9	28 1	0 2	105 7	70 5	21 39	0 98	1 05	2 42E-08	311 87	
08/31/94	14 15	109380	1 8	105 9	100 2	28 1	28 1	0 0	100 2	72 0	22 22	0 98	1 06	2 13E-08	342 25	

Time weighted average for K1 = 8 06E-08

Borehole Permeameter Stage 1 Calculations

Project RMA 93 03, 21907 207030
Test Locat RMA, Section 25, Test Fill 1
Test Num B1B

Test Dimensions and Equations'

(cm)
d = 1 27
D = 10 16
Z = 33 02
R_A = 5 92
b_1 = 58 42
+ R_A + b_1 = 97 36
t_0 = 8/17/94 16 30

K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
G_1 = 0 043

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	08 15	56700	29 2		126 6		30 3	30 3	96 3	74 1	23	0 91	0 00		15 75	
08/18/94	08 45	1800	29 0	126 6	126 4	30 3	30 3	0 0	126 4	74 5	24	0 91	1 00	3 44E-08	16 25	
08/18/94	09 15	1800	28 7	126 4	126 1	30 3	30 3	0 0	126 1	74 7	24	0 91	1 00	5 17E-08	16 75	
08/18/94	10 15	3600	28 2	126 1	125 6	30 3	30 0	-0 3	125 9	75 6	24	0 91	1 00	1 73E-08	17 75	
08/18/94	12 15	7200	27 6	125 6	125 0	30 0	29 8	-0 2	125 2	76 3	25	0 89	1 00	1 70E-08	19 75	
08/18/94	16 15	14400	27 0	125 0	124 4	29 8	30 4	0 6	123 8	76 3	25	0 89	1 01	2 56E-08	23 75	
08/19/94	07 59	56640	17 8	124 4	115 2	30 4	30 1	-0 3	115 5	73 4	23	0 93	1 08	5 24E-08	39 48	
08/19/94	15 57	28680	14 2	115 2	111 6	30 1	29 7	0 4	112 0	75 4	24	0 91	1 03	3 84E-08	47 45	
08/19/94	16 05		30 0	111 6	127 4	29 7	29 7	0 0	127 4	75 4	24	0 91	0 88		47 58	Refill
08/20/94	09 51	63960	20 4	127 4	117 8	29 7	29 1	-0 6	118 4	70 9	22	0 95	1 08	4 68E-08	65 35	
08/21/94	09 33	85320	13 7	117 8	111 1	29 1	29 0	-0 1	111 2	71 4	22	0 95	1 06	2 76E-08	89 05	
08/21/94	09 35		29 9	111 1	127 3	29 0	29 0	0 0	127 3	71 4	22	0 95	0 87		89 08	Refill
08/22/94	16 13	110280	20 3	127 3	117 7	29 0	29 0	0 0	117 7	71 4	22	0 95	1 08	2 91E-08	119 72	
08/22/94	16 14		29 9	117 7	127 3	29 0	29 0	0 0	127 3	74 8	24	0 91	0 92		119 73	Refill
08/23/94	11 06	67920	23 6	127 3	121 0	29 0	28 3	-0 7	121 7	74 3	24	0 91	1 05	2 59E-08	138 60	
08/23/94	11 07		29 6	121 0	127 0	28 3	28 3	0 0	127 0	74 3	24	0 91	0 95		138 62	Refill
08/24/94	09 46	81540	23 4	127 0	120 8	28 3	28 7	0 4	120 4	74 5	24	0 91	1 05	2 56E-08	161 27	
08/24/94	09 47		29 9	120 8	127 3	28 7	28 7	0 0	127 3	74 5	24	0 91	0 95		161 28	Refill
08/26/94	14 38	190260	15 6	127 3	113 0	28 7	27 6	-1 1	114 1	75 2	24	0 91	1 12	2 25E-08	214 13	
08/26/94	14 39		29 8	113 0	127 2	27 6	27 6	0 0	127 2	75 2	24	0 91	0 89		214 15	Refill
08/27/94	09 53	69240	24 2	127 2	121 6	27 6	27 3	-0 3	121 9	75 4	24	0 91	1 04	2 41E-08	233 38	
08/28/94	11 05	159960	18 4	121 6	115 8	27 3	27 8	0 5	115 3	75 9	24	0 91	1 05	1 30E-08	258 58	
08/29/94	09 06	169980	13 8	115 8	111 2	27 8	27 9	0 1	111 1	71 2	22	0 95	1 04	9 96E-09	280 60	
08/30/94	07 54	82080	9 3	111 2	106 7	27 9	28 1	0 2	106 5	70 5	21	0 97	1 04	2 20E-08	303 40	
08/31/94	14 17	109380	3 2	106 7	100 6	28 1	28 1	0 0	100 6	72 0	22	0 95	1 06	2 20E-08	333 78	

Time weighted average for K1 = 2 29E-08

Borehole Permeameter Stage 1 Calculations

Project	RMA 93 03, 21907 207030
Test Location·	RMA, Section 25, Test Fill 1
Test Number	B1C

Test Dimensions and Equations

(cm)

$d =$ 1 27

$D =$ 10 16

$Z =$ 33 02

$R_A =$ 6 02

$b_1 =$ 58 42

$Z + R_A + b_1 =$ 97 46

$t_0 =$ 08/18/94 12 20

$K_1 = Rt\ G_1\ LN(H1/H2)/(t2 - t1)$

$G_1 =$ 0 043

Date	Time	^t =	Test Unit			TEG		C =	H'2 =							
		t2 - t1 (sec)	R (cm)	H1 (cm)	H2 (cm)	Ro (cm)	Rf (cm)	Rf - Ro (cm)	H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	14 34	8040	20 3		117 8		30 5	30 5	87 3	78 9	26 1	0 87	0 00		2 23	
08/18/94	14 36	120	10 1	117 8	107 6	30 5	30 5	0 0	107 6	78 9	26 1	0 87	1 09	2 82E-05	2 27	
08/18/94	14 38		23 3	107 6	120 8	30 5	30 5	0 0	120 8	78 9	26 1	0 87	0 89		2 30	Refill
08/18/94	14 42	240	7 9	120 8	105 4	30 5	30 5	0 0	105 4	78 9	26 1	0 87	1 15	2 13E-05	2 37	
08/19/94	07 43		29 3	105 4	126 8	30 5	30 1	-0 4	127 2	73 4	23 0	0 93	0 83		19 38	Refill
08/19/94	08 13	1800	27 9	126 8	125 4	30 1	30 0	-0 1	125 5	73 4	23 0	0 93	1 01	2 29E-07	19 88	
08/19/94	08 44	1860	26 5	125 4	124 0	30 0	29 9	-0 1	124 1	73 6	23 1	0 93	1 01	2 24E-07	20 40	
08/19/94	09 44	3600	23 6	124 0	121 1	29 9	29 9	0 0	121 1	74 3	23 5	0 91	1 02	2 57E-07	21 40	
08/19/94	11 44	7200	18 4	121 1	115 9	29 9	29 9	0 0	115 9	74 8	23 8	0 91	1 04	2 39E-07	23 40	
08/19/94	15 44	14400	8 3	115 9	105 8	29 9	29 7	-0 2	106 0	75 4	24 1	0 91	1 09	2 43E-07	27 40	
08/19/94	16 07		29 6	105 8	127 1	29 7	29 7	0 0	127 1	75 4	24 1	0 91	0 83		27 78	Refill
08/20/94	09 52	63900	0 0	127 1	97 5	29 7	29 1	-0 6	98 1	70 9	21 6	0 95	1 30		45 53	Water drained, rodents
08/20/94	09 58		30 0	97 5	127 5	29 1	29 1	0 0	127 5	70 9	21 6	0 95	0 76		45 63	Refill
08/21/94	09·36	85080	0 0	127 5	97 5	29 1	29 0	-0 1	97 6	71 4	21 9	0 95	1 31		69 27	Water drained, rodents
08/21/94	09 37		30 4	97 5	127 9	29 0	29 0	0 0	127 9	71 4	21 9	0 95	0 76		69 28	Refill
08/22/94	16 20	110580	6 6	127 9	104 1	29 0	29 0	0 0	104 1	74 8	23 8	0 91	1 23	7 29E-08	100 00	
08/22/94	16 22		30 0	104 1	127 5	29 0	29 0	0 0	127 5	74 8	23 8	0 91	0 82		100 03	Refill
08/23/94	11 09	67620	18 2	127 5	115 7	29 0	28 3	0 7	116 4	74 3	23 5	0 91	1 10	5 27E-08	118 82	
08/23/94	11 10		29 8	115 7	127 3	28 3	28 3	0 0	127 3	74 3	23 5	0 91	0 91		118 83	
08/24/94	09 52	81720	21 1	127 3	118 6	28 3	28 7	0 4	118 2	74 5	23 6	0 91	1 08	3 55E-08	141 53	
08/24/94	09 53		30 2	118 6	127 7	28 7	28 7	0 0	127 7	74 5	23 6	0 91	0 93		141 55	Refill
08/26/94	14 40	190020	13 2	127 7	110 7	28 7	27 6	-1 1	111 8	75 2	24 0	0 91	1 14	2.74E-08	194 33	
08/26/94	14 41		30.3	110 7	127 8	27 6	27 6	0 0	127 8	75 2	24 0	0 91	0 87		194 35	Refill
08/27/94	09·54	69180	23 3	127 8	120 8	27 6	27 3	-0 3	121 1	75 4	24 1	0 91	1 06	3 05E-08	213 57	
08/28/94	11·06	90720	16 0	120 8	113 5	27 8	27 3	-0 5	114 0	75 9	24 4	0 91	1 06	2 50E-08	238 77	
08/29/94	09·07	169980	10 1	120 8	107 6	27 3	27 9	0 6	107 0	71 2	21 8	0 95	1 13	2.92E-08	260 78	

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	Test Unit H1 (cm)	Test Unit H2 (cm)	TEG Ro (cm)	TEG Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/30/94	07 55	82080	5 2	107 6	102 7	27 9	28 1	0 2	102 5	70 5	21 4	0 98	1 05	4 61E 08	283 58	
08/30/94	07 56		29 5	102 7	127 0	28 1	28 1	0 0	127 0	70 5	21 4	0 98	0 81		283 60	Refill
08/31/94	14 19	109380	18 8	127 0	116 3	28 1	28 1	0 0	116 3	72 0	22 2	0 95	1 09	3 13E 08	313 98	

Time weighted average for K1 = 4 47E-08

Borehole Permeameter Stage 1 Calculations

Project RMA 93 03, 21907 207030
Test Location RMA, Section 25, Test Fill 1
Test Number · B1D

Test Dimensions and Equations·

(cm)

d = 1 27 K_1 = Rt G_1 LN(H1/H2)/(t2 t1)

D = 10 16 G_1 = 0 043

Z = 33 02

R_A = 5 84

b_1 = 58 42

Z + R_A + b_1 = 97 42

t_0 = 08/18/94 12 20

Date	Time	^t =	Test Unit			TEG		C =	H'2 =							
		t2 - t1 (sec)	R (cm)	H1 (cm)	H2 (cm)	Ro (cm)	Rf (cm)	Rf - Ro (cm)	H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	14 48	8880	30 1		127 5		30 5	30 5	97 0	78 9	26 1	0 87	0 00		2 47	
08/18/94	15 42	3240	28 2	127 5	125 6	30 5	30 5	0 0	125 6	76 1	24 5	0 89	1 02	1 77E-07	3 37	
08/19/94	07 46	57840	15 7	125 6	113 1	30 5	30 1	0 4	113 5	73 4	23 0	0 93	1 11	7 00E-08	19 43	
08/19/94	08 16	1800	15 6	113 1	113 0	30 1	30 0	0 1	113 1	73 4	23 0	0 93	1 00		19 93	
08/19/94	08 46	1800	15 3	113 0	112 7	30 0	29 9	-0 1	112 8	73 6	23 1	0 93	1 00	3 93E-08	20 43	
08/19/94	09 46	3600	15 0	112 7	112 4	29 9	29 9	0 0	112 4	74 3	23 5	0 91	1 00	2 90E-08	21 43	
08/19/94	11 46	7200	14 9	112 4	112 3	29 9	29 9	0 0	112 3	74 8	23 8	0 91	1 00	4 84E-09	23 43	
08/19/94	15 46	14400	13 1	112 3	110 5	29 9	29 7	-0 2	110 7	75 4	24 1	0 91	1 01	3 90E-08	27 43	
08/19/94	16 10		29 8	110 5	127 2	29 7	29 7	0 0	127 2	75 4	24 1	0 91	0 87		27 83	Refill
08/20/94	09 51	63660	22 3	127 2	119 7	29 7	29 1	-0 6	120 3	70 9	21 6	0 95	1 06	3 58E-08	45 52	
08/21/94	09 43	85920	15 4	119 7	112 8	29 1	29 0	-0 1	112 9	71 4	21 9	0 95	1 06	2 78E-08	69 38	
08/21/94	09 45		30 6	112 8	128 0	29 0	29 0	0 0	128 0	71 4	21 9	0 95	0 88		69 42	Refill
08/22/94	16 15	109800	22 0	128 0	119 4	29 0	29 0	0 0	119 4	74 8	23 8	0 91	1 07	2 48E-08	99 92	
08/22/94	16 16		29 9	119 4	127 3	29 0	29 0	0 0	127 3	74 8	23 8	0 91	0 94		99 93	Refill
08/23/94	11 14	68280	23 6	127 3	121 0	29 0	28 3	-0 7	121 7	74 3	23 5	0 91	1 05	2 58E-08	118 90	
08/23/94	11 15		29 2	121 0	126 6	28 3	28 3	0 0	126 6	74 3	23 5	0 91	0 96		118 92	Refill
08/24/94	09 49	81240	23 7	126 6	121 1	28 3	28 7	0 4	120 7	74 5	23 6	0 91	1 05	2.30E-08	141 48	
08/24/94	09 50		30 1	121 1	127 5	28 7	28 7	0 0	127 5	74 5	23 6	0 91	0 95		141 50	Refill
08/26/94	14 42	190380	17 8	121 1	115 2	28 7	27 6	-1 1	116 3	75 2	24 0	0 91	1 04	8 31E-09	194 37	
08/26/94	14 43		29 5	115 2	126 9	27 6	27 6	0 0	126 9	75 2	24 0	0 91	0 91		194 38	Refill
08/27/94	09 54	69060	24 9	126 9	122 3	27 6	27 3	-0 3	122 6	75 4	24 1	0.91	1 04	1 95E-08	213 57	
08/28/94	11·06	90720	19 6	122 3	117 0	27 3	27 8	0 5	116 5	75 9	24 4	0 91	1 05	2 10E-08	238 77	
08/29/94	09 08	79320	15 3	117 0	112 7	27 8	27 9	0 1	112 6	71 2	21 8	0 95	1 04	1 97E-08	260 80	
08/30/94	07 56	82080	11 6	112 7	109 0	27 9	28 1	0 2	108 8	70 5	21 4	0 98	1 04	1 81E-08	283 60	
08/31/94	14·20	109440	2 5	109 0	99 9	28 1	28 1	0 0	99 9	72 0	22 2	0.95	1 09	3 09E-08	314 00	

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks

Time weighted average for K1 = 2 45E-08

Borehole Permeameter Stage 1 Calculations

Project RMA 93 03, 21907 207030
Test Location. RMA, Section 25, Test Fill 1
Test Number : B1E

Test Dimensions and Equations:

(cm)
d = 1 27
D = 10 16
Z = 33 02
R_A = 6 02
b_1 = 58 42
$Z + R_A + b_1$ = 97 46
t_0 = 08/18/94 12 20

K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
G_1 = 0 043

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	14 45	8700	29 4		126 9		30 5	30 5	96 4	78 9	26 1	0 87	0 00			
08/18/94	15 23	2280	27 6	126 9	125 1	30 5	30 5	0 0	125 1	76 1	24 5	0 87	1 01	2 34E-07	3 05	
08/19/94	07 45	58920	15 7	125 1	113 2	30 5	30 1	-0 4	113 6	73 4	23	0 93	1 10	6 55E-08	19 42	
08/19/94	08 15	1800	15 6	113 2	113 1	30 1	30 0	-0 1	113 2	73 4	23	0 93	1 00	0 00E+00	19 92	
08/19/94	08 45	1800	15 3	113 1	112 8	30 0	29 9	0 1	112 9	73 6	23 1	0 93	1 00	3 93E-08	20 42	
08/19/94	09 45	3600	14 8	112 8	112 3	29 9	29 9	0 0	112 3	74 3	23 5	0 91	1 00	4 83E-08	21 42	
08/19/94	11 45	7200	14 1	112 3	111 6	29 9	29 9	0 0	111 6	74 8	23 8	0 91	1 01	3 40E-08	23 42	
08/19/94	15 45	14400	12 3	111 6	109 8	29 9	29 7	-0 2	110 0	75 4	24 1	0 91	1 01	3 93E-08	27 42	
08/19/94	16 09		29 7	109 8	127 2	29 7	29 7	0 0	127 2	75 4	24 1	0 91	0 86		27 82	Refill
08/20/94	09 52	63780	18 3	127 2	115 8	29 7	29 1	0 6	116 4	70 9	21 6	0 95	1 09	5 68E-08	45 53	
08/20/94	10 35	2580	17 9	115 8	115 4	29 1	29 0	-0 1	115 5	74 3	23 5	0 91	1 00	3 94E-08	46 25	
08/20/94	10 36		30 3	115 4	127 8	29 0	29 0	0 0	127 8	74 3	23 5	0 91	0 90		46 27	Refill
08/21/94	09 38	82920	0 0	127 8	97 5	29 0	29 0	0 0	97 5	71 4	21 9	0 95	1 31	1 33E-07	69 30	
08/21/94	09 41		29 8	97 5	127 3	29 0	29 0	0 0	127 3	71 4	21 9	0 95	0 77		69 35	Refill
08/22/94	16 17	110160	15 6	127 3	113 1	29 0	29 0	0 0	113 1	74 8	23 8	0 91	1 13	4 20E-08	99 95	
08/22/94	16 19		30 1	113 1	127 6	29 0	29 0	0 0	127 6	74 8	23 8	0 91	0 89		99 98	Refill
08/23/94	11 11	67920	21 7	127 6	119 2	29 0	28 3	-0 7	119 9	74 3	23 5	0 91	1 06	3 59E-08	118 85	
08/23/94	11 12		27 9	119 2	125 4	28 3	28 3	0 0	125 4	74 3	23 5	0 91	0 95		118 87	Refill
08/24/94	09 57	81900	20 4	125 4	117 9	28 3	28 7	0 4	117 5	74 5	23 6	0 91	1 07	3 11E-08	141 62	
08/24/94	09·58		30 0	117 9	127 5	28 7	28 7	0 0	127.5	74 5	23 6	0 91	0 92		141 63	Refill
08/26/94	14 44	189960	14 9	127 5	112 4	28 7	27 6	-1 1	113 5	75 2	24	0 91	1 12	2 40E-08	194 40	
08/26/94	14 45		30 5	112 4	128 0	27 6	27 6	0 0	128 0	75 2	24	0 91	0 88		194 42	Refill
08/27/94	09 55	69000	24 4	128 0	121 9	27 6	27 3	-0 3	122 2	75 4	24 1	0 91	1 05	2 63E-08	213 58	
08/28/94	11 07	90720	18 3	121 9	115 8	27 3	27 8	0 5	115 3	75 9	24 4	0 91	1 06	2 40E-08	238 78	
08/29/94	09·09	79320	12 8	115 8	110 3	27 8	27 9	0 1	110 2	71 2	21 8	0 95	1 05	2 43E-08	260 82	
08/31/94	14 21	191520	6 3	110 3	103 8	27.9	28 1	0 2	103 6	72.0	22 2	0 95	1 06	4 10E-08	314 02	

Time weighted average for K1 = 4 13E-08

Borehole Permeameter Stage 1 Calculations

Project· RMA 93 03, 21907 207030
Test Location· RMA, Section 25, Test Fill 1
Test Number · B2A

Test Dimensions and Equations·

(cm)

d = 1 27 K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)

D = 10 16 G_1 = 0 043

Z = 33 02

R_A = 6 02

b_1 = 58 42

Z + R_A + b_1 = 97 46

t_0 = 08/17/94 08 33

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/17/94	08 33	0	23 5		121 0		26 8		121 0	77 4	25 2		0 00		0 00	
08/17/94	08 34	60	9 9	121 0	107 4	26 8	26 8	0 0	107 4	77 4	25 2	0 89	1 13	7 61E-05	0 02	
08/17/94	08 35		30 0	107 4	127 5	26 8	26 8	0 0	127 5	77 4	25 2	0 89	0 84		0 03	Refill
08/17/94	08 37	120	6 1	127 5	103 6	26 8	26 8	0 0	103 6	77 4	25 2	0 89	1 23	6 62E-05	0 07	
08/17/94	08 38		23 6	103 6	121 1	26 8	26 8	0 0	121 1	77 4	25 2	0 89	0 86		0 08	Refill
08/17/94	08 40	120	4 5	121 1	102 0	26 8	26 8	0 0	102 0	77 4	25 2	0 89	1 19	5 48E-05	0 12	
08/17/94	08 41		26 4	102 0	125 9	26 8	26 8	0 0	125 9	77 4	25 2	0 89	0 81		0 13	Refill
08/17/94	08 48	420	11 3	125 9	108 8	26 8	26 8	0 0	108 8	77 4	25 2	0 89	1 16	1 33E-05	0 25	
08/17/94	08 49		29 1	108 8	126 6	26 8	26 8	0 0	126 6	77 4	25 2	0 89	0 86		0 27	Refill
08/17/94	08 51	120	14 3	126 6	111 8	26 8	26 0	-0 8	112 6	77 2	25 1	0 89	1 12	3 74E-05	0 30	
08/17/94	08 53		27 9	111 8	125 4	26 0	26 8	0 8	124 6	77 2	25 1	0 89	0 90		0 33	Refill
08/17/94	08 56	180	12 2	125 4	109 7	26 8	26 8	0 0	109 7	77 2	25 1	0 89	1 14	2 84E-05	0 36	
08/17/94	09 00		30 0	109 7	127 5	26 8	26 8	0 0	127 5	77 2	25 1	0 89	0 86		0 45	Refill
08/17/94	09 03	180	4 2	127 5	101 7	26 8	26 8	0 0	101 7	77 2	25 1	0 89	1 25	4 81E-05	0 50	
08/17/94	09 10		25 1	101 7	122 6	26 8	26 7	-0 1	122 7	77 2	25 1	0 89	0 83		0 62	Refill
08/17/94	09 14	240	6 5	122 6	104 0	26 7	26 7	0 0	104 0	77 2	25 1	0 89	1 18	2 62E-05	0 68	
08/17/94	09 17		24 4	104 0	121 9	26 7	26 7	0 0	121 9	77 2	25 1	0 89	0 85		0 73	Refill
08/17/94	09 20	180	9 1	121 9	106 6	26 7	26 7	0 0	106 6	77 4	25 2	0 89	1 14	2 85E-05	0 78	
08/17/94	09 33		26 6	106 6	124 1	26 7	26 7	0 0	124 1	77 4	25 2	0 89	0 86		1 00	Refill
08/17/94	09 41	480	5 6	124 1	103 1	26 7	26 7	0 0	103 1	77 2	25 1	0 89	1 20	1 48E-05	1 13	
08/17/94	10 34		27 6	103 1	125 1	26 7	26 7	0 0	125 1	77 0	25 0	0 89	0 82		2 02	Refill
08/17/94	11 28	3240	2 8	125 1	100 3	26 7	26 3	-0 4	100 7	77 0	25 0	0 89	1 24	2 56E-06	2 92	
08/17/94	12 33		23 8	100 3	121 3	26 3	26 5	0 2	121 1	76 6	24 8	0 89	0 83		4 00	Refill
08/17/94	16 33	18300	20 3	121 3	117 8	26 5	26 2	-0 3	118 1	76 6	24 8	0 89	1 03	5 59E-08	8 00	
08/17/94	16 34		29 8	117 8	127 3	26 2	26 2	0 0	127 3	76 6	24 8	0 89	0 93		8 02	Refill
08/18/94	14 17	78180	18 3	127 3	115 8	26 2	26 2	0 0	115 8	73 0	22 8	0 95	1 10	4 95E-08	29 73	
08/18/94	08 31		30 1	115 8	127 6	26 2	26 4	0 2	127 4	73 0	22 8	0 93	0 91		23 97	Refill

Date	Time	^t =	Test Unit			TEG		C =	H'2 =							
		t2 - t1 (sec)	R (cm)	H1 (cm)	H2 (cm)	Ro (cm)	Rf (cm)	Rf - Ro (cm)	H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/19/94	07 55	84240	12 6	127 6	110 1	26 4	26 0	-0 4	110 5	73 0	22 8	0 93	1 15	6 83E-08	47 37	
08/19/94	16 12	29820	9 9	110 1	107 4	26 0	25 8	-0 2	107 6	74 3	23 5	0 91	1 02	3 02E-08	55 65	
08/19/94	16 13		29 7	107 4	127 2	25 8	25 8	0 0	127 2	74 3	23 5	0 91	0 84		55 67	Refill
08/20/94	09 47	63240	18 8	127 2	116 3	25 8	25 2	-0 6	116 9	70 7	21 5	0 95	1 09	5 46E-08	73 23	
08/20/94	10 45	3480	18 4	116 3	115 9	25 2	25 0	-0 2	116 1	71 2	21 8	0 95	1 00	2 02E-08	74 20	
08/20/94	10 47		30 0	115 9	127 5	25 0	25 0	0 0	127 5	71 2	21 8	0 95	0 91		74 23	Refill
08/21/94	09 15	80880	21 2	127 5	118 7	25 0	25 1	0 1	118 6	71 4	21 9	0 95	1 08	3 66E 08	96 70	
08/22/94	16 31	1E+05	13 4	118 7	110 9	25 1	25 1	0 0	110 9	73 9	23 3	0 93	1 07	2 42E-08	127 97	
08/22/94	16 32		29 9	110 9	127 4	25 1	25 1	0 0	127 4	73 9	23 3	0 93	0 87		127 98	Refill
08/23/94	10 42	65400	23 2	127 4	120 7	25 1	24 5	-0 6	121 3	73 2	22 9	0 93	1 05	3 00E-08	146 15	
08/23/94	10 59		30 1	120 7	127 6	24 5	24 5	0 0	127 6	73 4	23 0	0 93	0 95		146 43	Refill
08/24/94	10 05	83160	23 5	127 6	121 0	24 5	24 6	0 1	120 9	74 5	23 6	0 91	1 06	2 54E-08	169 53	
08/24/94	10 06		29 8	121 0	127 3	24 6	24 6	0 0	127 3	74 5	23 6	0 91	0 95		169 55	Refill
08/26/94	14 55	2E+05	16 7	127 3	114 2	24 6	24 3	-0 3	114 5	74 8	23 8	0 91	1 11	2 18E-08	222 37	
08/26/94	14 56		29 4	114 2	126 9	24 3	24 3	0 0	126 9	74 8	23 8	0 91	0 90		222 38	Refill
08/27/94	09 57	68460	23 8	126 9	121 3	24 3	24 2	-0 1	121 4	75 9	24 4	0 91	1 05	2 53E-08	241 40	
08/28/94	11 00	90180	18 3	121 3	115 8	24 2	24 1	-0 1	115 9	75 9	24 4	0 91	1 05	1 98E-08	266 45	
08/29/94	09 11	79860	13 3	115 8	110 8	24 1	24 3	0 2	110 6	71 6	22 0	0 95	1 05	2 35E 08	288 63	
08/30/94	07 45	81240	9 2	110 8	106 7	24 3	24 7	0 4	106 3	70 9	21 6	0 95	1 04	2 09E-08	311 20	
08/31/94	14 25	1E+05	4 0	106 7	101 5	24 7	24 6	-0 1	101 6	72 3	22 4	0 95	1 05	1 81E-08	341 87	

Time weighted average for K1 = 8 20E-08

Borehole Permeameter Stage 1 Calculations

Project: RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number : B2B

Test Dimensions and Equations:

(cm)

d = 1 27 K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
D = 10 16 G_1 = 0 043
Z = 33 02
R_A = 6 02
b_1 = 58 42
Z + R_A + b_1 = 97 46
t_0 = 08/18/94 10 15

Date	Time	^t =	Test Unit			TEG		C =	H'2 =							
		t2 - t1	R	H1	H2	Ro	Rf	Rf - Ro	H2 - C	T	T	Rt	(H1/H2)	K1	Cum Hrs	
		(sec)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(F)	(C)	Factor		(cm/sec)	(hrs)	Remarks
08/18/94	14 22	14820	25 4		122 9		26 2		122 9	74 3	23 5		0 00		4 12	
08/18/94	14 32	600	18 7	122 9	116 2	26 2	26 2	0 0	116 2	74 3	23 5	0 91	1 06	3 66E-06	4 28	
08/19/94	07 40		29 9	116 2	127 4	26 2	26 0	-0 2	127 6	73 0	22 8	0 93	0 91		21 42	
08/19/94	08 12	1920	28 1	127 4	125 6	26 0	26 0	0 0	125 6	72 9	22 7	0 93	1 01		21 95	Rodents chewed fill line
08/19/94	08 42	1800	26 6	125 6	124 1	26 0	26 0	0 0	124 1	73 0	22 8	0 93	1 01		22 45	Rodents chewed fill line
08/19/94	09 42	3600	24 4	124 1	121 9	26 0	25 8	-0 2	122 1	73 2	22 9	0 93	1 02		23 45	Rodents chewed fill line
08/19/94	11 42	7200	21 0	121 9	118 5	25 8	25 8	0 0	118 5	74 1	23 4	0 93	1 03		25 45	Rodents chewed fill line
08/19/94	15 42	14400	15 8	118 5	113 3	25 8	25 8	0 0	113 3	74 3	23 5	0 91	1 05		29 45	Rodents chewed fill line
08/19/94	18 15		29 9	113 3	127 4	25 8	25 8	0 0	127 4	74 3	23 5	0 91	0 89		30 00	Refill
08/20/94	09 47	63120	10 9	127 4	108 4	25 8	25 2	0 6	109 0	70 7	21 5	0 95	1 17		47 53	Rodents chewed fill line
08/20/94	10 48	3660	10 3	108 4	107 8	25 2	25 0	-0 2	108 0	71 2	21 8	0 95	1 00		48 55	Rodents chewed fill line
08/20/94	10 50		30 3	107 8	127 8	25 0	25 0	0 0	127 8	71 2	21 8	0 95	0 84		48 58	Refill
08/21/94	09 17		0 0	127 8	97 5	25 0	25 1	0 1	97 4	71 4	21 9	0 95	1 31		71 03	Rodents chewed fill line
08/21/94	09 19		30 5	97 5	128 0	25 1	25 1	0 0	128 0	71 4	21 9	0 95	0 76		71 07	Rodents chewed fill line
08/22/94	16 29		0 0	128 0	97 5	25 1	25 1	0 0	97 5	73 9	23 3	0 93	1 31		102 23	Rodents chewed fill line
08/22/94	16 30		30 2	97 5	127 7	25 1	25 1	0 0	127 7	73 9	23 3	0 93	0 76		102 25	Refill
08/23/94	10 47	65820	4 3	127 7	101 8	25 1	24 5	0 6	102 4	73 2	22 9	0 93	1 25	1 34E-07	120 53	
08/23/94	10 49		29 5	101 8	127 0	24 5	24 5	0 0	127 0	73 2	22 9	0 93	0 80		120 57	Refill
08/24/94	10 08	83940	5 9	127 0	103 4	24 5	24 6	0 1	103 3	74 5	23 6	0 91	1 23	9 63E-08	143 88	
08/24/94	10 09		30 3	103 4	127 8	24 6	24 6	0 0	127 8	74 5	23 6	0 91	0 81		143 90	Refill
08/26/94	14 58		0 0	127 8	97 5	24 6		-24 6	122 1		-18		1 05		196 72	Rodents chewed fill line
08/26/94	14 59		29 1	97 5	126 6	0 0	24 3	24 3	102 3	74 8	23 8	0 91	0 95		196 73	Refill
08/27/94	09 59	68400	11 0	126 6	108 5	24 3	24 2	-0 1	108 6	75 9	24 4	0 91	1 17	8 78E-08	215 73	
08/27/94	10 01		30 1	108 5	127 6	24 2	24 2	0 0	127 6	75 9	24 4	0 91	0 85		215 77	Refill
08/28/94	11 00	89940	7 7	127 6	105 2	24 2	24 1	-0 1	105 3	75 9	24 4	0 91	1 21	8 36E-08	240 75	
08/29/94	09 14		28 5	105 2	126 0	24 1	24 3	0 2	125 8	71 6	22	0 95	0 84		262 98	Refill
08/30/94	07 46	81120	8 1	126 0	105 6	24 3	24 7	0 4	105 2	70 9	21 6	0 95	1 20	9 09E-08	285 52	

Date	Time	^t =	Test Unit			TEG		C =	H'2 =							
		t2 - t1	R	H1	H2	Ro	Rf	Rf - Ro	H2 - C	T	T	Rt	(H1/H2)	K1	Cum Hrs	
		(sec)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(F)	(C)	Factor		(cm/sec)	(hrs)	Remarks
08/30/94	07 49		29 7	105 6	127 2	24 7	24 7	0 0	127 2	70 9	21 6	0 95	0 83		285 57	Refill
08/31/94	14 27	110280	4 8	127 2	102 3	24 7	24 6	0 1	102 4	72 3	22 4	0 95	1 24	8 04E-08	316 20	

Time weighted average for K1 = 8 00E 08

Borehole Permeameter Stage 1 Calculations

Project. RMA 93 03, 21907 207030
Test Location· RMA, Section 25, Test Fill 1
Test Number· B2C

Test Dimensions and Equations

(cm)
d = 1 27
D = 10 16
Z = 33 02
R_A = 6 42
b_1 = 58 42
$Z + R_A + b_1$ = 97 86
t_0 = 08/18/94 10 15

K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
G_1 = 0 043

Date	Time	^t = (t2 - t1) (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	14 13	14280	26 7		124 6	(cm)	26 2		124 6	74 3	23 5	0 91				
08/18/94	14 31	1080	10 4	124 6	108 3	26 2	26 2	0 0	108 3	74 3	23 5	0 91	1 15	5 08E-06	4 27	
08/19/94	07 39		30 0	108 3	127 9	26 2	26 0	-0 2	128 1	73 0	22 8	0 93	0 85		21 40	Refill
08/19/94	08 12	1980	28 8	127 9	126 7	26 0	26 0	0 0	126 7	72 9	22 7	0 93	1 01	1 90E-07	21 95	
08/19/94	08 43	1860	28 0	126 7	125 9	26 0	26 0	0 0	125 9	73 0	22 8	0 93	1 01	1 36E 07	22 47	
08/19/94	09 43	3600	26 8	125 9	124 7	26 0	25 8	-0 2	124 9	73 2	22 9	0 93	1 01	8 86E-08	23 47	
08/19/94	11 43	7200	25 2	124 7	123 1	25 8	25 8	0 0	123 1	74 1	23 4	0 93	1 01	7 17E-08	25 47	
08/19/94	15 43	14400	22 7	123 1	120 6	25 8	25 8	0 0	120 6	74 3	23 5	0 91	1 02	5 58E 08	29 47	
08/19/94	16 16		29 7	120 6	127 6	25 8	25 8	0 0	127 6	74 3	23 5	0 91	0 95		30 02	Refill
08/20/94	09 48	63120	19 7	127 6	117 6	25 8	25 2	0 6	118 2	70 7	21 5	0 95	1 08	4 95E-08	47 55	
08/21/94	09 20	84720	10 3	117 6	108 2	25 2	25 1	0 1	108 3	71 4	21 9	0 95	1 09	3 97E-08	71 08	
08/21/94	09 22		30 3	108 2	128 2	25 1	25 1	0 0	128 2	71 4	21 9	0 95	0 84		71 12	Refill
08/22/94	16 27	111900	19 0	128 2	116 9	25 1	25 1	0 0	116 9	73 9	23 3	0 93	1 10	3 30E-08	102 20	
08/22/94	16 28		29 9	116 9	127 8	25 1	25 1	0 0	127 8	73 9	23 3	0 93	0 91		102 22	
08/23/94	10 50	66120	22 8	127 8	120 7	25 1	24 5	-0 6	121 3	73 2	22 9	0 93	1 05	3 16E-08	120 58	
08/23/94	11 00		30 2	120 7	128 1	24 5	24 5	0 0	128 1	73 4	23 0	0 93	0 94		120 75	Refill
08/24/94	10 12	83520	23 0	128 1	120 9	24 5	24 6	0 1	120 8	74 5	23 6	0 91	1 06	2 75E-08	143 95	
08/24/94	10 13		30 1	120 9	128 0	24 6	24 6	0 0	128 0	74 5	23 6	0 91	0 94		143 97	Refill
08/26/94	15 00	190020	17 0	128 0	114 9	24 6	24 3	-0 3	115 2	74 8	23 8	0 91	1 11	2 17E-08	196 75	
08/26/94	15 01		30 1	114 9	128 0	24 3	24 3	0 0	128 0	74 8	23 8	0 91	0 90		196 77	Refill
08/27/94	10 02	68460	23 7	128 0	121 6	24 3	24 2	-0 1	121 7	75 9	24 4	0 91	1 05	2 89E-08	215 78	
08/28/94	11 02	90000	17 1	121 6	115 0	24 2	24 1	0 1	115 1	75 9	24 4	0 91	1 06	2 39E-08	240 78	
08/29/94	09 14		0 0	115 0	97 9	24 1	24 3	0 2	97 7	71 6	22 0	0 95	1 18		262 98	Rodents chewed fill line
08/29/94	09 15	60	29 8	97 9	127 7	24 3	24 3	0 0	127 7	71 6	22 0	0 95	0 77		263 00	Refill
08/30/94	07 47	81120	22 1	127 7	120 0	24 3	24 7	0 4	119 6	70 9	21 6	0 95	1 07	3 14E-08	285 53	
08/31/94	14 26	110340	12 8	120 0	110 7	24 7	24 6	-0 1	110 8	72 3	22 4	0 95	1 08	3 75E-08	316 18	

Time weighted average for K1 = 3 80E 08

Borehole Permeameter Stage 1 Calculations

Project RMA 93-03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number: B2D

Test Dimensions and Equations

(cm)
d = 1 27 K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
D = 10 16 G_1 = 0 043
Z = 33 02
R_A = 6 12
b_1 = 58 42
$Z + R_A + b_1$ = 97 56
t_0 = 08/17/94 16 30

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	Test Unit H1 (cm)	Test Unit H2 (cm)	TEG Ro (cm)	TEG Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	07 55	55500	29 5		127 1		26 5			73 0	22 8	0 93				
08/18/94	08 25	1800	26 2	127 1	123 8	26 5	26 4	-0 1	123 9	73 0	22 8	0 93	1 03	5 67E-07	15 92	
08/18/94	08 55	1800	23 2	123 8	120 8	26 4	26 3	-0 1	120 9	73 2	22 9	0 93	1 02	5 27E-07	16 42	
08/18/94	09 55	3600	18 8	120 8	116 4	26 3	26 1	-0 2	116 6	73 9	23 3	0 93	1 04	3 93E-07	17 42	
08/18/94	10 00		28 9	116 4	126 5	26 1	26 1	0 0	126 5	73 9	23 3	0 93	0 92		17 50	Refill
08/18/94	12 00	7200	15 6	126 5	113 2	26 1	25 8	-0 3	113 5	74 7	23 7	0 91	1 11	5 90E-07	19 50	
08/18/94	12 01		30 0	113 2	127 6	25 8	25 8	0 0	127 6	74 7	23 7	0 91	0 89		19 52	Refill
08/18/94	16 01	14400	16 5	127 6	114 1	25 8	26 2	0 4	113 7	74 5	23 6	0 91	1 12	3 14E-07	23 52	
08/18/94	16 03		29 8	114 1	127 4	26 2	26 2	0 0	127 4	74 5	23 6	0 91	0 90		23 55	Refill
08/19/94	07 49	56760	6 4	127 4	104 0	26 2	26 0	-0 2	104 2	73 0	22 8	0 93	1 22	1 42E-07	39 32	
08/19/94	07 53		30 1	104 0	127 7	26 0	26 0	0 0	127 7	73 0	22 8	0 93	0 81		39 38	Refill
08/19/94	16 17	30240	23 8	127 7	121 4	26 0	25 8	-0 2	121 6	74 3	23 5	0 93	1 05	6 47E-08	47 78	
08/19/94	16 18		30 2	121 4	127 8	25 8	25 8	0 0	127 8	74 3	23 5	0 93	0 95		47 80	Refill
08/20/94	09 46	62880	19 1	127 8	116 7	25 8	25 2	-0 6	117 3	70 7	21 5	0 95	1 09	5 57E-08	65 27	
08/20/94	10 42	3360	18 6	116 7	116 2	25 2	25 0	-0 2	116 4	71 2	21 8	0 95	1 00	3 13E-08	66 20	
08/20/94	10 44		30 2	116 2	127 8	25 0	25 0	0 0	127 8	71 2	21 8	0 95	0 91		66 23	Refill
08/21/94	09 24	81600	18 5	127 8	116 1	25 0	25 1	0 1	116 0	71 4	21 9	0 95	1 10	4 85E-08	88 90	
08/21/94	09 26		30 0	116 1	127 6	25 1	25 1	0 0	127 6	71 4	21 9	0.95	0 91		88 93	Refill
08/22/94	16 25	111540	15 9	127 6	113 5	25 1	25 1	0 0	113 5	73 9	23 3	0 93	1 12	4 20E-08	119 92	
08/22/94	16 26		29 9	113 5	127 5	25 1	25 1	0 0	127 5	73 9	23 3	0 93	0 89		119 93	Refill
08/23/94	10 52	66360	21 0	127 5	118 6	25 1	24 5	-0 6	119 2	73 2	22 9	0 93	1 07	4 06E-08	138 37	
08/23/94	10 56		30 3	118 6	127 9	24 5	24 5	0 0	127 9	73 4	23	0 93	0 93		138 43	Refill
08/24/94	10 14	83880	20 8	127 9	118 4	24 5	24 6	0 1	118 3	74 5	23 6	0,93	1 08	3 72E-08	161 73	
08/24/94	10'15	60	30 0	118 4	127 6	24 6	24 6	0 0	127 6	74 5	23 6	0 93	0 93		161 75	Refill
08/26/94	15'02	190080	12 5	127 6	110 1	24 6	24 3	-0 3	110 3	74 8	23 8	0 91	1 16	2.89E-08	214 53	
08/26/94	15 03		29 8	110 1	127 4	24 3	24 3	0 0	127 4	74 8	23 8	0.91	0 86		214 55	Refill
08/27/94	10'03	68400	23 5	127 4	121 1	24 3	24 2	-0 1	121 2	75 9	24 4	0 95	1 05	2 97E-08	233 55	

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/28/94	11 02	89940	16 9	121 1	114 5	24 2	24 1	-0 1	114 6	75 9	24 4	0 91	1 06	2 40E-08	258 53	
08/29/94	09 15	79980	11 5	114 5	109 1	24 1	24 3	0 2	108 9	71 6	22	0 95	1 05	2 56E-08	280 75	
08/30/94	07 50	81300	6 9	109 1	104 5	24 3	24 7	0 4	104 1	70 9	21 6	0 95	1 05	2 36E 08	303 33	
08/31/94	14 28	110280	1 0	104 5	98 6	24 7	24 6	0 1	98 7	72 3	22 4	0 95	1 06	2 01E-08	333 97	

Time weighted average for K1 = 4 52E-08

Borehole Permeameter Stage 1 Calculations

Project· RMA 93 03, 21907 207030
Test Location· RMA, Section 25, Test Fill 1
Test Number · B2E

Test Dimensions·

(cm)
d = 1 27
D = 10 16
Z = 33 02
R_A = 5 82
b_1 = 58 42
$Z + R_A + b_1$ = 97 26
t_0 = 08/17/94 16 30

K_1 = Rt G_1 LN(H1/H2)/(t2 - t1)
G_1 = 0 043

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/18/94	07 45	54900	30 0		127 3		26 5	26 5	100 8	73 0	22 8	0 93	0 00			
08/18/94	08 15	1800	24 7	127 3	122 0	26 5	26 4	-0 1	122 0	73 0	22 8	0 93	1 04	9 36E-07	15 75	
08/18/94	08 45	1800	21 5	122 0	118 8	26 4	26 3	-0 1	118 9	73 2	22 9	0 93	1 03	5 72E-07	16 25	
08/18/94	09 45	3600	16 0	118 8	113 3	26 3	26 1	-0 2	113 5	73 9	23 3	0 93	1 05	5 07E-07	17 25	
08/18/94	09 50		29 3	113 3	126 6	26 1	26 1	0 0	126 6	73 9	23 3	0 93	0 89		17 33	Refill
08/18/94	11 50	7200	18 6	126 6	115 9	26 1	25 8	-0 3	116 2	74 7	23 7	0 91	1 09	4 66E-07	19 33	
08/18/94	11 55		29 4	115 9	126 7	25 8	25 8	0 0	126 7	74 7	23 7	0 91	0 91		19 42	Refill
08/18/94	15 55	14400	13 3	126 7	110 6	25 8	26 2	0 4	110 2	74 5	23 6	0 91	1 15	3 79E-07	23 42	
08/18/94	15 57		29 8	110 6	127 1	26 2	26 2	0 0	127 1	74 5	23 6	0 91	0 87		23 45	Refill
08/19/94	07 48	57060	0 7	127 1	98 0	26 2	26 0	-0 2	98 2	73 0	22 8	0 93	1 29	1 81E-07	39 30	
08/19/94	07 51		29 8	98 0	127 1	26 0	26 0	0 0	127 1	73 0	22 8	0 93	0 77		39 35	Refill
08/19/94	16 19	30480	19 6	127 1	116 9	26 0	25 8	-0 2	117 1	74 3	23 5	0 91	1 09	1 05E 07	47 82	
08/19/94	16 20		30 2	116 9	127 5	25 8	25 8	0 0	127 5	74 3	23 5	0 91	0 92		47 83	Refill
08/20/94	09 47	62820	15 6	127 5	112 9	25 8	25 2	-0 6	113 5	70 7	21 5	0 95	1 12	7 57E-08	65 28	
08/20/94	10 38	3060	15 0	112 9	112 3	25 2	25 0	-0 2	112 5	71 2	21 8	0 95	1 00	4 74E-08	66 13	
08/20/94	10 41		30 2	112 3	127 5	25 0	25 0	0 0	127 5	71 2	21 8	0 95	0 88		66 18	Refill
08/21/94	09 27	81960	15 0	127 5	112 3	25 0	25 1	0 1	112 2	71 4	21 9	0 95	1 14	6 37E-08	88 95	
08/21/94	09·29		30 3	112 3	127 6	25 1	25 1	0 0	127 6	71 4	21 9	0 95	0 88		88 98	Refill
08/22/94	16 23	111240	13 7	127 6	111 0	25 1	25 1	0 0	111 0	73 9	23 3	0 93	1 15	5 01E-08	119 88	
08/22/94	16 24		30 0	111 0	127 3	25 1	25 1	0 0	127 3	73 9	23 3	0 93	0 87		119 90	Refill
08/23/94	10 56	66720	20 3	127 3	117 6	25 1	24 5	-0 6	118 2	73 4	23 0	0 93	1 08	4 45E-08	138 43	
08/23/94	10 57		30 0	117 6	127 3	24 5	24 5	0 0	127 3	73 4	23 0	0 93	0 92		138 45	Refill
08/24/94	10·17	84000	20 5	127 3	117 8	24 5	24 6	0 1	117 7	74 5	23 6	0 91	1 08	3 65E-08	161 78	
08/24/94	10·18		30 0	117 8	127 3	24 6	24 6	0 0	127 3	74 5	23 6	0 91	0 93		161 80	Refill
08/26/94	15·04	189960	13 6	127 3	110 9	24 6	24 3	-0 3	111 2	74 8	23 8	0.95	1 14	2.91E-08	214 57	
08/26/94	15 05		29 7	110 9	127 0	24 3	24 3	0 0	127 0	74 8	23 8	0.95	0 87		214 58	Refill
08/27/94	10·03	68340	23 7	127 0	121 0	24 3	24 2	-0 1	121 1	75 9	24 4	0 91	1 05	2 72E-08	233 55	

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H'2 = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2)	K1 (cm/sec)	Cum Hrs (hrs)	Remarks
08/28/94	11 03	90000	17 8	121 0	115 1	24 2	24 1	-0 1	115 2	75 9	24 4	0 91	1 05	2 14E-08	258 55	
08/29/94	09 17	80040	0 0	115 1	97 3	24 1	24 2	0 1	97 2	71 6	22 0	0 95	1 18		280 78	Rodents chewed fill line
08/29/94	09 18		28 6	97 3	125 9	24 2	24 2	0 0	125 9	71 6	22 0	0 95	0 77		280 80	Refill
08/30/94	07 51	81180	22 8	125 9	120 1	24 2	24 7	0 5	119 6	71 1	21 7	0 95	1 05	2 46E-08	303 35	
08/31/94	14 29	110280	16 4	120 1	113 7	24 7	24 6	0 1	113 8	72 3	22 4	0 95	1 06	1 90E-08	333 98	

Time weighted average for K1 = 5 16E-08

Borehole Permeameter Stage 2 Calculations

Project: RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number: B1A

Test Dimensions and Equations

	(cm)				
d =	1 27	L =	15 50	G5 =	1 165
D =	10 16	1/2 L =	7 75	G4 =	3 350
Z =	33 02	b_2 =	50 67	G3 =	2 265
R_A =	6 92	$4b_2/D$ =	19 95	F =	0 948
b_1 =	58 42	L/D =	1 53	G2 =	0 016
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 31				

Date	Time	^t =	Test Unit			TEG		C =	H2' =							
		t2 - t1	R	H1	H2	Ro	Rf	Rf - Ro	H2 - C	T	T	Rt	(H1/H2)	K2	Cum Hrs	
		(sec)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(F)	(C)	Factor		(cm/sec)	(hrs)	Remarks
09/01/94	08 31	0	30 2		128 6		27 8			68 2	20 1	1				
09/01/94	09 04	1980	29 8	128 6	128 2	27 8	27 7	-0 1	128 3	68 5	20 3	1	1 00	1 83E 08	0 55	
09/01/94	09 31	1620	29 8	128 2	128 2	27 7	27 6	-0 1	128 3	68 9	20 5	0 98	1 00			
09/01/94	10 35	3840	29 3	128 2	127 7	27 6	27 2	0 4	128 1	69 6	20 9	0 98	1 00	3 09E-09	2 07	
09/01/94	12 34	7140	28 5	127 7	126 9	27 2	27 2	0 0	126 9	70 8	21 4	0 98	1 01	1 34E-08	4 05	
09/01/94	15 34	10800	26 5	126 9	124 9	27 2	27 9	0 7	124 2	71 6	22 0	0 95	1 02	2 94E-08	7 05	
09/02/94	09 45	65460	12 0	124 9	110 4	27 9	27 4	-0 5	110 9	68 7	20 4	1	1 13	2 82E-08	25 23	
09/02/94	16 36	24660	10 8	110 4	109 2	27 4	27 1	-0 3	109 5	71 6	22 0	0 95	1 01	4 90E-09	32 08	
09/02/94	16 37		29 0	109 2	127 4	27 1	27 1	0 0	127 4	71 6	22 0	0 95	0 86			Refill
09/03/94	09 05	59280	21 7	127 4	120 1	27 1	27 8	0 7	119 4	70 9	21 6	0 95	1 07	1 61E-08	48 57	
09/03/94	09 06		30 0	120 1	128 4	27 8	27 8	0 0	128 4	70 9	21 6	0 95	0 94			Refill
09/06/94	14 43	279420	7 6	128 4	106 0	27 8	26 5	-1 3	107 3	72 0	22 2	0 95	1 20	9 48E-09	126 20	
09/06/94	14 44		30 0	106 0	128 4	26 5	26 5	0 0	128 4	72 0	22 2	0 95	0 83			Refill
09/09/94	09 37	240780	10 9	128 4	109 3	26 5	27 0	0 5	108 8	71 2	21 8	0 95	1 18	1 02E-08	193 10	
09/12/94	11 39		0 0	109 3	98 4	27 0	26 2	-0 8	99 2	72 7	22 6	0 93	1 10			Water level below scale
09/12/94	11 54	900	30 2	98 4	128 6	26 2	26 2	0 0	128 6	72 7	22.6	0 93	0 77			Refill
09/14/94	13 22	178080	14 7	128 6	113 1	26 2	26 5	0 3	112 8	72.5	22 5	0 93	1 14	1 06E-08	316 85	
09/14/94	13 27	300	28 6	113 1	127 0	26 5	26 5	0 0	127 0	72 5	22 5	0 93	0 89			Refill
09/16/94	10 50	163380	7 4	127 0	105 8	26 5	26 3	-0 2	106 0	67 1	19 5	1	1 20	1 72E-08	362 32	

Time weighted average for K2 = 1 27E-08

Borehole Permeameter Stage 2 Calculations

Project RMA 93-03, 21907 207030
Test Location. RMA, Section 25, Test Fill 1
Test Number· B1B

Test Dimensions and Equations

	(cm)				
d =	1 27	L =	15 00	G5 =	1 157
D =	10 16	1/2 L =	7 50	G4 =	3 260
Z =	32 5	b_2 =	51 44	G3 =	2 217
R_A =	6 92	$4b_2/D$ =	20 25	F =	0 944
b_1 =	58 94	L/D =	1 48	G2 =	0 016
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 33				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 33		29 6		128 0		27 8			68 2	20 1	1				
09/01/94	09 05	1920	29 7	128 0	128 1	27 8	27 7	0 1	128 2	68 5	20 3	1	1 00		0 53	
09/01/94	09 32	1620	30 0	128 1	128 4	27 7	27 6	-0 1	128 5	68 9	20 5	0 98	1 00		0 98	
09/01/94	10 37	3900	29 9	128 4	128 3	27 6	27 2	-0 4	128 7	69 6	20 9	0 98	1 00		2 07	
09/01/94	12 35	7080	29 1	128 3	127 5	27 2	27 2	0 0	127 5	70 9	21 6	0 95	1 01	1 32E-08	4 03	
09/01/94	15 35	10800	27 0	127 5	125 4	27 2	27 9	0 7	124 7	71 6	22 0	0 95	1 02	3 08E-08	7 03	
09/02/94	09 46	65460	12 8	125 4	111 2	27 9	27 4	-0 5	111 7	68 7	20 4	1	1 12	2 79E-08	25 22	
09/02/94	16 38	24720	11 6	111 2	110 0	27 4	27 1	0 3	110 3	71 6	22 0	0 95	1 01	4 93E-09	32 08	
09/02/94	16 39	60	29 2	110 0	127 6	27 1	27 1	0 0	127 6	71 6	22 0	0 95	0 86			Refill
09/03/94	09 07	59280	21 0	127 6	119 4	27 1	27 8	0 7	118 7	70 9	21 6	0 95	1 08	1 83E-08	48 57	
09/03/94	09 08	60	30 5	119 4	128 9	27 8	27 8	0 0	128 9	70 9	21 6	0 95	0 93			Refill
09/06/94	14 47	279540	6 5	128 9	104 9	27 8	26 5	-1 3	106 2	72 0	22 2	0 95	1 21	1 04E-08	126 23	
09/06/94	14 48	60	30 5	104 9	128 9	26 5	26 5	0 0	128 9	72 0	22 2	0 95	0 81			Refill
09/09/94	09 38	240600	8 9	128 9	107 3	26 5	27 0	0 5	106 8	71 2	21 8	0 95	1 21	1 17E-08	193 08	
09/12/94	11 40	266520	0 0	107 3	98 4	27 0	26 2	-0 8	99 2	72 7	22 6	0 93	1 08			Water level below scale
09/12/94	11 55	900	29 4	98 4	127 8	26 2	26 2	0 0	127 8	72 7	22 6	0 93	0 77			Refill
09/14/94	13 23	178080	0 0	127 8	98 4	26 2	26 5	0 3	98 1	72 5	22 5	0 93	1 30			Water level below scale
09/14/94	13 29	360	30 4	98 4	128 8	26 5	26 5	0 0	128 8	72 5	22 5	0 93	0 76			Refill
09/16/94	10 52	163380	0 0	128 8	98 4	26 5	26 3	-0 2	98 6	67 1	19 5	1	1 31			Water level below scale

Time weighted average for K2 = 1 34E-08

Borehole Permeameter Stage 2 Calculations

Project. RMA 93-03, 21907 207030
Test Location RMA, Section 25, Test Fill 1
Test Number . B1C

Test Dimensions and Equations

	(cm)				
d =	1 27	L =	17 00	G5 =	1 188
D =	10 16	1/2 L =	8 50	G4 =	3 623
Z =	33 5	b_2 =	49 44	G3 =	2 402
R_A =	6 92	$4b_2/D$ =	19 46	F =	0 959
b_1 =	57 94	L/D =	1 67	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_e =	09/01/94 08 34				

Date	Time	^t =	Test Unit			TEG		C =	H2' =							
		t2 - t1 (sec)	R (cm)	H1 (cm)	H2 (cm)	Ro (cm)	Rf (cm)	Rf - Ro (cm)	H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 34		29 9		128 3	29 9	27 8			68 2	20 1	1				
09/01/94	09 06	1920	30 0	128 3	128 4	27 8	27 7	-0 1	128 5	68 5	20 3	1	1 00		0 53	
09/01/94	09 33	1620	30 2	128 4	128 6	27 7	27 6	-0 1	128 7	68 9	20 5	0 98	1 00		0 98	
09/01/94	10 38	3900	30 2	128 6	128 6	27 6	27 2	-0 4	129 0	69 6	20 9	0 98	1 00		2 07	
09/01/94	12 36	7080	29 4	128 6	127 8	27 2	27 2	0 0	127 8	70 9	21 6	0 95	1 01	1 24E-08	4 03	
09/01/94	15 36	10800	27 4	127 8	125 8	27 2	27 9	0 7	125 1	71 6	22 0	0 95	1 02	2 79E-08	7 03	
09/02/94	09 47	65460	10 5	125 8	108 9	27 9	27 4	-0 5	109 4	68 7	20 4	1	1 15	3 17E-08	25 22	
09/02/94	16 40	24780	8 5	108 9	106 9	27 4	27 1	-0 3	107 2	71 6	22 0	0 95	1 02	8 96E-09	32 10	
09/02/94	16 41		29 2	106 9	127 6	27 1	27 1	0 0	127 6	71 6	22 0	0 95	0 84			Refill
09/03/94	09 09	59280	20 9	127 6	119 3	27 1	27 8	0 7	118 6	70 9	21 6	0 95	1 08	1 74E-08	48 58	
09/03/94	09 10		30 0	119 3	128 4	27 8	27 8	0 0	128 4	70 9	21 6	0 95	0 93			Refill
09/06/94	14 49	279540	9 4	128 4	107 8	27 8	26 5	-1 3	109 1	72 0	22 2	0 95	1 18	8 22E-09	126 25	
09/06/94	14 50		30 2	107 8	128 6	26 5	26 5	0 0	128 6	72 0	22 2	0 95	0 84			Refill
09/09/94	09 39	240540	7 2	128 6	105 6	26 5	27 0	0 5	105 1	71 2	21 8	0 95	1 22	1 18E-08	193 08	
09/12/94	11 40	266460	0 0	105 6	98 4	27 0	26 2	-0 8	99 2	72 7	22 6	0 93	1 06			Water level below scale
09/12/94	11 56		29 4	98 4	127 8	26 2	26.2	0 0	127 8	72 7	22 6	0 93	0 77			Refill
09/14/94	13.24	178080	12 3	127 8	110 7	26 2	26 5	0 3	110 4	72 5	22 5	0 93	1 16	1 14E-08	316 83	
09/14/94	13 31		30 0	110 7	128 4	26 5	26 5	0 0	128 4	72 5	22.5	0 93	0 86			Refill
09/16/94	10 58	163620	10 9	128 4	109 3	26 5	26 3	-0 2	109 5	67 1	19 5	1	1 17	1 45E-08	362 40	
09/16/94	10 59		29 8	109 3	128 2	26 3	26 3	0 0	128 2	67 1	19 5	1	0 85		362 42	Refill
09/20/94	14 12	357180	0 0	128 2	98 4	26 3	26 1	-0 2	98 6	69 6	20 9	0 95	1 30	1 04E-08	461 63	
09/20/94	14 13		30 0	98 4	128 4	26 1	26 1	0 0	128 4	69 6	20 9	0 95	0 77		461 65	Refill
09/25/94	15 50	437820	2.3	128 4	100 7	26 1	26 6	0 5	100 2	62 8	17 1	1 08	1 28	9 09E-09	583 27	
09/23/94	15 51		29 8	100 7	128 2	26 6	26 6	0 0	128 2	62 8	17 1	1 08	0 79		535 28	Refill
09/25/94	15 13	170520	10 0	128 2	108 4	26 6	26 3	-0.3	108 7	63 0	17.2	1 08	1 18	1 55E-08	582 65	

Time weighted average for K2 = 1 04E-08

Borehole Permeameter Stage 2 Calculations

Project RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number: B1D

Test Dimensions and Equations:

	(cm)				
d =	1 27	L =	16 50	G5 =	1 179
D =	10 16	1/2 L =	8 25	G4 =	3 531
Z =	33	b_2 =	50 19	G3 =	2 359
R_A =	6 92	$4b_2/D$ =	19 76	F =	0 956
b_1 =	58 44	L/D =	1 62	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 38				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 38		29 5		127 9	29 9	27 8			68 2	20 1	1				
09/01/94	09 07	1740	29 6	127 9	128 0	27 8	27 7	0 1	128 1	68 5	20 3	1	1 00		0 48	
09/01/94	09 34	1620	30 1	128 0	128 5	27 7	27 6	-0 1	128 6	68 9	20 5	0 98	1 00		0 93	
09/01/94	10 39	3900	30 2	128 5	128 6	27 6	27 2	-0 4	129 0	69 6	20 9	0 98	1 00		2 02	
09/01/94	12 37	7080	30 0	128 6	128 4	27 2	27 2	0 0	128 4	70 9	21 6	0 95	1 00	3 15E-09	3 98	
09/01/94	15 36	10740	28 7	128 4	127 1	27 2	27 9	0 7	126 4	71 6	22 0	0 95	1 02	2 09E-08	6 97	
09/02/94	09 47	65460	15 0	127 1	113 4	27 9	27 4	-0 5	113 9	68 7	20 4	1	1 12	2 53E-08	25 15	
09/02/94	16 42	24900	15 6	113 4	114 0	27 4	27 1	-0 3	114 3	71 6	22 0	0 95	0 99		32 07	
09/02/94	16 43		30 2	114 0	128 6	27 1	27 1	0 0	128 6	71 6	22 0	0 95	0 89			Refill
09/03/94	09 12	59340	23 1	128 6	121 5	27 1	27 8	0 7	120 8	70 9	21 6	0 95	1 06	1 51E-08	48 57	
09/03/94	09 13		30 3	121 5	128 7	27 8	27 8	0 0	128 7	70 9	21 6	0 95	0 94			Refill
09/06/94	14 51	279480	13 9	128 7	112 3	27 8	26 5	-1 3	113 6	72 0	22 2	0 95	1 13	6 40E-09	126 22	
09/06/94	14 52		30 0	112 3	128 4	26 5	26 5	0 0	128 4	72 0	22 2	0 95	0 87			Refill
09/09/94	09 40	240480	12 2	128 4	110 6	26 5	27 0	0 5	110 1	71 2	21 8	0 95	1 17	9 16E-09	193 03	
09/12/94	11 41	266460	0 0	110 6	98 4	27 0	26 2	0 8	99 2	72 7	22 6	0 93	1 11			Water level below scale
09/12/94	11 57		30 0	98 4	128 4	26 2	26 2	0 0	128 4	72 7	22 6	0 93	0 77			Refill
09/14/94	13 24	178020	17 9	128 4	116 3	26 2	26 5	0 3	116 0	72 5	22 5	0 93	1 11	8 00E-09	316 77	
09/14/94	13 34		28 7	116 3	127 1	26 5	26 5	0 0	127 1	72 5	22 5	0 93	0 92			Refill
09/16/94	11 02	163680	9 1	127 1	107 5	26 5	26 3	-0 2	107 7	67 1	19 5	1	1 18	1 53E-08	362 40	

Time weighted average for K2 = 8 27E-09

Borehole Permeameter Stage 2 Calculations

Project: RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number : B1E

Test Dimensions and Equations

	(cm)				
d =	1 27	L =	18 00	G5 =	1 200
D =	10 16	1/2 L =	9 00	G4 =	3 806
Z =	33	b_2 =	49 44	G3 =	2 491
R_A =	6 92	$4b_2/D$ =	19 46	F =	0 965
b_1 =	58 44	L/D =	1 77	G2 =	0 014
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 37				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 37		30 0		128 4	29 9	27 8			68 2	20 1	1				
09/01/94	09 08	1860	30 0	128 4	128 4	27 8	27 7	-0 1	128 5	68 5	20 3	1	1 00		0 52	
09/01/94	09 35	1620	30 4	128 4	128 8	27 7	27 6	-0 1	128 9	68 9	20 5	0 98	1 00		0 97	
09/01/94	10 40	3900	30 5	128 8	128 9	27 6	27 2	-0 4	129 3	69 6	20 9	0 98	1 00		2 05	
09/01/94	12 38	7080	29 9	128 9	128 3	27 2	27 2	0 0	128 3	70 9	21 6	0 95	1 00	9 05E-09	4 02	
09/01/94	15 37	10740	28 3	128 3	126 7	27 2	27 9	0 7	126 0	71 6	22 0	0 95	1 02	2 31E-08	7 00	
09/02/94	09 48	65460	14 0	126 7	112 4	27 9	27 4	-0 5	112 9	68 7	20 4	1	1 12	2 55E-08	25 18	
09/02/94	16 44	24960	12 7	112 4	111 1	27 4	27 1	-0 3	111 4	71 6	22 0	0 95	1 01	4 92E-09	32 12	
09/02/94	16 45		30 0	111 1	128 4	27 1	27 1	0 0	128 4	71 6	22 0	0 95	0 87			Refill
09/03/94	09 14	59340	23 5	128 4	121 9	27 1	27 8	0 7	121 2	70 9	21 6	0 95	1 06	1 34E 08	48 62	
09/03/94	09 15		29 6	121 9	128 0	27 8	27 8	0 0	128 0	70 9	21 6	0 95	0 95			Refill
09/06/94	14 53	279480	13 9	128 0	112 3	27 8	26 5	-1 3	113 6	72 0	22 2	0 95	1 13	5 87E-09	126 27	
09/06/94	14 54		30 0	112 3	128 4	26 5	26 5	0 0	128 4	72 0	22 2	0 95	0 87			Refill
09/09/94	09 41	240420	13 0	128 4	111 4	26 5	27 0	0 5	110 9	71 2	21 8	0 95	1 16	8 37E-09	193 07	
09/12/94	11 42	266460	0 0	111 4	98 4	27 0	26 2	-0 8	99 2	72 7	22 6	0 93	1 12			Water level below scale
09/12/94	11 57		30 3	98 4	128 7	26 2	26 2	0 0	128 7	72 7	22 6	0 93	0 76			Refill
09/14/94	13 25	178080	0 0	128 7	98 4	26 2	26 5	0 3	98 1	72 5	22 5	0 93	1 31	2 05E-08	316 80	
09/14/94	13 32		30 2	98 4	128 6	26 5	26 5	0 0	128 6	72 5	22 5	0 93	0 77			Refill
09/16/94	11 00	163680	13 0	128 6	111 4	26 5	26 3	-0 2	111 6	67 1	19 5	1	1 15	1 25E-08	362 38	
09/16/94	11 01		30 0	111 4	128 4	26 3	26 3	0 0	128 4	67 1	19 5	1	0 87		362 40	
09/20/94	14 01	356400	3 1	128 4	101 5	26 3	26 1	-0 2	101 7	69 6	20 9	0 98	1 26	9 27E-09	461 40	

Time weighted average for K2 = 9 42E-09

Borehole Permeameter Stage 2 Calculations

Project RMA 93 03, 21907 207030
Test Location· RMA, Section 25, Test Fill 1
Test Number · B2A

Test Dimensions and Equations.

	(cm)				
d =	1 27	L =	16 00	G5 =	1 172
D =	10 16	1/2 L =	8 00	G4 =	3 440
Z =	33	b_2 =	50 44	G3 =	2 312
R_A =	6 92	$4b_2/D$ =	19 86	F =	0 952
b_1 =	58 44	L/D =	1 57	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 30				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 30		29 7		128 1	29 9	24 3			68 7	20 4	1				
09/01/94	09 00	1800	30 4	128 1	128 8	24 3	24 2	-0 1	128 9	69 3	20 7	0 97	0 99		0 50	Erroneous reading
09/01/94	09 30	1800	30 5	128 8	128 9	24 2	24 2	0 0	128 9	69 6	20 9	0 97	1 00		1 00	Erroneous reading
09/01/94	10 32	3720	30 9	128 9	129 3	24 2	23 8	-0 4	129 7	70 5	21 4	0 97	0 99		2 03	Erroneous reading
09/01/94	12 30	7080	31 4	129 3	129 8	23 8	23 6	-0 2	130 0	70 9	21 6	0 95	0 99		4 00	Erroneous reading
09/01/94	15 38	11280	29 7	129 8	128 1	23 6	24 3	0 7	127 4	71 2	21 8	0 95	1 02	2 41E-08	7 13	
09/02/94	09 40	64920	13 7	128 1	112 1	24 3	23 8	-0 5	112 6	69 3	20 7	0 97	1 14	2 95E-08	25 17	
09/02/94	16 47	25620	16 1	112 1	114 5	23 8	23 8	0 0	114 5	72 0	22 2	0 95	0 98		32 28	Erroneous reading
09/02/94	16 48		30 1	114 5	128 5	23 8	23 8	0 0	128 5	72 0	22 2	0 95	0 89			Refill
09/03/94	09 16	59280	19 8	128 5	118 2	23 8	24 2	0 4	117 8	72 0	22 2	0 95	1 09	2 13E-08	48 77	
09/03/94	09 17		30 3	118 2	128 7	24 2	24 2	0 0	128 7	72 0	22 2	0 95	0 92			Refill
09/06/94	14 56	279540	22 0	128 7	120 4	24 2	23 0	-1 2	121 6	72 7	22 6	0 93	1 06	2 89E-09	126 43	
09/06/94	14 57		30 1	120 4	128 5	23 0	23 0	0 0	128 5	72 7	22 6	0 93	0 94			Refill
09/09/94	09 59	241320	12 0	128 5	110 4	23 0	22 8	-0 2	110 6	73 0	22 8	0 93	1 16	8 85E-09	193 48	
09/12/94	11 47	265680	2 2	110 4	100 6	22 8	22 5	-0 3	100 9	73 4	23 0	0 93	1 09	4 82E-09	267 28	
09/12/94	11 50		29 7	100 6	128 1	22 5	22 5	0 0	128 1	73 4	23 0	0 93	0 79			Refill
09/14/94	13 38	179280	20 5	128 1	118 9	22 5	22 6	0 1	118 8	72 5	22 5	0 93	1 08	5 98E-09	317 13	
09/16/94	11 07	163740	6 0	118 9	104 4	22 6	22 3	0 3	104 7	68 5	20 3	1	1 14	1 19E-08	362 62	
09/16/94	11 08		30 0	104 4	128 4	22 3	22 3	0 0	128 4	68 5	20 3	1	0 81			Refill
09/20/94	14 14	356760	9 7	128 4	108 1	22 3	22 2	-0 1	108 2	70 7	21 5	0 95	1 19	6 98E 09	461 73	

Time weighted average for K2 = 8 00E-09

Borehole Permeameter Stage 2 Calculations

Project RMA 93 03, 21907 207030
Test Location· RMA, Section 25, Test Fill 1
Test Number · B2B

Test Dimensions and Equations:

(cm)

d =	1 27	L =	16 00	G5 =	1 172
D =	10 16	1/2 L =	8 00	G4 =	3 440
Z =	33	b_2 =	50 44	G3 =	2 312
R_A =	6 92	$4b_2/D$ =	19 86	F =	0 952
b_1 =	58 44	L/D =	1 57	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 32				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	Test Unit H1 (cm)	Test Unit H2 (cm)	TEG Ro (cm)	TEG Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 32		30 3		128 7	29 9	24 3			68 7	20 4	1				
09/01/94	09 01	1740	31 1	128 7	129 5	24 3	24 2	-0 1	129 6	69 3	20 7	0 97	0 99		0 48	Erroneous reading
09/01/94	09 31	1800	31 6	129 5	130 0	24 2	24 2	0 0	130 0	69 6	20 9	0 97	1 00		0 98	Erroneous reading
09/01/94	10 32	3660	31 8	130 0	130 2	24 2	23 8	-0 4	130 6	70 5	21 4	0 97	1 00		2 00	Erroneous reading
09/01/94	12 32	7200	31 7	130 2	130 1	23 8	23 6	-0 2	130 3	70 9	21 6	0 95	1 00		4 00	Erroneous reading
09/01/94	15 38	11160	30 7	130 1	129 1	23 6	24 3	0 7	128 4	71 2	21 8	0 95	1 01	1 71E-08	7 10	
09/02/94	09 40	64920	17 0	129 1	115 4	24 3	23 8	0 5	115 9	69 3	20 7	0 97	1 11	2 47E-08	25 13	
09/02/94	16 49	25740	17 0	115 4	115 4	23 8	23 8	0 0	115 4	72 0	22 2	0 95	1 00		32 28	Erroneous reading
09/02/94	16 50		29 4	115 4	127 8	23 8	23 8	0 0	127 8	72 0	22 2	0 95	0 90			Refill
09/03/94	09 18	59280	22 9	127 8	121 3	23 8	24 2	0 4	120 9	72 0	22 2	0 95	1 06	1 36E-08	48 77	
09/03/94	09 19		29 7	121 3	128 1	24 2	24 2	0 0	128 1	72 0	22 2	0 95	0 95			Refill
09/06/94	14 48	278940	17 9	128 1	116 3	24 2	23 0	-1 2	117 5	72 7	22 6	0 93	1 09	4 41E-09	126 27	
09/06/94	14 59		30 2	116 3	128 6	23 0	23 0	0 0	128 6	72 7	22 6	0 93	0 90			Refill
09/09/94	10 00	241260	14 7	128 6	113 1	23 0	22 8	-0 2	113 3	73 0	22 8	0 93	1 14	7 47E-09	193 47	
09/12/94	11 46	265560	3 7	113 1	102 1	22 8	22 5	-0 3	102 4	73 4	23 0	0 93	1 10	5 33E-09	267 23	
09/12/94	11 50		30 2	102 1	128 6	22 5	22 5	0 0	128 6	73 4	23 0	0 93	0 79			Refill
09/14/94	13 38	179280	20 4	128 6	118 8	22 5	22 6	0 1	118 7	72 5	22 5	0 93	1 08	6 36E-09	317 10	
09/16/94	11 09	163860	8 5	118 8	106 9	22 6	22 3	-0 3	107 2	68 5	20 3	1	1 11	9 60E-09	362 62	
09/16/94	11 10		30 3	106 9	128 7	22 3	22 3	0 0	128 7	68 5	20 3	1	0 83			Refill
09/20/94	14 16	356760	10 9	128 7	109 3	22 3	22 2	-0 1	109 4	70 7	21 5	0 95	1 18	6 62E-09	461 73	
09/20/94	14 17		30 2	128 7	128 6	22 3	22 2	-0 1	128 7	70 7	21 5	0 95	1 00		461 75	Refill
09/23/94	16 02	265560	10 2	109 3	108 6	22 2	21 9	-0 3	108 9	64 9	18 3	0 98	1 00	2 07E-10	535 50	

Time weighted average for K2 = 6 34E 09

Borehole Permeameter Stage 2 Calculations

Project RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number: B2C

Test Dimensions and Equations:

	(cm)				
d =	1 27	L =	15 75	G5 =	1 169
D =	10 16	1/2 L =	7 88	G4 =	3 395
Z =	33	b_2 =	50 57	G3 =	2 289
R_A =	6 92	$4b_2/D$ =	19 91	F =	0 950
b_1 =	58 44	L/D =	1 55	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 34				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 34		30 4		128 8	29 9	24 3			68 7	20 4	1				
09/01/94	09 01	1620	31 2	128 8	129 6	24 3	24 2	-0 1	129 7	69 3	20 7	0 97	0 99		0 45	
09/01/94	09 32	1860	31 6	129 6	130 0	24 2	24 2	0 0	130 0	69 6	20 9	0 97	1 00		0 97	
09/01/94	10 33	3660	31 8	130 0	130 2	24 2	23 8	-0 4	130 6	70 5	21 4	0 97	1 00		1 98	
09/01/94	12 33	7200	31 7	130 2	130 1	23 8	23 6	-0 2	130 3	70 9	21 6	0 95	1 00		3 98	
09/01/94	15 38	11100	30 0	130 1	128 4	23 6	24 3	0 7	127 7	71 2	21 8	0 95	1 02	2 46E-08	7 07	
09/02/94	09 41	64980	11 8	128 4	110 2	24 3	23 8	-0 5	110 7	69 3	20 7	0 97	1 16	3 41E-08	25 12	
09/02/94	16 51	25800	11 6	110 2	110 0	23 8	23 8	0 0	110 0	72 0	22 2	0 95	1 00	1 03E-09	32 28	
09/02/94	16 52		30 1	110 0	128 5	23 8	23 8	0 0	128 5	72 0	22 2	0 95	0 86			Refill
09/03/94	09 22	59400	22 1	128 5	120 5	23 8	24 2	0 4	120 1	72 0	22 2	0 95	1 07	1 67E-08	48 80	
09/03/94	09 23		30 2	120 5	128 6	24 2	24 2	0 0	128 6	72 0	22 2	0 95	0 94			Refill
09/06/94	15 00	279420	11 6	128 6	110 0	24 2	23 0	-1 2	111 2	72 7	22 6	0 93	1 16	7 46E-09	126 43	
09/06/94	15 01		30 0	110 0	128 4	23 0	23 0	0 0	128 4	72 7	22 6	0 93	0 86			Refill
09/09/94	10 00	241140	3 5	128 4	101 9	23 0	22 8	-0 2	102 1	73 0	22 8	0 93	1 26	1 36E-08	193 43	
09/09/94	10 02		30 0	101 9	128 4	22 8	22 5	-0 3	128 7	73 4	23 0	0 93	0 79			Refill
09/12/94	11 46	265440	7 2	128 4	105 6	22 5	22 5	0 0	105 6	73 4	23 0	0 93	1 22	1 06E-08	267 20	
09/12/94	11 51		30 4	105 6	128 8	22 5	22 6	0 1	128 7	73 4	23 0	0 93	0 82			Refill
09/14/94	13 39	179280	16 0	128 8	114 4	22 6	22 3	-0 3	114 7	72 5	22 5	1	1 12	9 97E-09	317 08	
09/14/94	13 40		30 6	114 4	129 0	22 6	22 3	-0 3	129 3	72 5	22 5	1	0 88		317 10	Refill
09/16/94	11 11	163860	0 0	129 0	98 4	22 3	22 2	-0 1	98 5	68 5	20 3	0 95	1 31	2 41E-08	362 62	

Time weighted average for K2 = 1 20E 08

Borehole Permeameter Stage 2 Calculations

Project· RMA 93 03, 21907 207030
Test Location RMA, Section 25, Test Fill 1
Test Number B2D

Test Dimensions and Equations:

	(cm)				
d =	1 27	L =	17 50	G5 =	1 193
D =	10 16	1/2 L =	8 75	G4 =	3 714
Z =	33	b_2 =	49 69	G3 =	2 448
R_A =	6 92	$4b_2/D$ =	19 56	F =	0 962
b_1 =	58 44	L/D =	1 72	G2 =	0 015
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 36				

Date	Time	^t = t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum Hrs (hrs)	Remarks
09/01/94	08 36		30 8		129 2	29 9	24 3			68 7	20 4	1				
09/01/94	09 02	1560	31 0	129 2	129 4	24 3	24 2	-0 1	129 5	69 3	20 7	0 97	1 00		0 43	
09/01/94	09 32	1800	31 4	129 4	129 8	24 2	24 2	0 0	129 8	69 6	20 9	0 97	1 00		0 93	
09/01/94	10 33	3660	31 4	129 8	129 8	24 2	23 8	-0 4	130 2	70 5	21 4	0 97	1 00		1 95	
09/01/94	12 33	7200	31 1	129 8	129 5	23 8	23 6	-0 2	129 7	70 9	21 6	0 95	1 00	1 49E 09	3 95	
09/01/94	15 39	11160	29 7	129 5	128 1	23 6	24 3	0 7	127 4	71 2	21 8	0 95	1 02	2 04E-08	7 05	
09/02/94	09 41	64920	12 4	128 1	110 8	24 3	23 8	-0 5	111 3	69 3	20 7	0 97	1 15	3 08E-08	25 08	
09/02/94	16 53	25920	14 7	110 8	113 1	23 8	23 8	0 0	113 1	72 0	22 2	0 95	0 98		32 28	Erroneous reading
09/02/94	16 53		30 0	113 1	128 4	23 8	23 8	0 0	128 4	72 0	22 2	0 95	0 88			Refill
09/03/94	09 24	59460	23 0	128 4	121 4	23 8	24 2	0 4	121 0	72 0	22 2	0 95	1 06	1 39E-08	48 80	
09/03/94	09 25		30 2	121 4	128 6	24 2	24 2	0 0	128 6	72 0	22 2	0 95	0 94			Refill
09/06/94	15 02	279420	15 9	128 6	114 3	24 2	23 0	-1 2	115 5	72 7	22 6	0 93	1 11	5 24E-09	126 43	
09/06/94	15 03		29 7	114 3	128 1	23 0	23 0	0 0	128 1	72 7	22 6	0 93	0 89			Refill
09/09/94	10 03	241200	14 2	128 1	112 6	23 0	22 8	-0 2	112 8	73 0	22 8	0 93	1 14	7 19E-09	193 45	
09/12/94	11 45	265320	0 5	112 6	98 9	22 8	22 5	-0 3	99 2	73 4	23 0	0 93	1 14	6 51E-09	267 15	
09/12/94	11 52		30 0	98 9	128 4	22 5	22 5	0 0	128 4	73 4	23 0	0 93	0 77			Refill
09/14/94	13 41	179340	19 4	128 4	117 8	22 5	22 6	0 1	117 7	72 4	22 4	0 93	1 09	6 62E-09	317 08	
09/16/94	11 14	163980	6 0	117 8	104 4	22 6	22 3	-0 3	104 7	68 5	20 3	1	1 13	1 05E-08	362 63	
09/16/94	11 15		30 4	104 4	128 8	22 3	22 3	0 0	128 8	68 5	20 3	1	0 81		362 65	Refill
09/20/94	14 20	356700	8 6	128 8	107 0	22 3	22 2	-0 1	107 1	70 7	21 5	0 95	1 20	7 20E-09	461 73	

Time weighted average for K2 = 8 14E-09

Borehole Permeameter Stage 2 Calculations

Project RMA 93 03, 21907 207030
Test Location: RMA, Section 25, Test Fill 1
Test Number · B2E

Test Dimensions and Equations

(cm)

d =	1 27	L =	20 50	G5 =	1 238
D =	10 16	1/2 L =	10 25	G4 =	4 270
Z =	33	b_2 =	48 19	G3 =	2 690
R_A =	6 92	$4b_2/D$ =	18 97	F =	0 976
b_1 =	58 44	L/D =	2 02	G2 =	0 014
$Z + R_A + b_1$ =	98 36	a =	-1	K2 =	R_tG2 LN(H1/H2')/(t2 - t1)
t_0 =	09/01/94 08 38				

Date	Time	^t = (t2 - t1 (sec)	Test Unit R (cm)	H1 (cm)	H2 (cm)	TEG Ro (cm)	Rf (cm)	C = Rf - Ro (cm)	H2' = H2 - C (cm)	T (F)	T (C)	Rt Factor	(H1/H2')	K2 (cm/sec)	Cum hrs (hrs)	Remarks
09/01/94	08 38		30 2		128 6	29 9	24 3			68 7	20 4	1				
09/01/94	09 03	1500	30 6	128 6	129 0	24 3	24 2	-0 1	129 1	69 3	20 7	0 97	1 00		0 42	
09/01/94	09 33	1800	31 0	129 0	129 4	24 2	24 2	0 0	129 4	69 6	20 9	0 97	1 00		0 92	
09/01/94	10 43	4200	30 9	129 4	129 3	24 2	23 8	-0 4	129 7	70 5	21 4	0 97	1 00		2 08	
09/01/94	12 34	6660	30 3	129 3	128 7	23 8	23 6	0 2	128 9	70 9	21 6	0 95	1 00	5 99E-09	3 93	
09/01/94	15 40	11160	28 7	128 7	127 1	23 6	24 3	0 7	126 4	71 2	21 8	0 95	1 02	2 08E-08	7 03	
09/02/94	09 42	64920	15 1	127 1	113 5	24 3	23 8	0 5	114 0	69 2	20 7	0 97	1 11	2 20E-08	25 07	
09/02/94	16 54	25920	14 5	113 5	112 9	23 8	23 8	0 0	112 9	72 0	22 2	0 95	1 01	2 63E-09	32 27	
09/02/94	16 55		30 1	112 9	128 5	23 8	23 8	0 0	128 5	72 0	22 2	0 95	0 88			Refill
09/03/94	09 29	59640	22 7	128 5	121 1	23 8	24 2	0 4	120 7	72 0	22 2	0 95	1 06	1 35E-08	48 85	
09/03/94	09 30		29 9	121 1	128 3	24 2	24 2	0 0	128 3	72 0	22 2	0 95	0 94			Refill
09/06/94	15 04	279240	12 9	128 3	111 3	24 2	23 0	-1 2	112 5	72 7	22 6	0 93	1 14	5 93E-09	126 43	
09/06/94	15 05		30 2	111 3	128 6	23 0	23 0	0 0	128 6	72 7	22 6	0 93	0 87			Refill
09/09/94	10 04	241140	13 9	128 6	112 3	23 0	22 8	-0 2	112 5	73 0	22 8	0 93	1 14	6 99E-09	193 43	
09/12/94	11 43	265140	0 2	112 3	98 6	22 8	22 5	-0 3	98 9	73 4	23 0	0 93	1 14	6 04E-09	267 08	
09/12/94	11 53		29 9	98 6	128 3	22 5	22 5	0 0	128 3	73 4	23 0	0 93	0 77			Refill
09/14/94	13 42	179340	18 3	128 3	116 7	22 5	22 6	0 1	116 6	72 5	22 5	0 93	1 10	6 72E-09	317 07	
09/14/94	13 43		30 1	116 7	128 5	22 6	22 6	0 0	128 5	72 5	22 5	1	0 91			Refill
09/16/94	11 16	163980	13 4	128 5	111 8	22 6	22 3	-0 3	112 1	68 5	20 3	1	1 15	1 13E-08	362 63	

Time weighted average for K2 = 8 15E-09

Appendix E

LITHOLOGIC BORING LOGS

MAJOR DIVISIONS			SYMBOLS	TYPICAL NAMES
COARSE-GRAINED SOILS OVER 50%>No 200 SIEVE SIZE	GRAVELS MORE THAN 1/2 OF COARSE FRACTION> No 4 SIEVE SIZE	CLEAN GRAVELS WITH LESS THAN 5% FINES	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines
		GRAVELS WITH OVER 15% FINES	GM	Silty gravels, gravel-sand mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	SANDS MORE THAN 1/2 OF COARSE FRACTION< No 4 SIEVE SIZE	CLEAN SANDS WITH LESS THAN 5% FINES	SW	Well-graded sands or gravelly sands, little or no fines
			SP	Poorly graded sands or gravelly sands, little or no fines
		SANDS WITH OVER 15% FINES	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
FINE-GRAINED SOILS OVER 50%<No 200 SIEVE SIZE	SILTS & CLAYS LIQUID LIMIT 50% OR LESS		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
			OL	Organic silts and organic silty clays of low plasticity
	SILTS & CLAYS LIQUID LIMIT GREATER THAN 50%		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
			CH	Inorganic clays of high plasticity, fat clays
			OH	Organic clays of medium to high plasticity, organic silty clays, organic silts
HIGHLY ORGANIC SOILS			PT	Peat and other highly organic soils
DEBRIS ZONE*				Metal, concrete, plastic, brick, wood, etc.
CONSTRUCTION DEBRIS*				Concrete, wood, rebar asphalt

SYMBOLS KEY

	Bulk or classification sample
	No sample recovery
	"Undisturbed" sample
	First-encountered groundwater level
	Static groundwater level
(10YR 4/4)	Munsell soil color chart 1990 edition

GRAIN SIZE CHART

CLASSIFICATION	RANGE OF GRAIN SIZES	
	U.S. Standard Sieve Size	Grain Size in Millimeters
BOULDERS	Above 12"	Above 305
COBBLES	12" to 3"	305 to 76.2
GRAVEL	3" to No.4	76.2 to 4.75
coarse	3" to 3/4"	76.2 to 19.1
fine	3/4" to No 4	19.1 to 4.75
SAND	No 4 to No.200	4.75 to 0.075
coarse	No 4 to No.10	4.75 to 2.00
medium	No 10 to No.40	2.00 to 0.425
fine	No 40 to No.200	0.425 to 0.075
SILT & CLAY	Below No.200	Below 0.075

Source ASTM D 2488-90, based on Unified Soil Classification System
* Not part of ASTM Classification System

SOILCLS2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

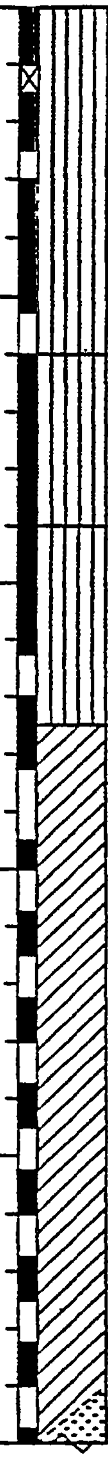
Prepared by:
Harding Lawson Associates

Unified Soil Classification

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
3		0	
8			
11			
12			
15			
11			
7			
7			
6			
4		5	
4			
5			
4			
5			
6			
7			
9			
10			
7			
8		10	
10			
12			
13			
15			
10			
14			
15			
9			
19			
20		15	
17			
33			
50			
29			
35			
31			
19			
19			
26			
20		20	
32			
65			
23			
28			
35			
17			
28			
47			
40			
96		25	



SM, silty sand, fine- to medium-grained sand, some clay 10 YR 6/4 – light yellowish brown loose nonplastic, dry alluvium

Color change to 10 YR 7/4 – very pale brown

ML, sandy silt, very fine- to medium-grained sand 10 YR 6/4 – light yellowish brown loose, slightly plastic slightly moist calcareous alluvium

SM, silty sand very fine-grained sand, some clay 10 YR 7/3 – very pale brown, loose nonplastic slightly moist, calcareous micaeous alluvium

Color change to 10 YR 6/4 – light yellowish brown

CL, clay with silt and medium-grained sand 10 YR 5/6 – yellowish brown medium dense nonplastic dry

10 YR 6/6 – brownish yellow

Color change to 7 5 YR 5/6 – strong brown

Color change to 10 YR 5/6 – yellowish brown

Color change to 10 YR 8/2 – white caliche due to increase in calcium carbonate

Increase in coarse-grained sand, color change to 10 YR 5/6 – yellowish brown, abundant white caliche

Color change to 10 YR 7/4 – very pale brown

Color change to 2.5 Y 5/4 – light olive brown

SANDSTONE, very fine- to fine-grained sand, 10 YR 6/6 – brownish yellow locally very thinly laminated low hardness friable, moist, calcareous weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 1

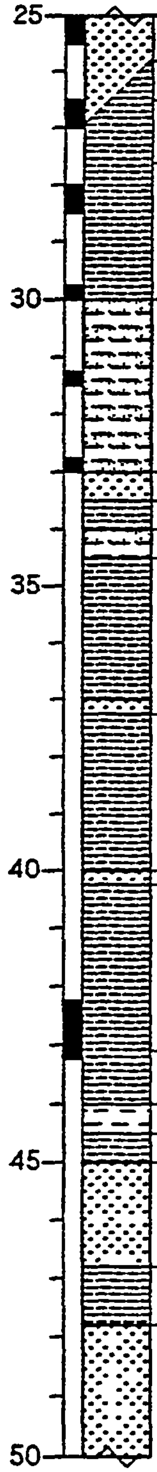
Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
23		
41		
83		
48		
64		
58		
32		
53		
71		30
30		
65		
50		
26		
123		
100		
26		
63		
75		
24		35
38		
50		

Sample



CLAYSTONE, 10 YR 6/2 - light brownish gray soft plastic moist black lignite fragments, gypsum weathered bedrock

Abundant iron oxide and gypsum, minor lignite

Color change to 2 5 Y 5/3 - light olive brown

INTERBEDDED CLAYSTONE AND SILTSTONE TO SANDSTONE, 2.5 Y 5/2 - grayish brown, splitting along sandy layers at 1- to 2-inch intervals, weathered bedrock

SANDSTONE, very fine-grained sand to silt 2.5 Y 6/4 - light yellowish brown, low hardness, friable dry noncemented to locally weakly cemented weathered bedrock

CLAYSTONE, 2 5 Y 5/3 - light olive brown locally dark gray, laminated, fractured soft, plastic, iron oxide weathered bedrock

INTERBEDDED CLAYSTONE AND SILTSTONE, 10 YR 5/3 -light olive brown, low and high angle fractures some slickensides weathered bedrock

CLAYSTONE, very fine-grained sand, 2 5 Y 5/6 - light olive brown soft, plastic weathered bedrock

Color change to 2 5 Y 5/0 - gray high angle fractures with iron oxide and slickensides

SANDSTONE to SILTSTONE, very fine-grained sand to silt massive no bedding, not fractured, moderately hard, moderately strong, 10 YR 4/2 - dark grayish brown, calcareous, weathered bedrock

CLAYSTONE, locally intensly fractured with iron-oxide fractures/joints, breaks in blacky to concoidal fragments 2 5 Y 4/2 - dark grayish brown weathered bedrock

Color change to 2 5 Y 4/3 - olive brown

SILTSTONE, clayey 2 5 Y 5/4 - light olive brown, thinly laminated, low hardness, friable, weathered bedrock

CLAYSTONE, 2.5 Y 4/3 - olive brown, fractured, weathered bedrock

SANDSTONE, very fine- to fine-grained sand, 2 5 Y 6/4 - light yellowish brown low hardness, friable, compacted, uncemented, weathered bedrock

CLAYSTONE, 2.5 Y 4/3 - olive brown, weathered bedrock

SANDSTONE, very fine- fine-grained sand, locally silty, 2 5 Y 6/4 - light yellowish brown and 2 5 Y 7/6 - yellow low hardness, friable, compacted noncemented

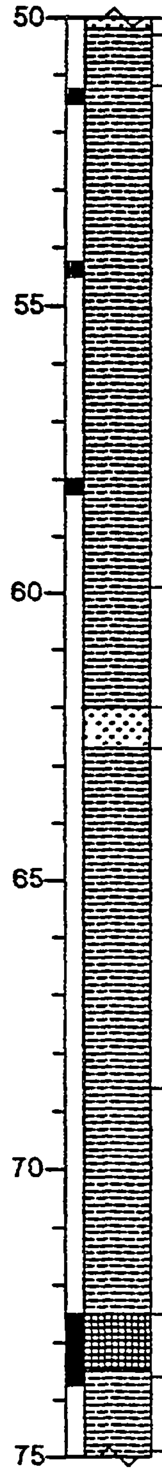
RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	Figure 1 Log of Boring BRB11094

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94



CLAYSTONE, 2.5 YR 5/2 – grayish brown, thinly laminated closely fractured soft, plastic, slightly to nonweathered bedrock, iron oxide fractures and horizontal partings silty lamination, trace thin black lignite laminations, bedrock

2 5 Y 4/2 – to 2 5 Y 3/2 – dark gray brown to very dark gray brown, very thinly laminated, closely fractured

Becomes lignitic, color change to 2 5 Y 3/2 – to 2 5 Y 2/0 – very dark gray brown to black, thinly laminated

Color change to 2 5 Y 5/3 – light olive brown due decrease in lignite

SANDSTONE. very fine-grained sand silty, clayey 2 5 Y 5/3 – light olive brown, moist, low hardness friable compact non-to weakly cemented noncalcareous bedrock

CLAYSTONE, 2 5 Y 4/2 – dark grayish brown thinly laminated soft plastic iron oxide on low angle to horizontal parting spaced 1 to 3 inches bedrock

Becomes lignitic color change to 10 YR 3/2 – very dark grayish brown, very thinly laminated, soft plastic lignite fragments bedrock

Mottled olive and gray

LIGNITE, 2 5 Y 2/0 – black flaky coal-like material moist bedrock

CLAYSTONE, 10 YR 3/2 – very dark gray brown, 10 YR 3/2 to 10 YR 2/2 – very dark brown thinly laminated low hardness plastic iron oxide, waxy, bedrock

LIGNITE black thinly laminated low hardness friable fissile locally clayey, moist, bedrock

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Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

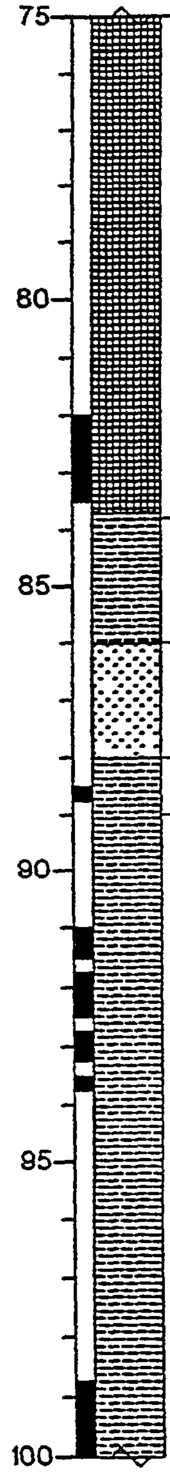
Figure 1

Log of Boring BRB11084

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94



Contains thin laminations of crushed olive-brown blocky clay fragments and very light grayish ashy material

CLAYSTONE, 2 5 Y 3/0 - very dark gray low hardness plastic moist iron oxide bedrock

Becomes silty

SANDSTONE, very fine- to fine-grained sand, some silt, 2 5 Y 7/0 - light gray low hardness, friable moist bedrock

CLAYSTONE, 2 5 Y 3/0 - very dark gray, massive (no fracturing) low hardness plastic moist bedrock

2 5 Y 3/2 - very dark grayish brown

Silty 2 5 Y 4/0 - dark gray to 2 5 Y 2/0 - black, low and high angle slickensides

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

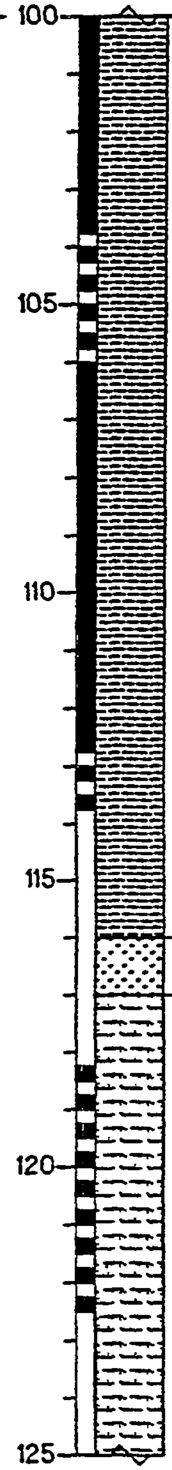
Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Becomes lignitic color change to 2 5 Y 2/0 – black to
2.5 Y 3/ 0 – 2.5 Y 3/0 – very dark gray, thinly laminated local shiny black lignite layers slickensides at 107 8 ft , soft plastic, locally fissile locally waxy moist, lignite content decreases downward at 109 0 ft. becomes ashy

SANDSTONE, very fine-grained sand, 2 5 Y 5/0 – gray and 2 5 Y 4/0 – dark gray, layered, bedrock

INTERBEDDED SILTSTONE to CLAYSTONE, some very fine-grained sand 5 Y 3/1 – very dark gray (moist) 5 Y 7/1 – light gray (dry) soft to low hardness plastic to friable moist local slickensides bedrock

Increase in sand content laminated, locally interbedded, becomes moist

Trace silt

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

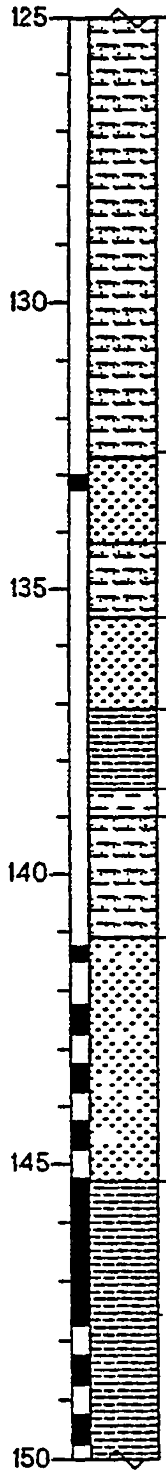
Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5199.23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Increase in clay and silt content

Interbedded silty claystone, clayey siltstone and very fine sandstone

Color change to 5 Y 5/1 - gray

SANDSTONE, very fine- to fine-grained sand, locally clayey, 5 Y 5/1 - gray low hardness friable, moist bedrock

CLAYSTONE and SILTSTONE, alternating light gray and dark gray laminations

SANDSTONE, very fine- to fine-grained sand, 2 5 Y 5/1 - gray, local thin layer lignitic laminations low angle low hardness friable, moist bedrock

CLAYSTONE, occasional silty sandy laminations, high angle fractures silt content increases, bedrock

SILTSTONE, minor clay, 2 5 Y 4/1 - dark gray, low hardness friable moist bedrock

CLAYSTONE AND SILTSTONE, black waxy, massive soft, low hardness, plastic slickensides bedrock

SANDSTONE, fine-grained sand, some medium-grained sand, 2 5 Y 5/0 - gray to 5 Y 4/1 - dark gray, low hardness, friable, moist, noncalcareous bedrock

CLAYSTONE, 5 Y 2 5/1 - black, thinly laminated zones, little fracturing low hardness, plastic, moist unweathered, bedrock, somewhat fissile, high angle slickensides

RMA2

Prepared for. Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 1** **Log of Boring BRB11094**

Equipment Mobile CME-75 HSAs

Elevation 5199 23 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
		150		
				INTERBEDDED CLAYSTONE AND SILTSTONE, 5 Y 6/1 - gray and 5 Y 4/1 - dark gray, massive thin laminated fractured low to moderately hard, plastic, friable moist bedrock Silt content increases downward interbedded claystone and very fine- to fine-grained sandstone/sandy siltstone
				Interbedded sandstone and clayey siltstone
		155		
		160		
				LIGNITE, fractured deformed bedrock
		165		
				CLAYSTONE, 2 5 Y 2/0 - black, massive little fractured, soft, low hardness plastic moist bedrock
		170		
				Color change to 5 Y 3/1 - very dark gray
		175		Total depth = 175 1 ft

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

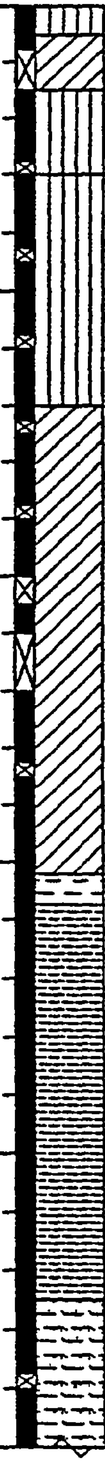
Figure 1

Log of Boring BRB11094

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
17		0	
16			
8			
10			
9			
5			
5			
5			
5			
7		5	
7			
8			
8			
6			
4			
1			
5			
20			
27			
28		10	
17			
17			
13			
8			
10			
8			
8			
8			
10			
19		15	
25			
35			
18			
40			
32			
17			
28			
36			
20			
27		20	
28			
17			
31			
33			
105			
50			
35			
70			
107		25	



ML, silty with medium-grained sand, 10 YR 5/4 - yellowish brown stiff nonplastic dry, minor roots, alluvium

CL, clay with some silt and sand 10 YR 5/4 - yellowish brown, very stiff, nonplastic, dry, alluvium

SM, silty sand with clay medium-grained sand, 10 YR 6/4 - light yellowish brown, loose, nonplastic, dry, minor white calcium carbonate, silt and sand content decrease with depth, alluvium

ML, silt with some fine- to medium-grained sand and clay, 10 YR 6/3 - pale brown nonplastic, dry to very slightly moist, carbonate matrix alluvium

Increase in very fine-grained sand

CL, clay with medium- to coarse-grained sand, some silt 10 YR 6/4 - light yellowish brown medium stiff nonplastic slightly moist, calcareous matrix alluvium

Color change to 10 YR 8/2 - white, very stiff, dry

CL/SC clay with fine- to medium-grained sand and silt 10 YR 7/4 - very pale brown stiff,

Color change to 10 YR 7/6 - yellow

Zone of white calcium carbonate crystals, color change to 10 YR 6/4 - light yellowish brown

SILTSTONE, 2 5 Y 6/6 - olive yellow very fine-grained sand and silt to trace clay, low hardness, friable dry locally weakly cemented, calcareous matrix oxidized, weathered bedrock

CLAYSTONE, 5 Y 4/3 - olive, fractured, high and low angle with iron oxide on fracture, soft plastic slightly moist gypsum and calcium carbonate weathered Denver

Color change to 2 5 Y 5/2 - grayish brown trace silt, dry, iron oxide gypsum oxidized noncalcareous, weathered bedrock

Low angle fractures spaced 1/2 to 1 inch, high angle fractures spaced 2 to 6 inches

Color change to 2 5 Y 4/0 -dark gray along fractures oxidized to 2 5 Y 6/2 - light yellowish gray

Color change to 2.5 Y 5/2 - grayish brown, intensely fractured to crushed

INTERBEDDED CLAYSTONE and SILTSTONE to VERY FINE-GRAINED SANDSTONE, 2 5 Y 7/3 - pale yellow low hardness, friable, dry to slightly moist with very minor iron oxide on low angle fractures layers 1/2 to 2 inches thick, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

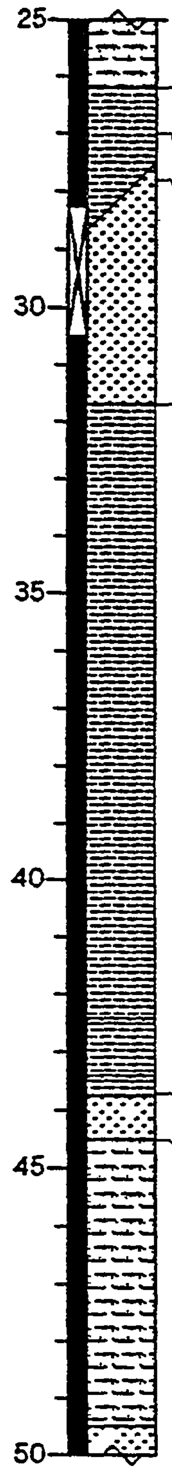
Figure 2

Log of Boring SAB11194

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
62			
71			
80			



CLAYSTONE, paper thin silty parting spaced 1 to 2 inches apart 2 5 Y 4/2 - dark grayish brown, low angle fractures, intensely fractured to crushed, soft, plastic, slightly moist, iron oxide on fractures, oxidized weathered bedrock

Color change to 2 5 Y 5/2 - grayish brown

SANDSTONE, medium-grained sand 10 YR 4/6 - dark yellowish brown, low hardness fraible, weathered bedrock

CLAYSTONE, 2 5 Y 4/2 - dark grayish brown, papery to shaly, thinly laminated intensely fractured, soft, plastic, moist, iron oxide on fractures laminations, weathered bedrock

Becomes lignitic, color change to 5 Y 3/1 - very dark gray closely fractured

Thin sand lens approximately 0 1 inch thick

Thin sand lens approximately 0 1 inch thick

SANDSTONE, 2 5 Y 6/4 - light yellowish brown, compact noncemented soft to low hardness, friable, loose moist weathered bedrock

INTERBEDDED CLAYSTONE AND SILTSTONE, 2 5 Y 4/2 - dark grayish brown locally shaley thinly laminated closely fractured soft, plastic, moist, local iron oxide, weathered bedrock

Sandstone lenses fine- to very fine-grained sand 2.5 Y 5/6 - light olive brown, moist

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Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

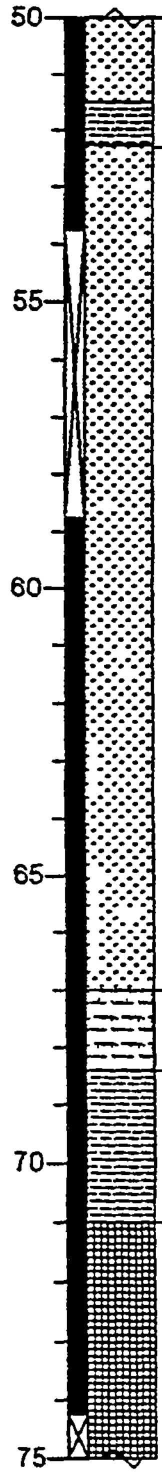
Figure 2

Log of Boring SAB11194

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94



SANDSTONE, 2 5 Y 5/6 – light olive brown very fine-grained sand, locally clayey with occasional very thin bedded gray claystone, thinly laminated no to low hardness, no strength moderately fractured moist, weathered, varible iron oxide along laminations, weathered bedrock

INTERBEDDED SILTSTONE/CLAYEY SILTSTONE/ SILTY CLAYSTONE, 2.5 Y 5/6 – light olive brown somewhat platey, thinly laminated closely fractured low angle soft to low hardness base of iron oxide oxidation, weathered bedrock

SILTY CLAYSTONE, 5 Y 3/1 – very dark gray, shaley laminated, closely fractured, low and high angle, soft, plastic, moist, bedrock

LIGNITE, 2 5 Y 2/0 – black, shaley, thinly laminated closely fractured, low hardness, friable, moist, coal-like, bedrock

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

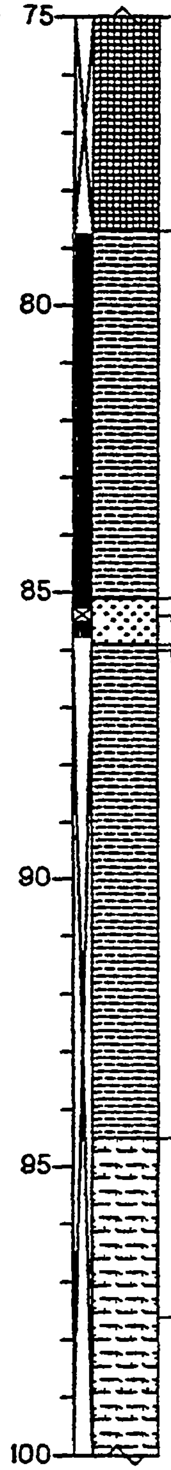
Figure 2

Log of Boring SAB11194

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94



CLAYSTONE, 2 5 Y 4/0 – dark gray, occasional shaley laminated close to moderately fractured, soft plastic unweathered, moist, trace lignite fragments bedrock

Lignitic from 78 7 to 79 2 feet

Thin sand lens, gray very fine-grained sand uncemented

SANDSTONE, fine-grained sand silt, 10 YR 4/1 – dark gray, thinly laminated low hardnmess friable, unweathered moist bedrock, thin zone approximately 0 1 inch thick, moderately cemented locally clayey

Pyrite nodule

CLAYSTONE, 10 YR 4/1 – very dark gray slabby, locally laminated, moderate to little fractured soft plastic moist bedrock

Pyrite and lignite at 85 9 to 86 0 feet, some high angle slickensides

Intensely to closely fractured claystone, slickensides

INTERBEDDED CLAYSTONE, SILTSTONE, SANDSTONE, 2 5 Y 2 5/1 – black (claystone) to 5 Y 5/1 – gray (sandstone) thinly laminated interbedded claystone and siltstone thinly bedded sandstone, little fractured to massive soft to low hardness plastic to friable, moist soft sediment deformation features in interbedded siltstone claystone varied fracture filling, sandstone lenses 3 to 4 inches thick poor to moderately cemented fine-grained sand, well sorted rounded, quartz, iron oxide, feldspar, bedrock

Color change to 5 Y 2.5/1 – black

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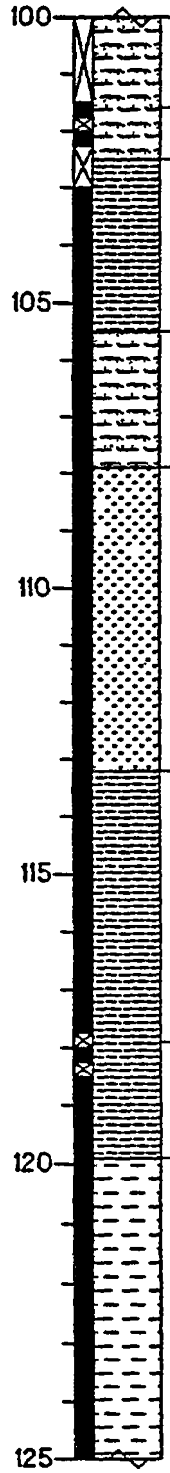
Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 2** **Log of Boring SAB11194**

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94



LIGNITIC CLAYSTONE, black to very dark brown-black occasional shaley, thinly laminated close to moderately fractured with occasional slickensides, soft to low hardness, plastic, locally friable, moist bedrock

CLAYSTONE, 2 5 Y 2/0 black, blocky to massive, locally thinly laminated, moderately fractured, plastic, moist, bedrock

INTERBEDDED CLAYEY SILTSTONE, SANDSTONE and MINOR CLAYSTONE, 2 5 Y 5/0 - gray, massive to blocky, locally thinly laminated (alternating siltstone/claystone laminations) moderately fractured, low angle, occasional high and vertical fractures, soft to low hardness locally weak to friable to plastic moist bedrock pyrite nodule at 107 0 feet

SANDSTONE, thinly laminated, low to moderately hard, weak to friable, moist bedrock

CLAYSTONE, locally silty with minor siltstone interbeds mottled, 2 5 Y 5/0 - gray and 2 5 Y 3/0 - very dark gray, blocky to massive, locally thinly laminated, moderate to little fractured, soft to low hardness, plastic, moist, soft sediment deformation features trace lignite, waxy bedrock

Grades to very dark gray claystone

Color change to 2 5 Y 4/0 - dark gray

SILTSTONE, 2 5 Y 5/0 - gray, massive to blocky, thinly laminated, moderately fractured low and high angle, slickensides (high angle), bedrock

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

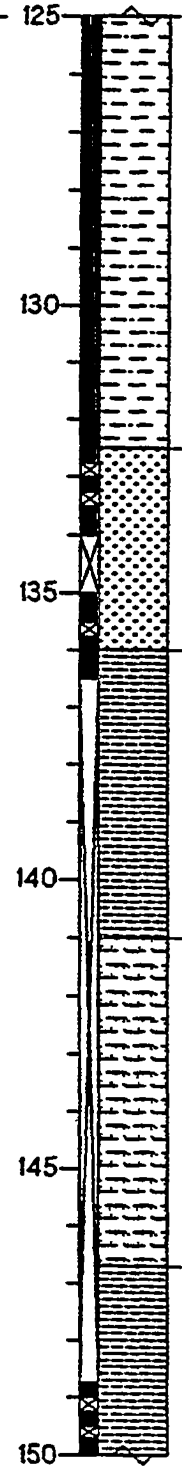
Figure 2

Log of Boring SAB11194

Blows/6" | HNU/OVA (ppm) | Depth (ft.) | Sample

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94



SANDSTONE, 2 5 Y 4/0 - dark gray, caliche fracture filling high angle fracture contact, 2 5 Y 6/1 - gray with green cast, low hardness, friable, moist bedrock

CLAYSTONE, 2.5 Y 2/0 - black, locally mottled to 2 5 Y 5/0 - gray, some green-black streaks massive to blocky occasional thinly laminated close to moderately fractured occassional high angle slickensides soft to low hardness, plastic, moist, scattered white flecks bedrock

INTERBEDDED CLAYSTONE AND SILTSTONE, 5 Y 5/1 - gray, massive thinly bedded occasionally thinly laminated moderately to closely fractured high and low angle fractures, low hardness, friable moist trace organics, bedrock

CLAYSTONE, 2 5 Y 2/0 - black, massive occasional shaley, occasional thin laminated, closely fractured soft to low hardness, plastic, moist unweathered, waxey, slickensides on high angle fracture black organic (lignite), fracture filling and fragments, bedrock

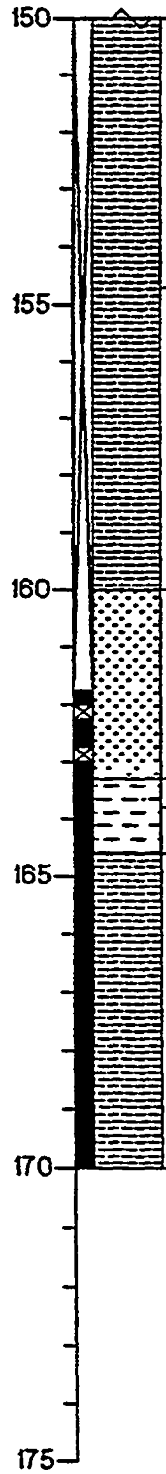
RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 2** **Log of Boring SAB11184**

Blows/6" | HNU/OVA (ppm) | Depth (ft.) | Sample

Equipment Mobile CME-75 HSAs

Elevation 5262 79 Date 8/24/94



Color change to 5 Y 3/1 – very dark gray

Black coal seam, approximately 0 5 inches thick, brittle blocky break

Becomes lignitic, 2 5 Y 2/0 – black, thin laminated closely fractured high angle slickensides, low hardness, plastic moist scattered fine-grained white flecks bedrock

High angle slickensides

Lignitic claysonte black and lignite fragments, pyrite and calcite fracture filling

SANDSTONE, fine-grained sand to 5 Y 5/1 – gray, slabby to blocky, laminated to very thinly bedded moderately fractured, low to medium abgle with thin black organic material on fracture low to medium hardness, weak to friable moist bedrock

SILTSTONE, 2 5 Y 5/0 – gray, thinly laminated (varved) low to moderately hard friable to weak, unweathered, bedrock

Interbedded to thinly laminated claystone

CLAYSTONE, 2 5 Y 5/0 – and 2 5 Y 4/0 – gray and dark gray occassional silty massive occassional intensely fracutured, high angle slickensides soft to low hardness, plastic, moist, bedrock

Total depth = 170 0 ft

RMA2

Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 2** **Log of Boring SAB11194**

Equipment Mobile CME-75 HSAs

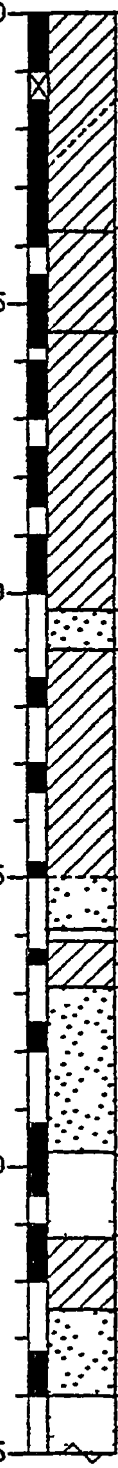
Elevation 5239 41 Date 8/30/94

Blows/6": 4, 8, 8, 6, 5, 4, 6, 9, 12, 7, 8, 10, 10, 13, 18, 18, 17, 21, 12, 14, 12, 7, 8, 10, 6, 12, 11, 7, 10, 13, 7, 8, 8, 12, 24, 21, 6, 11, 10, 4, 8, 8, 13, 12, 20, 22, 14, 5, 7, 8

HNU/OVA (ppm)

Depth (ft.) 0, 5, 10, 15, 20, 25

Sample



SC, sand, very fine-grained sand with silt and clay 10 YR 6/4 - light yellowish brown, loose, plastic dry, fine roots alluvium

CL, clay with silt and fine- to medium-grained sand, 10 YR 6/4 - light yellowish brown, medium stiff, plastic dry caliche alluvium

SC, sand with clay matrix, fine- to very fine-grained sand, some granules 7 5 YR 5/4 - brown, medium dense, loose, dry, caliche alluvium

CL, clay with medium- to coarse-grained sand 10 YR 8/2 - white very stiff plastic dry abundant caliche matrix, iron-oxide staining alluvium

Increase in coarse-grained sand granules and fine pebbles color change to 10 YR 6/4 - light yellowish brown

SW, 10% clay matrix silt to very coarse-grained sand some granules and small pebbles 10 YR 7/3 - very pale brown mediumk dense, locally plastic moist alluvium

CL, clay with sand and gravel 10 YR - 7/3 - very pale brown stiff to very stiff plastic moist, with thin layers of very fine-grained sand locally caliche with minor caliche, sand lenses - SW to SP 0 01-inch to 0 10- inch thick alluvium

SW, sand with some silt very fine- to very coarse-grained sand, 10 YR 6/4 - light yellowish brown, medium dense nonplastic moist fining downward alluvium

SP, very fine-grained sand lens

CL, clay with sand and granules (pea gravel), 10 YR 6/4 - light yellowish brown, medium dense (very stiff) nonplastic moist alluvium

Color change to 10 YR 5/3 - brown, becomes plastic

SW, sand, very fine- to very coarse-grained sand with silt and gravel 10 YR 7/3 - very pale brown dense loose dry alluvium

SP, sand, very fine-grained sand 10 YR 6/3 - pale brown medium dense nonplastic moist, noncalcareous subrounded alluvium

CL, clay with 40% very fine-grained sand and silt, 10 YR 6/4 - light yellowish brown stiff, plastic moist iron-oxide staining on horizontal partings spaced micaceous, alluvium

SW, sand very fine- to very coarse-grained sand with granite pea gravel occasionally up to 3/4-inch grains dense dry alluvium

SP, sand 10 YR 7/3 - very pale brown medium dense loose dry, alluvium

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239.41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Description
		25	Very fine gravel 1/10-inch to 1/4-inch gravel
5			
6			
6			SANDSTONE, very fine-grained sand and silt, 2.5 Y 7/3 - pale yellow, low hardness friable dry to slightly moist oxidized, fines downward to siltstone 2 Y 7/2 -light gray, weathered bedrock
13			
20			
47			
28			CLAYSTONE, silt and very fine-grained sand, 2.5 Y 7/2 - light gray, locally 2.5 Y 6/8 - olive yellow, soft plastic to friable, slightly moist, weakly cemented slightly cohesive, oxidized, weathered bedrock
42			
50		30	
50			
100			SANDSTONE, fine- to coarse-grained sand rounded silty, no hardness no strength, moist, weathered local weak cement oxidized, weathered bedrock
56			
68			
50			
		35	
			Color change to 2.5 Y 7/3 - pale yellow, friable
			Medium- to coarse-grained sand some gravel, color change to 2.5 Y 5/6 - light olive brown
		40	
		45	
			Slightly more cohesive occasional horizontal iron-oxide stained layers, color change to 2.5 Y 5/4 - light olive brown
		50	

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

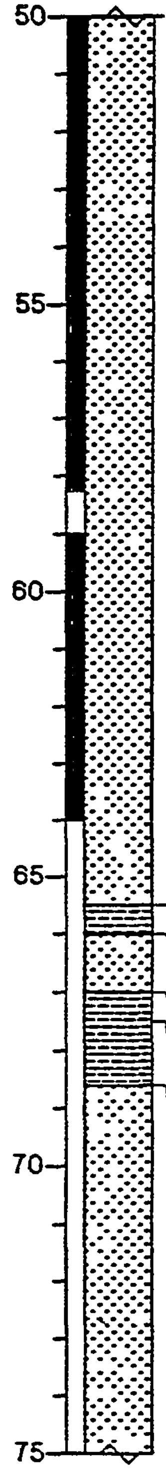
Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239 41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)	Sample



CLAYSTONE, 2 5 Y 4/4 – olive brown shaley laminated intensely fractured soft plastic moderately weathered, moist, bedrock, lignitic claystone, 2 5 Y 3/2 – very dark grayish brown, shaley, fractured soft, plastic, weathered, moist, local heavy iron oxide weathered bedrock

SANDSTONE, medium-grained sand, low hardness friable moist weathered bedrock

CLAYSTONE, 2.5 Y 2/0 – black, slabby, thinly laminated closely fractured soft plastic moist lignitic moderately weathered bedrock

Color change to 2 5 Y 5/0 – gray interbedded with 2 5 Y 3/0 – very dark gray becomes silty/sandy with thin lignitic laminations, some layers have dark green black cast

SANDSTONE, medium-grained sand, shaley, low hardness friable moist lignitic fragments, bedrock

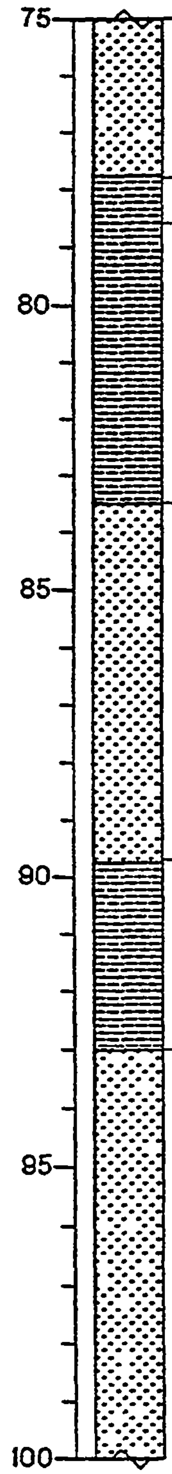
RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	Figure 3 Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5239 41 Date 8/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



CLAYSTONE, silty, 5 Y 5/2 – olive gray, closely fractured, soft to low hardness, plastic, moist, iron-oxide staining weathered bedrock

Color change to 5 Y 4/1 – dark gray

SANDSTONE, very fine-grained sand 2 5 Y 5/0 – 4/0 – gray to dark gray, slabby, thinly laminated moderate to little fractured low hardness friable interbedded with claystone and siltstone bedrock

CLAYSTONE, silty, 10 YR 4/1 – dark gray, massive thinly laminated little fractured, low hardness plastic moist, bedrock

SANDSTONE, silty to very fine-grained sand 5 Y 4/1 – or 10 YR 4/1 – dark gray, massive, thinly laminated little fractured to massive, low to moderately fractured, hard, friable to weak, moist cross-bedded sandstone bedrock

RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 3** **Log of Boring ASB11294**

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Equipment Mobile CME-75 HSAs Elevation 5239 41 Date 8/30/94
		100		
		105		
				CLAYSTONE, 5 Y 2 5/1 - black thinly laminated, closely fractured, high angle, slickensides low hardness (soft) plastic moist lignitic, bedrock
		110		
				Total depth = 112 9 feet
		115		

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

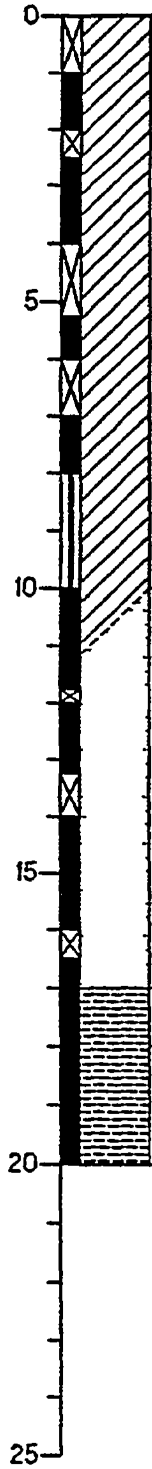
Figure 3

Log of Boring ASB11294

Equipment Mobile CME-75 HSAs

Elevation 5199.23 ft Date 11/16/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Blows/6": 3, 6, 9, 14, 3, 5, 5, 6, 3, 5, 6, 6, 9, 3, 5, 6, 6, 17, 30, 45, 50, 25, 35, 50, 27, 37, 45, 50, 21, 15, 14, 15, 12, 21, 30, 34

CL, clay, 35 percent very fine-grained sand, 10 YR 5/3 - brown, medium dense, nonplastic dry caliche, alluvium

Color change to 10 YR 6/4 - light yellowish-brown, increase in very fine-grained sand and trace medium-grained sand

Heavy white caliche zone

Heavy white caliche zone, clay increase to 45 percent

SP, silty sand very fine- to fine-grained sand 10 percent clay 10 YR 6/6 - brownish yellow, very dense, dry to slightly moist alluvium

Decrease in clay content to 5 percent, 10 percent very fine-grained sand 85 percent fine-grained sand

CLAYSTONE, 5 YR 4/1 - dark gray, unable to determine bedding medium hard to weak, iron-oxide stained, weathered bedrock

Claystone becomes bentonitic with orange oxidation

Total depth = 20 0 feet

Notes 1. All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Commerce City, Colorado

Prepared by:
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Figure 4

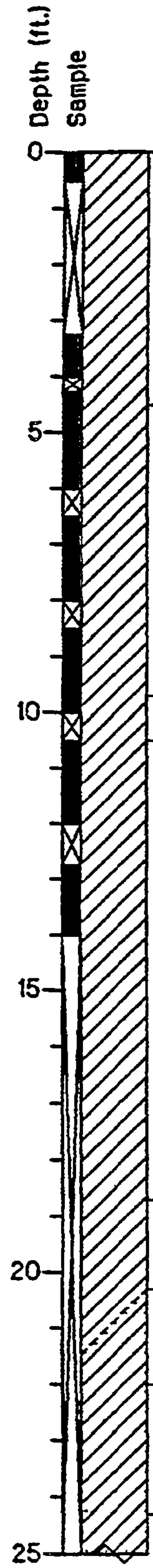
Log of Boring SAB11394

Equipment Mobile CME-75 HSAs

Elevation 5206.26 ft Date 11/15/94

Blows/6": 4, 7, 9, 7, 4, 8, 7, 10, 8, 10, 18, 20, 4, 10, 8, 8, 10, 10, 9, 10, 5, 5, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6, 6

HNU/OVA (ppm)



CL, sandy clay, 40 percent very fine-grained sand, 10 YR 5/6 - yellowish brown dense nonplastic dry, micaceous, cemented alluvium

Color changes to 10 YR 6/4 - light yellowish brown with increased caliche

Color changes to 10 YR 5/6 - yellowish brown mottled caliche

Coarsening downward becomes moist

Rounded granite cobble and decrease in clay content

Increased very fine- to coarse-grained sand low plasticity slightly moist

Change in color to 10 YR 6/4 - light yellowish brown

Thin layer of coarse-grained sand

Increase in coarse-grained sand and gravel, medium plastic

Interbedded thin medium- to coarse-grained sand lenses between 17 7 and 20 3 ft

Granite cobbles and pea gravel

SC, clayey sand, very fine- to medium-grained sand trace coarse sand 10 YR 5/4 - yellowish brown medium dense, medium plastic, moist, alluvium

Increase in clay content to 45 percent, sand coarsening

Color changes to 10 YR 6/4 - yellowish brown, decreased clay content

Some rounded gravel

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RMA2

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Program Manager for
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Commerce City, Colorado

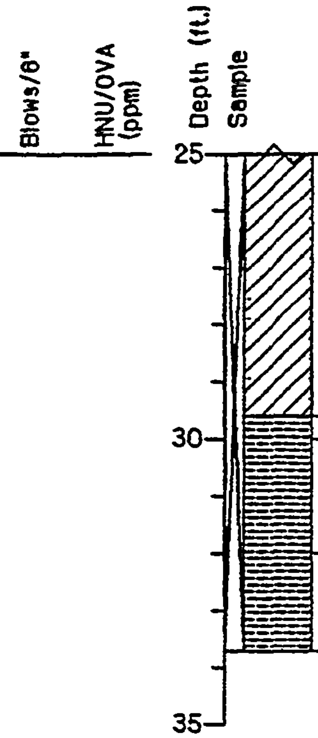
Prepared by:
Harding Lawson Associates

Figure 5

Log of Boring WEB11484

Equipment Mobile CME-75 HSAs

Elevation 5206.26 ft. Date 11/15/94



Coarse sand layer with gravel from 26 0 26 3 ft with sequence coarsening downward to 29 6 ft

Granite cobbles

CLAYSTONE, 2 5 YR 5/3 – light olive brown, closely fractured medium hard, friable, weathered bedrock

High angle fractures and color change to 10 YR 6/8 – brownish yellow, oxidation along fractures and bedding

Thin interbedded very fine-grained sandstone layers alternating 10 YR 6/6 – olive yellow and 2 5 Y 7/7 – light gray sandstone

Total depth = 33 7 feet

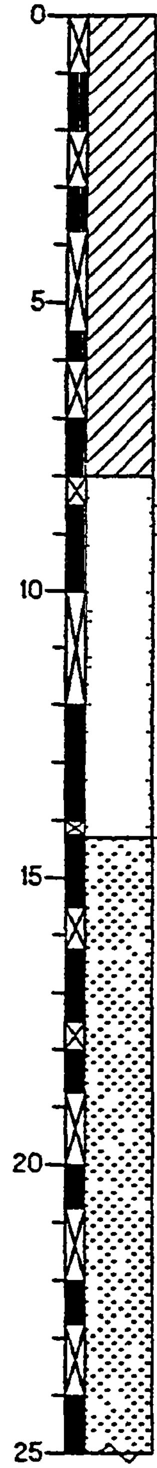
RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 5** **Log of Boring WEB11494**

Equipment Mobile CME-75 HSAs

Elevation 5211.37 ft. Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.) / Sample	Description
4, 8, 10, 8, 4, 5, 7, 9, 10, 9, 8, 4, 4, 5, 9, 7, 7, 6, 5		0–10	CL, sandy clay, 40 percent very fine-grained sand 10 YR 4/3 - brown to dark brown, dense, nonplastic, dry alluvium Color change to 10 YR 6/4 - yellowish brown due to increased caliche, trace coarse sand Color change to 10 YR 8/3 - very pale brown due to increased caliche Trace rounded gravel SC, clayey sand, 20 percent clay, very fine- to fine-grained sand trace coarse sand 10 YR 6/3 - pale brown medium dense nonplastic dry alluvium Rounded cobbles Color change to 10 YR 6/6 - brownish yellow becomes moist
4, 5, 15, 25, 15, 30, 50		10–15	Granite cobbles SANDSTONE, 90 percent fine-grained sand, trace clay 10 YR 6/6 - brownish yellow, weathered bedrock
24, 35, 50, 35, 50, 35, 50, 35, 50, 35, 45, 50		15–25	Increase in clay to 15 percent and very fine-grained sand to 10 percent, decrease in fine-grained sand to 75 percent



Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

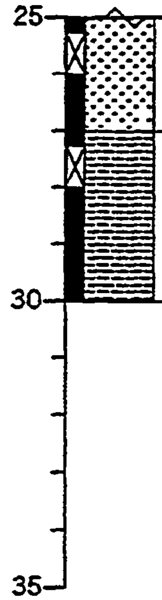
Figure 8

Log of Boring ASB11594

Equipment Mobile CME-75 HSAs

Elevation 5211.37 ft Date 11/16/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)
18		
30		
50		
8		
13		
19		
27		



CLAYSTONE, 5 YR 4/2 – olive gray with white caliche brownish red oxidation zones, medium hard friable, weathered bedrock

Total depth = 30 feet

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

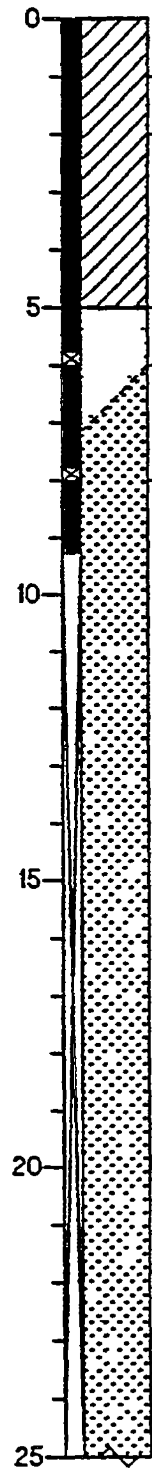
Figure 6

Log of Boring ASB11594

Equipment Mobile CME-75 HSAs

Elevation 5215 21 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)
2	
8	
18	
15	
7	
8	
7	
14	0 6
7	
7	
8	
11	
6	
14	
27	
50	0 9
7	
33	
50	
	1.4
	1 4



SC, clayey sand very fine- to fine-grained, 10 YR 4/4 - dark yellow brown to 10 YR 6/4 - light yellowish brown medium dense, nonplastic dry rooted caliche-rich, alluvium

90 percent caliche-rich clay

SP, sand, very fine- to fine-grained, 10 YR 6/4 - light yellowish brown, medium dense, nonplastic, dry, lightly cemented alluvium

SANDSTONE, very fine- to fine-grained sand, 10 YR 7/4 - very pale brown massive, no visible no visible fracturing low hardness, friable, noncemented weathered bedrock

1 percent medium-grained sand

Color change to 10 YR 6/8 - brownish yellow

Color change to 10 YR 5/8 - yellow brown

Color change to 2.5 YR 5/4 - light olive brown

Notes LAll HNU/OVA readings equal to zero parts per million except as indicated.
2.Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

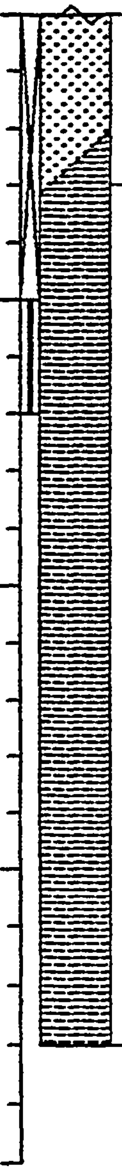
Figure 7

Log of Boring ASB11694

Equipment Mobile CME-75 HSAs

Elevation 5215.21 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Description
		25	
		28	CLAYSTONE, 10 YR 4/1 – dark gray to 10 YR – 7/1 light gray, unable to determine bedding closely fractured low hardness friable ashy welded appearance oxidized, weathered bedrock
7		30	
7	2.3		
21			
21			
		36	Color change to 2.5 YR 4/4 – olive brown, becomes slightly moist
		40	Color change to 10 YR 5/6 – yellowish brown
		43	Totl depth = 43 feet
		45	



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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

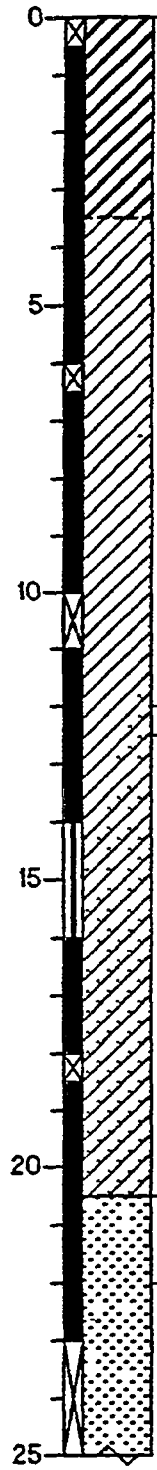
Figure 7

Log of Boring ASB11684

Equipment Mobile CME-75 HSAs

Elevation 5223 39 ft Date 11/17/84

Blows/6"	HNU/OVA (ppm)
5	
14	
18	
20	1 7
15	
16	
18	
20	
13	
12	3.5
17	
20	
9	
10	
8	
15	3 5
9	
2	
2	
2	
6	
7	2 0
9	
7	
8	
8	
10	
5	
10	
11	
8	
10	
12	
20	
8	
7	
16	
45	
45	
50	
25	
50	



CH, sandy clay, 40 percent very fine-grained sand, 10 YR 5/3 – brown hard nonplastic, dry rooted caliche cemented, alluvium

Heavy white caliche

SC, clayey sand, very fine- to fine-grained sand, 40 percent clay 10 YR 5/4 – yellowish brown medium dense to hard, dry, caliche, cemented, alluvium

Slight increase in clay content, low plasticity trace coarse sand and fine gravel

Color change to 10 YR 5/3 – brown to 10 YR 4/3 – dark brown with 10 YR 8/3 – very pale brown

Decrease in clay and caliche increase in very fine-grained sand

Sand becomes poorly sorted and 5 percent coarse-grained sand, trace gravel

Color change to 10 YR 5/4 – yellowish brown increase in clay

Cobbles encountered from 15 to 20 5 feet

SANDSTONE, fine-grained, 10 YR 7/1 – light gray with oxidized layers thin bedding no fracturing weak to moderately weak, weathered bedrock

10 percent clay 10 percent fine-grained sand, 68 percent medium sand 2 percent coarse-grained subangular sand color change to 2 5 YR 5.3 – light olive brown

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

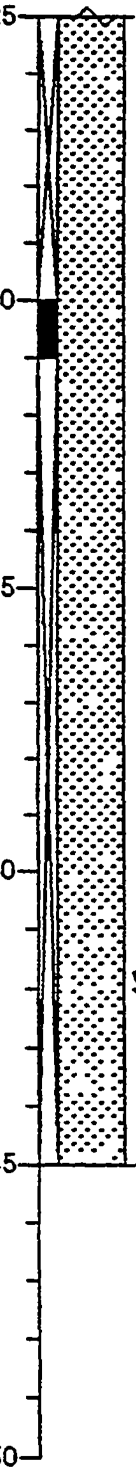
RMA2

Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	Figure 8 **Log of Boring SAB11784**

Equipment Mobile CME-75 HSAs

Elevation 5223.39 ft Date 11/17/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
		25		
12 50		30		Decrease in medium grains to 50 percent, increase in fine-grained sand to 30 percent, 10 percent very fine-grained sand 5 percent coarse-grained sand
		35		Color change to 10 YR 6/4 – light yellow brown
		40		
				∇ Water level estimated during drilling
		45		Becomes saturated
				Total depth = 45.0 feet
		50		



RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

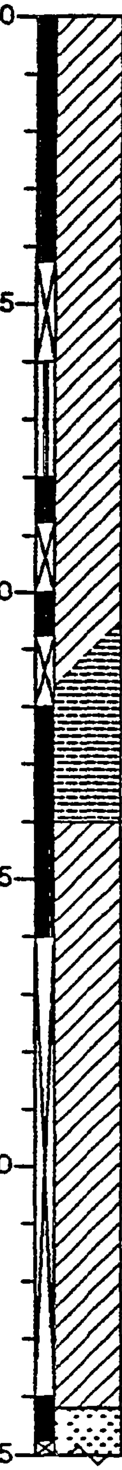
Figure 8

Log of Boring SAB11794

Equipment Mobile CME-75 HSAs

Elevation 5240 78 ft   Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
2, 5, 11, 14, 10, 10, 10		0		CL, clay, 10 YR 4/2 – dark grayish brown, stiff, low plasticity dry fractured, brecciated claystone fragments gypsum or caliche volcanoclastics, alluvium
				Silt increasing color change to 10 YR 4/4 – dark yellowish brown
				Color change to 10 YR 7/4 – very pale brown with caliche
		5		Increase in very fine-grained sand to 10 percent color change to 10 YR 6/3 – pale brown, becomes very stiff with caliche nodules
4, 7, 6, 6, 5, 7, 9, 8, 7, 8, 10, 22, 7				Increase in very fine-grained sand to 30 percent, color change to 10 YR 4/4 – dark brown with caliche
				Heavy white caliche zone
		10		CLAYSTONE, clasts of clay, oxidized soft, siltstone layers weathered bedrock
				Color 2 5 YR 5/2 – gray brown massive, closely fractured low hardness weak, iron-oxide stained, gypsum weathered bedrock
		15		SILTSTONE, 2 5 YR 6/2 – light olive brown, massive moderately fractured low hardness weak, gypsum crystals oxidation, weathered bedrock
13, 21, 30				Color change to 2 5 Y 5/4 – olive brown, trace coarse sand
		20		
15, 50		25		SANDSTONE, fine- to medium-grained sand, pale yellow thin-laminated, low hardness friable, dry weathered bedrock



Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RHA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

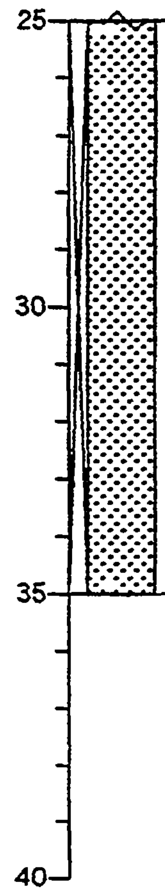
Figure 9

Log of Boring ASB11894

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	

Equipment Mobile CME-75 HSAs

Elevation 5240 78 ft Date 12/06/94



Color change to 2 5 Y 5/6 – olive brown, medium-grained sand becomes moist

Total depth = 35 0 feet

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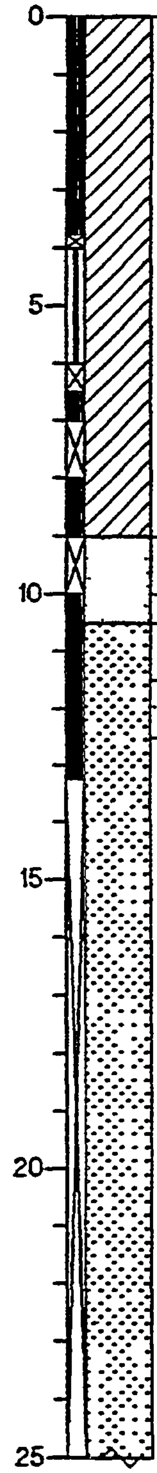
Figure 9

Log of Boring ASB11894

Equipment Mobile CME-75 HSAs

Elevation 5234 48 ft Date 12/07/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
4			
12			
25			
25			
14			
15			
19			
19			
		5	
6			
6			
7			
2			
2			
3			
4			
45		10	
42			
38			
36			
9			
28			
50			
		15	
		20	
		25	



CL. clay, fine- to coarse-grained sand, 10 YR 5/4 - yellowish brown hard nonplastic, moist, alluvium

White caliche zone

Color change to 10 YR 6/4 - light yellowish brown trace very coarse-grained sand, becomes soft, calcareous

SC, clayey sand fine- to medium-grained sand, trace coarse-grained sand, 10 YR 7/4 - very pale brown, nonplastic dry, alluvium

Color change to 10 YR 7/3 - very pale brown becomes very dense caliche-cemented

SANDSTONE, medium- to coarse-grained sand, trace fine-grained sand and silt, 10 YR 7/4 - very pale brown low hardness, friable dry, weathered bedrock

Slightly calcareous with iron-oxide staining

Slightly cohesive increase in coarse-grained sand, noncalcareous

Fine- to coarse-grained sand, quartz grains, 10 YR 6/4 - light yellowish brown

Color change to 2.5 YR 4/4 - light olive brown

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 10

Log of Boring ASB11984

Equipment Mobile CME-75 HSAs

Elevation 5234 48 ft Date 12/07/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Description
		25	
		30	
			Increase in medium-grained sand
		35	
			Trace silt becomes slightly moist, color change to 2 5 Y 5/6 - light olive brown
		40	
			CLAYSTONE, fine- to medium-grained sand 2 5 Y 4/4 - olive brown, moist, weathered bedrock
14		45	
22			
36			
50			Color change to 10 YR 3/2 - very dark grayish brown massive to blocky to thinly laminated, moderately fractured iron-oxide stained, lignitic, weathered bedrock
		50	Total depth = 50 ft

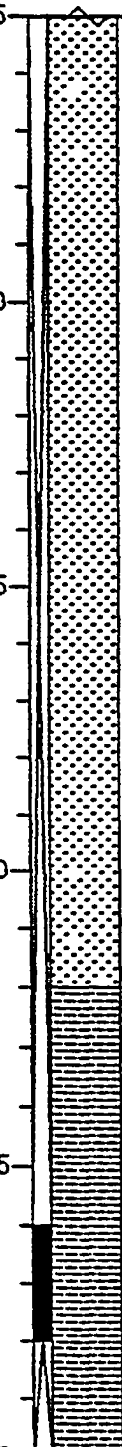

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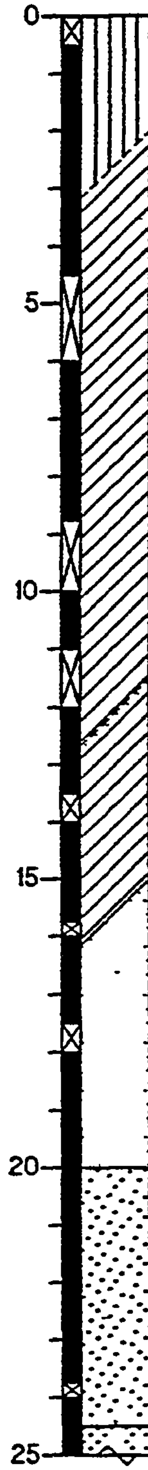
Figure 10

Log of Boring ASB11984

Equipment Mobile CME-75 HSAs

Elevation 5230 59 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft)
8, 20, 21, 18, 7, 8, 8, 12, 7, 7		0–5
7, 8, 3, 6, 5, 5, 4, 5, 4, 5		5–10
7, 9, 7, 7, 11, 12, 13, 12, 8, 8		10–15
10, 6, 6, 11, 9		15–20
2, 21, 26, 25, 15, 16, 21, 18, 18, 36, 50		20–25



ML, silt, very fine- to fine-grained, 10 YR 3/3 - dark brown medium dense, nonplastic, dry rooted alluvium

CL, sandy clay very fine-grained sand, 10 YR 6/4 - light yellow brown, medium hard, nonplastic dry alluvium

Color change to 10 YR 4/4 - dark yellowish brown, increase in fine- grained sand and caliche

Color change to 10 YR 6/4 - light brown increase in very fine-grained sand

Color change to 10 YR 7/4 - very pale brown due to increase in caliche

SC, clayey sand very fine- to coarse-grained sand 7 5 YR 5/4 - brown medium dense nonplastic, dry alluvium

Becomes well-cemented with caliche 10 percent cobbles and fine gravel

Sand coarsening downward poorly sorted, cobbles

SP-SM, Poorly sorted to silty sand very fine- to very coarse-grained sand trace fine gravel, 7 5 YR 7/4 - pink loose dry, alluvium

Increase in clay to 5 percent, 3-inch-diameter granite cobbles

SW-SM, well-graded sand cobbles and gravel, 10 YR 6/4 - light yellowish brown loose, dry, oxidized alluvium

Increase in clay content to 10 percent increase in gravel

SANDSTONE, very fine- to medium-grained sand 10 YR 5/6 - yellowish brown very dense, weak noncemented very thin bedding, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used.

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

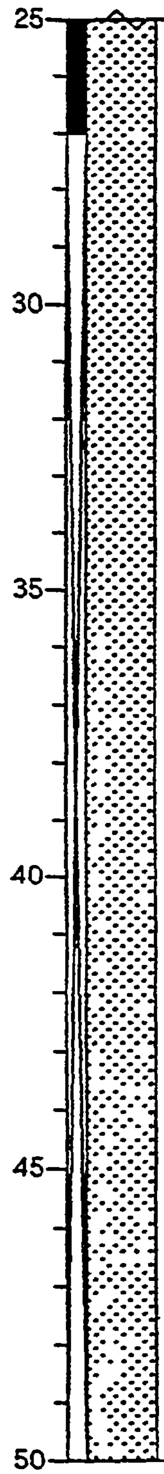
Figure 11

Log of Boring ASB12094

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
50			
35			
50			

Equipment Mobile CME-75 HSAs

Elevation 5230.59 ft Date 11/18/94



Color change to 10 YR 5/4 – yellowish brown, cobbles

Total depth = 50 feet

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Figure 11

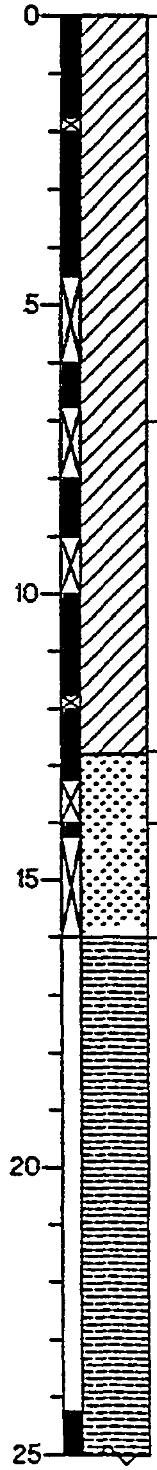
Log of Boring ASB12084

Equipment Mobile CME-75 HSAs

Elevation 5249.27 ft Date 12/7/94
b

Blows/6"	HNU/OVA (ppm)
4	
6	
12	
13	
7	
9	
11	
11	
5	
8	
12	
14	
11	
11	
12	
17	
10	
9	
11	
14	
7	
17	
50	
4	
9	
12	
17	

Depth (ft.) Sample



CL, sandy clay, fine- to coarse-grained sand, 10 YR 6/4 - light yellowish brown, stiff slightly plastic moist caliche alluvium

Color change to 10 YR 7/4 - very pale brown, sand becomes fine- to medium-grained

Color change to 10 YR 8/2 - white sand becomes fine- to coarse-grained

Becomes nonplastic rounded gravel 3/4-inch in diameter

Abundant caliche

SANDSTONE, very fine- to fine-grained sand 2 5 Y 7/3 - pale yellow low hardness friable dry, weathered bedrock

Color change to 2 5 Y 6/4 - light yellowish brown due to increase in caliche

CLAYSTONE, 10 YR 5/3 - brown to 2 5 Y 5/3 - light olive brown, low hardness, friable, dry, weathered bedrock

Color change to 2.5 Y 5/3 - light olive brown due to increased caliche

Color change to 2 5 Y 5/2 - grayish brown, lignitic iron oxide on fracture planes

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

RMA2

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Prepared by:
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Figure 12

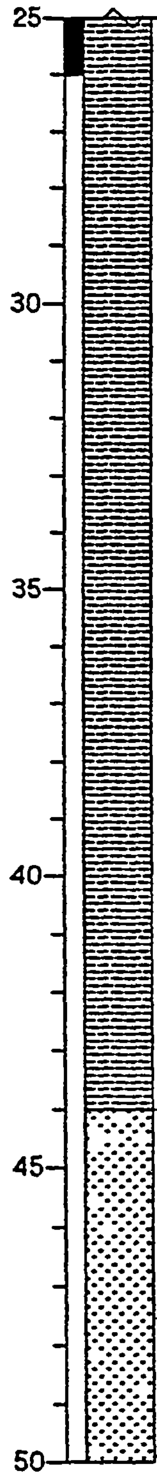
Log of Boring ASB12194

Equipment Mobile CME-75 HSAs

Elevation 5249.27 ft   Date 12/7/94

b

Blows/6" HNU/OVA (ppm) Depth (ft.) Sample



Color grades to 7 5 YR 3/2 – dark brown, lignitic clayshale to 34 ft

Color change to 10 YR 3/3 – dark brown

Color change to 2 5 Y 4/4 – olive brown, becomes soft moist

SANDSTONE, medium- to coarse-grained sand, 2.5 Y 4/4 – olive brown moist, noncemented, weathered bedrock

Total depth = 50 0 feet

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Commerce City, Colorado

Prepared by:
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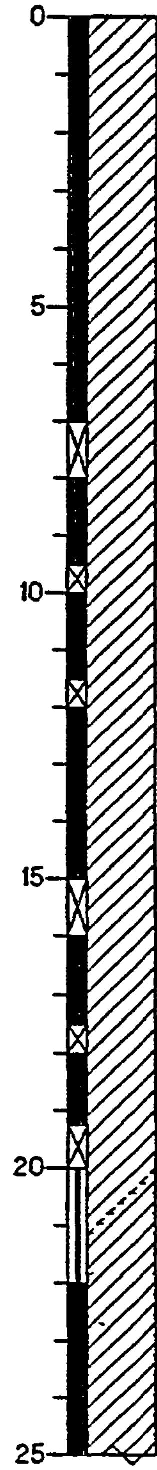
Figure 12

Log of Boring ASB12194

Equipment Mobile CME-75 HSAs

Elevation 5238.14 ft   Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Blows/6": 5, 10, 14, 15, 5, 6, 5, 7, 4, 5, 10, 13, 5, 5, 7, 7, 6, 9, 9, 7, 6, 9, 13, 13, 7, 9, 10, 10, 5, 7, 12, 11, 6, 9, 11, 11, 10, 13, 13, 15, 14, 14, 9, 10, 5, 10, 19

CL, sandy clay, 30 percent very fine-grained sand, 10 YR 4/3 - brown to dark brown, medium hard nonplastic dry, rooted, alluvium

Color change to 10 YR 6/4 - light yellowish brown due to caliche

Decrease in very fine-grained sand to 15 percent with 15 percent silt

Color change to 10 YR 5/4 yellowish brown with 10 percent silt and 20 percent very fine-grained sand

Slight increase in very fine-grained sand content to 30 percent, cemented with white caliche trace coarse-grained sand

Heavy caliche zone

Heavy caliche zone

Hard caliche zone

Trace gravel with rounded granite cemented with caliche

Sand size increasing with 7 percent coarse-grained sand with subrounded to rounded fine gravel

40 percent poorly sorted sand

SW, poorly sorted sand, very fine- to very coarse-grained sand 2 percent fine gravel 10 YR 6/6 - brownish yellow, medium dense dry, partially cemented, alluvium

Increase in clay content

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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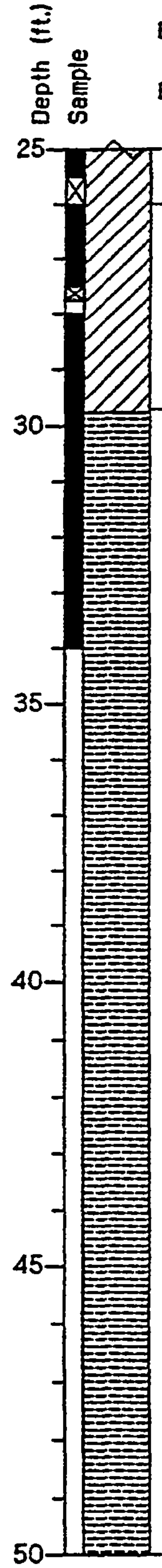
Figure 13

Log of Boring ASB12294

Equipment Mobile CME-75 HSAs

Elevation 5238 14 ft   Date 11/18/94

Blows/6"	HNU/OVA (ppm)
50	
12	
10	
20	
16	
13	
20	
25	
25	
7	
15	
20	
25	
7	
15	
22	
30	



Becomes well-cemented, granite gravel and cobbles

Increase in gravel and cobbles to 25 percent

Well cemented, cobble-rich, oxided layer

CLAYSTONE, clay with very fine-grained sandstone lens 2 5 YR 6/4 light yellowish brown, thinly interbedded low hardness weak, dry weathered bedrock

Color change to 2 5 YR 5/4 light olive brown, very fine- to fine- grained sandstone bed approximately 0 2 foot thick, oxidized, partially cemented friable

Cuttings become moist

Total depth = 50 0 feet

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Commerce City, Colorado

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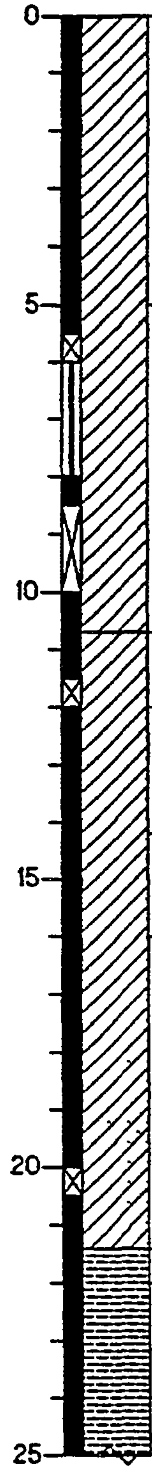
Figure 13

Log of Boring ASB12294

Equipment Mobile CME-75 HSAs

Elevation 5248 08 ft Date 11/18/94

Blows/6" | HNU/OVA (ppm) | Depth (ft) | Sample



Blows/6": 5, 11, 13, 13, 7, 9, 9, 10, 5, 7, 11, 26, 5, 11, 13, 18, 9, 10, 12, 8, 2, 9, 11, 12, 8, 11, 12, 9, 7, 8, 11, 13, 8, 12, 13, 15, 9, 11, 13, 15, 6, 8, 12, 13, 8, 12, 12

CL, sandy clay very fine-grained sand, 10 YR 6/4 - light yellowish brown stiff, nonplastic dry rooted partially caliche cemented, alluvium

Color change to 10 YR 4/6 - dark yellowish brown

Color change to 10 YR 8/2 - white due to heavy caliche cement

Very fine- to coarse-grained sand, trace fine gravel poorly sorted color change to 10 YR 6/4 - light yellowish brown

SC, clayey sand very fine- to medium-grained sand trace coarse sand 10 YR 4/3 - dark brown medium dense low plastic dry, alluvium granite cobble

Color change to 10 YR 4/4 - dark yellowish brown slightly moist, thin oxidized stringers appears bentonitic

SW/SM, sand to silty sand very fine- to coarse-grained sand 10 YR 7/4 - very pale brown medium dense nonplastic dry alluvium partially cemented, angular grains, trace fine granite gravel

Becomes loose less well cemented

Gravel size and content increases some cobbles

CLAYSTONE, 2 5 Y 5/2 - grayish brown, blocky, closely fractured, moderately hard, weak dry, moderately weathered bedrock, heavy dark brownish orange oxidation along high angle fractures gypsum crystals limonitic

Interbeds of papery thin laminated, sandstone, very fine-grained sand 10 YR 6/2 - light brownish gray becomes less oxidized

Becomes more oxidized heavy black mineralization

Notes 1. All HNU/OVA readings equal to zero parts per million except as indicated
2. Munsell color chart used

RMA2

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Commerce City, Colorado

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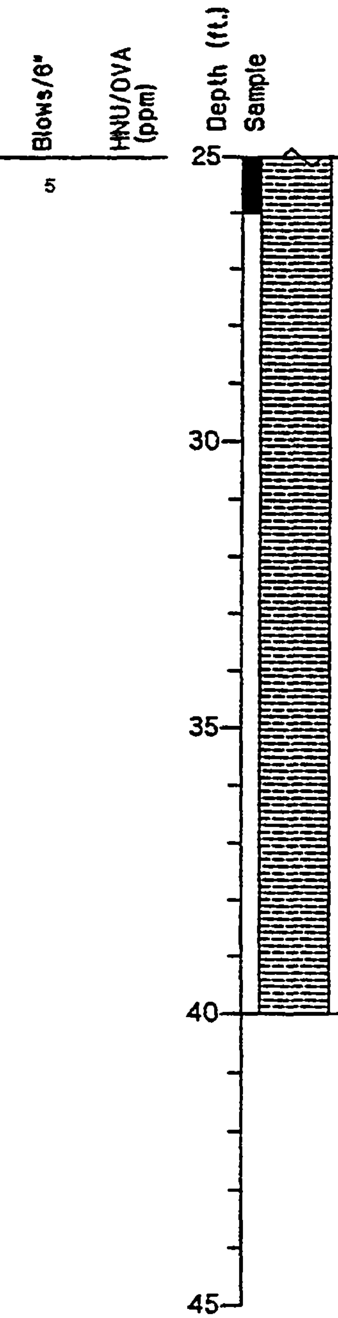
Figure 14

Log of Boring ASB12384

Equipment Mobile CME-75 HSAs

Elevation 5248 08 ft Date 11/18/94



Carbonization

Carbonaceous

Becomes less carbonaceous

Total depth = 40 0 feet

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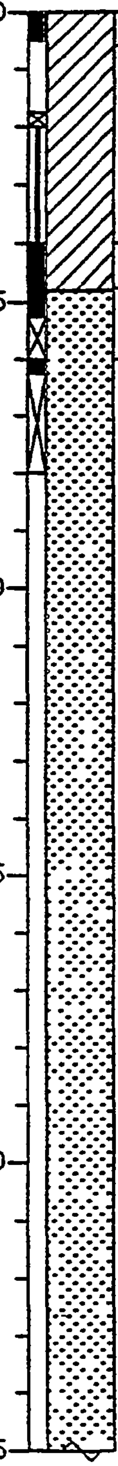
Figure 14

Log of Boring ASB12384

Equipment Mobile CME-75 HSAs

Elevation 5272 46 ft. Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
5		0	
11			
15			
15			
4			
15			
11		5	
10			
5			
50			
		10	
		15	
		20	
		25	



CL, sandy clay fine- to medium-grained sand, 10 YR 4/4 - dark yellowish brown stiff plastic moist alluvium, noncalcareous rooted

CL, silty clay trace fine- to coarse-grained sand, 10 YR 7/3 - very pale brown stiff, nonplastic dry alluvium local caliche

Color change to 10 YR 8/2 - white due to heavy caliche cement

Color change to 10 YR 7/4 - very pale brown, some granite gravel

SANDSTONE, very fine- to fine-grained sand, 2.5 Y 7/4 - pale yellow, low hardness, friable to weak weathered bedrock weakly cemented calcareous

Siltstone/sandstone,very fine-grained sand 2.5 Y 7/3 - pale yellow, mottled with white caliche

Color change to 2 5 Y 7/4 - pale yellow

Becomes noncalcareous

Sand fine- to medium-grained, 2.5 Y 5/6 - light olive brown, noncemented noncalcerous dry

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Commerce City, Colorado

Prepared by:
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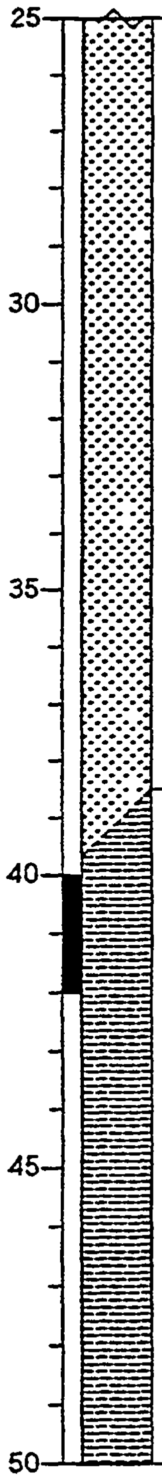
Figure 15

Log of Boring ASB12494

Equipment Mobile CME-75 HSAs

Elevation 5272.46 ft Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
8		40	
16			
23			
31			



CLAYSTONE, 2.5 Y 3/3 - dark olive brown, massive thick bedded moderately fractured, soft, plastic, little weathered, bedrock, moist, minor lignite fragments, noncalcareous, iron-oxide stained fractures and partings

Trace silt

Total depth = 50.0 feet

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 15

Log of Boring ASB12494

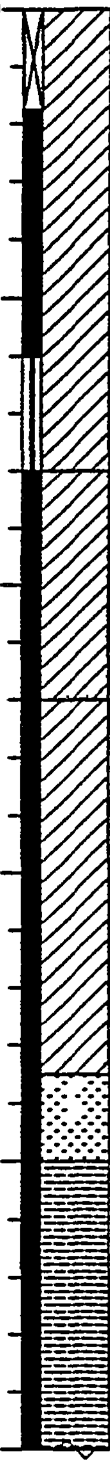
Equipment Mobile CME-75 HSAs

Elevation 5257.30 ft. Date 12/08/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Blows/6": 6, 11, 13, 15, 6, 6, 8, 7, 5, 7, 8, 13, 3, 7, 12, 12, 8, 12, 14, 14, 6, 6, 12, 42, 13, 20, 17, 13, 4, 8, 12, 13, 7, 13, 8, 13, 6, 11, 13, 14

Depth (ft.): 0, 5, 10, 15, 20, 25



CL, clay, 10 YR 4/6 – dark yellowish brown, stiff, plastic moist, alluvium, rooted, trace sand and pea gravel

Color change to 10 YR 7/3 – very pale brown mottled with white caliche some silt and very fine sand

Increase in sand and silt content, locally grades to SC clayey sand sand coarsens to fine- to coare-grained

SC, clayey silty sand fine- to medium-grained sand, 10 YR 6/4 – light yellowish brown medium dense nonplastic, dry alluvium, mottled with white caliche in veinlets and fractures

CL, sandy silty clay, fine- to medium-grained sand 10 YR 6/4 – light yellowish brown stiff nonplastic, dry alluvium mottled with white caliche in veinlets and fractures

Increase in sand and gravel content some fine- to coarse-grained sand fine gravel color change to 10 YR 6/4 – light yellowish brown and grades to 5 YR 7/4 – pink becomes hard

Color change to 10 YR 5/6 – yellowish brown, becomes stiff decrease in caliche content

Gradually grades to entirely white caliche color change to 10 YR 8/1 – white

SANDSTONE, 2.5 Y 7/4 – pale yellow, low hardness, weak weathered bedrock

CLAYSTONE, 2 5 Y 5/3 – light olive brown, slightly flaggy locally thin laminated, locally intensely fractured, soft plastic, weathered bedrock moist, local caliche, gypsum fracture filling, minor iron oxide

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

RMA2

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Commerce City, Colorado

Prepared by:
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Figure 18

Log of Boring ASB12594

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Equipment Mobile CME-75 HSAs Elevation 5257 30 ft Date 12/08/94
		25		
		30		
		35		
		40		Color change to 2 5 Y 4/3 - olive brown
				Color change to 10 YR 3/3 - dark brown, some lignite may be present noncalcareous
		45		
		50		Total depth = 50 0 feet

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Prepared by:
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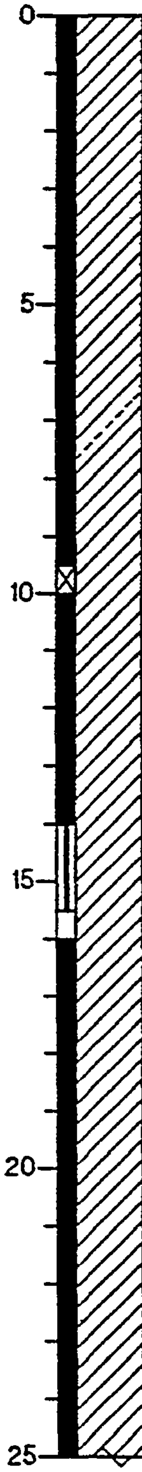
Figure 18

Log of Boring ASB12594

Equipment Mobile CME-75 HSAs

Elevation 5243.92 ft Date 11/23/94

Blows/6" | HNU/OVA (ppm) | Depth (ft.) | Sample



Blows/6": 2, 9, 15, 15, 9, 11, 13, 12, 5, 4, 7, 7, 3, 3, 5, 6, 5, 5, 5, 6, 4, 4, 8, 15, 18, 18, 9, 12, 14, 13, 4, 9, 11, 12, 7, 8, 15, 16, 3, 8, 8, 9, 3, 6, 9

SC, clayey sand very fine grained, 10 YR 5/4 – yellowish brown, medium dense 30 percent plastic clay dry alluvium, rooted

Becomes partially caliche cemented

Color change to 10 YR 6/4 – light yellowish brown clay content decreases to 20 percent

Clay content increases to 40 percent becomes silty

CL, sandy clay, 30 percent very fine-grained sand 10 percent silt 10 YR 5/3 – brown stiff, nonplastic dry alluvium

Clay content decreases silt content increases to 10 percent

Heavy caliche cement

Mottled with caliche

Caliche cemented

Trace fine rounded gravel

Increase in sand content very fine- to medium-grained sand

Trace to some coarse sand and fine rounded gravel color change to 10 YR 5/4 – yellowish brown, mottled with white caliche, ashy appearance, elongated black mineral grains well cemented

Sand content decreases to 25 percent, micaceous color change to 10 YR 5/3 – brown

Sand content increases to 60 percent very fine- to fine-grained, some medium- to coarse-grained sand, trace rounded gravel, color change to 10 YR 5/4 – yellowish brown, medium dense low plastic clay dry alluvium, elongate black mineralization

Locally very sandy, poorly sorted sand, very fine- to coarse-grained subrounded fine gravel layers 1-inch thick

Sand content decreases to 20 percent, very fine- to very coarse-grained sand poorly sorted trace fine subrounded gravel, medium hard caliche stringers contains several thin sandy veneers

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

RMA2

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

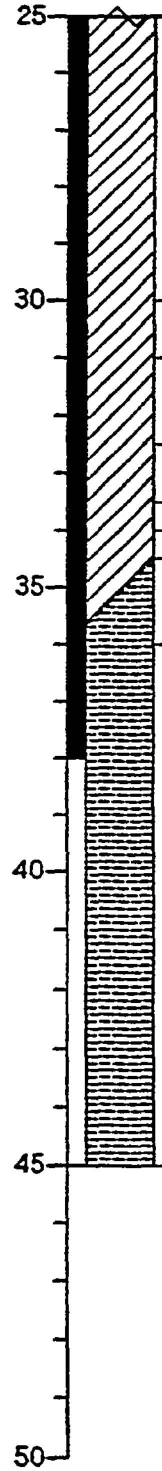
Figure 17

Log of Boring ASB12694

Equipment Mobile CME-75 HSAs

Elevation 5243 92 ft   Date 11/23/84

Blows/6"	HNU/OVA (ppm)
12	
6	
9	
10	
10	
3	
4	
7	
8	
7	
8	
8	
8	
6	
9	
9	
10	
7	
9	
12	
15	
9	
15	
27	
33	



Sand content increases, thin, intercalated layers of sand and fine gravel

Interbedded layers of sand and clay, slightly less well cemented

Granite cobble

Decrease in sand content, trace fine gravel slightly moist

Caliche

Sandy

Increase in sand content very fine- to coarse-grained sand some gravel very well cemented

Caliche very thin layers of poorly sand, medium- to coarse-grained sand

Quartz cobble

CLAYSTONE, 2 5 Y 5/3 - light olive brown, blockly, closely fractured medium hard, weak moderately weathered bedrock some caliche oxidized along fractures

Very thin bedded slightly less fractured, caliche, mottled with orange oxidation to 38 feet

Total depth = 45 0 feet

RMA2

Prepared for.
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

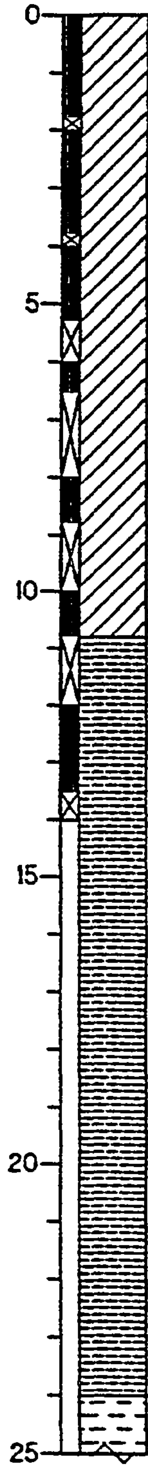
Figure 17

Log of Boring ASB12694

Equipment Mobile CME-750 HSAs

Elevation 5268 37 ft Date 12/09/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
2		0	
6			
13			
13			
7			
7			
8			
9			
3			
5		5	
8			
14			
4			
8			
10			
16			
7			
7			
8			
6		10	
4			
4			
6			
8			
7			
12			
12			
14			
		15	
		20	
		25	



CL, clay, fine- to medium-grained sand, some silt 10 YR 4/6 - dark yellowish brown medium stiff, plastic moist alluvium, rooted, noncalcerous

Color changes to 10 YR 7/3 - very pale brown

Some fine- to coarse-grained sand stiff, nonplastic dry, alluvium, calcereous, fine roots

Trace pink granite gravel, color change to 10 YR 5/4 - yellowish brown slightly plastic slightly moist local white caliche locally very sandy

Color change to 10 YR 6/6 - brownish yellow nonplastic

Color change to 10 YR 4/6 - dark yellowish brown, stiff plastic, moist alluvium abundant caliche at contact

CLAYSTONE, 2 5 Y 6/5 - light yellowish brown flaggy, intensely fractured, soft plastic weathered bedrock iron oxide on fractures gypsum crystals in voids

Color change to 10 YR 3/3 - dark brown moist

Becomes sandier fine- to medium-grained sand color change to 2.5 Y 6/5 light yellowish brown

Interbedded clayshale and sand, color change to 2 5 Y 5/6 - light olive brown

SILTSTONE, clayey sandy 2 5 Y 7/3 - pale yellow thin laminated, low hardness weak weathered, bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

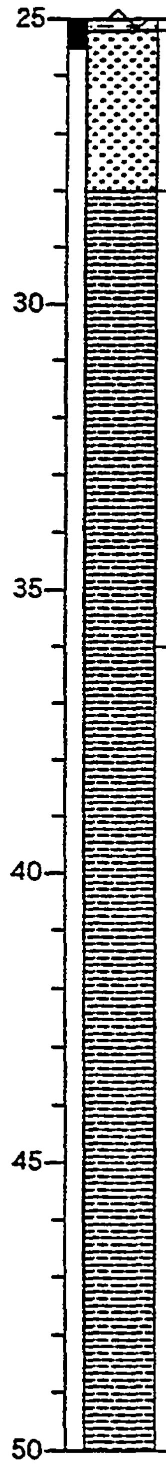
Figure 18

Log of Boring ASB12784

Equipment Mobile CME-750 HSAs

Elevation 5288 37 ft Date 12/09/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
50		25		SANDSTONE, very fine- to fine-grained sand, 2 5 Y 7/3 - pale yellow, low hardness, friable bedrock, dry, noncalcareous
				CLAYSTONE, silty sandy very fine- to fine-grained sand 2 5 Y 5/4 - light olive brown soft, plastic, bedrock, moist, noncalcerous
		30		
10 50		35		Locally silty, some fine-grained sand, color change to 2 5 Y 5/3 - light olive brown, locally thin laminated intensely fractured, soft plastic, weathered bedrock, moist, noncalcareous, iron oxide on fractures
				Color change to 2 5 Y 5/4 - light olive brown, soft, plastic bedrock, moist noncalcareous small angular fragments
		40		
		45		
		50		Total depth = 50 0 feet



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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

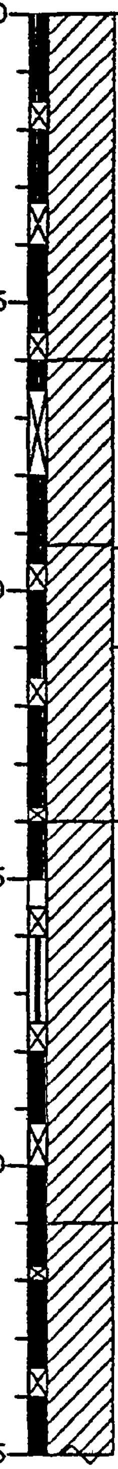
Figure 18

Log of Boring ASB12794

Equipment Mobile CME-750 HSAs

Elevation 5242 72 ft Date 12/13/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
10		0	
13			
15			
12			
5			
2			
3			
3			
5			
10		5	
9			
10			
4			
5			
5			
5			
10			
10			
18			
20		10	
10			
8			
9			
9			
10			
18			
25			
35			
10			
13		15	
9			
10			
9			
10			
10			
10			
8		20	
12			
12			
16			
8			
10			
11			
12			
8			
12			
13		25	



SC, clayey sand, fine- to medium-grained sand, some silt, 10 YR 4/4 – dark yellowish brown, dense slightly plastic moist alluvium, rooted

Color change to 10 YR 8/3 – pale brown, mottled with white caliche

Increase in clay content

Locally sandy, trace gravel

Scattered gravel caliche content increases

SC, clayey sand fine- to coarse-grained sand, 10 YR 8/4 – light yellowish brown, dense nonplastic, moist alluvium, mottled with white caliche

Trace scattered gravel

Clay content gradually increases with depth

CL, sandy clay fine- to coarse-grained sand, 10 YR 4/4 – dark yellowish brown stiff slightly plastic moist, mottled with caliche, trace black lithic fragments alluvium

Color change to 10 YR 5/4 – yellowish brown

Some medium sand color change to 10 YR 6/4 – light yellowish brown trace iron oxide

Sand content increases with depth interlayered clayey sand and sandy clay, trace scattered gravel

SC, clayey sand fine- to coarse-grained sand, scattered gravel 10 YR 5/4 – yellowish brown, dense slightly plastic, moist alluvium, calcerous matrix

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used.

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

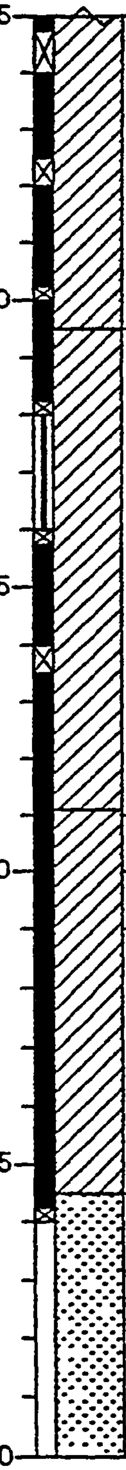
Figure 19

Log of Boring ASB12894

Equipment Mobile CME-750 HSAs

Elevation 5242.72 ft Date 12/13/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Blows/6": 12, 6, 6, 8, 10, 8, 9, 17, 21, 5, 8, 10, 14, 5, 7, 7, 9, 4, 7, 10, 13, 4, 7, 14, 7, 10, 14, 20, 5, 12, 15, 21, 10, 17, 15, 19

Depth (ft.): 25, 30, 35, 40, 45, 50

Sand content increases with depth

Color change to 10 YR 5/8 - yellowish brown

CL, clay some medium-grained sand, some silt, trace very coarse sand 2.5 YR 4/4 - olive brown, stiff, plastic moist alluvium

Trace scattered gravel minor caliche minor iron oxide

SC, clayey sand, 10 YR 5/4 - yellowish brown to 2.5 YR 5/3 - light olive brown dense, plastic clay matrix, moist noncalcareous reworked Denver Formation alluvium

Clay content decreases with depth, color change to 10 YR 6/4 - light yellowish brown, locally very sandy, layers of fine- to coarse-grained sand up to 0.2 foot thick, 10 YR 8/3 - very pale brown

Sand coarsens with depth, fine- to very coarse-grained sand, trace gravel

Very coarse sand and pea gravel

SANDSTONE, fine- to coarse-grained sand, trace clay, 10 YR 6/4 - light yellowish brown, thin laminated, low hardness, friable to weak, minor local iron oxide staining minor caliche, weathered bedrock

Total depth = 50 feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

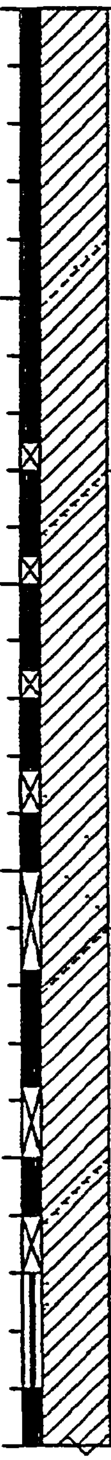
Figure 19

Log of Boring ASB12894

Equipment Mobile CME-750 HSAs

Elevation 5258 54 ft Date 11/28/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
8		0
15		
25		
20		
8		
8		
9		
11		
4		
7		5
11		
12		
4		
5		
7		
8		
5		
7		
8		
11		10
10		
18		
18		
18		
8		
10		
8		
7		
5		
7		15
9		
10		
3		
5		
9		
11		
9		
13		
13		
8		20
5		
7		
7		
9		
6		
6		
9		25



SC, clayey sand fine- to fine-grained sand some silt 10 YR 3/6 – dark yellowish brown, dense 15 to 20 percent low plastic clay rooted, alluvium

Color change to 10 YR 6/4 – light yellowish brown lightly caliche cemented

Clay content increases locally grades to CL, sandy clay becomes well cemented

White caliche

Sand becomes coarser grained 30 percent clay 10 YR 4/6 – dark yellowish brown local white caliche

Color change to 10 YR 5/4 – yellow brown well cemented with calcihe

Clay content increases to 40 percent medium plastic clay, heavy caliche black mineralization

Caliche content increases to 100 percent

CL, sandy clay fine- to very coarse-grained sand, 10 YR 6/4 – light yellowish brown medium stiff medium plastic, moist caliche veining and fracture filling minor black mineral grains, alluvium

Sand content increases with depth calcihe content decreases

SC clayey sand fine- to coarse-grained sand, gravel 10 YR 6/4 – light yellowish brown medium dense nonplastic dry, alluvium

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by.
Harding Lawson Associates

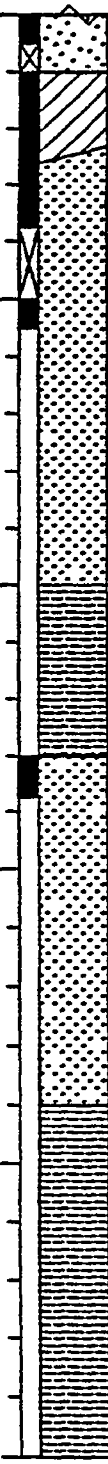
Figure 20

Log of Boring ASB12894

Equipment Mobile CME-750 HSAs

Elevation 5258 54 ft Date 11/28/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
15		25	
10			
30			
48			
50			
10			
43			
50			
50		30	
		35	
35			
50			
		40	
		45	
		50	



SW, sand, fine- to coarse-grained sand, 10 YR 6/6 – brownish yellow medium dense nonplastic, dry alluvium

CL, sandy clay fine- to coarse-grained sand pea gravel 10 YR 6/4 – light yellowish brown hard nonplastic dry alluvium, calcareous

SANDSTONE, fine- to medium-grained sand, 2 5 YR 7/4 – pale yellow, low hardness friable, noncalcareous, rounded to subrounded grains, local iron oxide staining weathered bedrock

Color change to 2 5 YR 6/4 – light yellowish brown, 5 percent medium-grained sand

CLAYSTONE, 2 5 YR 5/2 – grayish brown, soft plastic weathered bedrock

SANDSTONE, laminated with claystone very fine-grained 2 5 YR 6/6 – olive yellow papery, moderately fractured at low angles low hardness friable moderately weathered bedrock iron-oxide staining along fractures

CLAYSTONE, 2.5 YR 5/4 – light olive brown, papery moderately fractured, soft, plastic moderately weathered, bedrock

Becomes moist, claystone content increases with depth

Becomes wet

Total depth = 50 0 feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

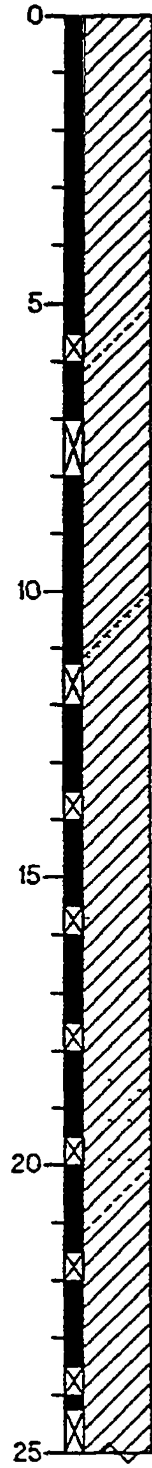
Figure 20

Log of Boring ASB12894

Equipment Mobile CME-75 HSAs

Elevation 5258 30 ft   Date 11/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Blows/6": 9, 9, 11, 12, 9, 11, 8, 9, 6, 6, 9, 13, 5, 7, 9, 9, 5, 8, 9, 9, 9, 15, 15, 15, 14, 15, 18, 20, 9, 11, 14, 22, 9, 19, 21, 28, 12, 20, 28, 18, 8, 18, 18, 18, 13, 13, 19, 23, 11, 20

SC–SM, clayey sand to silty sand, very fine- to medium-grained, medium dense, nonplastic, dry alluvium lightly caliche cemented, trace silt

Increase in medium-grained sand

Fining downward, increase in fine sand and clay content

CL, sandy clay 10 YR 6/4 – light yellowish brown, low plastic clay, alluvium

Decrease in clay content trace silt poorly sorted 5 percent medium sand 2 percent coarse-grained sand, less well-cemented

SC, clayey sand poorly sorted, very fine- to coarse-grained sand 10 YR 6/4 – light yellowish brown, medium dense, 20 percent low plastic clay dry alluvium, trace subrounded quartz gravel

Heavy white caliche

Very well cemented with caliche

Clay content increases to 35 percent

Color change to 10 YR 5/4 – yellowish brown scattered white caliche nodules, dense, very well cemented poorly sorted 5 percent silt

Increase in clay content 40 percent low to medium plastic clay

CL, sandy clay very fine- to coarse-grained sand, 10 YR 5/3 – brown, very stiff, low plasticity dry, alluvium

Ashy appearance some black mineral grains

Trace fine gravel

Becomes micaceous

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2. Munsell color chart used

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Commerce City, Colorado

Prepared by:
Harding Lawson Associates

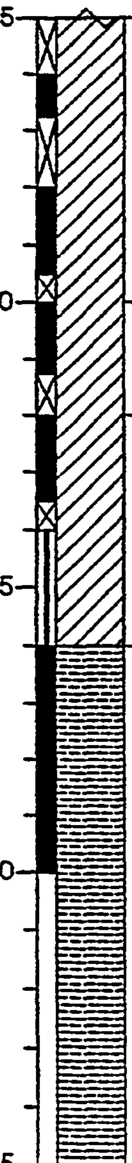
Figure 21

Log of Boring BRB13094

Equipment Mobile CME-75 HSAs

Elevation 5258.30 ft. Date 11/30/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
20		25
18		
9		
18		
15		
16		
8		
15		
40		
28		30
18		
25		
25		
25		
8		
15		
9		
11		
		35
8		
18		
20		
22		
12		
18		
40		
40		
		40
		45
		50



Sand size increasing, coarsening downward, coarse sand and fine subangular gravel, color change to 10 YR 4/3 - dark brown with white caliche, medium plasticity, black mineralization veining

Increase in sand content very fine- to very coarse-grained sand, trace fine gravel poorly sorted color change to 10 YR 5/3 - brown with white caliche in nodules and anastomozing veinlets

Some clayey sand layers, micaceous

Becomes gravelly, color change to 10 YR 6/4 - light yellowish brown

CLAYSTONE, 2 5 Y 6/4 - light yellowish brown to 2 5 Y 6/6 - olive yellow thick bedded little to moderately fractured low hardness weak moderately weathered bedrock

Very carbonaceous

Total depth = 45 0 feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

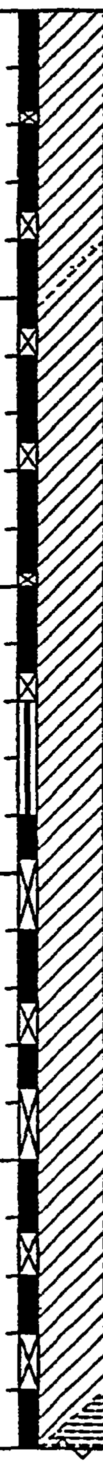
Figure 21

Log of Boring BRB13094

Equipment Mobile CME-750 HSAs

Elevation 5258 30 ft Date 12/14/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
8		0
10		
13		
11		
5		
6		
6		
7		
7		
11		5
4		
15		
6		
6		
9		
11		
10		
11		
11		
14		10
9		
7		
4		
11		
12		
10		
12		
7		15
9		
9		
9		
5		
6		
8		
9		
7		
12		
12		20
14		
7		
12		
14		
19		
10		
44		
50		
50		
6		25



SC, clayey sand, fine- to medium-grained sand, some silt and clay, 10 YR 6/4 light yellowish brown dense, plastic clay matrix, moist noncalcareous thin clay layers, alluvium

Becomes calcareous

CL, sandy, silty, clay fine- to medium-grained sand, 10 YR 6/4 - light yellowish brown, stiff, nonplastic, dry, calcareous minor white caliche mottling locally very sandy, alluvium

SC, clayey sand, fine- to medium-grained sand some silt, 10 YR 6/4 - light yellowish brown, dense nonplastic, dry, calcareous, alluvium

CL, sandy silty, clay, fine- to medium-grained sand, 10 YR 6/4 - light yellowish brown, stiff nonplastic dry calcareous alluvium

SM, silty sand fine- to medium-grained sand, trace clay, 10 YR 6/4 - light yellowish brown dense nonplastic calcareous alluvium

CL, sandy clay scattered fine- to medium-grained sand 10 YR 6/4 - light yellowish brown, stiff, nonplastic dry, calcareous alluvium

Some coarse-grained sand trace pea gravel 10 YR 5/6 - yellowish brown, stiff slightly plastic, slightly moist, mottled with white caliche

Some very coarse sand and pea gravel

Color change to 10 YR 6/3 - pale brown non-plastic dry mottled with common white caliche rare pink granite gravel

CLAYSTONE, fine- to coarse-grained sand, some silt flaggy, thin laminated soft to low hardness plastic to friable, white crystalline gypsum fracture filling calcareous, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

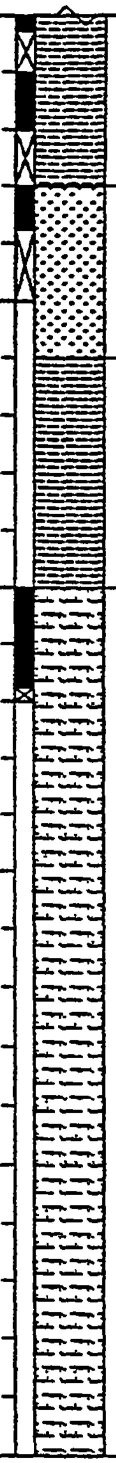
Figure 22

Log of Boring SAB13194

Equipment Mobile CME-750 HSAs

Elevation 5258 30 ft   Date 12/14/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Description
16		25	Locally silty
16			
16			
9			
18			
15			SANDSTONE, clayey with pink granite gravel, 10 YR 6/4 – light yellowish brown, slight olive cast soft to low hardness, plastic to friable dry, white crystalline gypsum fracture filling, calacreous weathered bedrock
15			
		30	
			CLAYSTONE, olive brown (based on auger cuttings)
			Olive brown claystone some sand and gravel (based on auger cuttings)
12		35	INTERBEDDED CLAYSTONE AND SILTSTONE, claystone 2 5 Y 5/3 – light olive brown, fractured soft plastic, weathered bedrock, moist locally calcareous minor iron-oxide staining on fractures siltstone 2 5 Y 7/8 yellow, low hardness friable, dry weathered bedrock
16			
30			
35			
		40	Olive brown claystone soft plastic bedrock moist noncalcareous (based on auger cuttings)
			Olive brown claystone trace silt soft, plastic, bedrock moist, noncalcareous (based on auger cuttings)
		45	
		50	Total depth = 50 0 feet



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Commerce City, Colorado

Prepared by:
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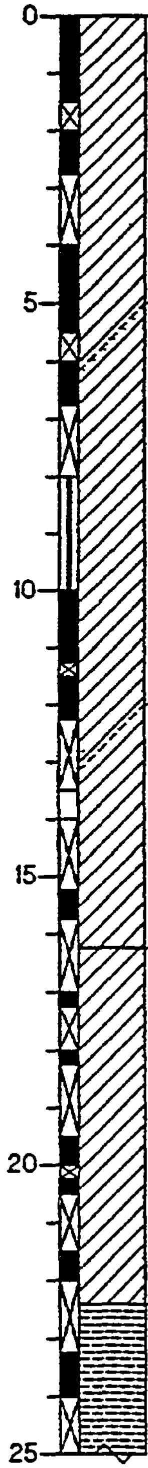
Figure 22

Log of Boring SAB13184

Equipment Mobile CME-75 HSAs

Elevation 5259 70 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample



Depth 0–25 ft.

Blows/6": 7, 10, 12, 14, 5, 6, 5, 6, 7, 8, 9, 10, 7, 8, 13, 13, 15, 30, 50, 15, 21, 25, 21, 11, 15, 35, 50, 21, 27, 50, 7, 50, 23, 25, 26, 18, 50, 30, 50, 50, 25, 26, 11, 19, 11, 30

CLAY, clay with fine- to medium-grained sand, trace coarse-grained sand 10 YR 6/4 light yellowish brown stiff nonplastic dry alluvium

Becomes calcareous

SC, clayey sand fine to coarse-grained sand 10 YR 4/6 - dark yellowish brown stiff, nonplastic dry mottled with caliche alluvium

CL, clay with fine- to medium-grained sand 10 YR 7/2 - light gray hard nonplastic dry caliche-rich alluvium

SC, sandy clay clay coarse-grained sand, gravel 10 YR 5/4 yellowish brown hard, nonplastic slightly moist, alluvium

Color change to 2.5 Y 4/4 olive brown clay, increase in fine-grained sand with trace cobbles becomes moist

CLAYSTONE, sandy clayshale with trace coarse sand, 2 5 YR 4/4 - olive brown, fractured, soft, plastic moist, gypsum, calcareous iron oxide, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

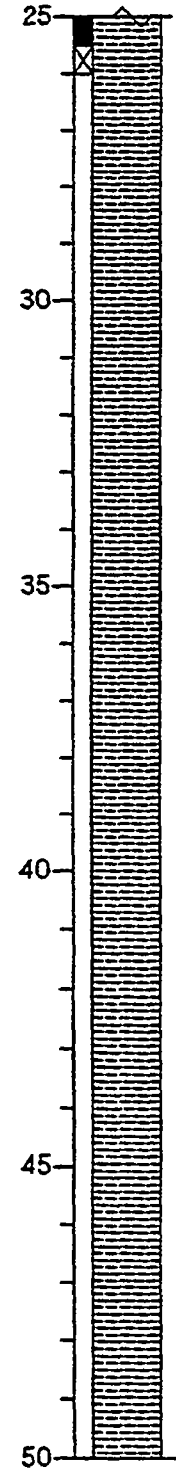
Figure 23

Log of Boring ASB13284

Equipment Mobile CME-75 HSAs

Elevation 5259 70 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
30			
30			



Total depth = 50 0 feet

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 23

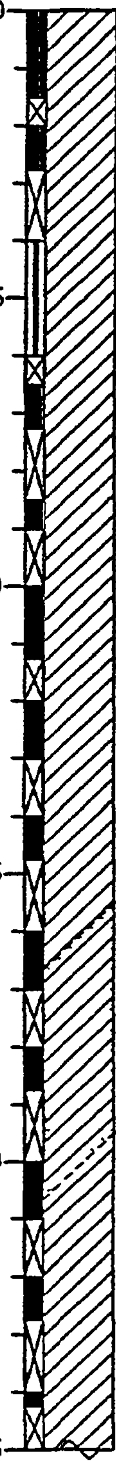
Log of Boring ASB13284

Equipment Mobile CME-75 HSAs

Elevation 5250 88 ft   Date 11/18/84

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
		0
12		
15		
15		
16		
7		
7		
8		
8		
		5
5		
8		
8		
10		
5		
7		
6		
7		10
10		
10		
11		
8		
11		
11		
13		
8		
17		
17		15
16		
8		
20		
15		
12		
15		
20		
50		
12		20
25		
25		
18		
8		
12		
11		
12		
15		
15		
16		25

Sample



CL, clay fine-grained sand and silt, 10 YR 4/4 - dark yellowish brown very stiff, slightly plastic moist rooted alluvium

Caliche zone becomes stiff dry

Color change to 10 YR 6/4 - light yellowish brown with white caliche

SC, clayey sand fine- to coarse-grained sand, trace gravel, 10 YR 4/4 - dark yellowish brown dense nonplastic, dry calcareous moderately cemented, alluvium

Increase in gravel

CL, sandy clay, clay with gravel, 10 YR 6/3 - pale brown to 10 YR 4/4 - light yellowish brown hard nonplastic, calcareous alluvium

Color change to 10 YR 6/3 - pale brown with 20 percent fine- to coarse-grained sand

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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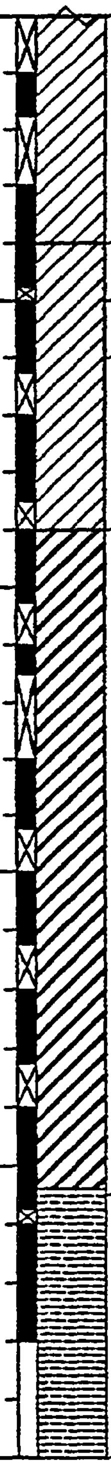
Prepared for: Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	**Figure 24** **Log of Boring ASB13384**

Equipment Mobile CME-75 HSAs

Elevation 5250 88 ft. Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
23		25		
11				Increase in sand to 40 percent with trace pebbles and gravel
26				
33				
45				
19				
20				
22				SC, clayey sand sand and gravel, 7 5 YR 4/6 – strong brown, hard plastic moist, calcareous, alluvium
20				
12		30		Color change to 2 5 Y 5/4 – light olive brown to 2 5 Y 4/4 – olive brown, becomes slightly plastic
18				
22				Color change to 10 YR 7/1 – light grey with grey volcanics vuggy with iron-oxide staining, welded tuff
30				
11				
20				
23				
32				
12				CH, clay, trace gravel, 2 5 Y 4/4 – olive brown, hard, plastic, moist, reworked Denver Formation fragments, calcareous alluvium
14				
22		35		
26				
7				
10				
16				
17				
7				Color change to 2 5 Y 5/4 – light olive brown, noncalcareous
7				
10				
10				
4		40		
10				
14				
14				
7				
8				
11				
11				
5				
7				
8		45		
21				CLAYSTONE, 2 5 Y 5/4 – light olive brown, laminated soft, fractured, moist, iron-oxide on fractures, weathered bedrock
8				
16				
31				
36				
		50		Total depth = 50 0 feet



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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

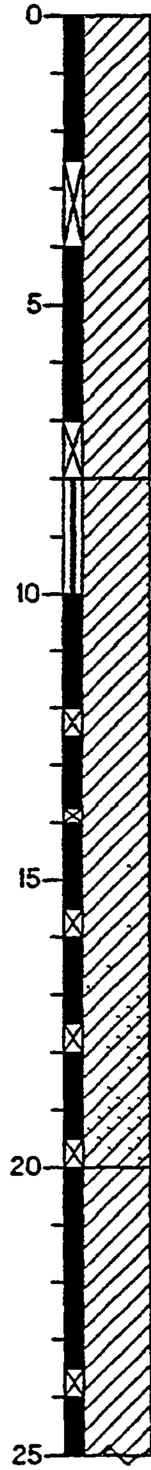
Figure 24

Log of Boring ASB13394

Equipment Mobile CME-75 HSAs

Elevation 5242 02 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)
6	
6	
7	
6	
7	
7	
7	
5	
7	
7	
6	
6	
5	
4	
10	
16	
16	
20	
25	
23	
4	
16	
23	
18	
5	
6	
7	
16	
4	
12	
15	
16	
8	
9	
16	
20	
10	
12	
15	
20	
6	
7	
18	
15	
8	
12	
16	



CL, sandy silty clay, 20 percent sand 10 YR 5/4 – yellowish brown stiff, slightly plastic slightly moist, rooted alluvium

Decrease in sand content to 10 percent, color change to 10 YR 7/3 – very pale brown caliche

Increase in sand to 40 percent color change to 10 YR 6/4 – light yellowish brown becomes medium dense and dry

Decrease in sand to 10 percent, becomes stiff

SC, clayey sand fine- to medium-grained sand 40 percent clay matrix 10 YR 6/4 – light yellowish brown hard nonplastic, dry, caliche-rich, alluvium

Decrease in fine- to medium-grained sand content to 25 percent

Sand content increases downward to 40 percent

CL sandy clay less than 40 percent fine- to medium-grained sand trace pea gravel 10 YR 5/6 – yellowish brown stiff slightly plastic, slightly moist caliche-rich alluvium

Decrease in gravel

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Commerce City, Colorado

Prepared by:
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Figure 25

Log of Boring BRB13494

Equipment Mobile CME-75 HSAs

Elevation 5242.02 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
22		25		
8				SC, clayey sand fine- to coarse-grained sand, 10 YR 5/6 - yellowish brown, dense, slightly plastic moist alluvium
14				
14				
20				
7				
16				
26				
32				
10		30		Increase in clay content, color changes to 10 YR 6/4 - light yellowish brown
12				
13				
28				Interbedded sandy clay and clayey sand with color change to 10 YR 5/6 yellowish brown stiff plastic with trace pea gravel
11				
22				
14				
19				
6				
7				
10		35		
22				
5				
11				
14				
14				CL, sandy clay trace gravel 10 YR 5/6 - yellowish brown stiff plastic moist minor caliche, alluvium
6				
7				
8				
17				
3		40		
7				
12				
15				
3				
4				
7				
19				
4				
8				
12		45		
15				
5				
8				
12				
15				
5				
5				Very fine- to fine-grained sand
10				
12				
		50		Total depth = 50 0 feet

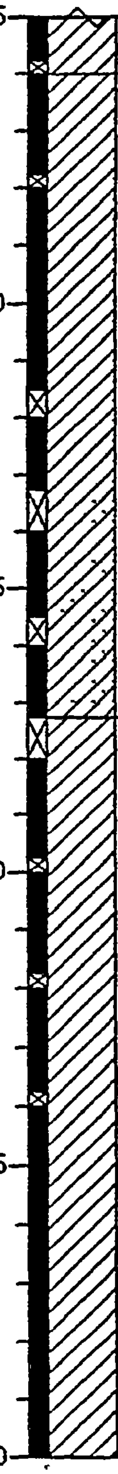

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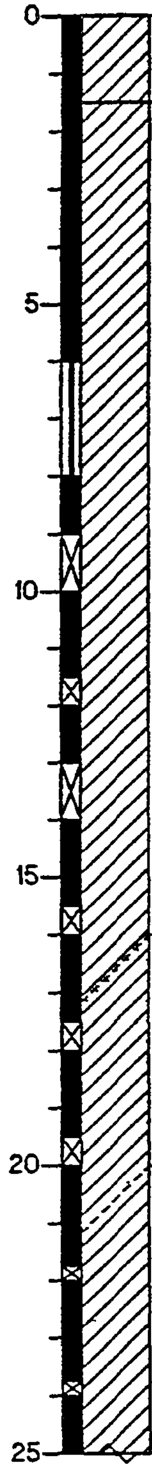
Figure 25

Log of Boring BRB13494

Equipment Mobile CME-75 HSAs

Elevation 5251.59 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
9, 12, 11		0		SC, clayey sand, very fine- to fine-grained sand, 10 YR 5/4 – yellowish brown, medium dense, nonplastic, caliche-rich, rooted, alluvium
12, 8, 7, 9, 10, 7, 8, 12, 8		5		CL, clay very fine- to fine-grained sand, 10 YR 5/4 – yellowish brown, low plasticity, dry, caliche cemented alluvium
5, 4, 4, 4				Color change to 10 YR 6/4 – light yellowish brown
4, 4, 15, 18		10		Heavy caliche zone
7, 8, 11, 13, 9, 15, 19, 19, 8		15		Sand becomes poorly sorted and micaceous
15, 15, 15, 7, 13, 15, 17				SC, clayey sand 10 YR 4/4 – dark yellow brown loose dry alluvuim
10, 15, 15, 15		20		CL, sandy clay 10 YR 5/6 – yellow brown, dry alluvrum
10, 20, 20, 21				Heavy caliche zone
4, 15, 20		25		Thin gravel layer slight increase in clay



Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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Figure 28

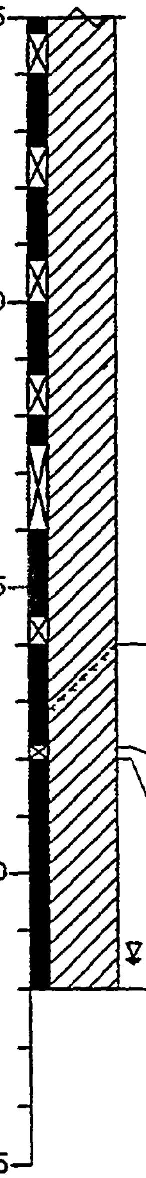
Log of Boring BRB13584

Equipment Mobile CME-75 HSAs

Elevation 5251 59 ft   Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
21		25
2		
2		
5		
10		
5		
15		
18		
19		
4		30
15		
21		
23		
7		
20		
15		
20		
5		
10		
19		35
20		
8		
9		
14		
14		
8		
11		
11		
11		
9		40
9		
12		
12		
		45

Sample



Increase in sand content, color changes to 10 YR 5/3 - brown, low plasticity dry, well-cemented, caliche-rich alluvium

Dendritic caliche, fine to coarse gravel

Sand content increases to 15 percent, no caliche

SC, clayey sand, very fine- to very coarse-grained sand 10 YR 5/2 - grayish brown to 10 YR 5/3 - brown medium dense nonplastic poorly sorted dry, alluvium

Very fine- to medium-grained sand layers 1-inch thick

Sand and gravel well-graded color change to 2 5 Y 5/3 - light olive brown, becomes slightly moist

Water level estimated during drilling at 41 5 feet

Total depth = 42 0 feet

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Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 28

Log of Boring BRB13594

Equipment Mobile CME-75 HSAs

Elevation 5287 15 ft   Date 11/18/94

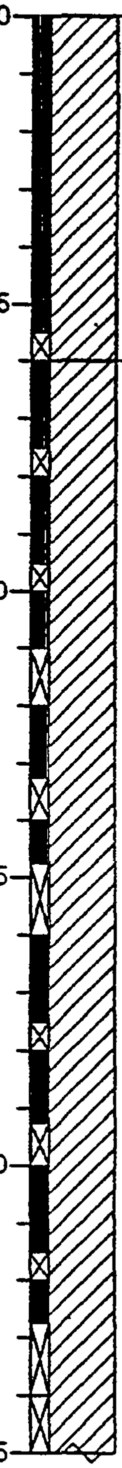
Blows/6"

3
18
20
20
9
10
10
12
8
8
9
8
6
8
7
10
10
9
8
9
6
6
6
10
12
22
35
35
12
22
22
21
9
21
20
19
5
14
20
25
10
20
20
18
12
18
30

HNU/OVA (ppm)

Depth (ft.) Sample

0
5
10
15
20
25



SP, sand, very fine-grained to fine-grained sand 10 YR 6/4 – light yellowish brown medium dense, nonplastic, dry, rooted, lightly cemented, alluvium

Color change to 10 YR 6/6 – brownish yellow, less cemented, localized caliche veins

SC, , clayey sand, 10 YR 6/4 – light yellowish brown, loose low plasticity, dry, caliche-cemented alluvium

Very heavy caliche dense well-cemented

Sand becoming poorly sorted, 5 percent medium- to very coarse-grained trace fine subrounded, subangular gravel medium gravel

Caliche in veins well-cemented, becoming fine-grained

Very fine- to fine-grained sand trace medium-grained to coarse-grained cobbles

Increase in clay to 40 percent

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated.
2 Munsell color chart used

RMA2

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Figure 27

Log of Boring BRB13694

Equipment Mobile CME-75 HSAs

Elevation 5287 15 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
30		25		
6				Color change to 10 YR 5/4 - yellowish brown becomes very stiff to hard
24				
24				CLAYSTONE, 2 5 Y 5/2 - grayish brown, flaggy, closely fractured at high angles low hardness weak, iron-oxide stained, interbedded with siltstone and sandstone, weathered bedrock
19				
6				
17				Increase in very fine-grained sand color change to 10 YR 7/3 - very pale brown to 10 YR 7/6 yellow with oxidation zones from 29 5 to 34 feet
24		30		
22				
6				
24				
35				
50				
				Color change to 10 YR 4/2 - dark grayish brown
		35		
		40		
				Cuttings become plastic
		45		
				Cuttings become slightly moist, medium plastic
		50		Total depth = 50 0 feet

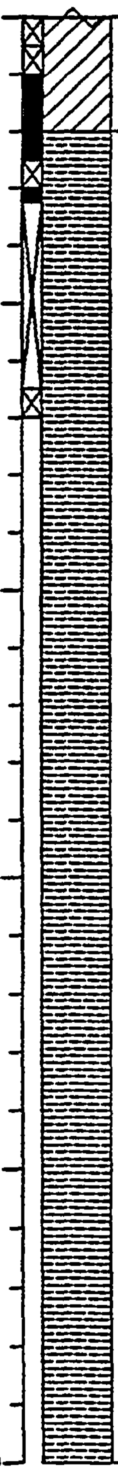

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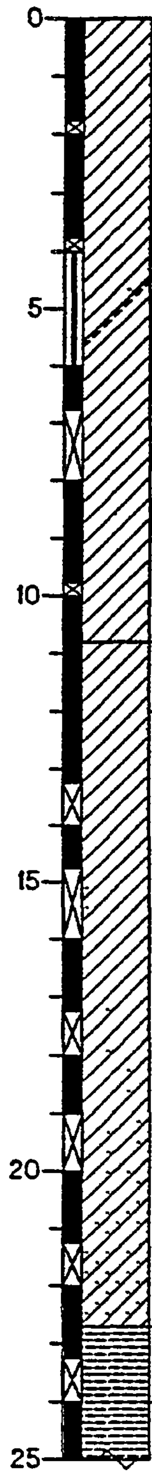
Figure 27

Log of Boring BRB13894

Equipment Mobile CME-75 HSAs

Elevation 5269.04 ft   Date 11/18/94

Blows/6"	HNU/OVA (ppm)
11	
16	
24	
20	
10	
7	
7	
9	
10	
8	
10	
10	
12	
16	
12	
13	
8	
10	
11	
15	
10	
19	
24	
20	
10	
12	
14	
16	
6	
16	
20	
23	
11	
19	
19	
14	
10	
29	
30	
25	
10	
12	
20	
13	
10	
20	
30	



SC, clayey sand fine- to medium-grained sand, 25 percent silt and clay 10 YR 5/4 - yellowish brown medium dense, nonplastic, moist, rooted, alluvium

Increase in clay color changes to 10 YR 5/6 - yellowish brown, becomes hard, dry

Decrease in clay

CL, sandy clay, fine- to medium-sand, 10 YR 6/4 - light yellowish brown, nonplastic dry, caliche-rich alluvium

Sand content increasing

SC, clayey sand fine- to medium-grained sand 10 YR 6/4 - light yellowish brown stiff to hard nonplastic, dry alluvium

Color change to 10 YR 6/3 - pale brown due to increased caliche

Trace coarse-grained sand and gravel color change to 2/5 Y 6/3 light brown becomes dense slightly plastic moist

Coarse gravel and cobbles composed of pink granite with white quartz

CLAYSTONE, 2 5 YR 5/4 - light olive brown closely fractured soft plastic, moist iron-oxide stained weathered bedrock

Grades to 2.5 Y 5/2 grayish brown to 2 5 5/0 grey

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

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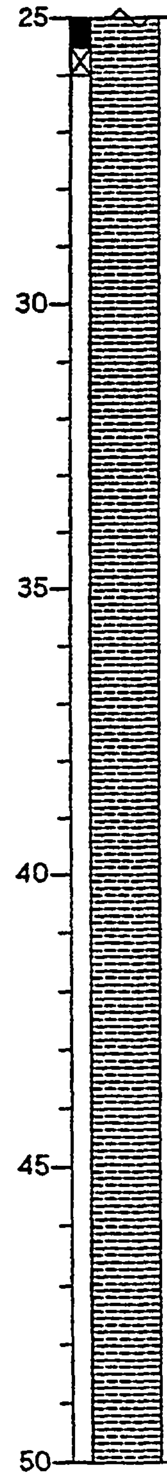
Figure 28

Log of Boring BRB13794

Equipment Mobile CME-75 HSAs

Elevation 5269 04 ft Date 11/18/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
32		25	



Cuttings olive brown

Total depth = 50 0 feet

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Figure 28

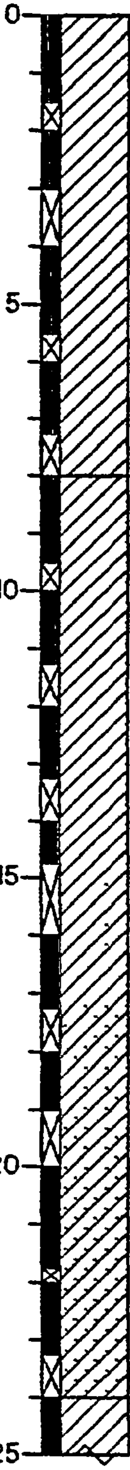
Log of Boring BRB13794

Equipment Mobile CME-75 HSAs

Elevation 5239.31 ft Date 1/6/94

Blows/6"	* HNU/OVA (ppm)	Depth (ft)
8		0
8		
15		
18		
9		
6		
8		
7		
		5
9		
10		
10		
9		
5		
7		
7		
7		
10		10
15		
11		
12		
5		
7		
11		
13		
12		
22		
22		15
22		
7		
12		
12		
13		
13		
17		
14		
12		
6		20
6		
10		
10		
18		
32		
27		
34		
18		
23		
16		25

Sample



CL, clay, fine- to medium-grained sand, 10 YR 4/6 dark yellowish brown low plasticity stiff, slightly moist, rooted, alluvium

Becomes calcareous

SC, clayey sand 50 percent fine- to medium-grained sand 10 YR 6/6 – brownish yellow stiff, nonplastic dry, alluvium

Becomes calcareous

Decrease in sand content to 20 percent color change to 10 YR 6/4 – light yellowish brown

Slight increase in sand content to 25 percent

White caliche filling fractures

CL, sandy clay, less than 20 percent fine- to medium-grained sand 10 YR 6/4 – light yellowish brown stiff, high plasticity, slightly moist alluvium

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated.
2.Munsell color chart used

RMA2

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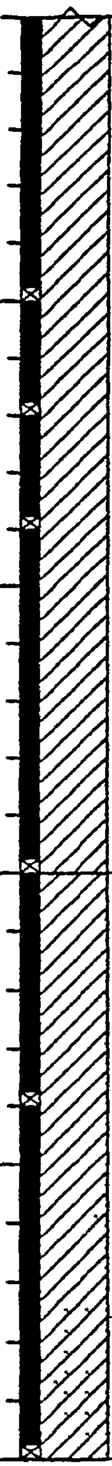
Figure 28

Log of Boring BRB13884

Equipment Mobile CME-75 HSAs

Elevation 5239 31 ft Date 1/6/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
22		25	
7			
12			
12			
20			
18			
38			
38			
40			
8		30	
12			
18			
18			
5			
15			
20			
22			
8			
10			
14		35	
20			
9			
17			
25			
29			
5			
8			
14			
14			
8		40	
18			
25			
24			
10			
15			
15			
16			
9			
18			
17		45	
25			
20			
19			
18			
20			
10			
15			
16			
20			
		50	



Scattered pea-sized gravel

Becomes moist

Slight increase in sand content

Increase in sand content

SC, sandy clay well sorted, poorly graded sand, fine- to medium-grained sand, 10 YR 7/3 - very pale brown, dense, nonplastic, moist, alluvium

Interbedded 1-inch thick clay layers

Becomes very moist trace coarse sand

Total Depth = 50 0 feet

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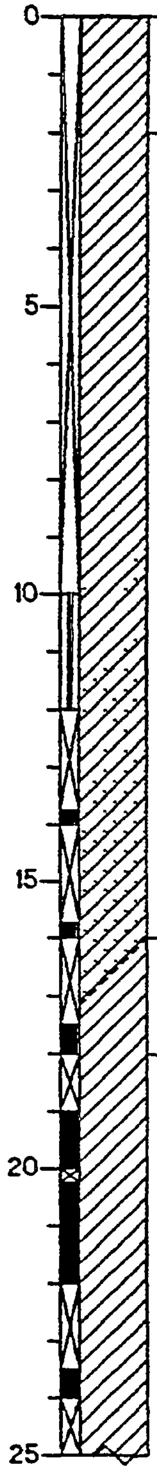
Figure 29

Log of Boring BRB13894

Equipment Mobile CME-750 HSAs

Elevation 5276.44 ft Date 12/05/94

Blows/6"	HNU/OVA[1] (ppm)	Depth (ft.)	Sample



Blows/6": 3, 7, 18, 13, 9, 10, 12, 12, 6, 6, 7, 8, 6, 6, 7, 7, 5, 7, 6, 7, 6, 6, 6, 7, 4, 8, 5, 6, 10, 12, 9, 17, 11, 9, 8, 13, 10, 23, 21, 15, 5, 4, 5, 5, 4, 6, 6

SC, clayey sand, very fine- to fine-grained sand, 10 YR 4/6 - dark yellowish brown grading to 10 YR 6/6 - brownish yellow, medium dense nonplastic dry trace silt, rooted lightly cemented alluvium

Caliche

Thin layers of well sorted coarse sand up to 1/2 inch thick at 1 inch intervals, loose

Some medium- and coarse-grained sand

Increase in clay content cemented

Color change to 10 YR 4/6 - dark yellowish brown with white caliche well cemented with caliche

Heavy caliche trace fine glassy quartz with a welded appearance

CL, sandy clay very fine- to coarse-grained sand 10 YR 8/4 - very pale brown stiff, low-plastic, dry trace fine glassy gravel, trace very coarse sand cemented alluvium

Color change to 10 YR 5/3 - brown well cemented caliche in white nodules trace fine subrounded gravel

Becomes less well cemented heavy caliche

Color change to 10 YR 5/4 - yellowish brown, slightly moist white crystals black mineralization, locally very sandy very fine- to fine-grained trace gravel

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2 Munsell color chart used

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Prepared by:
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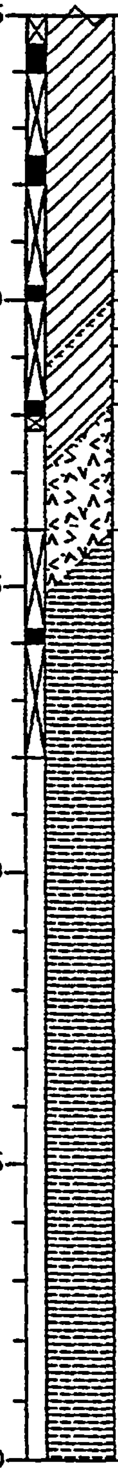
Figure 30

Log of Boring SAB13884

Equipment Mobile CME-750 HSAs

Elevation 5276 44 ft   Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
7		25
4		
7		
5		
8		
4		
8		
10		
15		
4		30
14		
28		
50		
50		
10		
12		
25		35
50		
10		
20		
35		
37		
		40
		45
		50



Clay becomes medium plastic

Sand becomes coarse- to very coarse-grained

Fine gravel and cobbles, oxidized

Rounded gravel and cobbles

SC, clayey sand, poorly sorted sand,

Quartz cobbles

Granite cobbles

Well sorted medium sand, minor clay content loose black mineralization

VOLCANOCLASTIC SANDSTONE, 10 YR 7/1 - light gray hard moderately strong, ashy appearance, glassy sand grains, weathered bedrock

SANDSTONE, 2 5 YR 7/6 - yellow very fine-grained, blocky, thick, moderately fractured low hardness, weak friable, minor 7 5 YR 6/8 - reddish yellow, oxidation moderately weathered bedrock

Sandstone beds become thinner

Becomes moist, plastic

Total depth = 50 0 feet

RMA2

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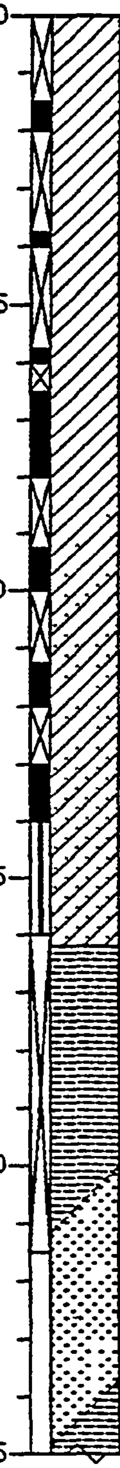
Figure 30

Log of Boring SAB13894

Equipment Mobile CME-750 HSAs

Elevation 5279.99 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Description
11, 12, 20, 16		0		SC, clayey sand, fine- to coarse-grained sand 10 YR 5/4 - yellowish brown dense nonplastic, moist rooted alluvium
11, 8, 6, 6				Becomes calcareous, sand fining downward, color change to 10 YR 6/3 - pale brown, medium dense, dry
13, 10, 7, 6		5		
4, 4, 6, 7				Increase in clay content becomes stiff
10, 12, 12, 14				Granite and quartz-rich gravel Color change to 10 YR 8/2 - white well cemented with caliche
12, 12, 14, 16		10		
11, 15, 11, 12				Gravel layer
		15		
9, 21				Color change to 10 YR 6/3 - pale brown to 2.5 Y 6/3 - light yellowish brown
28, 49, 12, 18, 21, 24				CLAYSTONE, silty claystone 10 YR 4/2 - dark grayish brown fractured soft oxidized, weathered bedrock
19, 29, 50		20		SANDSTONE, silty sandstone 2.5 Y 5/6 - light olive brown slightly flaggy locally thin laminated to laminated, soft gypsum crystals weathered bedrock
		25		CLAYSTONE, silty claystone 2.5 Y 6/3 - light yellowish brown, thin laminated soft moist weathered bedrock



Notes 1. All HNU/OVA readings equal to zero parts per million except as indicated
2. Munsell color chart used.

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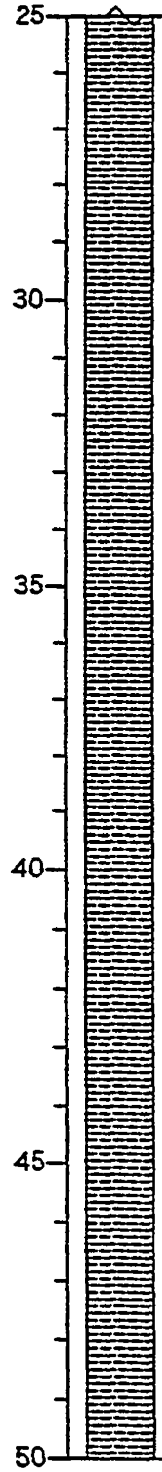
Figure 31

Log of Boring BRB14094

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample	Equipment Mobile CME-750 HSAs
				Elevation 5279 89 ft Date 12/05/94



Color change to 10 YR 4/2 – dark grayish brown

Color change to 2 5 Y 4/3 – olive brown

Color change to 2 5 Y 5/3 – light olive brown

Color change to 2 5 Y 4/3 – olive brown

Total depth = 50 0 feet

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Commerce City, Colorado

Prepared by·
Harding Lawson Associates

Figure 31

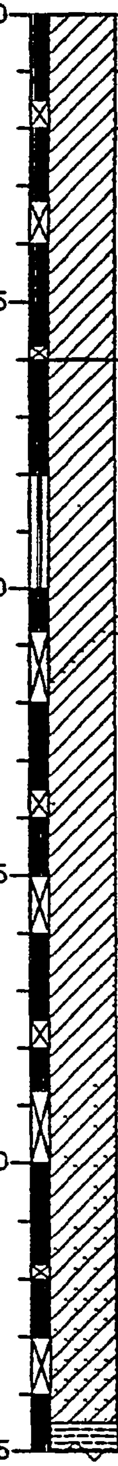
Log of Boring BRB14094

Equipment Mobile CME-750 HSAs

Elevation 5264.28 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
		0
16		
16		
15		
14		
4		
5		
7		
8		
9		
11		5
11		
13		
7		
6		
5		
6		
12		10
11		
12		
12		
8		
27		
22		
24		
14		
14		
18		15
20		
10		
28		
33		
41		
35		
35		
33		
42		
29		20
3		
30		
30		
27		
11		
17		
12		
14		
7		
11		25

Sample



SC, clayey sand, fine- to medium-grained sand, 10 YR 4/4 - dark yellowish brown hard plastic, moist rooted alluvium

Color change to 10 YR 6/4 - light yellowish brown becomes dense

Color change to 10 YR 74 - very pale brown, becomes medium dense nonplastic, dry increase in caliche

CL, sandy clay fine- to medium-grained sand 10 YR 7/3 - very pale brown stiff nonplastic dry calareous, alluvium

SC, clayey sand fine- to medium-grained sand and silt, 10 YR 6/4 - light yellowish brown stiff nonplastic dry calareous alluvium

Sand content increases

Sand content decreases

Heavy caliche zone

CLAYSTONE, silty claystone 10 YR 5/2 - grayish brown thin laminated fractured soft, oxidized, weathered bedrock

Notes 1 All HNU/OVA readings equal to zero parts per million except as indicated
2. Munsell color chart used

RMA2

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Figure 32

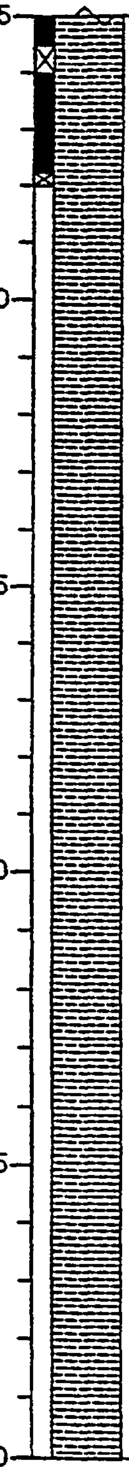
Log of Boring BRB14194

Equipment Mobile CME-750 HSAs

Elevation 5264.28 ft Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)
21		25
38		
7		
7		
10		
24		
		30
		35
		40
		45
		50

Sample



Color change to 2 5 Y 8/3 – light yellowish brown, fractured, soft oxidized, slightly calcareous, weathered bedrock

Color change to 2.5 Y 5/4 – light olive brown

Total depth = 50 0 feet

RMA2

Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

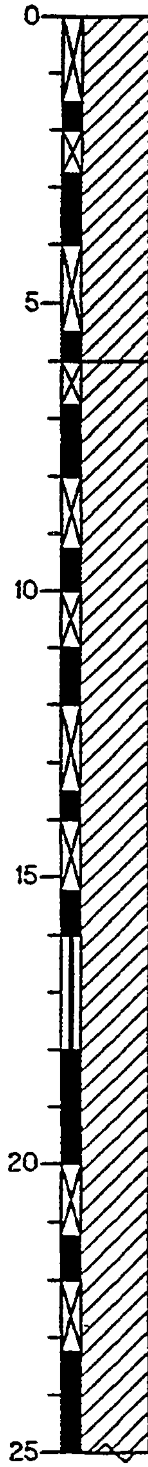
Figure 32

Log of Boring BRB14184

Equipment Mobile CME-750 HSAs

Elevation 5242 76 ft   Date 12/05/94

Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample
2 7 14 12 8 16 12 14 8 6 14 10 3 7 12 11 12 22 26 31 12 28 31 16 16 42 26 24 11 19 15		0–15	
7 9 12 14 11 4 26 19 3 7 7 6		18–25	



SC, clayey sand, fine- to coarse-grained sand, 10 YR 6/4 - dark yellowish brown stiff moist, rooted alluvium

CL, clay, 25 percent fine- to coarse-grained sand, 10 YR 6/3 - pale brown stiff nonplastic, dry, calcareous alluvium

Heavy white caliche color change to 10 YR 8/2 - white

Increase in gravel to 5 percent

Increase in fine- to medium-grained sand to 15 percent color change to 10 YR 6/3 - pale brown

Increase in fine- to medium-grained sand to 20 percent color change to 10 YR 6/4 - light yellowish brown becomes slightly moist some caliche

Increase in sand content

Pea gravel and calcium carbonate

Color change to 10 YR 5/4 - yellowish brown

Notes 1.All HNU/OVA readings equal to zero parts per million except as indicated
2.Munsell color chart used

RMA2

Prepared for:
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
Harding Lawson Associates

Figure 33

Log of Boring BRB14294

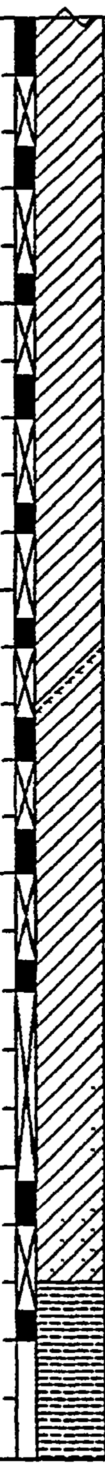
Blows/6"	HNU/OVA (ppm)	Depth (ft.)	Sample

Equipment Mobile CME-750 HSAs

Elevation 5242 76 ft Date 12/05/94

Blows/6": 3, 11, 50, 5, 14, 18, 23, 6, 9, 12, 17, 6, 12, 20, 28, 4, 7, 9, 12, 4, 12, 16, 14, 5, 7, 7, 9, 3, 9, 17, 15, 14, 9, 8, 15, 5, 16, 30, 18, 5, 11, 15, 9, 3, 4, 4, 7

Depth (ft.): 25, 30, 35, 40, 45, 50



SC, medium-grained sand trace silt, clay 10 YR 6/3 – pale brown dense slightly plastic moist, calcareous alluvium

CLAYSTONE, silty claystone very fine-grained sand, 10 YR 5/2 – to 10 YR 5/3 – grayish dark brown, stiff plastic moist, weathered bedrock

Color change to 10 YR 5/4 – yellowish brown with olive cast, becomes very moist

Total depth = 50 0 feet

RMA2

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Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by:
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Figure 33

Log of Boring BRB14294

Appendix F

BORING SURVEY LOCATIONS AND ELEVATIONS

Table F.1: Rocky Mountain Arsenal Task 93-03, Geotechnical Boring Program Boring Coordinates, Elevations, and Total Depths

Boring Number	Northing	Easting	Elevation (feet)	Total Depth (feet)
BRB11094	1732796 46	3185199.74	5262 79	175.0
SAB11194	1733519.50	3184717.12	5261.09	170.0
ASB11294	1735065 73	3184067 77	5239.41	112 9
SAB11394	1737090 25	3185094.11	5199.23	20.0
WEB11494	1736578.29	3183652.39	5206.26	33 7
ASB11594	1736523.14	3184082.64	5211.37	30.0
ASB11694	1736517.92	3184942 96	5215.21	43 0
SAB11794	1735696 10	3184268 72	5223 39	45 0
ASB11894	1735535.45	3184941.71	5240.78	35.0
ASB11994	1735673.26	3185567.50	5234.48	50.0
ASB12094	1735318.49	3183567 17	5230.59	50 0
SAB12194	1734748 81	3184933.56	5249.27	50 0
SAB12294	1734602.71	3183908.97	5238.14	50 0
SAB12394	1734552 40	3184378.05	5248 06	40.0
ASB12494	1734198 45	3184942 70	5272.46	50.0
ASB12594	1734314 95	3185416 76	5257.30	50 0
SAB12694	1734039.94	3183924 62	5243.92	45 0
ASB12794	1733757 10	3184937.14	5268.37	50.0
SAB12894	1734085.12	3185832 84	5242.72	50 0
BRB12994	1733262 00	3183856 48	5256.54	50 0
BRB13094	1733214 84	3184323 49	5258.30	45.0
SAB13194	1733018 63	3184904 60	5264 65	50.0
ASB13294	1732998.91	3185633.99	5259.70	50.0
ASB13394	1733663 16	3185845 40	5250 88	50 0
BRB13494	1733215 95	3186095.84	5242 02	50.0
BRB13594	1733627 82	3184009.06	5251.59	42.0
BRB13694	1732773.51	3184382 37	5267 15	50.0
BRB13794	1732639.27	3184914 28	5269 04	50 0
BRB13894	1732718.00	3186237.23	5239 31	50 0
WEB13994	1732294 74	3184257 85	5276 44	50.0
BRB14094	1732290.62	3184924 20	5279.99	50 0
BRB14194	1732311 69	3185622 90	5264.28	50.0
BRB14294	1732309.24	3186349.99	5242.76	50.0

The boreholes were surveyed by a State of Colorado licensed surveyor using the 1983 horizontal datum and the 1988 vertical datum

Appendix G

GEOPHYSICAL LOGGING DATA
(not included in this copy)

Appendix H

COST ESTIMATES
(not included in this copy)

Appendix I

FINAL WORK PLAN FOR MATERIAL AND AREA FEASIBILITY STUDIES

Technical Support For Rocky Mountain Arsenal

Final Work Plan for Material and Area Feasibility Studies Soils Support Program Rocky Mountain Arsenal Commerce City, Colorado

Prepared for

Program Manager for Rocky Mountain Arsenal
Building 111, Rocky Mountain Arsenal
Commerce City, Colorado 80022-2180

HLA Project No 21907 102010 3
Contract No DAAA05-92-D-0003
Delivery Order No 0007 (Task 93-03)

THIS DOCUMENT IS INTENDED TO COMPLY WITH THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

THE INFORMATION AND CONCLUSIONS PRESENTED IN THIS REPORT REPRESENT THE OFFICIAL POSITION OF THE DEPARTMENT OF THE ARMY UNLESS EXPRESSLY MODIFIED BY A SUBSEQUENT DOCUMENT THIS REPORT CONSTITUTES THE RELEVANT PORTION OF THE ADMINISTRATIVE RECORD FOR THIS CERCLA OPERABLE UNIT

November 9, 1994

Harding Lawson Associates
Engineering and Environmental Services
2400 ARCO Tower, 707 Seventeenth Street
Denver, CO 80202 - (303) 292-5365

CONTENTS

TABLES

FIGURES

APPENDIXES

1.0 INTRODUCTION

This Work Plan was prepared for the Material and Area Feasibility Studies portion of the Feasibility Study (FS) Soils Support Program as Data Requirement A002, a contract deliverable under Delivery Order 0007 (Modification to Task 93-03 Feasibility Study Soils Support Program) of Contract DAAA05-92-D-0003 between Harding Lawson Associates (HLA) and the U.S. Department of the Army (Army) This report was prepared by HLA at the direction of the Army for the sole use of the Army and the signatories of the Federal Facilities Agreement (FFA) of Rocky Mountain Arsenal (RMA), the only intended beneficiaries of this work.

1.1 Document Purpose, Scope, and Organization

The purpose of this Work Plan is to outline the procedures and logic used to conduct the Material and Area Feasibility Subtasks for the FS Soils Support Program. The purpose of these additional subtasks is to (1) evaluate whether onsite materials are suitable for constructing landfill liners and caps, (2) identify a potential landfill site at RMA, and (3) evaluate the suitability of the proposed site for hazardous waste disposal.

The scope of this Work Plan includes a description of the Material and Area Feasibility field subtasks The Material Feasibility subtask includes borrow area selection, test fill construction, and infiltration testing (sealed double-ring infiltrometer [SDRI] testing and two-stage borehole [TSB] permeability testing) The Area Feasibility subtask consists of 3 deep boreholes (continuously cored for geologic data) and up to 30 boreholes (continuously sampled for geotechnical and geological data)

This Work Plan is organized to present the requisite task background and objectives; describe each subtask's design; provide construction, drilling, and sampling procedures for the field programs; present proposed geotechnical testing methods, and discuss data evaluation and reporting procedures and protocols Section 1 2 of this document presents task background and objectives, Section 2.0

presents test fill construction, testing procedures, and data evaluation, and Section 3 0 presents geologic and geotechnical subtask design, procedures, geotechnical testing, and data evaluation.

1.2 Task Background and Objectives

The primary objective of this task is to collect soil data to support the Detailed Analysis of Alternatives (DAA) portion of the Onpost Operable Unit at RMA and the Record of Decision (ROD) RMA task background and specific task objectives are discussed in the following subsections

1.2.1 Task Background

RMA was established in 1942 by the Army as a manufacturing facility for the production of chemical and incendiary munitions Military, industrial, and agricultural chemicals, primarily pesticides and herbicides, were also manufactured at RMA by several lessees from 1947 to 1982 The industrial waste liquid produced from operations performed by the Army and its lessees was initially discharged to Basin A, an unlined basin in Section 36. Subsequently, liquid wastes were discharged to other unlined basins and, after 1956, to Basin F, which was asphalt-lined. Although solid wastes were disposed of primarily in Section 36, other onpost disposal sites were also used. Some of the basins, pits, burn sites, sewers, and structures (buildings, pipes, and tanks) became sources of soil and groundwater contamination as a result of spills, leaks, or other releases

Based on the National Contingency Plan (NCP) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance, and consistent with the FFA, the Development and Screening of Alternatives (DSA) portion of the FS was performed to establish remedial alternatives capable of achieving the remedial action objectives (RAOs) for RMA. Alternatives retained after the screening process are currently being further evaluated as part of the DAA portion of the FS

The soils DSA focused on several remedial alternatives for the soils medium including onpost landfilling of materials and capping. The soils medium that is addressed in the soils DSA consists of unsaturated soils, bedrock, fill material, process water lines, chemical and sanitary sewer lines, lake sediment, and soil/debris mixtures in disposal trenches or landfills, the term "soils" is used for convenience in this document to refer to any of these materials Recognizing that interactions will occur between soils and other contaminated media such as structures and groundwater during the implementation of remedial alternatives, the impacts and interactions of other media on remedial approaches developed for RMA are being addressed in the DAA portion of the FS Since landfilling and capping remedial alternatives were retained as remedial alternatives in the DAA, the Program Manager for Rocky Mountain Arsenal (PMRMA) identified additional data needs that are required to support completion of the DAA. The data needs addressed under this task are discussed below.

1.2.2 Task Objectives

The objective of the test fills and infiltration testing of the test fills (material feasibility) is to evaluate whether onsite materials are suitable for constructing landfill liners and caps The objective of the geologic/geotechnical borings (area feasibility) is to obtain adequate data regarding the geology and geotechnical characteristics of the site to evaluate the feasibility of constructing a landfill in the existing foundation materials The work will include constructing two clay soil test fills and conducting permeability tests on the test fills to evaluate the suitability of onpost materials for use as liner and cap material. The work also includes coring, geophysical logging, soil sampling, and physical property testing to evaluate the geologic and geotechnical characteristics of the preferred landfill area.

This program will support the evaluation of remedial alternatives in the DAA involving onpost landfilling of materials and capping The program is scoped as an FS-level investigation to validate and refine feasibility and cost information in the DAA-FS Investigations will be conducted in a manner consistent with the NCP and CERCLA as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA)

2.0 TEST FILL CONSTRUCTION AND TESTING

This section presents the test fill construction and testing program to be performed under the FS Soils Support Program, Subtask 1 entitled, Material Feasibility The test fill construction and testing program includes the construction of two test fills using two soil types native to RMA and the subsequent field testing of the test fills for in situ permeability The Material Feasibility portion of the FS Soils Support Program has two main objectives (1) to verify that onpost soils are capable of meeting the required liner permeability of less than or equal to 1 x 10^{-7} centimeters per second (cm/s) and (2) to evaluate the optimum lift thickness, moisture content, density, and the compactive effort necessary to achieve this permeability Permeability of the constructed test fills will be measured both in the field and in the laboratory to evaluate the suitability of the materials and methodology used to construct the test fills Adjustments to the material type, density, and moisture content of the recompacted soil liner may be necessary pursuant to the results of the test fill program.

2.1 Test Fill Location and Proposed Borrow Material

To simulate future landfill clay liner construction conditions as closely as possible, the test fills will be constructed at the site currently considered to be the preferred landfill location, the western half of Section 25 (Figure 2.1) (Ebasco, 1988) The site was approved by the U.S. Fish and Wildlife Service (USFWS) prior to construction of the test fills

Figure 2 1 also illustrates the two proposed borrow areas where soil for the test fill construction will be excavated The borrow areas were identified in the Draft Final Feasibility Study Soils Support Program Report (HLA, 1994a) to contain suitable borrow material. The borrow sites were also approved by USFWS for excavation provided the areas were reseeded following excavation. The revegetation plan for the borrow areas is presented in Section 2.2.

2.2 Test Fill Construction Procedures

Each of the proposed test fills will be approximately 100 feet long by 40 feet wide at the top of the test fill (Figure 2 2) The 100-foot length and 40-foot width will allow the SDRI and TSB permeability testing equipment to be placed at the recommended 12 to 15 feet from the sides and slopes of each test fill to avoid encountering edge effects (as shown in Figure 2 3) The recommended spacing is designed to avoid contact with the sides and slopes of the test fill where the lift construction may not meet minimum specifications and therefore may not be representative of most of the clay liner test fill

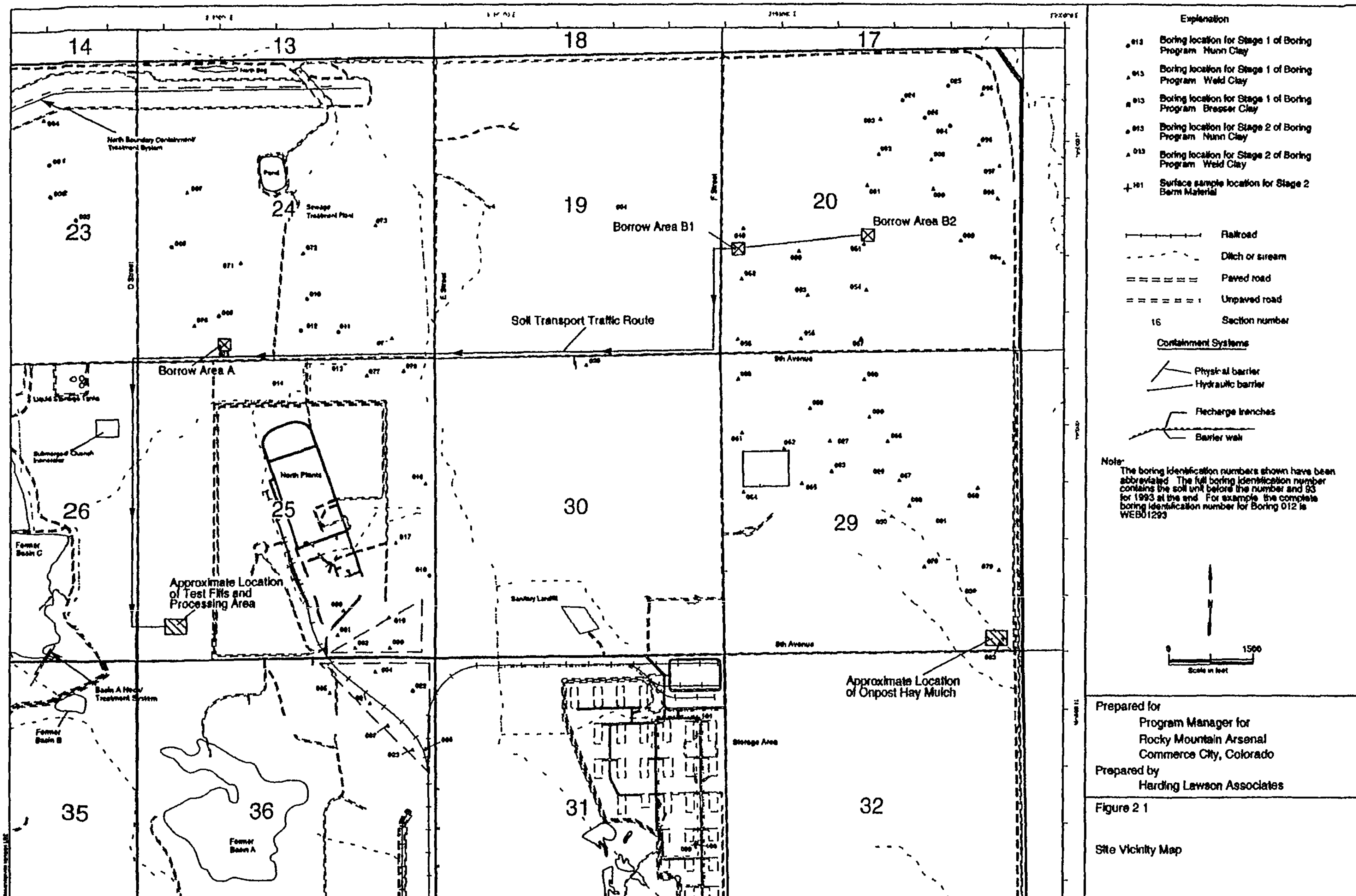
As described below in the construction procedures, the test fills will be constructed by first stripping approximately 4 inches of topsoil, then placing the various test fill layers on the prepared subgrade Test fill soil will be processed for clod size and moisture content prior to compaction. This will be accomplished in the large processing areas adjacent to the test fills

Each test fill surface will slope uniformly to one side at a 2 percent slope. This design will provide positive drainage and will simulate actual liner construction conditions Surface-water run-on control will not be necessary because of the above-grade configuration of the test fills

Upon completion of the test fills, the area will be regraded to smooth out the contours of the test fills and the immediate surroundings The stockpiled topsoil will be spread over the test fills and other disturbed areas This topsoil will prevent desiccation cracking of the test fill surface and also serve as the final "closure" layer of the test fill No further closure activities, other than seeding and mulching, will be performed.

2.2.1 Excavation

Topsoil will be stripped from the affected area of the borrow sites prior to excavation of actual test fill material This topsoil will be stored adjacent to each respective borrow site Necessary volumes of soil from each borrow area will be excavated under the supervision of the Engineer (HLA) The Engineer will visually inspect all borrowed material prior to transport. Scrapers and trucks will be used to excavate and transport borrow soils to the prepared stockpile areas. Once the excavation is



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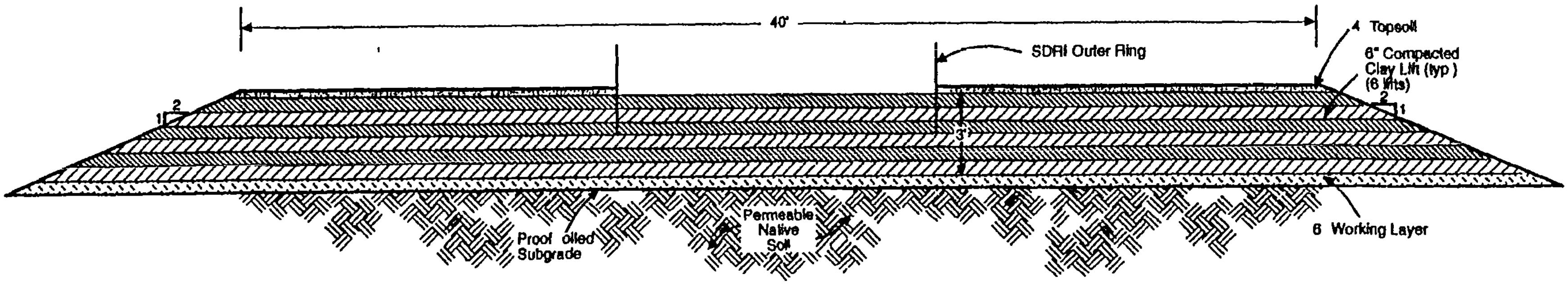
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
Harding Lawson Associates

Figure 2 1

Site Vicinity Map

2-2A

Typical Test Fill Section



Explanation

SDRI Sealed double-ring infiltrometer

Typ. Typical

Note Maximum slope shall be 2H 1V on long sides and 3H:1V on ends of test fill Minimum slope shall be 3H 1V on long sides and 4H 1V on ends of test fill

0 25 5

Scale in feet

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Commerce City Colorado

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Figure 2 2

Typical Test Fill Section

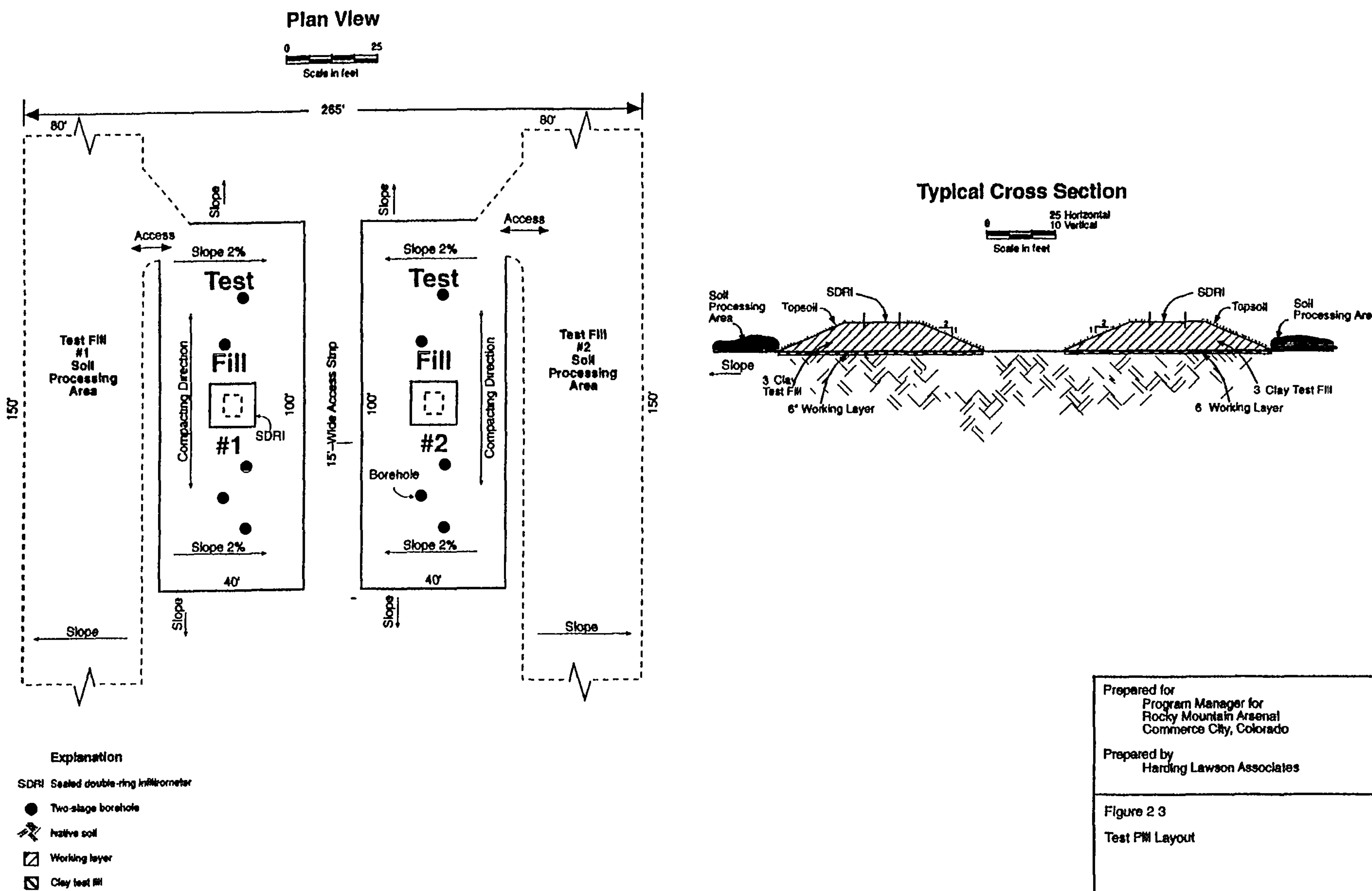

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Figure 2 3

Test Fill Layout

completed, the borrow pits will be graded smooth, covered with the adjacent stored topsoil, and seeded.

2.2.2 Processing Area Preparation

The processing areas adjacent to each proposed test fill will be stripped of topsoil. The surface will be smoothed (proof-rolled) with the pneumatic tires on the front-end loader This topsoil will be stored adjacent to the processing areas

2.2.3 Test Fill Area Preparation

The test fill area will be stripped of topsoil. The topsoil will be stored adjacent to the test fills along with topsoil from the processing areas Once stripping of the surface soil is completed, the test fill areas will be proof-rolled, scarified, and smooth-drum compacted.

2.2.4 Soil Processing

This portion of the work will be completed prior to actual test fill placement to allow adequate time for clod size reduction, moisture addition, blending, curing, and testing to verify the optimal moisture content range has been achieved. These activities will be performed using a dozer to spread and move soil, a disc harrow or other appropriate equipment to reduce clod size and blend moisture into soil, and a water truck with a sprayer to adjust moisture content Tests to be performed on processed material are included in Table 2.1

2.2.5 Subgrade Preparation and Working Layer Placement

To ensure that there is no head build-up in the test fills (which could adversely affect the permeability test results), the test fills will be constructed on a foundation of in situ sandy soil. The sandy soil will be thoroughly wetted to a depth of at least 1 foot prior to placement of the next layer to avoid surface tension and capillary effects on downward infiltration. Directly above the wetted sandy soil will be a 6-inch (compacted lift thickness) layer of clay borrow material that will be designated a "working layer" This layer is important to ensure proper placement, bonding, and compaction of the first lift within the test fills

2.2.6 Test Fill Placement

Once the subgrade and working layer are completed for each test fill, and the specified moisture content of the processed soil has been achieved, placement of the test fills will be initiated Using a front-end loader, dozer, or a backhoe, processed soil will be moved to the test fills The soil will be spread by a dozer into 8- to 9-inch loose lifts A heavy tamping foot or sheepsfoot compactor (Caterpillar Model 825 or equal) will be used to compact the clay into 6-inch compacted lifts. Six lifts will be constructed to form the 3-foot-thick test fill. Each lift surface will be scarified and/or rewetted as necessary to ensure adequate bonding between lifts.

Based on the results of the earlier soils testing program, failure to meet a specification of 95 percent of the Standard Proctor maximum dry density (American Society for Testing and Materials [ASTM] D 698-78) will require removal and replacement of that lift.

Moisture content shall be in the range of 1 to 4 percent wet of optimum moisture Each compacted lift will be tested using a nuclear gauge to verify that the compaction and moisture content specifications have been met. Additionally, to determine the appropriate number of equipment passes to meet the compaction requirement, the density will be measured after every two passes for each of the first three lifts This methodology will (1) enable the last three lifts to be constructed with the appropriate number of lifts and minimal testing and (2) enable development of a "compaction vs equipment passes" curve to use in preparing method specifications for the actual clay liner It is anticipated that three density test locations will be used for each lift at each test fill These and other tests that will be performed during construction are listed in Table 2.1.

2.2.7 Test Fill Completion and Permeability Test Preparation

To complete the test fills and provide a smooth, uniform surface, the top of the uppermost completed lift will be compacted and sealed with a smooth-drum roller The completed test fill surface must be protected from excessive desiccation cracking prior to and during the field permeability tests Therefore, a topsoil layer or plastic sheeting will be placed over both test fills, except for the

Table 2.1: Test Fill Testing Program (Per Test Fill)

Test	Method	Stockpile	Frequency During Construction	Post-Construction
Moisture Content	Oven drying ASTM D2216-90	3 initial; as needed during processing (approx 12); 3 final; estimate 18 total	3 per lift (18 total)	---
Moisture Content	Nuclear gauge ASTM D3017	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6, estimate 45 total	---
Atterberg Limits	Grab sample ASTM D4318-84	3	---	---
Grain Size (incl clay content)	Sieve and hydrometer analysis ASTM D422-63	3	---	---
		3	---	---
Optimum Moisture Content and Max Dry Density	Standard Proctor test (grab samples) ASTM D698-78	3	---	---
In-place Density (% compaction)	Nuclear gauge ASTM D2922	---	3 per each 2 passes per lift for first three lifts; 3 per lift for lifts 4, 5, 6; estimate 45 total	---
Lift Thickness (loose)	Manual	---	25-foot intervals down centerline of test fill	---
Lift Thickness (compacted)	Manual	---	25-foot intervals down centerline of test fill	---

Table 2.1 (continued)

Test	Method	Stockpile	Frequency During Construction	Post-Construction
Final Test Fill Thickness	Survey	---	---	3
Lift Bonding	Visual Test Pits	---	2 per lift (manual)	3 (backhoe)
Laboratory Permeability	Shelby tubes, flexible wall permeameter (falling-head test) ASTM D5084-90	---	---	3
Field Permeability (large-scale)	Sealed double-ring infiltrometer (SDRI)	---	---	1
Field Permeability (small-scale)	Two-stage borehole (Boutwell)	---	---	5
Shear Strength	Consolidated undrained ASTM D4767-88	---	---	2
Shear Strength	Unconsolidated undrained ASTM D2850-87	---	---	2

--- Not performed
ASTM American Society for Testing and Materials

immediate areas designated for the SDRI tests Each SDRI area, approximately 12 feet by 12 feet, will be blocked off and sealed with a tarp until the SDRI test set-up is initiated.

2.2.8 Field Permeability Tests

One SDRI and five TSB permeability tests will be performed at each test fill. The SDRI test will be located in the center of each test fill to avoid edge effects The TSB tests will be placed at least 15 feet from test fill edges. Figure 2.3 illustrates the proposed test locations Performance of the tests will include strict adherence to the published testing procedures and thorough documentation of all observations and results as described in Sections 2.3 and 2 4.

Protection of the SDRI areas from temperature changes and damage by animals will be accomplished by building a plywood cover built for each SDRI test site The SDRI area will be staked and marked with tape to prevent access by unauthorized personnel.

2.2.9 Test Fill Closure

Once the field permeability tests are completed and the testing apparatus disassembled, the SDRI areas and the center strip between the test fills will be seeded with native grasses and wildflower seed and mulched with native grass hay as specified by the USFWS

2.2.10 Test Fill Documentation

In addition to the test results from the formal testing program outlined in Table 2.1, the following information on test fill construction will be documented.

- Field description of the borrow material used in each test fill
- Soil processing procedures
- Soil transport traffic routes
- Dozer spreading and grading patterns
- Lift thicknesses (loose and compacted)
- Compaction patterns and number of passes

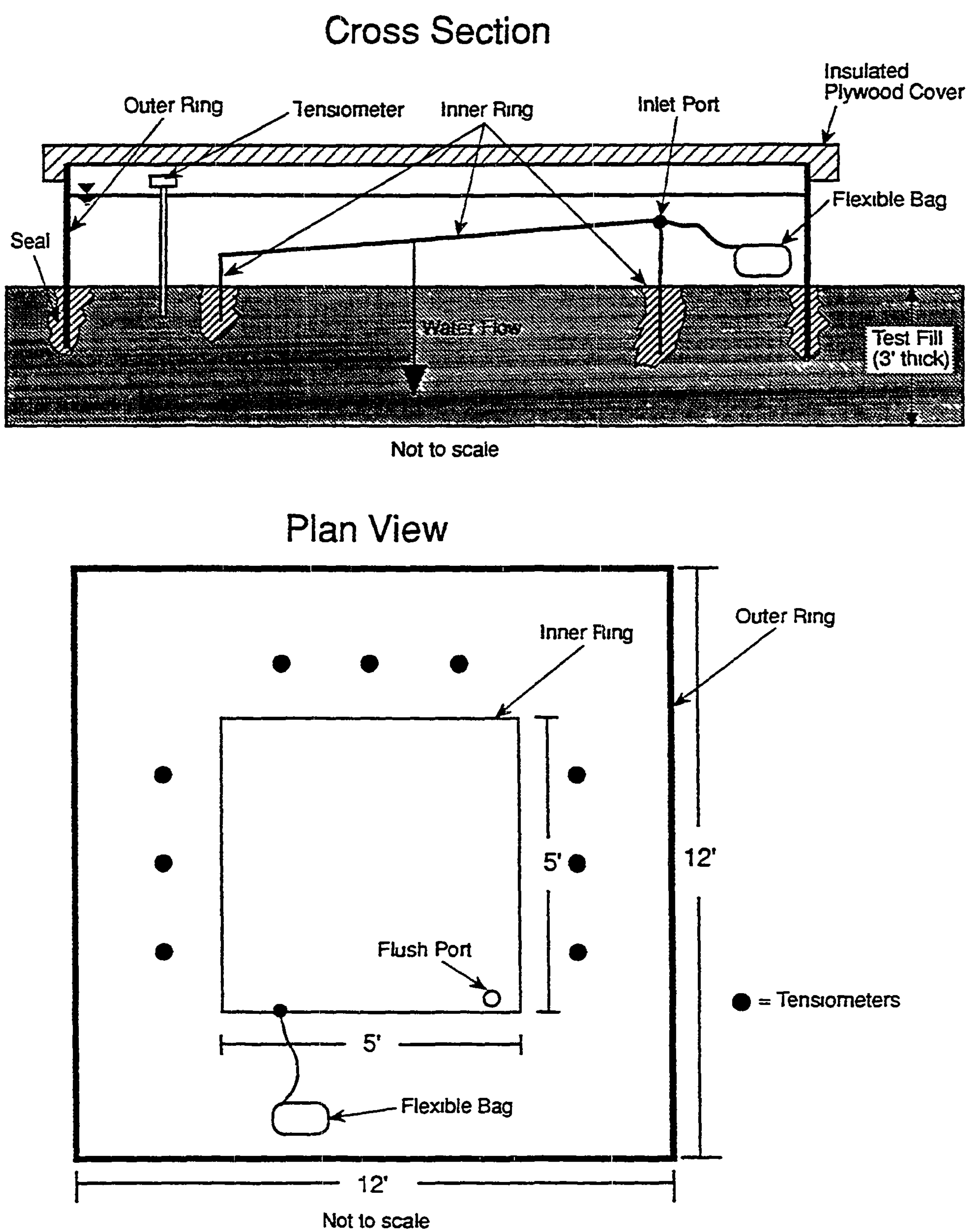
- Test locations
- Lift bonding check results and observations
- Any failed results and corrective action taken

2.3 Sealed Double-Ring Infiltrometers

This section describes the test method, the installation, monitoring, and data reduction and evaluation procedures to be used for the SDRI tests. The SDRI test measures the vertical infiltration rate of water through the constructed test fills. The SDRIs are specifically designed to measure low infiltration rates in the range of 1×10^{-5} to 1×10^{-8} cm/s Based on previous laboratory results (HLA, 1994a), the permeability of the soil at the proposed borrow areas ranges from 3.02×10^{-9} to 8.24×10^{-8} cm/s. This range of soil permeability coincides with the optimal range for the SDRI test method

A summary of the SDRI test method is provided in Appendix A along with the manufacturer's installation and operating instructions A synopsis of the test method from the installation instructions (Appendix A) is as follows The SDRI consists of a 12-foot by 12-foot outer ring and a 5-foot by 5-foot inner ring, as illustrated in Figure 2 4. The rings are grouted within trenches excavated into the top of the test fill The outer ring is installed at a depth of 14 to 18 inches below ground surface (bgs), and the inner ring is installed to a depth of 4 to 6 inches bgs After grouting is complete, the area between both rings is filled with water The outer ring area is filled to a depth of approximately 12 inches, which completely submerges the inner ring. The inner ring area is sealed by placing a cover over the top of the inner ring This seals the water within the inner ring from the atmosphere

Monitoring the flow of water in the SDRI is accomplished by filling a flexible bag with a known weight of water and connecting the bag to a port on the inner ring. As the water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag After a specified time interval, the flexible bag is removed and weighed. The weight loss is then converted into milliliters of water that has infiltrated into the test fill Infiltration rate is calculated using an equation with the following parameters: the volume of water loss, the



Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by Harding Lawson Associates	Figure 2 4 Proposed Sealed Double-Ring Infiltrometer Construction Schematic

area of the inner ring, and the interval of time that the bag was connected onto the inner ring The tests will be monitored until the infiltration rate reaches a steady state Upon completion, a plot of the infiltration rate over time is prepared For the purposes of this test, the specified permeability value to be achieved is 1 x 10^{-7} cm/s It is anticipated that the tests will require monitoring for approximately two to three months.

2.3.1 Sealed Double-Ring Infiltrometer Installation Procedures

The SDRIs will be installed immediately following completion of the test fills The SDRIs will be installed according to manufacturer's installation instructions under the direction of the installation subcontractor, Mr Steve Trautwein of Trautwein Soil Testing Equipment (manufacturer of the SDRIs). Further information regarding the installation of the SDRIs is presented in Appendix A.

2.3.2 Sealed Double-Ring Infiltrometer Monitoring Procedures

SDRI monitoring procedures will include flow measurements, water temperature readings, water level measurements, swell measurements, and tensiometer readings In general, the readings will be taken on a daily basis until the infiltration rate slows sufficiently to allow measurements to be collected every several days The readings will be taken by field personnel trained and experienced in taking SDRI measurements The readings will be recorded in field logbooks and then transferred onto the SDRI data forms (Appendix A)

2.3.3 Sealed Double-Ring Infiltrometer Data Reduction and Evaluation

Data reduction and evaluation will be accomplished by transferring the field measurements recorded on the data forms onto computer spreadsheets for ease of computation. The infiltration rate can be determined by using the following equation.

$I = Q/(At)$

where.

I = infiltration in cm/s

Q = volume of flow in cubic cm

A = area of flow in square cm

t = time interval in seconds

There are two factors that can have a significant effect on the infiltration rate of the SDRI temperature changes and soil swelling The field measurements of temperature and swell will be reviewed to evaluate whether they could have affected the infiltration rates of the SDRIs. If either factor is found to be significant such that it could account for as much as 10 percent of the total infiltration of the SDRI, corrections for these effects will be made

The hydraulic conductivity within the SDRI is calculated by using the following equation·

$k = Q/(iAt)$

where.

k = hydraulic conductivity in cm/s

Q = volume of flow in cubic cm

t = time interval in which Q was determined in seconds

i = $\Delta h/\Delta s$ (gradient) dimensionless

Δh = head loss

Δs = length of flow path for which Δh is measured

A = area of flow in square cm

Plots of the infiltration rate and hydraulic conductivity will be evaluated concurrently to evaluate when the tests can be terminated as discussed above (i e., when steady state conditions or the desired hydraulic conductivity has been achieved).

2.4 Two-Stage Borehole Permeameters

This section presents the installation, monitoring, and data reduction and evaluation procedures for the TSB permeameter tests The TSB procedure is a falling-head infiltration test conducted in a cased borehole The first stage of the TSB procedure is performed with a cased borehole that is open at the bottom The first stage of the test is used to calculate vertical permeability (k_v) The second stage of the test is conducted after advancing the borehole another 6 to 8 inches below the bottom of the casing and measuring the flow rates to calculate horizontal permeability (k_h).

2.4.1 Two-Stage Borehole Permeameter Installation Procedures

Five TSB permeameters will be installed at each test fill immediately following installation of the SDRIs The TSBs will be installed following the installation procedures described in Appendix B The boreholes will be excavated using a hand auger and reamed to the desired depth. Polyvinyl chloride (PVC) casing will be grouted in place, and the surface of the borehole will be completed with the measurement stand pipe and fill tube, as illustrated in Figure 2.5.

Along with five TSBs at each test fill, one temperature effect gauge (TEG) will be installed at each test fill. The purpose of the TEG is to measure any changes in flow rates that could be the result of temperature changes during the monitoring period. Field measurements on previous TSBs have indicated that rising temperature causes the water column in the standpipe to expand, thereby causing a lower apparent flow rate (see Appendix B) The net effect is a lower apparent permeability If the temperature decreases during the monitoring period, then the converse is true For this reason, TEGs will be installed and monitored throughout the testing program

TEGs are set up and installed similarly to the typical TSB with one exception; the bottom of the casing is sealed with a cap Because there is no flow of water from the TEG, any changes in the readings must be the result of changes in the ambient air temperature and/or barometric pressure As described in Appendix B, any changes noted in the TEGs can then be corrected for in the TSB measurements The construction of the SDRI and the TSB will be supervised by the SDRI manufacturer's representative

2.4.2 Two-Stage Borehole Permeameter Monitoring Procedures

Monitoring of the TSBs will include flow measurements, water temperature readings, and TEG readings The monitoring equipment manufacturer's operating procedures are presented in Appendix B The readings will be taken by field personnel trained and experienced in TSB monitoring. The readings will be recorded in field logbooks and then transferred onto the TSB data forms (Appendix B)

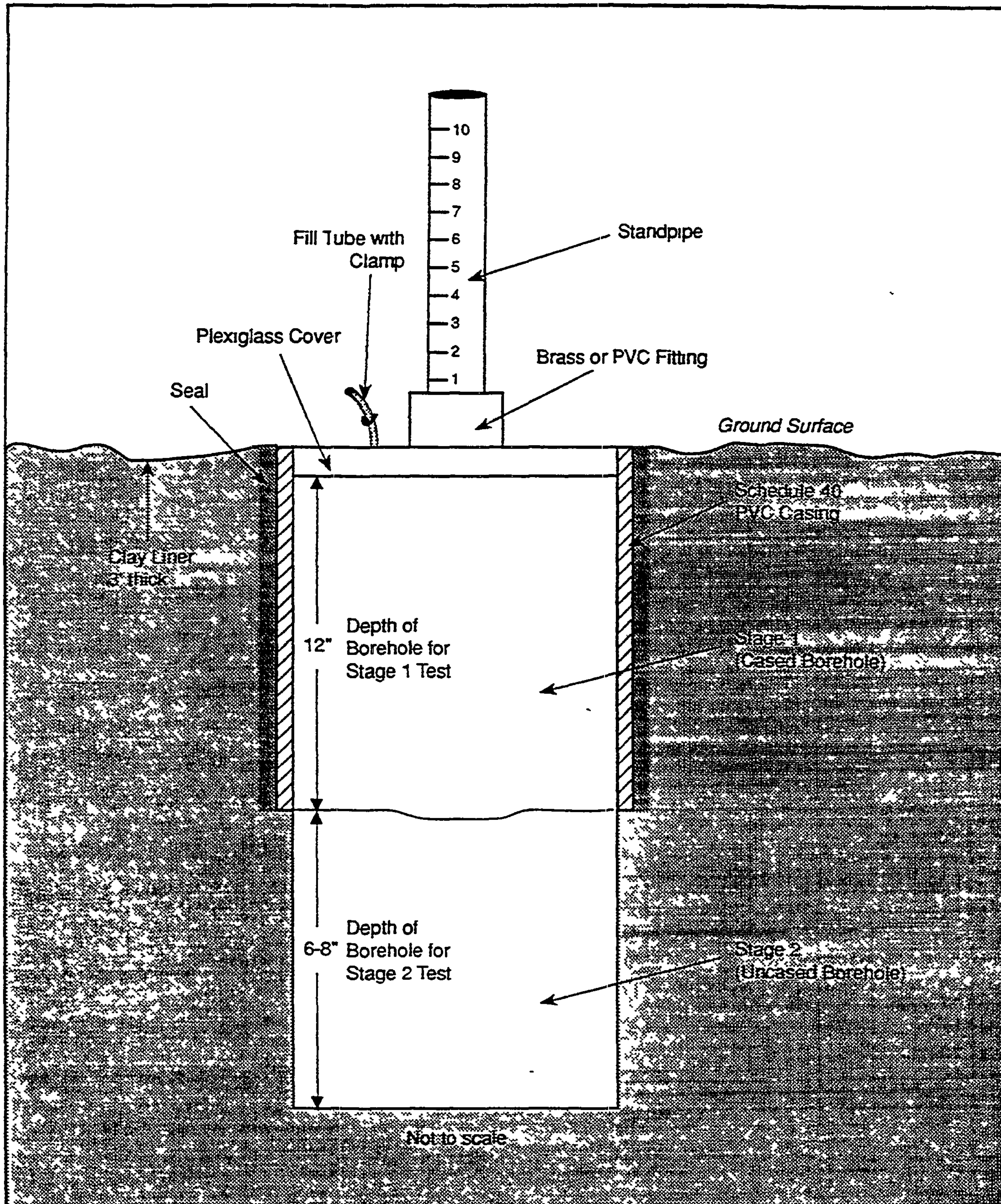
2.4.3 Two-Stage Borehole Permeameter Data Reduction and Evaluation Procedures

Data reduction and evaluation will be accomplished by transferring the field measurements recorded on the data forms onto computer spreadsheets for ease of computation. Apparent permeability for both Stage 1 and Stage 2 of the TSB tests will be calculated using the following falling-head test equations as specified in the test method calculations (Appendix B)

$k = R_T G \ln(H_1/H_2)/t_2\text{-}t_1)$

where

- k = permeability in cm/s
- H_1 = initial head at $t=t_1$
- H_2 = initial head at $t=t_2$
- t_1 = initial time
- t_2 = final time
- $\ln$ = natural logarithm
- G = geometric constant, depends on the individual test dimensions and is calculated separately for each test
- R_T = kinematic viscosity correction to water at 68 degrees Fahrenheit as defined in ASTM D5084



Prepared for Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: Harding Lawson Associates	Figure 2.5 Proposed Two-stage Borehole Permeameter Installation (cross section)

Throughout each stage of the tests, variations in apparent permeability will be evaluated, and the test will be terminated when steady-state conditions are achieved. It is anticipated that each stage of the two-stage test will require monitoring for approximately three weeks

3.0 GEOLOGICAL AND GEOTECHNICAL DRILLING, SAMPLING, AND TESTING

This section describes the geological and geotechnical drilling, sampling, and testing activities to be conducted under Task 93-03 Section 3.1 describes the selection process for locating the three deep boreholes within the proposed landfill site as well as the procedures for drilling, coring, sampling, and geological and geophysical logging Section 3.2 describes the rationale for shallow soil boring locations within the proposed landfill site Drilling, coring, and sampling procedures are also described. Section 3.3 describes the chain-of-custody (COC) procedures. Section 3.4 describes the geotechnical testing, and Section 3.5 describes data evaluation and reporting.

3.1 Borehole Coring Program

This subsection describes the rationale for the selection of the proposed landfill siting deep borehole locations, drilling equipment and procedures, and geological and geophysical logging procedures.

3.1.1 Borehole Locations

Three 150- to 175-foot boreholes will be located in the western half of Section 25 at RMA to further characterize the geology of this area as a potential landfill site The borehole locations were selected by reviewing existing geologic logs and cross sections prepared from those logs The boring locations were placed between existing well clusters and known borings to gather new data. These boring locations may be subject to minor changes in the field (with approval of PMRMA). Figure 3.1 shows the proposed borehole coring locations in Section 25

3.1.2 Drilling, Coring, and Geophysical Logging Equipment and Personnel

A drilling rig and crew will be furnished by the U.S Army Corps of Engineers Waterways Experiment Station (WES) The drilling rig is capable of both auger and rotary drilling. The WES drilling crew will also provide a supply truck and water truck. Drilling in the alluvium will be accomplished using an 8-inch-outside-diameter (OD) solid auger Continuous core samples of the alluvium will be collected by hammering a 24-inch-long, split-barrel sampler in the open borehole Continuous cores of bedrock will be collected in a 5-foot-long, 4 5-inch-OD split-spoon sampler using a rotary core drilling technique

Drilling activities will be directed by an HLA field geologist. The geologist will be responsible for directing the drilling crew, logging the core samples recovered, and directing the geophysical logging subcontractor (Colog, Inc.)

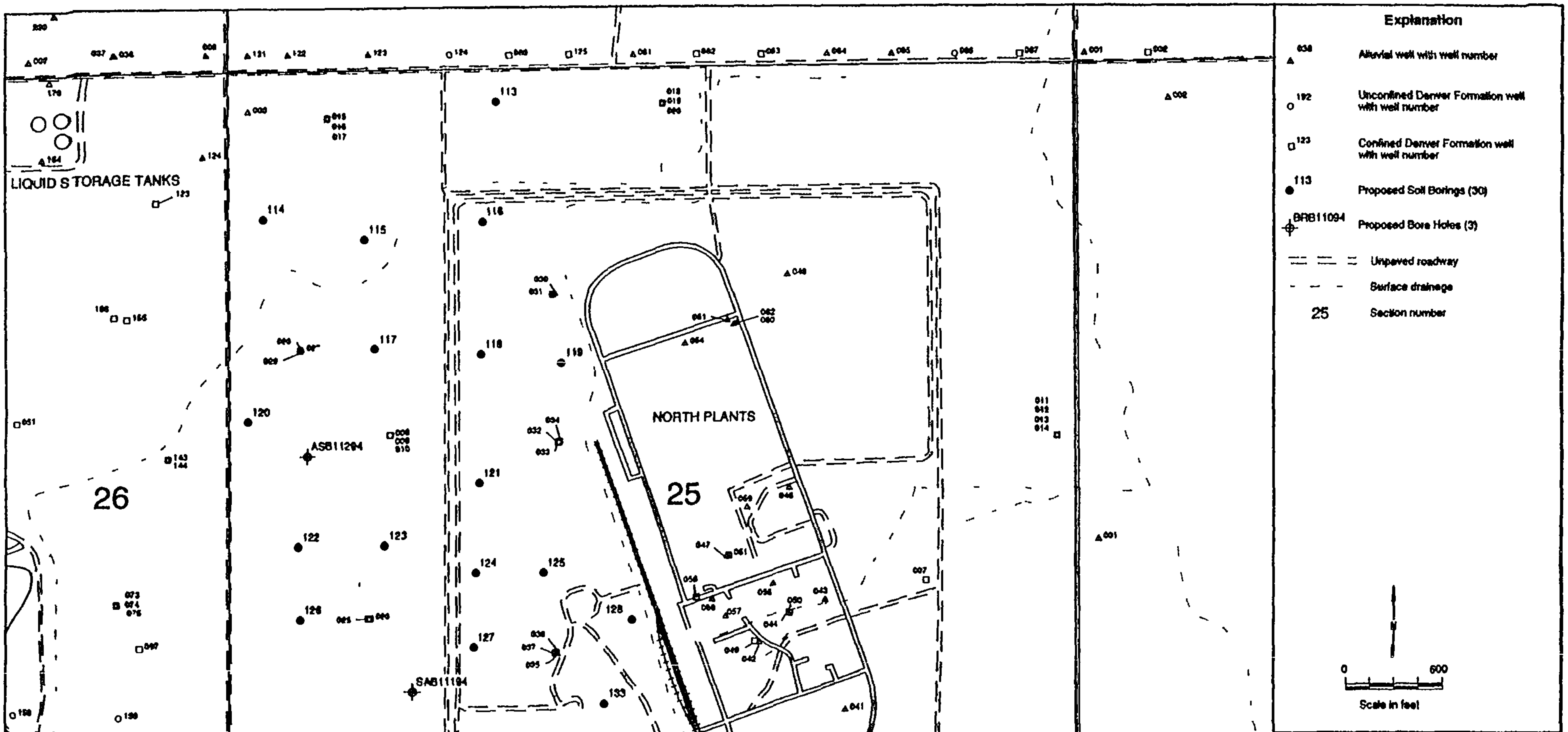
3.1.3 Borehole Coring Procedures

Before field work is started, the geologist will be responsible for assuring that personnel (1) read and sign the accident prevention safety plan, (2) are trained to operate the field equipment, and (3) understand the field procedures described in this Work Plan. All work will be performed in accordance with the Final Accident Prevention Plan (HLA. 1994b).

The boreholes are specifically located outside areas of known contamination; therefore, rigorous decontamination procedures normally followed when soil samples are collected for chemical analysis are not necessary for this program However, before starting and following completion of drilling operations, the drilling rig and associated downhole equipment will be decontaminated at the CERCLA Wastewater Treatment System (CWTS) Decontamination of downhole equipment between each borehole will only be necessary to maintain proper working order of the equipment.

A lithologic log will be prepared for split-spoon and core samples recovered at each borehole The samples will be logged immediately in the field and in more detail later using geophysical logs for comparison. These logs will include alluvium and bedrock descriptions, stratigraphic features, details of observed structural features, and other pertinent information. Sample recovery will be noted on the field logs, and the samples scanned with a photoionization detector (PID).

Colog, Inc (Colog), Golden, Colorado, will provide geophysical logging services during the coring program. Colog will geophysically log each completed borehole after coring has been completed.



Prepared for
Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by
Harding Lawson Associates

Figure 3 1

Proposed Boring Location Map
Section 25

Colog will use the following borehole geophysical techniques normal resistivity, spontaneous potential, single-point resistivity, gamma, full waveform sonic, neutron, and caliper. The geophysical logging tools will be calibrated for the methods specified above before logging operations are initiated and after logging operations are completed. The calibrations will be recorded and submitted to HLA for review. The depth indicators for the geophysical logging tools will be set so that zero corresponds with the ground surface before each run. The geophysical logging tools will be run twice over an interval in each borehole The results of both runs will be compared as a means of verifying the repeatability of results. The geophysical logging equipment will be decontaminated before and after working on this project. Field plots of the geophysical logs will be prepared with an expanded scale of 10 feet per inch. The final logs will be plotted on vellum

Upon arrival at individual boring sites, the following procedures will be implemented.

1 Water to be used in drilling and grouting will be obtained from a Contracting Officer's Representative (COR)-approved water source

2 The HLA geologist shall check the boring location stake against the site location map to verify the borehole location and perform borehole clearance for buried utilities and metallic objects

3 PID background readings will be taken before intrusive activities begin. Field documentation of all boring activities will begin at this time and include the following information. boring number; date, and pertinent observations such as weather, surface conditions, and field equipment identification numbers It is anticipated that the borings will be drilled in modified Level D personal protective equipment (PPE)

4 Once drilling starts, PID readings will be taken in the breathing zone and at the top of boring The PID readings are taken for health and safety monitoring and boring location evaluation. If the PID readings are above background levels, the rig geologist will notify the task manager immediately The level of PPE will be upgraded according to specific guidelines, and the boring will be backfilled and a new boring location identified.

5 The alluvium will be drilled with a solid-stem (8-inch-OD) auger and sampled with 2-foot split-spoon samplers Blow counts and sample recovery data will be recorded on preprinted boring logs and in bound field logbooks

6 After the alluvium has been split-spoon sampled and drilled, it will be cased with 5-inch-inside-diameter (ID) PVC casing, and pressure grouted in place

7 The PVC casing and grout will be left to set up for a minimum of 24 hours

8 The bedrock will be continuously cored at each borehole location to a consistent reference datum elevation of approximately 5085 feet. Therefore, one borehole will be less than

150-foot total depth and two boreholes will be greater than 150-foot total depth (see Table 3.1)

9 As the soil and rock core are recovered from the boring, they will be logged by the geologist on the lithologic log.

10 The core will be placed in core boxes with the top and bottom of depth labeled for each section of core The quantity recovered will also be marked on the core box. The outside of the core box shall be labeled with the boring number and core interval The core will be stored in Building 785 West until the core is no longer needed, at which time the core will be returned to the site and spread on the ground.

11 A metal mud tank will be used to recirculate the drilling mud during coring. Soil cuttings produced during drilling will be spread evenly around the drill site

12 Upon completion of the drilling and sampling, the boreholes will be geophysically logged by Colog using the following logging tools.

- Normal resistivity
- Spontaneous potential
- Single-point resistivity
- Gamma
- Full waveform sonic
- Neutron

13 After the boreholes have been geophysically logged, they will be grouted to the surface using a tremmie pipe and pumped with cement/bentonite grout.

14 A stake will be placed at the borehole location with the appropriate boring identification clearly marked The location and ground surface elevation of the borings will be surveyed by a licensed surveyor and the coordinates will be forwarded to RMA's data management subcontractor, D.P. Associates.

3.2 Soil Boring Program

Up to 30 shallow boreholes will be drilled and sampled in Section 25 of RMA to gather detailed geologic and geotechnical data for site characterization.

3.2.1 Soil Boring Locations

Geologic boring logs and cross sections from borings in Section 25 and northern Section 36 will be reviewed. The data review and cross sections will help locate the boreholes for the drilling program.

Table 3.1: Projected Borehole Drill Depths

Boring Number	Projected Thickness of Alluvium (feet)	Projected Total Depth (feet)	Projected Surface Elevation (feet)
BRB11094	22 5	175	5260
SAB11194	15 8	170	5254
ASB11294	27.2	145	5232

Borings will be terminated at approximately 5085 feet elevation above mean sea level.

The borehole locations will be cleared for utilities and other subsurface objects using utility maps and a metal detector before any drilling begins

Boring locations will be selected to optimize the density coverage within the proposed landfill siting area. The most desirable geologic areas for siting a landfill in Section 25 (based on the suitability criteria) will be targeted for study Figure 3.1 shows the proposed soil boring and coring locations

3.2.2 Drilling and Sampling Personnel, Equipment, and Procedures

This subsection presents soil boring and geotechnical soil sampling procedures Procedures for completing COC forms and shipping forms are also discussed.

Field Personnel

Soil boring activities will be accomplished by a two-person field team. The field team will consist of an HLA geologist and an engineering technician (ET). The rig geologist will log each boring in the field as it is drilled, and continuously collect soil samples The task manager (TM) will review the final field lithologic logs The ET will assist the rig geologist with sample collection and be responsible for sample handling, packaging, and shipment.

Field Equipment

Borehole drilling will be accomplished using 3-1/4-inch-ID hollow-stem augers and a Mobile drilling rig Split-spoon samplers and shelby tubes (when necessary) will be used to collect soil samples during drilling Layne Environmental Services, Inc., will provide a drilling rig, drill crew, water truck, and a vessel to mix grout in for borehole abandonment. HLA will have a truck to transport sample coolers, sample bottles, and sample equipment.

Soil Sampling Procedures

The rig geologist will be responsible for assuring that personnel (1) have read and signed the Site Safety and Health Plan, (2) are trained to operate the field equipment, and (3) understand the field procedures described in this Work Plan.

Each boring location must be cleared for utilities and metallic objects before drilling can begin. The TM will make sure that COC forms and labels are prepared for each borehole Information from previous boreholes in the areas being drilled will be provided to the rig geologist. Data from the boreholes will be recorded on preprinted boring logs and in bound field logbooks

Up to 30 borings will be drilled and sampled as part of the area feasibility subtask. The borings will be continuously sampled to a depth of approximately 50 feet or into bedrock. The alluvium will be logged for lithology and blow counts will be recorded to collect geotechnical information. Samples will be collected for geotechnical testing from every 5-foot interval. Undisturbed soil samples will be collected using split-spoon samplers and shelby tubes when necessary. It is anticipated that the borings will be drilled in Level D PPE. The borings have been located outside areas of known soil contamination, and if any sustained readings above background are detected in the field using a PID, drilling will be stopped and the level of PPE will be upgraded as necessary

Before starting and after completion of drilling operations, the drilling rig and associated downhole equipment will be decontaminated at the CWTS However, decontamination of downhole equipment between each borehole will not be necessary

Upon arrival at individual boring sites, the following procedures will be implemented.

1 Water to be used in drilling and grouting will be obtained from a COR-approved water source

2 The HLA geologist or technician shall check the boring location stake against site location maps and pertinent borehole clearance information to verify the boring location.

3 An HNu PID will be used to obtain background readings before intrusive activities begin. Field documentation of all boring activities will begin at this time and include the following information boring number; date, and pertinent observations such as weather, surface conditions, and field equipment identification numbers

4 Once drilling commences, PID readings will be taken in the breathing zone and at the top of boring The PID readings are taken for two purposes health and safety monitoring and boring location evaluation. If the PID readings are above background, the rig geologist will notify the TM immediately, and two actions will be taken. The level of PPE will be upgraded

according to specific guidelines, and the boring will be backfilled and a new boring location identified

5 Soil cuttings produced during drilling will be spread evenly around the drill site

6 As the soil core is recovered from the boring, it will be logged by the site geologist on the lithologic log Soil cuttings from the auger will also be monitored for lithologic changes and noted on the boring log

7 The samples will be continuously collected and those samples to be analyzed will be selected following completion of the borings and a review of the boring logs

8 Most samples will be collected in wide-mouth jars for geotechnical analysis Additional material will be collected in shelby tubes and 5-gallon buckets The 5-gallon bucket samples will be collected from the auger flights. Sampling technique, sample depth, and fractions collected will be recorded on the lithologic logs, COC forms, and sample tags.

9 The residual soil core will be packaged for storage at Building 785 West until no longer needed, at which time the residual soil cores will be returned to the site and spread on the ground.

10 The borings will be terminated at bedrock or at 50 feet, whichever is encountered first. If groundwater is encountered, the boring will be terminated at the groundwater level

11 Upon completion of the soil sampling, the boring will be backfilled with portland type I/II cement with 5 percent bentonite. Residual soil will be removed from the auger bits and soil sampling equipment.

12 A stake will be placed at the borehole location with the appropriate boring identification clearly marked The location of the boring will be surveyed by a licensed surveyor and the coordinates will be forwarded to D.P Associates

13 Samples will be labeled and stored onsite pending selection of samples for subsequent geotechnical analyses At the conclusion of the program, unused samples will be spread evenly over ground surface at a location approved by PMRMA.

3.3 Chain of Custody

The ET will place the correct COC forms within the designated sample cooler before relinquishing the cooler to the rig geologist. These forms include an inventory of the samples and a listing of those persons with access to the samples The forms will be transported with the samples at all times. Possession of the samples will begin with the sample collectors All subsequent sample transfers will require the relinquisher and the receiver to sign, date, and record the time of transfer on the COC forms

Data on final COC forms will be checked by the ET and will include the sample number, sampler's signature, collection date and time, fractions collected, and sample depth. The ET will check these data against the boring logs and field logbooks transmitted by the rig geologist.

At the end of each day, all samples will be brought back to the trailer for packaging The ET will complete the COC forms and review field logbooks and field data sheets for errors and omissions

Sample fractions will be repackaged with a layer of plastic bubble wrap below and above the samples, in heavy-duty coolers to ensure that the samples will not break during shipment COC forms will be placed in waterproof bags in their corresponding coolers. All coolers will be sealed and wrapped in accordance with PMRMA shipping requirements Evidence tape will be placed across each cooler to ensure that the contents are not violated during shipping The last person to sign the COC form for each cooler will sign and date the evidence tape. The COC forms will be signed over to PMRMA's transport courier PMRMA will ship the samples by air freight (Federal Express) to HLA's geotechnical laboratory

3.4 Geotechnical Testing

A series of laboratory geotechnical tests will be performed on soil samples collected during the soil boring program to evaluate the geotechnical characteristics of the soil in the preferred landfill area. The geotechnical testing will be performed by HLA's geotechnical laboratory in Houston. Texas

Samples for geotechnical testing will be selected at 5-foot intervals from the boreholes The following geotechnical tests will be performed·

- Geotechnical testing to include approximately 350 samples for the following tests·
  - Grain-size analysis (ASTM D422)
  - Atterberg limits (ASTM D4318-84)
  - Natural water content (ASTM 2216)

- Remolded compaction (ASTM D698)
- Remolded permeability (EM1110-2-19096) at 90 and 95 percent relative compaction
- Shrink swell (ASTM D427)
- Organic content (ASTM D2976)
- Flexible wall permeameter (ASTM D5084-90)
- Shear strength consolidated undrained (ASTM D4767-88)
- Shear strength unconsolidated undrained (ASTM D2850-87)

Approximately 100 percent of the samples will be analyzed for grain size, Atterberg limits, and natural water content. The remaining tests will be performed on approximately 10 percent of the samples

3.5 Data Evaluation and Reporting

The data from the borehole coring and geophysical logging, soil boring and sampling, and geotechnical laboratory testing subtasks will be included in the Site Feasibility Report. These data will be integrated into the area feasibility subtask and used to evaluate the feasibility of constructing a landfill using the existing foundation materials

The borehole coring and geophysical logging data will be used with existing geologic data to generate additional detailed geologic cross sections within Section 25 Drafted lithologic logs of each borehole will be produced. The geophysical logging data will be used to correlate between the boreholes and to compare with the geologic core. A map will be generated that includes the new and existing boreholes, and also shows the location of newly constructed cross sections

The soil boring geologic logs and geotechnical testing data will be used to generate shallower geologic cross sections and characterize the geotechnical properties of the soil in the western half of Section 25 The geotechnical test results will be submitted to PMRMA through the data management subcontractor, D.P Associates.

4.0 ACRONYMS AND ABBREVIATIONS

Army	U.S Department of the Army
ASTM	American Society for Testing and Materials
bgs	Below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/s	Centimeters per second
COC	Chain of custody
Colog	Colog, Inc
COR	Contracting Officer's Representative
CWTS	CERCLA Wastewater Treatment System
DAA	Detailed Analysis of Alternatives
DSA	Development and Screening of Alternatives
ET	Engineering technician
FFA	Federal Facilities Agreement
FS	Feasibility study
HLA	Harding Lawson Associates
ID	Inside diameter
K_v	Vertical permeability
K_h	Horizontal permeability
NCP	National Contingency Plan
OD	Outside diameter
PID	Photoionization detector
PMRMA	Program Manager for Rocky Mountain Arsenal
PPE	Personal protective equipment
RAOs	Remedial action objectives
RMA	Rocky Mountain Arsenal
ROD	Record of Decision

SARA	Superfund Amendments and Reauthorization Act of 1986
SDRI	Sealed double-ring infiltrometer
TEG	Temperature effect gauge
TM	Task manager
TSB	Two-stage borehole
USFWS	U S Fish and Wildlife Service
WES	Waterways Experiment Station

5.0 REFERENCES

EBASCO Services, Inc. 1994 *Final report, hazardous waste land disposal facility assessment,* September

Harding Lawson Associates. 1994a. *Draft final feasibility study soils support program report,* June

Harding Lawson Associates 1994b *Final accident prevention plan (site safety and health plan) for the feasibility study soils support program,* as amended June 1994.

Appendix A

INSTALLATION AND OPERATING INSTRUCTIONS FOR THE SEALED DOUBLE-RING INFILTROMETER

soil testing equipment
TRAUTWEIN
P.O.Box 31429 · Houston, Texas 77231 · Tel: (713) 721-1866

INSTALLATION AND OPERATING INSTRUCTIONS FOR THE SEALED-DOUBLE RING INFILTROMETER

(TRAUTWEIN 1/91)

1.0 SUMMARY OF TEST METHOD

The Sealed-Double Ring Infiltrometer (SDRI) can be used to measure the vertical, one-dimensional infiltration rate of water through soil This device provides a means to measure low infiltration rates, those associated with fine-grained, clayey soils, and are in the range of 1x10-5 cm/sec to 1x10-8 cm/sec The SDRI is particularly useful for measuring liquid flow through soil moisture barriers such as compacted clay liner or covers used at waste disposal facilities, and amended soil liners such as those used for retention ponds or storage tanks.

A schematic of a typical test installation is shown in Fig. 1 The infiltrometer consists of an outer ring (12' x 12') and an inner ring (5' x 5'). The rings are grouted in trenches excavated in the test area. The outer ring is placed at a depth of 14 in. to 18 in., the inner ring to a depth of 4 in. to 6 in. Both rings are filled with water. The outer ring is filled to a depth of approximately 12 in., submerging the inner ring The top on the inner ring seals the water within it from the atmosphere.

Installation requires a level, obstruction free work zone approximately 24' x 24' A primary concern before and during installation of the infiltrometer is desiccation. Before installation, desiccation can be minimized by covering the test area with plastic. Plastic sheets for this purpose, 20' x 100', are readily available at most building supply stores. Spreading a thin layer of soil over the plastic will prevent it from blowing away During installation, desiccation can be minimized by removing plastic only in areas being worked, and recovering areas once work has been completed. Water should be sprayed on any soil that is exposed for long periods of time.

Measurement of flow is made by connecting a flexible bag, filled with a known weight of water, to a port on the inner ring. As water infiltrates the ground and leaves the sealed inner ring, it is replaced with an equal amount of water drawn in from the flexible bag. After a known interval of time, the flexible bag is removed and weighed. The weight loss, converted to a volume, is equal to the amount of water that has infiltrated the ground. An infiltration rate, usually expressed in cm/sec, is then determined using this volume of water, the area of the inner ring, and the interval of time that the bag was connected to the inner ring This process is repeated and a plot of infiltration versus time is constructed. The test is continued until the infiltration rate becomes steady or until it becomes equals to or less than a specified value

The advantage of the SDRI over other infiltrometers is the capability to measure low infiltration rates. This is accomplished by measuring the actual quantity of flow rather than a drop of elevation in the water level and by eliminating evaporation from the ring where measurements are made.

2.0 PARTS LIST

First check to see that the following parts were included with the Sealed Double Ring Infiltrometer .

a 4 - aluminum panels approximately 12' x 36"
b 1- fiberglass inner ring approximately 5' x 5'

c. 36 - of each of the following 3/8" round head bolts and nuts
d. 2 - flexible bags with pinch valves and barbed connectors
e. 1 - 1/2" NPT plug fitting
f. 1 - 1/2" NPT fitting with straight-barbed connector
g. 1 - 1/2" NPT fitting with elbow -barbed connector
h. 1 - 15' length of 3/8"od x 1/4"id clear plastic tubing
i. 1 - 1/4" brass plug fitting for sealing end of plastic tubing
j. 1 - tee fitting
k 4 - rubber gasket strips
l. 1 - tensiometer set (optional -.see Appendix A)
m. 1.- swell gage (optional - see Appendix B)

In addition to the list above, the following items will be needed to assemble and install the SDRI

a. 1 - flat bladed screw driver for assembling the outer ring
b. 1 - 9/16" wrench for assembling the outer ring
c. 1 - brick or mason's hammer for excavating trench for the inner ring
d. 1 - adjustable wrench for installing fittings on inner ring
e 1 - knife or scissors for cutting tubing
f. 1 - trenching machine for excavating outer ring trench
g. 5 - 5 gal. buckets to mix grout and place on inner ring
h. water supply - approximately 1200 gallons is needed to fill rings
i bentonite grout to place in trenches
j cover for rings (see Appendix C)
k 1 - thermometer to monitor temperature in outer ring
l surveyor's level and rod
m. 1 - scale to measure the depth of the water in the outer ring
n grout mixer, shovels, and wheelbarrows for preparing grout.
o cinder blocks to stand on when connecting fittings to inner ring and also to hold down platform for flexible bag
p trowel
q scale - 4000g capacity sensitive to 1g
r. 1 - 14' 2x4 to use as guide when excavating trench
s plywood (2'x3'x1/2") to use as splashboard and platform for flexible bags

3.0 ASSEMBLY OF OUTER RING

Installation starts with the assembly of the outer ring as follows

1. Carefully uncrate the aluminum panels. Save the crate for future shipping.

2. Carefully tilt up two panels and align edges and bolts holes (Fig 2) Support panels on both ends as they bend easily, particularly in windy conditions.

3. Wipe panel edges clean around bolts holes Also wipe rubber gasket strips clean.

4 Place a rubber gasket between the panel edges and insert bolts through the holes Turn nuts on bolts until finger tight.

5 Tilt up remaining panels, one at a time, and bolt edges together as described above

6 Position outer ring so that it is square Turn nuts on bolts until snug. Do not overtighten as this will cause panel edges to bow apart between bolts.

4.0 EXCAVATION OF TRENCHES

The area to be tested should be level with a slope no greater than 4" over 12' Slopes of this magnitude are difficult to detect by eye, so a surveyor's level should be used to check elevations. High and low areas should be noted so that trench depthin these zones can be adjusted to keep rings level.

Procedures for excavating trenches are described below.

4.1 OUTER RING

1. Set the outer ring on the area to be tested so that it is square

2. Scribe a mark on the ground along the lower edge of the ring.

3. Lift ring and place it aside while trench is being excavated.

4. Place the edge of a 2x4 along scribe marks and paint a line on the ground. Extend line approximately 5' beyond each corner. This will help in aligning trenching machine. .

5. Use a trenching machine to excavate the trench (Ditch Witch Model No 1010 or equivalent). Select a machine that makes as narrow a trench as possible, no more than 4" - 6" in width. The narrower the trench, the less grout needed to fill it. Align the trenching machine with the boom over the paint line. The side of the trencher which removes the excavated dirt should be pointed away from the test area. Offset a 2x4 so that it is parallel to the paint line and against the wheel of the trenching machine inside the test area. Paint a line along edge of 2x4 to mark its position. Use the 2x4 as a guide by keeping the wheel of the trencher against it while excavating the trench. Excavate so that the deepest point is 18". Limit the amount of over excavation at corners as this will only increase the volume of grout needed.

   In some soils, several passes may be needed to reach the required depth. Typically, the higher the plasticity index, the greater the number of passes Loose soil in bottom of trench and packed in corners should be removed by hand.

6. Once trench has been excavated and loose material removed, carefully place outer ring in trench to check fit Make adjustments as needed The ring should be level (±1") After adjustments are made, lift ring out of trench and set aside Cover trench to keep soil from drying while grout is prepared.

4.2 INNER RING

1. Center fiberglass inner ring within outer ring. Scribe a mark on ground along lower edge of inner ring.

2. Note the orientation of inner ring and set it aside. Also lift outer ring and place it aside. Cover outer ring trench to keep from drying.

3. Use a brick hammer (mason's hammer) to excavate a narrow trench. Trench should be approximately 2" wide and 6" deep When using brick hammer, it is best to start by digging down several inches in one spot and advancing trench forward by chopping down on soil. Try not to pry soil up as this tends to lift up large wedges, open cracks, and causes the trench to be oversized .

4 Place the inner ring in the trench to check the fit. Excavate any areas where the ring does not fit. Use a surveyor's level to check elevation of the corners of the ring The inner ring should be level or tilted so that lower end is slightly below horizontal. If lower end of ring is above horizontal, air may be trapped in ring when ring is filled with water.

5 Set the ring aside and cover the trenches.

5.0 INSTALLATION OF THE RINGS

5.1 PREPARATION OF GROUT

A product sold by American Colloid called "Volclay Grout" works well for sealing the rings. Between 15 to 20 bags of Volclay Grout are needed for 4" wide by 18" deep trench. If this product is used, add between 15-20 gallons of water per 50 pound bag The most convenient way of mixing the grout is to use a 4 bag grout mixer. Two bags of grout can be prepared at a time. First add 15 gallons of water to the mixer and then slowly add the grout . Adding the grout too quickly will result in a mixture with large clumps. Add 15 more gallons of water and then add the second bag. Add additional water as needed until the grout flows easily

5.2 OUTER RING

1. Prepare enough grout to fill the outer ring

2 Remove the cover from the outer ring trenches and clean all loose dirt out of the trench.

3 Use a wheelbarrow to place grout in the outer ring trench Use a sheet of plywood from the outer ring crate as a splash board to guide grout into trench and from getting on ground inside the trenches

4. With one person at each corner of the outer ring, lift it and center it over the trench Slowly push the ring in place while keeping it level. Once in place, use a trowel to push the grout against both the inside and the outside of the ring , particularly at the corners, to obtain a good seal.

5. Pile loose soil (12" high) all around the outside edge of the outer ring (Fig. 3) This berm will prevent the ring from bowing and will keep grout from being pushed out of the trench when the ring is filled with water. The berm also serves to insulate the outer ring which minimizes temperature changes in the water.

5.3 INNER RING

1 Prepare a thicker mix of grout for the inner ring trench.

2. Remove the cover from the inner ring trench and clean all the loose dirt out of the trench. Also clean off the surface of the area surrounded by the inner ring trench.

3. Fill the trench to within 3/4" of the top. Rod the grout to remove any air pockets

4 Lift the inner ring and center it over the trench. Lower it into the trench and push it down into place Use a surveyor's level to check the elevation of the corners of the ring. Make sure that the lower end of the ring is not tilted or raised above horizontal as discussed before.

5 Use a trowel to press the grout against the outside wall of the ring in order to obtain a good seal.

6 Cover the grout to prevent desiccation.

6.0 TENSIOMETERS

If it is desired to know the position of the wetting front during infiltration, it is recommended that tensiometers be used. A description of tensiometers and installation procedures are given in Appendix A.

7.0 SWELL GAGES

If the soil has a high potential for swelling, it is recommended that swell be measured during the test. Swell can be measured by monitoring the vertical movement of the inner ring during the test. As the soil beneath the inner ring swells, it will lift the inner ring A procedure for monitoring swell is described in Appendix B

8.0 FILLING THE RINGS

It is best to fill the rings slowly so that the seal can be checked for leaks It is much easier to repair a leak when the water level is low than when it is high.

When filling the inner ring, it is important to realize that water causes an uplift force to act on the ring. If the ring is filled to too high a level, the uplift forces can lift the ring out of the ground. For this reason buckets of water are placed on the inner ring before water is is added to it.

The general procedure for filling the rings is as follows First, the inner ring is partially filled and let to sit to check its seal. Next, the outer ring filled. The ports on the inner ring are left open so it will fill as the water level in the outer ring rises

The fittings are attached to the inner ring after the outer ring is filled. The cinder blocks are used to provide a place to stand when attaching the fittings Place several cinder blocks on the ground in the vicinity of ports on the inner ring Also place several cinder blocks on the ground just inside the outer ring to provide a place to lay the flexible bag during the test.

Detailed instructions for filling the rings are given below

8.1 INNER RING

1 Fill two buckets with water and place one on each corners of the low edge of the inner ring Make sure that the buckets are placed on the edge of the ring and not in the center as this may cause the fiberglass to crack. Try not to spill any water around the inner ring as this will make it difficult to check for leaks around the seal later on.

2. Invert one bucket on the ground near the ports on the inner ring Fill a second bucket with water and place it on the inverted bucket.

3. Cut a length of the flexible tubing long enough to reach from the bucket to the top port. Use this tube to siphon the water from the bucket to the inner ring. Siphon a total of three buckets (15 gallons) of water into the inner ring.

4 Let the water in the inner ring stand for at least 30 min. Check for leaks in the inner ring seal and repair any that are found.

8.2 OUTER RING

1 Place a piece of plywood from the outer ring crate on the ground between the inner and outer ring Place a bucket on the plywood. Put the end of the hose that is to used to fill the rings into the bucket.

2. Slowly fill the rings at a rate that will not scour the soil

3. Should a leak occur, repair it by pushing down on the grout on the inside edge of the outer ring first, then pressing down on the grout along the outer edge.

5. When the water level is at the top port on the inner ring, stop filling and allow the water level in the inner ring equilibrate with the water in the outer ring.

6. Continue to fill the outer ring until the water level is approximately four inches above the top port on the inner ring (a depth of approximately 12"). Use a board or shovel handle to gently tap the inner ring to dislodge air bubbles that are trapped inside. Continue tapping on the inner ring until bubbles cease to emerge from the top port.

7. Remove the buckets from the top of the inner ring

9.0 INSTALLATION OF FITTINGS

Before installing any fittings into the ports of the inner ring, check that all the threads are wrapped with teflon tape. Screw fittings in slowly at first and check that they are not cross-threaded. The threads in the fiberglass can be stripped easily. Also, do not overtighten the fittings as this may crack the fiberglass.

Detailed instructions for installing the fittings are given below.

1. Find the plug fitting and install it in one of the lower ports.

2. Find the two fittings with the barbed hose connectors. The straight fitting goes in the lower port and the elbow fitting goes into the top port. Saturate the fittings before connecting them to the inner ring.

3. Cut two lengths of tubing, one 3' long and the other 7' long

4. Place the two pieces of tubing under water to saturate them. Be sure that all the air is removed from the tubing before connecting it to the inner ring Any air remaining in the tube will be drawn into the inner ring.

5. Push one end of the long piece of tubing onto the top port fitting Find the small brass plug fitting and insert it into the other end of

the tubing This tube is the flush tube and is used to purge air that has become trapped in the inner ring

6. Connect the short piece of tubing to the lower port fitting This is the inlet tube through which flow measurements are made Fix the open end of the tube to one of the cinder blocks near the wall of the outer ring. Be sure the end of the tube does not float to the surface and suck in air or fall to the bottom and suck in mud.

10.0 COVERING THE RINGS

The rings should be covered throughout the test. Its best to construct a cover of plywood, 2x4's, and insulation. The primary purpose of the cover is to minimize temperature change of the water in the rings, block sunlight, and prevent from wind blowing over the water surface. Supplies and material for building a cover are given in Appendix C.

11.0 DATA COLLECTION

The data collected during the test includes flow measurements, water temperature, water level measurements, swell measurements, and tensiometer readings Sample data sheets are attached to these instructions. The procedures used to collect these measurements are discussed below.

11.1 FLOW MEASUREMENTS

Measurement of flow during an SDRI test is made using a flexible bag The bag is filled water, weighed, connected to a port on the inner ring, and submerged in the water of the outer ring. Any water that flows out of the inner ring into the ground will be replaced by an equal amount of water from the bag. Periodically, the bag is removed and weighed to determine the amount of water that was lost.

Besides convenience and simplicity, a key feature of using a flexible bag to measure flow is that a constant pressure difference is maintained across the wall of the inner ring. Consequently, the inner ring does not expand or contract when the water level changes in the outer ring.

The flow measurement data is used to construct a plot of infiltration versus time. For unsaturated soils such as compacted clay liners and covers, infiltration decreases with time at first, changing rapidly at the beginning of the test, and then eventually becoming constant with time as the soil becomes saturated. Consequently, more frequent readings are needed at the beginning of the test and less frequent readings are need as the flow rate becomes steady

Typically, flow rates at the beginning of the test (< three weeks) range from 1000 ml to 3000 ml per day. One reading per day has been found to be sufficient during this time. When infiltration starts to level out (three to four weeks) one reading in several days is all that is necessary.

Temperature changes of the water in the inner ring can introduce significant error in the flow measurements A 1 change in water temperature can result in a flow of 50 ml due to volume change of the water in the inner ring as well as in the inner ring itself. To avoid this problem, the bag should be disconnected from the inner ring when the water temperature is within ± 1 °C of the water temperature when the bag was connected. This is particularly important if the flow rate is less than 500 ml/day

Experience has shown that if the rings are covered and a layer a polystyrene is used for insulation under the cover, the temperature of the water from one morning to the next does not vary by more than 1°C. More consistent readings are obtained if they are taken on a 24 hour basis and the bag is connected and disconnected between 7am and 9am. It should be noted that the water temperature may change by several degrees during the day but that these cyclic variations are only a problem if readings are made at different temperatures Allowing the bag to remain connected until at least 1500 ml of flow has occurred also helps to minimize the effect of temperature changes on the measurement of infiltration rate

The bag should never be allowed to empty when connected to the inner ring When the bag empties, a suction will develop in the inner ring and it may jepoardize the seal. The most likely time that the bag will empty is at the beginning of the test when flow rates are not known. For this reason, the bag should be checked often when first connected. An initial reading should be made after several hours so that a flow rate can be calculated and an estimate of when the bag will empty can be made

It should be noted that it is not necessary to have the bag connected to the inner ring continuously. If the flow rates are high, (>3000 ml/day) it may be more convenient to connect the bag up to the inner ring for several hours a day and let the inlet tube open in the outer ring for the remainder of the time. Whether the inlet tube is connected to the bag or open to the outer ring does not affect the infiltration rate. Just be sure if the tube is left open that it is propped in such a way that it does no suck in air or soil. If it is desired to measure flows greater than 3000 ml/day, a tee fitting has been provided so that two bags can be connected to the inlet tube at once.

Detailed instructions for using the bag given below

11.1.1 <u>Filling the bag.</u>

1 Fill a bucket or a 5 gallon water jug with water and allow to stand for 24 hours to degas.

2. Cut a piece of flexible tubing long enough to reach from the bottom of the jug or bucket to a flexible bag laying next to it.

3. Connect the tube to the valve on the bag and siphon water from the jug into the bag until it is filled.

4. Lift the bag above the water surface in the jug. Hold the bag with the inlet port at the top and squeeze it to remove all the air. Squeeze the bag long enough to force the air out of the tube and then lower the bag so that water will flow back into it. Repeat this process until all the air is removed.

5 Once all the air is removed, fill the bag slightly less than full and shut the valve. Avoid completely filling the bag so that the water in it is under pressure.

6. Dry the bag and valve thoroughly If small amounts of flow are expected (20 ml or less) then be sure that the tube connector remains full of water.

7 Weigh and record the initial weight of the bag to the nearest gram

11.1.2 Connecting the bag to the inner ring.

1. Connect the bag to the inlet tube as follows. Lower the bag into the water of the outer ring Orient the valve so that the tube connector is pointed up Flick the tube connector so that any entrapped air bubbles will be removed from it. It is important that no air bubbles are present in the tube connector or bag as they will be drawn into the inner ring or may even block the flow of water from the bag to the inner ring With the bag completely submerged push the tube connector into the inlet tube Lay the bag flat on the cinder blocks Be sure to position the valve so that it is not folded back onto the bag and possibly pinching off the flow path.

2. Start flow measurements immediately as follows. Use the attached data sheet and record the date and time next to the initial weight of the bag Carefully open the valve and allow flow to occur.

3. Periodically determine the amount of flow that has occurred as follows. Carefully close the valve and disconnect it from the inlet tube. Be sure to close the valve before handling the bag. Also, be sure to prop up the open end of the inlet tube for the reasons mentioned previously. Record the date and time that the valve was closed . Remove the bag from the inner ring, dry it thoroughly, and record its weight. As before, make sure that the tube connector is filled with water to be consistent. Subtract the final weight from the initial weight to obtain the amount of flow that has occurred.

4 Refill and reweigh the bag if necessary and connect it to the inner ring. Always check to see that the valve on the bag or the inlet tubing has not become clogged. With time, algae may grow in the tube. If this is the case then the tube should be cleaned or replaced.

Two bags have been supplied. If flow rates are greater than 3000 ml/day, both bags can be connected to the inner ring at the same time by using the tee fitting(Fig 4) that has been supplied. If the flow rate is less than 3000 ml/day, the extra bag can be filled and weighed in advance so that it can be connected to the inlet tube when the other is removed. By doing this, only one trip to the ring is needed to take a reading

When connecting a bag to the inner ring, be sure that the valve is closed. If the bag is accidentally lifted out of the water with the valve open, it is possible to lift the inner ring out of the ground or rupture the seal. Each inch of head of water produces an uplift force of about 125 pounds on the inner ring, so holding the bag several inches above the water level with the valve opened can easily lift the inner ring out of the ground.

11.2 WATER LEVEL

The infiltration rate varies with the depth of the water level in the outer ring. For this reason, the water level should be recorded each time a flow measurement is made. Water should be added to the outer ring occasionally in order to keep the water level to within $\pm 1/2$ inch of the initial level. A scale taped to the inside wall of the outer ring makes it convenient to monitor the water level.

11.3 TEMPERATURE

The temperature of the water in the rings should be monitored closely for reasons discussed previously. If temperature is monitored with a thermometer, then measurements need to be made as close to the inner ring as possible The recommended procedure is to put the thermometer in a soda can and then place the can on the ground next to the inner ring. Remove both the can and the thermometer to take a reading. The water in the can should remain at the same temperature as the water near the inner ring long enough to take a reading.

11.4 PURGING AIR FROM INNER RING

During the test, it is possible that air may rise out of the soil and become trapped in the inner ring This air should be purged from the inner ring and an estimate of its volume made. If the volume is significant (>20% of flow since the last time the ring was purged) the infiltration rate should be corrected to account for it.

The procedure for purging the inner ring of air is described below.

1 Disconnect bag inlet tube. Use a board or shovel handle and gently tap on the inner ring to get the air bubbles to rise to the flush port.

2. Lift the flush tube out of outer ring and lay end of tube on the ground. The end of the tube needs to be below the water level so that water can be siphoned out of inner ring.

3 Remove plug from end of flush tube. Water and air if present will start to flow out of inner ring. If air completely fills the tube, the syphon will be lost. If this happens, submerge end of tube in water of outer ring and work air out of tube. Once the

tube is saturated, place plug in end of tube, lift tube out of ring and place on ground. Remove the plug and allow water to flow from end of tube (if tensiometers are being used, the hand pump can be used instead to restart the siphon by pulling a vacuum on the end of the tube)

4. Allow water to flow from end of tube until air ceases to emerge from inner ring. Replace plug in end of flush tube and place tube back into outer ring.

5. Wait at least 30 min. before taking any flow measurements.

Purge the inner ring on a weekly basis until no significant amount of air is found.

12.0 DATA REDUCTION

12.1 INFILTRATION

Infiltration (I) can be determined as follows:

$$I = Q/(At)$$

where:

I = infiltration (cm/sec)
Q = volume of flow (cm^3)
A = area of flow (cm^2)
t = time interval in which Q was determined (sec)

Two factors that can have a significant effect on the infiltration rate are temperature changes and swelling of the soil. If either are significant, the infiltration rate should be corrected to account for it. The total flow (Q) that is measured is the sum of the following.

$$Q = Q_i + Q_s + Q_t$$

where

Q_i = flow due to infiltration

Q_s = flow due to swell

Q_t = flow due to temperature changes

The infiltration rate corrected for swell and temperature changes is.

$$I = Q_i / At$$

where:

$$Q_I = Q - Q_s - Q_t$$

Temperature changes can be minimized as discussed previously and consequently, Qt is seldom significant.

The remaining portion of flow to consider is Qs, the flow due to soil swell. The process of water infiltrating an unsaturated swelling soil is complex and difficult to analyze. Presently, there is not an accepted procedure to account for the effect of soil swell on the infiltration rate. The author is of the opinion however, that a close estimate of Qs can be obtained as follows. First, it is assumed that any volume change that occurs is vertical. Second, it is assumed that all of the additional volume generated by the swelling soil is filled with water that infiltrated the soil. Based on these two assumptions:

$$Q_s = \Delta h \times A$$

where

Δh = vertical swell of soil beneath inner ring

A = area of inner ring

12.2 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity (k) in the saturated zone can be determined as follows:

$$k = Q/(iAt)$$

where:

Q = volume of flow (cm^3)
A = area of flow (cm^2)
t = time interval in which Q was determined (sec)
i = gradient
= $\Delta h / \Delta s$
Δh = head loss
Δs = length of flow path for which Dh is measured

since.

$$I = Q/(At)$$

then

$$k = I/i$$

The determination of k depends on calculating a value for the gradient (i). Unlike the calculations for I and k, the determination of i is not straight forward. The parameters used to calculate i for a typical infiltration test are shown in Fig. 5. These parameters are used to calculate the gradient as follows:

$$i = (H + D + Hs) / D$$

where

H = depth of water ponded in rings
D = depth to the wetting front
Hs = suction at the wetting front

There are differing opinions on what value should be used for Hs One view is that Hs should be equal to the ambient suction in the soil below the wetting front. The ambient suction can be measured with tensiometers can be quite high, yielding values of Hs as high as 700 cm of water. Another view is that Hs should be equal to zero, ie the suction in the soil at the wetting front has no influence on the infiltration rate. Hence, if the position to the wetting front is known, the gradient is simply $(H + D) / D$.

The author feels that the second view ($Hs = 0$) yields a close approximation to the actual gradient Measurements made at several sites have shown that the drop in infiltration rate versus time can be accounted for by the increase in D as the wetting front moves through the soil. If suction had an influence, a much larger decrease in the infiltration rate would have occurred.

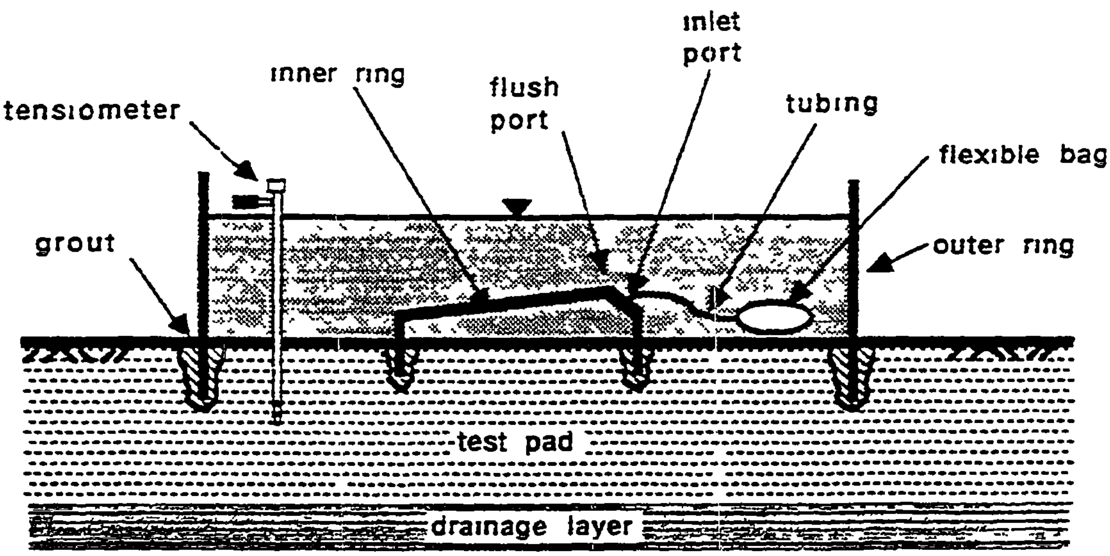


Figure 1. Schematic Of A Sealed-Double Ring Infiltrometer Installed On Test Pad

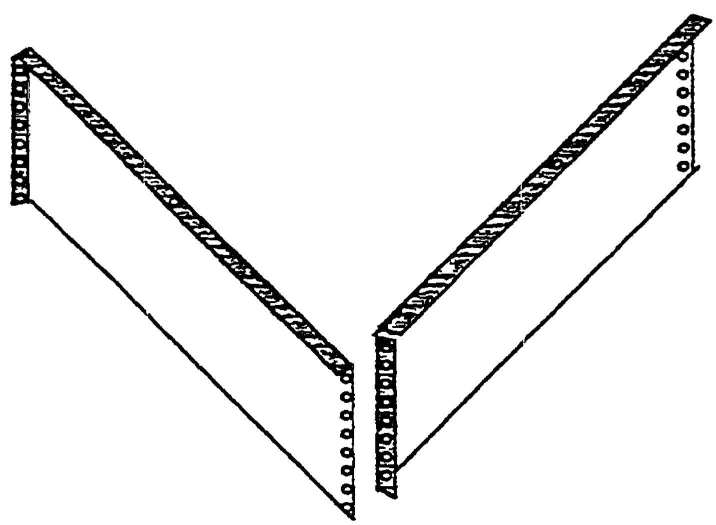


Figure 2. Orientation Of Panels For Assembly Outer Ring.

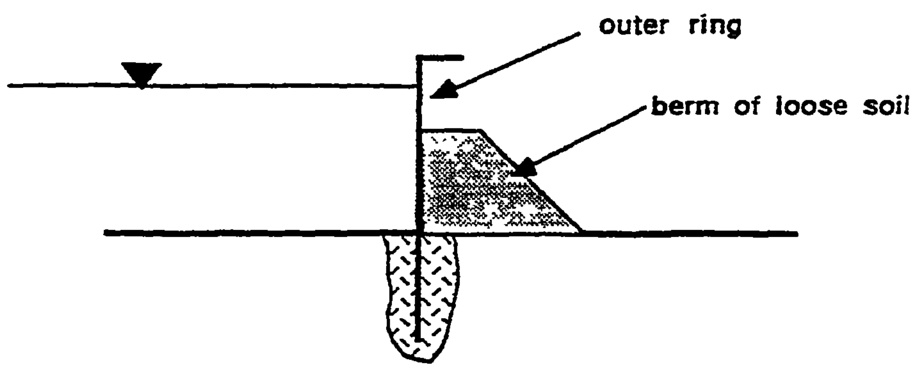


Figure 3. Berm Of Soil On Outside Of Outer Ring

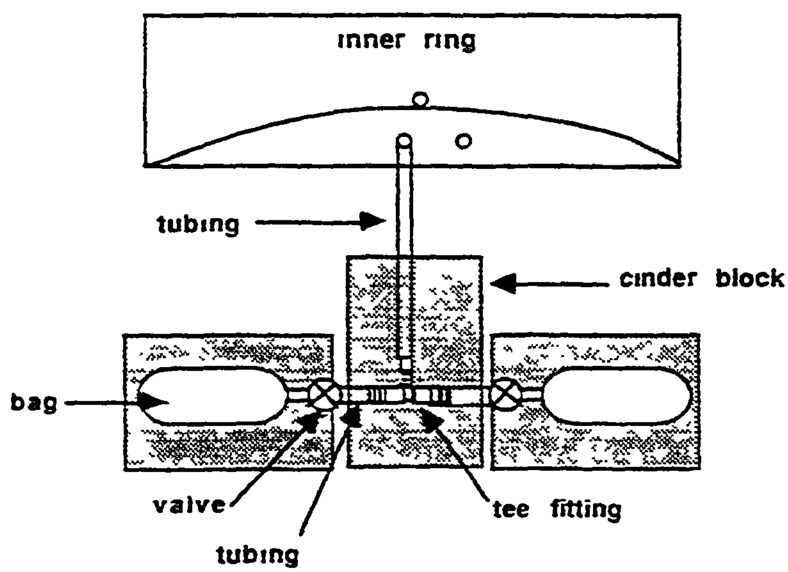


Figure 4. Arrangement Of Two Bags Connected To Inner Ring

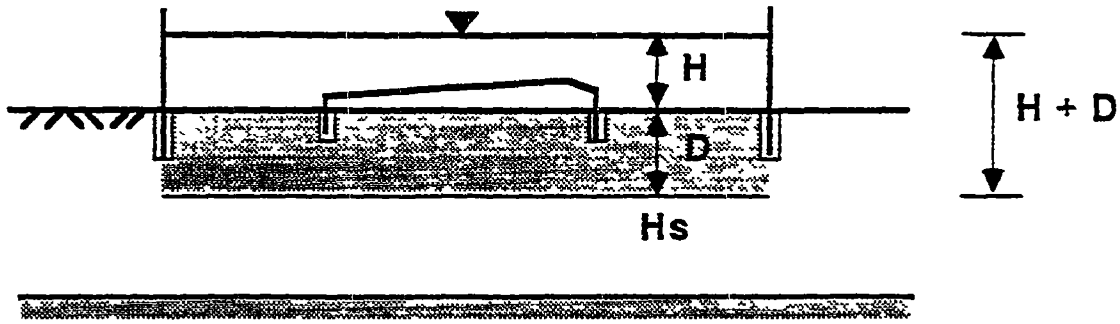


Figure 5. Diagram With Parameters Needed To Calculate Gradient

APPENDIX A

TENSIOMETER DESCRIPTION AND INSTALLATION INSTRUCTIONS

A schematic of a tensiometer is shown in Fig. 6. It consists of a sealed plastic tube with a porous tip on one end and a vacuum gage on the other The tube is filled with water and then sealed. Operating instructions have been included with the tensiometers A preferred method of installation however is described on Fig 6. Disregard the installation procedure described in the manufacturer's instructions. Driving a pipe may crack the soil and open up flow channels.

Tensiometers work as follows If the soil is unsaturated and there is good contact between the tip and the surrounding soil, water will be drawn out of the tube and the gage will register a suction. As the wetting front passes the the tip, the suction will decrease and water will reenter the tensiometer until the suction goes to zero Good performance of tensiometers depends on saturating the tensiometer and achieving good contact between the tensiometer and the surrounding soil.

It is recommended that nine tensiometers be used, three at each depth of 6", 12", and 18". A suggested layout for the tensiometers is shown in Fig. 7. Auguring a hole and pushing the tensiometer in place is preferred to forming a hole by driving a pipe into the ground.

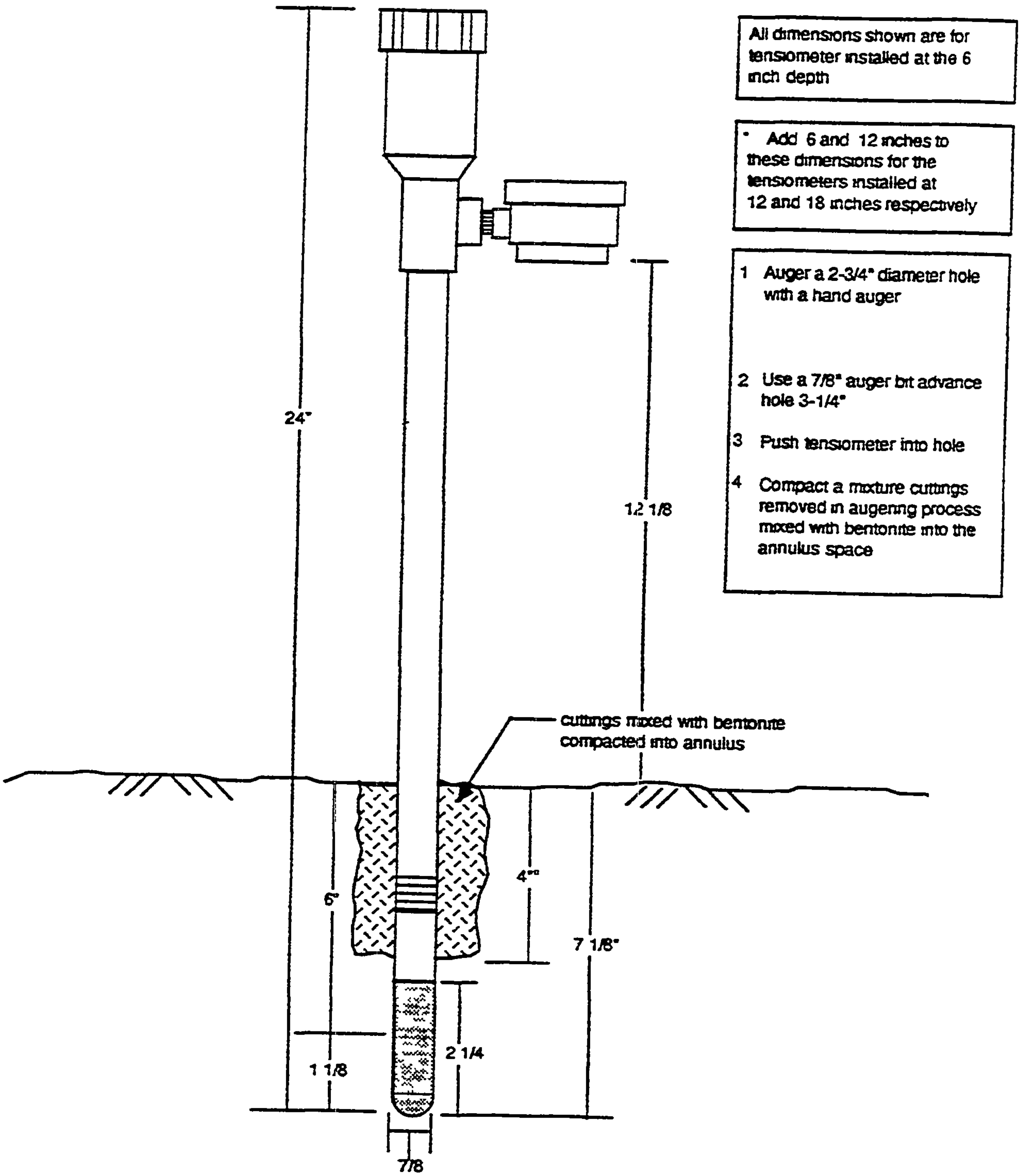


Figure 6. Schematic of a Typical Tensiometer Installation

APPENDIX B

SWELL MEASUREMENTS

An arrangement that can be used to measure swell is shown in Fig. 8. This arrangement consists of stretching thin wire between two fence stakes that have been driven into the ground close to the outer ring. The stakes are aligned so that the wire is positioned directly above two handles on the inner ring. The wire serves a a reference elevation to monitor upward movement of the inner ring. A swell gage is used to establish a reference distance between a reference mark on a handle and the wire. The swell gage consists of a dial gage mounted to a rod. The position of the dial gage on the rod is fixed.

It is recommended that two wires be used so that the elevation of all four handles on the inner ring can be monitored. A olt can be attached to the handle by drilling a 3/8" hole through the handle The bolt head can serve a reference point for the end of the swell gage rod. Initial readings are taken before the rings are filled to serve as a reference It is also recommended that the elevation of the wires be surveyed and referenced to a benchmark located away from the rings. If a discrepancy occurs in the readings, the wire can be surveyed to check that its position has not changed.

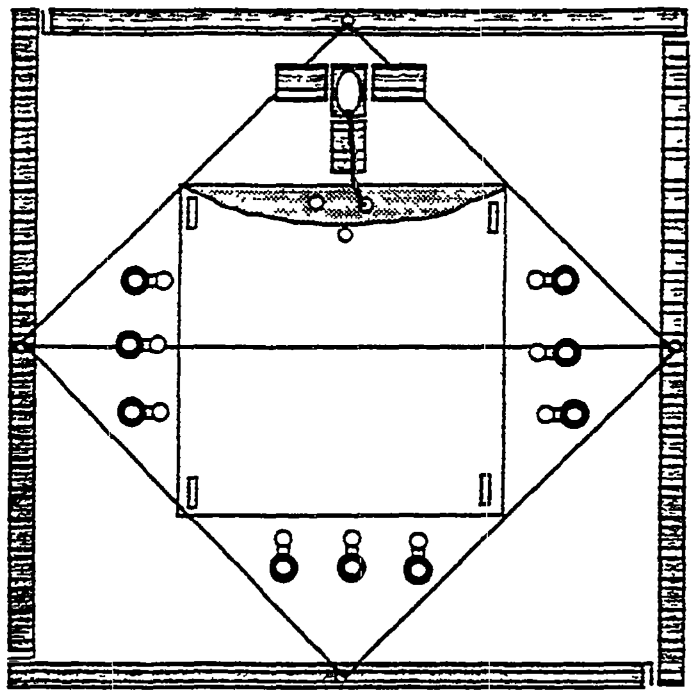


Figure 7. Top View Of SDRI Showing Layout Of Tensiometers

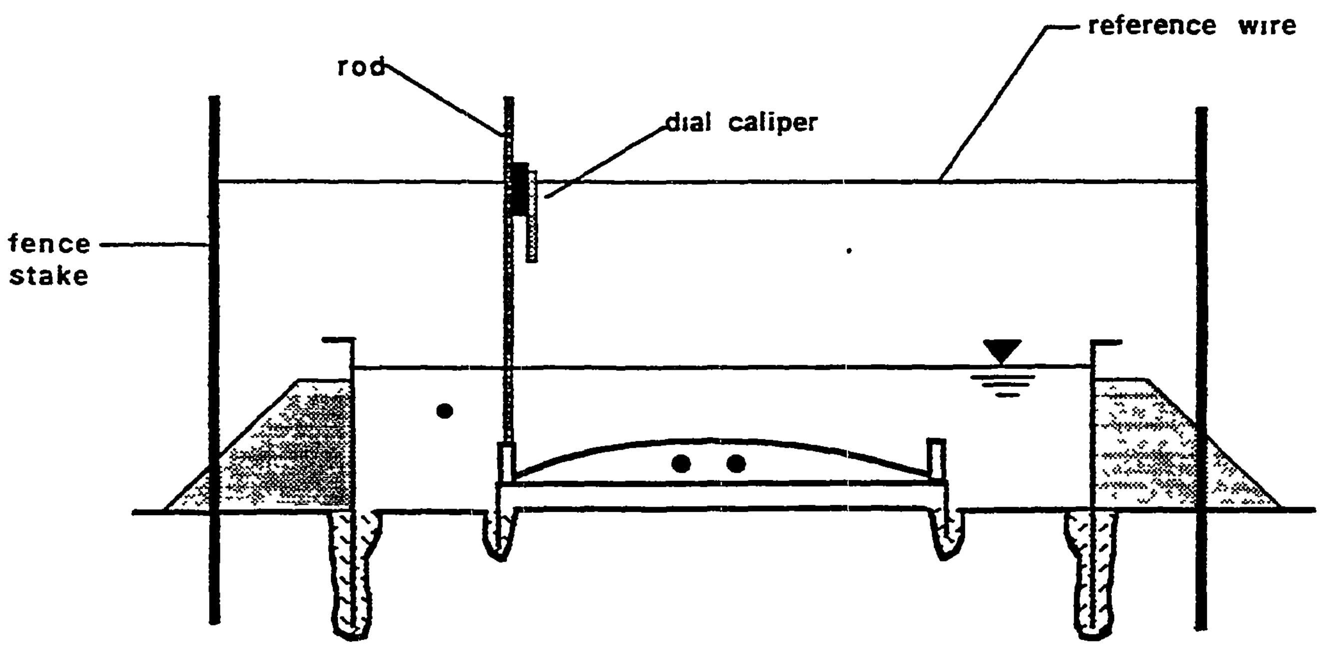


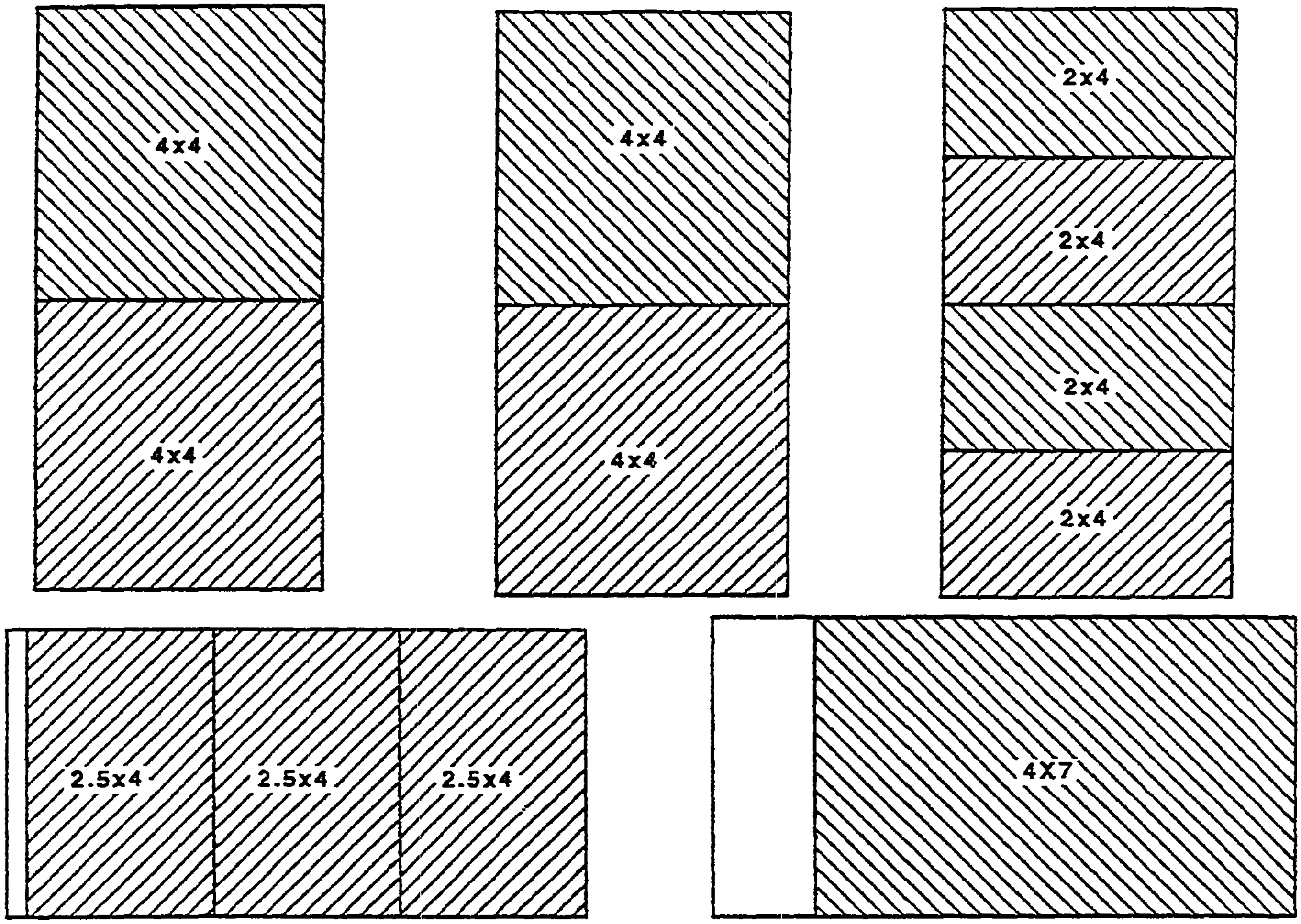
Fig. 8. Arrangement For Monitoring Swell

APPENDIX C

COVER DESCRIPTION

It is highly recommended that a cover which insulates the rings and blocks sunlight is be used during the test. A cover consisting of plywood, 2 x 4's, and insulation is shown in Fig. 9.

COVER MATERIAL LIST



MATERIALS

nails	2x4's	1/2" plywood	insulation
# 16 common 2" roofing	13 - 12'	(5) sheets cut as follows. 4 - 4x4 4 - 2x4 1 - 7x4 3 - 2.5x4	5 - 4x8x1/2 sheets (foil backed insulation- the type used on ext. walls of houses)

Fig. 9a. SDRI Cover

TOP VIEW OF SDRI COVER
WITH 2X4'S IN PLACE

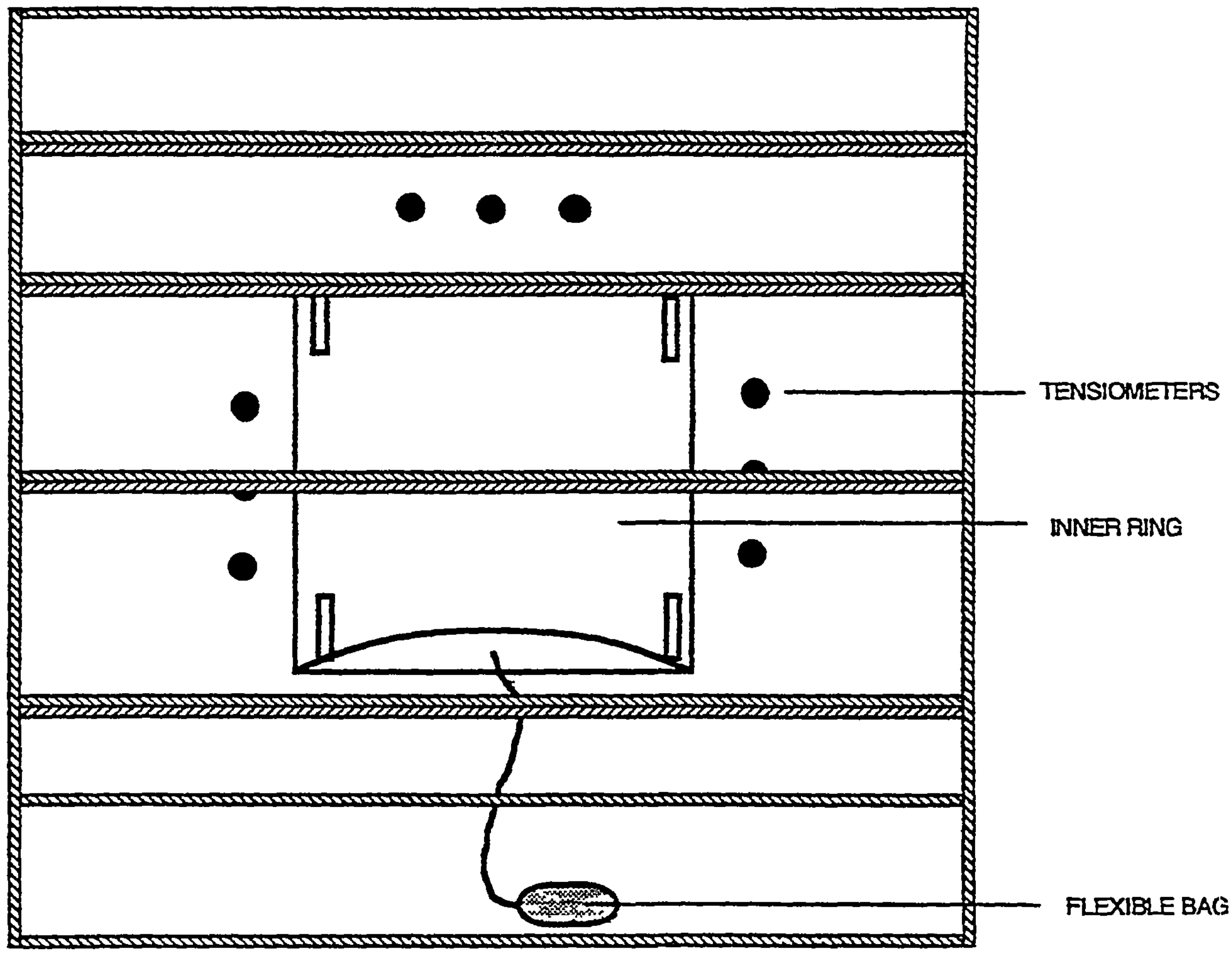


Fig. 9b. SDRI Cover

TOP VIEW OF SDRI COVER WITH PLYWOOD IN PLACE

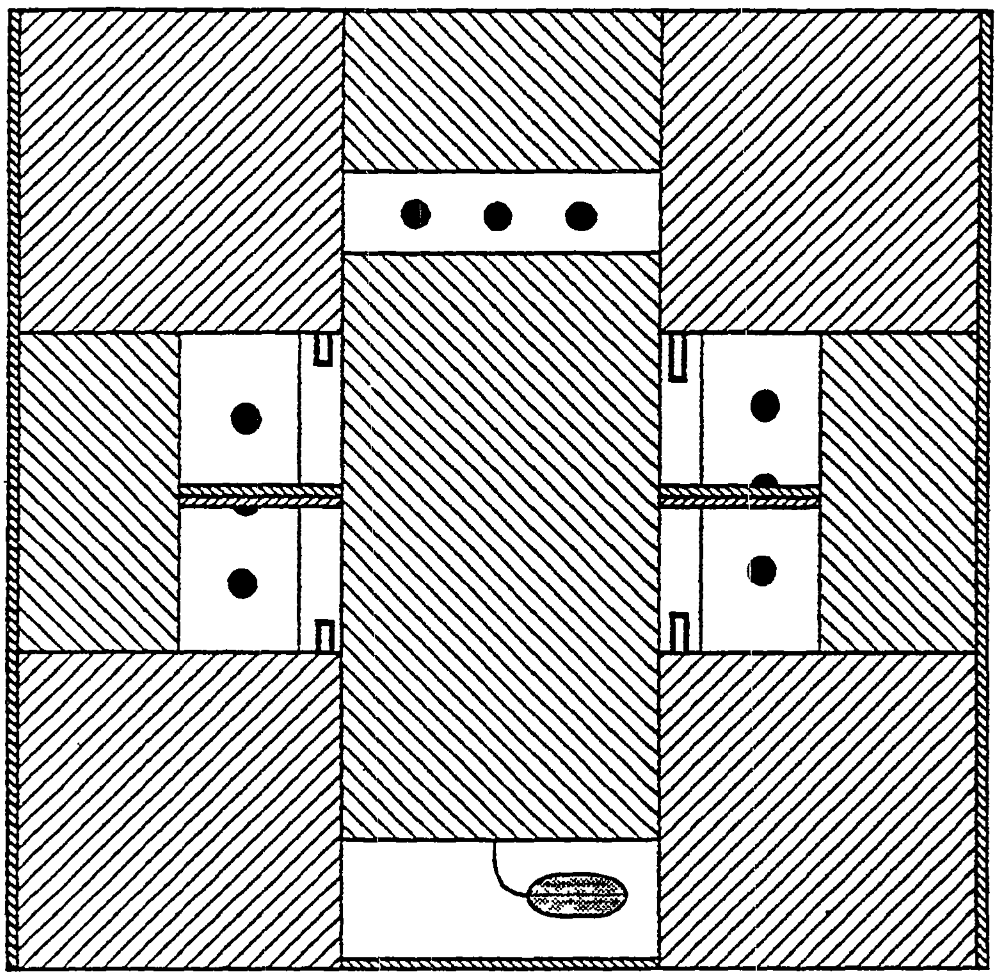
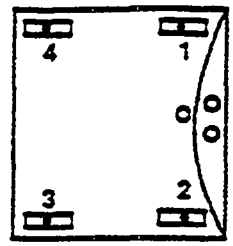


Fig. 9c. SDRI Cover

APPENDIX D

DATA FORMS

SWELL DATA



DATE	TIME	1	Δh	2	Δh	3	Δh	4	Δh	Δh_{avg}

NOTES

		TENSIOMETER READING - CENTIBARS											
		DEPTH - 6"				DEPTH - 12"				DEPTH - 18"			
DATE	TIME	GROUP 1	GROUP 2	GROUP 3	AVG	GROUP 1	GROUP 2	GROUP 3	AVG	GROUP 1	GROUP 2	GROUP 3	AVG

PROJECT: ______________________

TENSIOMETER TYPE: ______________________

NOTES:

DATA FORM FOR SDRI TEST

Project: ______________________

Inner ring info: ______________________

Outer ring info: ______________________

Liner thickness (cm) : ______________________

$$I = Q/(At)$$

I = infiltration (cm/sec)

Q = quantity of flow (ml)

t = interval of time (sec)

A = area of inner ring (cm 2) __________

Date	Initial time (sec)	Final Time (sec)	t Interval of Time (sec)	Initial Wt of Bag (grams)	Final Wt of Bag (grams)	Q Quan of Flow (ml)	I Infiltration (cm/sec)	Temp (C)	Water Depth (in)
on / off								on / off	on / off

NOTES:

Appendix B

THE STEI TWO-STAGE BOREHOLE FIELD PERMEABILITY TEST

THE STEI TWO-STAGE BOREHOLE FIELD PERMEABILITY TEST

by: Gordon P. Boutwell, PhD, P.E.

Presented to
"CONTAINMENT LINER TECHNOLOGY AND SUBTITLE D"
Seminar Sponsored by
Geotechnical Committee
Houston Branch, ASCE
Houston, Texas - March 12, 1992

SYNOPSIS

In 1991, the Texas Department of Health began requiring field verification of the hydraulic conductivity for the waste-retention barriers under its jurisdiction. The TDH has approved two procedures: the Two-Stage Borehole (TSB) method and the Sealed, Double-Ring Infiltrometer (SDRI) method. The TSB method is discussed herein.

It is a falling-head infiltration test conducted in a cased borehole, typically 4 inches in diameter. The first stage is performed with the bottom of the hole flush with the bottom of the casing for maximum effect of vertical permeability (k_v). After steady-state is achieved, the hole is advanced some 6 to 8 inches below the bottom of the casing so that horizontal permeability (k_h) has a greater effect. The two stages yield the following:

Stage 1 - The maximum possible value for (k_v).
Stage 2 - The minimum possible value for (k_h).
Stage 1 + Stage 2 - Constants for two equations which can then be solved for the real (k_h, k_v).

Procedures are available for reduction of the data in the cases of both above and below water table testing, and for the bottom boundary conditions of a material far more permeable, equally permeable, or far less permeable than the medium being tested. The test has been successful in evaluating both compacted and natural materials with permeabilities as low as 1x10(-9) cm/sec.

The major test precautions include proper sealing of the casing along the outside, accounting for temperature effects, and correcting for sidewall smear during the second stage. The test is quick, simple, and relatively inexpensive. It allows results in days, rather than months. Multiple installations are feasible so that statistical confidence can be achieved. It is recognized in the literature, including U.S. EPA publications, and accepted by many State regulatory authorities.

I. INTRODUCTION

Clay barriers are an important component of waste retention structures. Their primary geotechnical characteristic for this use is hydraulic conductivity, which must be verified during the Construction Quality Assurance program. Until recently, practice relied on laboratory testing of small (7 to 10 cm diameter) undisturbed samples taken from the barrier or a similarly constructed test pad. Day and Daniel (1985) reported conductivities measured in the field which were 3 to 4 orders of magnitude higher than they obtained with laboratory tests. While that study was justly criticized, the horse was out of the barn and regulators all over the country galloped into field testing for hydraulic conductivity evaluation at waste facilities.

From the regulatory standpoint, a test procedure should be accurate and avoid false positives, i.e., not indicate compliance with the specified conductivity when the liner or pad truly has a higher value. This normally means testing a large soil volume searching for the elusive "macropores" which are thought to evade, somehow, even numerous laboratory tests. The regulated community wants the accuracy and avoidance of false positives for their own protection, but also wants to minimize testing times (and costs), and to avoid false negatives, both for economy.

In about the last two years, two methods have become accepted as meeting these criteria to a satisfactory degree: the Sealed, Double-Ring Infiltrometer (SDRI) and the Two-Stage Borehole (TSB) procedure. Each has its stronger and weaker points (see Daniel, 1989).

II. BASIC CONCEPTS

The vertical conductivity (k_v) governs flow, even in sidewall liners if built in the preferred manner: lifts parallel to the slope. However, the horizontal conductivity (k_h) is greater than the vertical. All field tests are affected by this anisotropy, unless flow in the horizontal direction is artificially blocked; the effect is to increase the test conductivity by factors of 2 to 5 over the real (k_v) value. Equations for flow from various source geometries in a cross-anisotropic medium are available in Hvorslev (1951). However, each equation has two unknowns: (k_v) and ($m^2 = k_h/k_v$).

The TSB procedure combines four old concepts into one new idea to find (k_v). The field procedure is taken from long-established US Bureau of Reclamation methods: their flush-bottom borehole test (E-18) and borehole packer test (E-19). Computations are based on the Hvorslev equations adapted for various bottom boundary conditions by the three-dimensional Image Potential Technique (Carslaw and Jaeger, 1959). The new idea is performing both USBR tests in the same borehole, yielding two equations which can be solved for the two unknowns, (k_h) and (k_v).

The TSB is a field infiltration test, conducted in a cased borehole so that the geometry of the infiltrating zone can be controlled. It is normally conducted as a falling-head test. The basic idea is to vary the geometry of the infiltrating area so as to vary the relative effects of (k_h) and (k_v). In the first stage, the geometry is chosen so that (k_v) has its maximum effect. The second stage geometry is such that (k_h) has its maximum effect. The results of the two stages yield two equations in two unknowns (k_h, k_v), which can then be solved. This concept is illustrated on Figure 1, below:

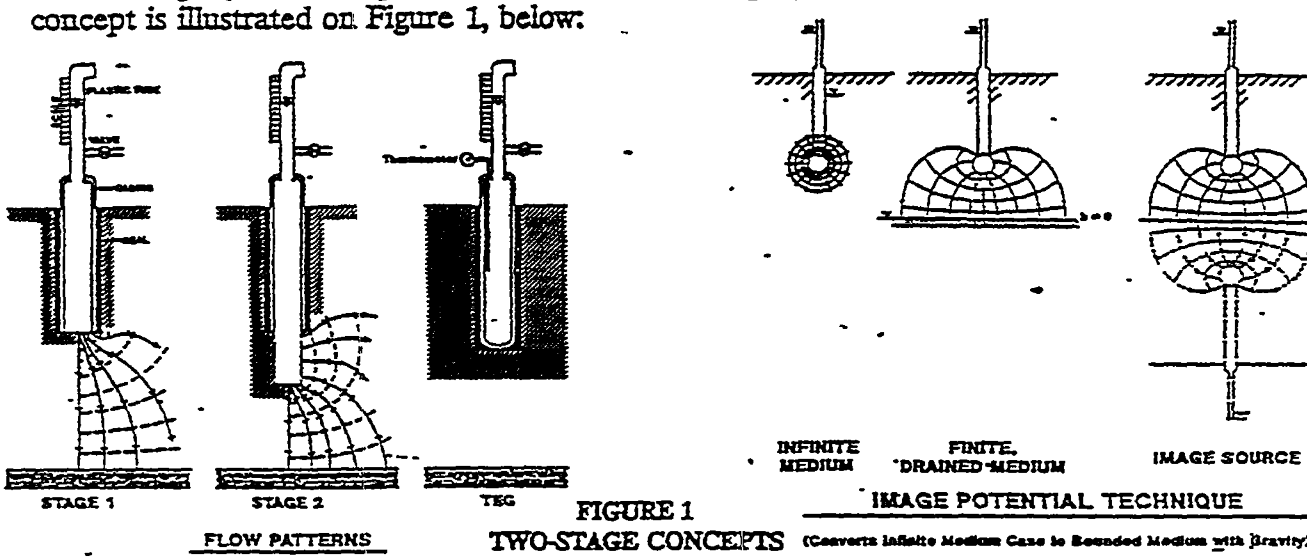


FIGURE 1
TWO-STAGE CONCEPTS

Stage 1 is normally conducted using a flat bottom flush with the base of the casing. Infiltration proceeds until a steady-state flow condition is achieved. Then, the borehole is advanced some 1.5 to 2 casing diameters (6 to 8 inches) below the bottom of the casing. The apparatus is refilled, and infiltration in this Stage 2 continues until it achieves steady-state flow.

During the test, the soil is assumed isotropic ($k_v = k_h$). Stage 1 then yields an apparent permeability (K1), and Stage 2 a different value (K2). The unknown ratio (k_h/k_v) is a unique function of the known test geometry and the known test ratio (K2/K1). When the former is determined, the real (k_v, k_h) can be computed from (K1) or (K2).

III. FIELD PROCEDURES

As is the case with virtually all field tests, and especially field permeability tests, the field procedures are of paramount importance. The most diligent office analyses cannot overcome all of the problems resulting from improper installation, inadequate monitoring, premature test termination, and the like.

3.1 Test Program Design. The test program should be designed to meet the conditions assumed in deriving the data reduction equations so that meaningful results can be obtained.

3.1.1 Vertical Boundaries. Certain clearances are required between the infiltrating surface and any boundaries, pervious or impervious. These can be summarized as:

a. **Minimum casing embedment below ground surface = 2.5D**
(Prevents uplift, minimizes hydraulic fracturing)

b. **Minimum thickness of tested material below bottom of Stage 2 = 2.0D**
(Avoids violating boundary conditions of equations)

c. **Minimum recommended Stage 2 extension = 1.5D**
(Avoids theoretical problems at finite but small L/D)

D = Casing inside diameter
L = Length of Stage 2 extension

3.1.2 Horizontal Spacings. It is intuitively obvious that the tests must be spaced "far enough" apart so that their flows do not interfere with each other causing a falsely low permeability. Also, the presence of a drainage boundary (such as the edge of a test pad) which is "too close" to the test will increase the flow, yielding a falsely high permeability.

This can be avoided by maintaining at least the following clearances:

a. **Minimum horizontal distance between tests = 30D**
b. **Minimum horizontal distance to free surface = 30D**

3.1.3 Number and Size of Tests. The number of tests required for evaluation depends on the project, the acceptance criteria, and the variability of the stratum/fill being evaluated. As in virtually any other geotechnical testing, "the bigger the better".

However, the general practice has been to use 4-inch (ID) tests, with 5 tests for the typical liner or test pad.

The scale effect, if any, of test size has not been fully researched. Virtually all of the known tests have been conducted using 4-inch (10 cm) ID casings. These tests typically permeate a volume of some 0.4 - 1.1 cubic feet each, or 2 to 5 cubic feet for a 5-test group. Benson (pers. comm., 1991) indicates that the minimum representative volume for a permeability determination is on the order of 0.5 - 1.0 cubic foot. This is about the volume permeated by a typical TSB test.

3.1.4 Other Details. There are a few other details in test planning which should be considered. Among these are:

a. Protect the test area surface from desiccation, usually with clear or white plastic.
(Avoids heat-induced problems).

b. Use a "sock" to prevent collapse of the Stage 2 open hole in susceptible materials. The sock is a rigid cylinder of open-mesh plastic, lined with a filter geofabric. The cylinder is somewhat smaller in diameter than the casing ID (and thus the Stage 2 hole), and an inch or so longer than the extension for Stage 2. It is fitted with retrieving lines and not left in the hole after the test.

c. Minimize the distance (R_y) from the ground surface to the bottom of the measuring scale, especially for shallow tests. This also aids in having the longest possible reading time between standpipe refills and avoiding hydraulic fracturing.

d. Match the standpipe size to the flow rate so that accuracy is achieved but overnight readings are possible. For a 4-inch casing, this usually means a 0.5 - 0.75 inch ID standpipe.

3.2 Permeameter Installation. Proper installation and checking the permeameters are vital to obtaining a valid test. Various field techniques have been developed through experience which minimize problems. These techniques are discussed in this section.

3.2.1 Permeameter. A typical permeameter is illustrated on Figure 2. The apparatus is simple; the permeameter can be assembled with a visit to a water-well driller and a hardware store. The elements for a falling-head system are:

a. Casing. Typically 4-inch ID Schedule 40 PVC monitoring well pipe, flush-threaded, with "O"-Ring joint. Other casings can be used.

b. Cap. To fit casing, preferably domed, and drilled and/or tapped to receive the standpipe apparatus.

c. Standpipe. *Clear* Schedule 40 PVC or acrylic tube, 0.5 to 1.0 inch ID, with scale. Include elbow with cover (having air-vent) to prevent rain entry and minimize evaporation.

d. Fittings. The small fittings necessary to assemble the apparatus.

All joints which are not glued are assembled with PTFE Plumber's Tape and silicone grease (not sealant).

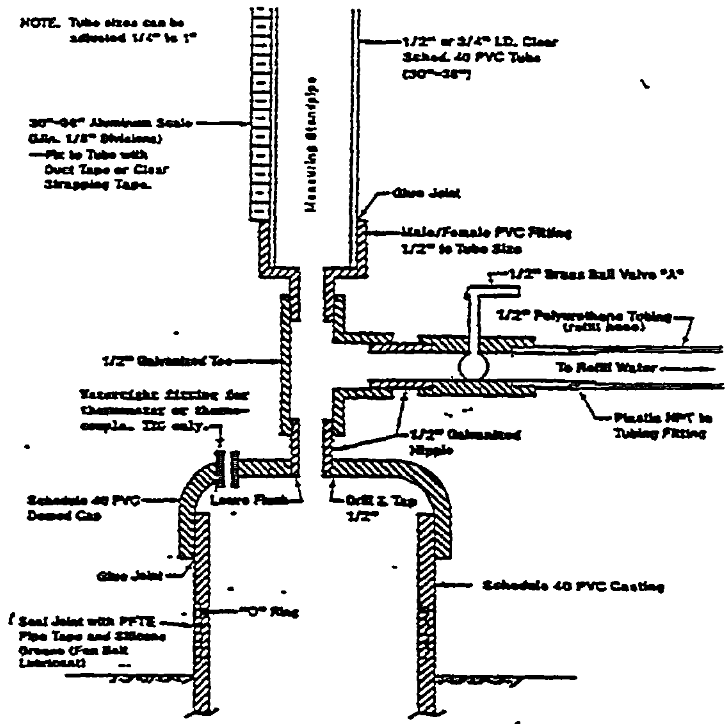


FIGURE 2
TYPICAL PERMEAMETER

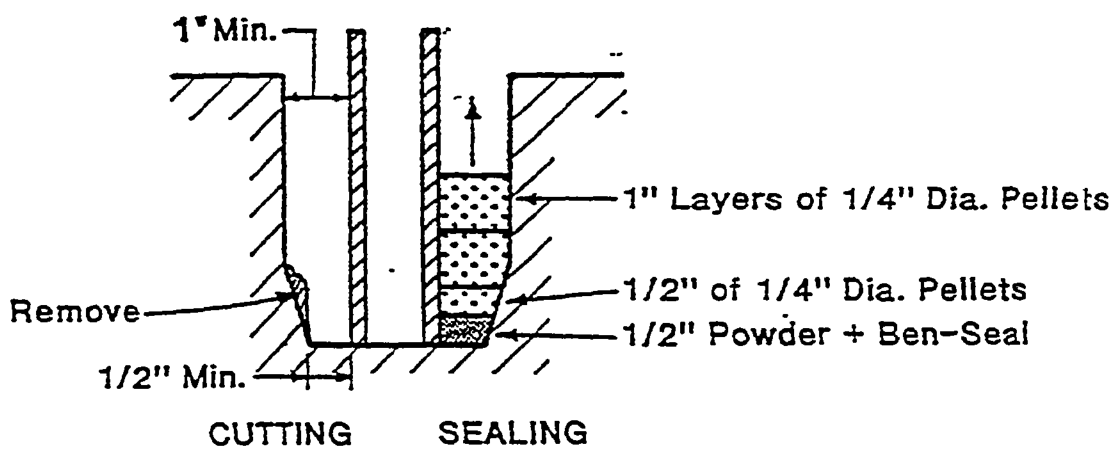


FIGURE 3
SEALING PROCEDURE

3.2.2 Borehole. The casing is set into a borehole. The holes have been drilled using rigs, power-operated hand equipment, and hand augers. The device depends on depth and hardness of material. The hole must have a large enough diameter to allow sealing the annular space between the borehole wall and the casing. Also, it must not disturb the soils below the casing bottom. The bottom must also be flat. Experience has shown the following to be acceptable:

a. **Borehole diameter at least 2 inches greater than the casing OD.** (To allow sealant to reach the bottom and for tamping).

b. **Stop point of auger about 1 inch above proposed casing bottom.** (To avoid testing in a disturbed material)

c. **Ream bottom of borehole to final depth with a flat auger.**

The bottom of the borehole should be flat and flush with the bottom of the casing in order to correspond with Hvorslev's (or H-I) Case "B" or "C" for Stage 1.

3.2.3 Sealing. This is the single most important step in installation. A poorly sealed test cannot be salvaged. The annular space between the casing and the wall of the borehole is sealed with bentonite. Best results have been attained using 1/4" (not 3/8" or larger) bentonite pellets or crushed bentonite (Baroid "Hole-Plug" or equivalent). The procedure, illustrated on Figure 3, is:

a. **Crush sufficient pellets, "Ben-Seal", or "Hole-Plug" to fill about 1/2 inch of the annulus. This should have about 1/16" size fragments with some powder.**

b. **Place this material into the annular space.**

c. **Place about 1/2 inch of bentonite pellets or "Hole-Plug" into hole,**

d. **Tamp the bentonite pellets or "Hole Plug",**

e. **Add water until it shows above the bentonite,**

f. **Repeat the process (but using only the pellets or "Hole Plug") in 1 inch increments to the ground surface or a minimum of 6D above the casing bottom, whichever occurs first. Grouting above the 6D level is allowable.**

g. **Allow the bentonite (and grout) to hydrate at least overnight.**

The casing must be steadied to prevent lateral motion while sealing. The bentonite seal is then allowed to hydrate overnight before any head is applied to the system.

3.2.4 Advancing for Stage 2. Upon completion of Stage 1, a borehole is advanced below the bottom of the casing to form the cylindrical infiltrating surface for Stage 2. The important points are:

a. **Do not disturb the casing - that can affect the seal.**

b. **Borehole diameter should equal casing ID.**

c. **Stop point of auger about 1 inch above proposed Stage 2 bottom. Ream flat and measure depth.**

d. **Roughen the sidewalls to minimize smear.**

This portion of the work is normally handled with hand equipment. The first step after removing the cap is to empty the casing of water (tests above groundwater level or where no seepage was noted during Stage 1 drilling and/or sealing). It is frequently useful to obtain an undisturbed sample during this process, using ASTM D2937 or D1587. However, undisturbed sampling should not be performed if the material being tested contains gravel-sized particles; they can disturb the sidewalls during the push or driving. After or in lieu of undisturbed sampling, the boring is augered until the point of the auger is about 1 inch above the desired bottom for Stage 2. The auger should be at least 1/2 inch in diameter smaller than the casing ID. The boring is then completed to depth and diameter with a flat-bottomed reamer.

The reamer is designed to minimize sidewall smear, having full casing ID only at the cutting edge. The sidewalls are then roughened with a wire brush or similar device, a procedure also recommended in USBR E-18. This step must not be omitted, since one of the significant problems encountered in Two-Stage testing has been artificially low values for Stage 2 due to smear. Equations to handle smear are included herein, but require some idea of the degree of smear.

After the borehole is completed and cleaned of cuttings, the depth is measured so that the correct length of the Stage 2 cylinder is known. For a typical test, a 1-inch depth error will yield the wrong Stage 2 permeability value by 7 to 8%. The cap is then reseated, and Stage 2 begins.

3.3 Ambient Condition Effects. Temperature changes cause the dominant effects of ambient conditions on this test, although there may be some contribution from barometric pressure changes. Temperature changes affect the test by:

* Volumetric changes in the water and apparatus.
* Viscosity changes with temperature.
* Freezing the test water.

The procedures for overcoming these effects are given below.

3.3.1 Volumetric Effects (TEG). At slow rates of flow, the field readings are affected by temperature, as has been noted on many such projects. Rising temperature causes the water column in the pressure/measurement standpipe to expand, so that the drop in water level is less than flow alone would produce. The net effect is a lower apparent permeability. Conversely, falling temperature produces a higher apparent permeability. A normal day's temperature variations can easily cause a 0.5 to 1 order of magnitude change in the apparent permeability of low-permeability materials.

Therefore, a complete "dummy" test setup is installed but with the bottom of the casing sealed with a cap which is normally glued on and pressure-tested. This dummy, or temperature effect gauge (TEG) is of the same construction and embedded to the same depth as the regular test setups. Since there is no flow from the TEG, any change in its readings must be due to changes in the ambient conditions (temperature and/or barometric pressure). Such changes would affect the regular test setups to exactly the same degree.

This correction is applied to the regular tests by:

* Reading the TEG at the same times as readings are taken on the regular tests.

* Determining any increase (decrease) in water levels in the TEG between regular test readings.

* Subtracting any increase (adding any decrease) at the TEG from the readings at the regular tests for the ends of the same time increments.

3.3.2 Viscosity Effects of Temperature. Permeability is normally reported as the value for water at 20°C (68°F). The density and viscosity of liquids, including water, are affected by temperature. The effect on permeability is in direct ratio to the kinematic viscosity (U), which is the viscosity divided by the density. The kinematic viscosity decreases at higher temperatures. The net effect is that the apparent permeability is greater than the 68°F value at low temperatures. The reverse occurs with decreasing temperatures. The effects for ordinary conditions can be from -50% to +15% on the permeability value. The normal correction to the standard condition is given in ASTM D5084:

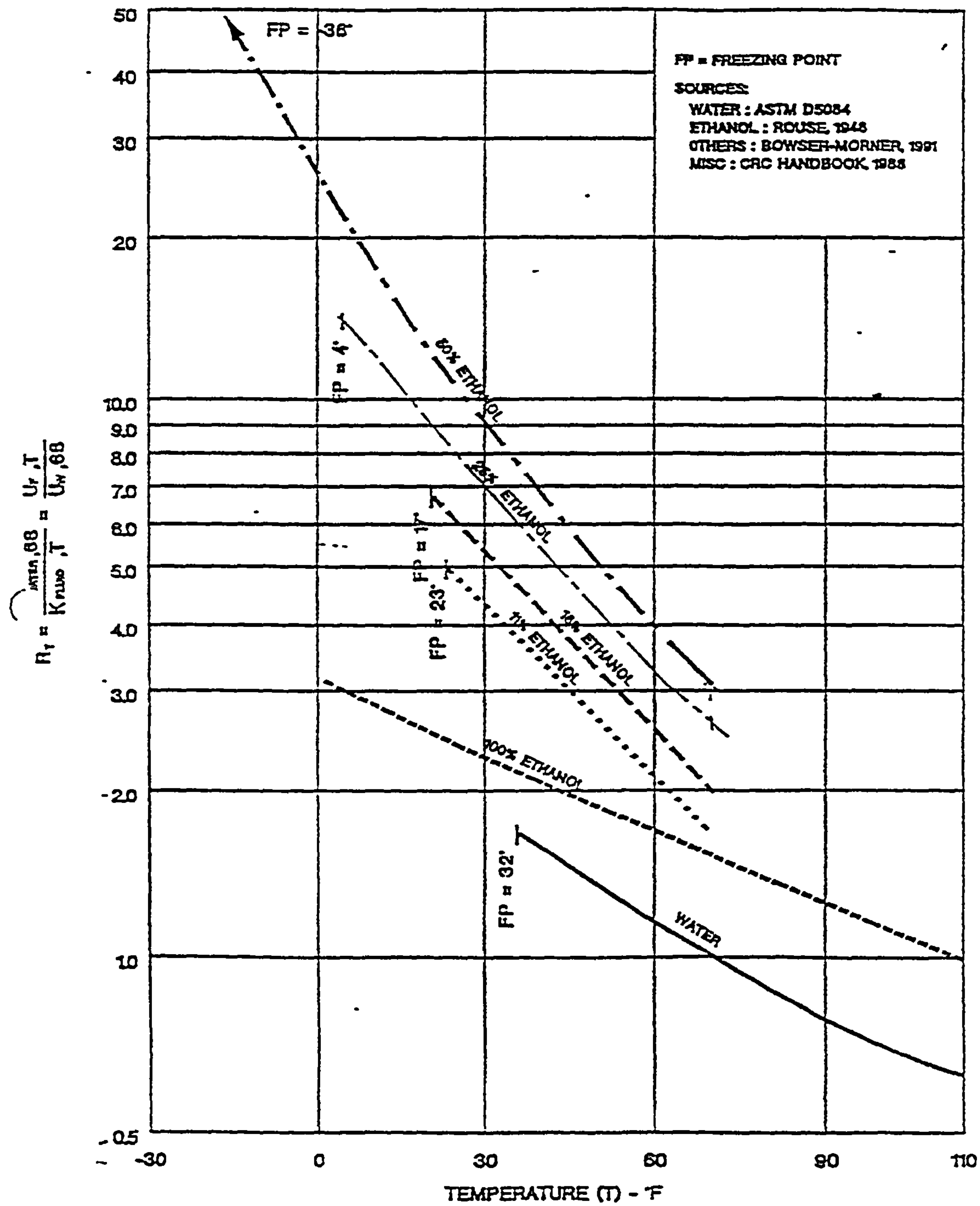


FIGURE 4
KINEMATIC VISCOSITY FACTORS

$$k_s/k_T = R_T = U_T/U_s \quad (3.3.-1)$$

where:

	k_s	=	Permeability for water at 68°F
	k_T	=	Permeability observed in test
	R_T	=	Correction Factor
	U_T	=	Kinematic viscosity for test fluid at test temperature
	U_s	=	Kinematic viscosity for water at 68°F

The factors (R_T) are given for water at temperatures between freezing and 120°F (0 to 49°C) in ASTM D5084. See also Figure 4 which reproduces that data.

The temperature of the exfiltrating water is measured by a thermometer or thermocouple in the TEG. It should extend to roughly the bottom of the casing. The thermometer or the leads for the thermocouple should have its own (sealed) port into the TEG cap or casing. Running either through the TEG standpipe could easily affect its function of volumetric correction.

<u>3.3.3 Freezing Conditions.</u> Unfortunately, field testing must sometimes proceed when the air temperatures are below freezing. Landfill operators often complete a test pad in late fall, so that they will have approval from the regulators for construction in the spring. Even if the ground temperatures stay above freezing, one cannot get decent readings from a frozen standpipe. Three procedures have been used:

a. Insulate the exposed test equipment, exposing only to make readings. (Only if mean daily air temperature exceeds freezing)

b. Use an antifreeze.
(Ethanol as Vodka is good, but needs its own R_T vs temperature graph. Does not attack clay at 25% or less alcohol).

c. Heat the test units.
(Potential for different temperatures - can invalidate the TEG).

<u>3.4 Conducting the Test.</u> The following discussion is applicable to both Stage 1 and Stage 2. Basically, the procedure is:

a. Fill and assemble permeameters.
(Use PTFE tape and silicone grease. Pour slowly to avoid bottom erosion).

b. **Read standpipe levels over time at the permeameter, plus level and temperature at the TEG.** (Levels: to 1/16", temperature to 1°F).

c. **Convert these readings to apparent permeabilities.**

d. **Continue the test until these permeabilities remain steady.**

3.5 Field Calculations - Apparent Permeability. The data from each reading is converted into an apparent permeability, termed (K1) for Stage 1 and (K2) for Stage 2. Keeping up with the data in terms of a permeability has a physical meaning, and also yields a better "feel" for the behavior of the medium being tested. If that medium were isotropic ($k_h = k_v$), then (K1,K2) would be "the" permeability. Remember that the objective of most field permeability tests on regulated facilities is to determine that the vertical permeability (k_v) of the liner is not greater than some value, usually 1x10(-7) cm/sec, or to show that the horizontal permeability (k_h) of a drainage material is not less than some value, typically 1x10(-2) cm/sec. It can be shown that (K1) is the maximum possible value for (k_v) and that (K2) is the minimum possible value for (k_h). Hence, using these apparent permeabilities (K1,K2) frequently allows "pass-or-fail" determination early in the testing process. For example, (K1<Spec) within 24 hours in 90% of tests where (k_v/Spec<0.6), and 70% of all tests.

The equations for both Stage 1 and Stage 2 follow the generic falling-head test format:

$$k = R_T G \, Ln(H_1/H_2)/(t_2-t_1) \qquad (3.5\text{-}1)$$

where:

k	=	Permeability
H_1	=	Initial head (at $t=t_1$)
H_2	=	Final head (at $t=t_2$)
t_1	=	Initial time
t_2	=	Final time
G	=	Geometric Constant, depends on test geometry
R_T	=	Kinematic viscosity correction to water at 68°F

In both Stages, the head is taken as the distance from the level in the standpipe to the groundwater level. The distance from the bottom of the casing to the groundwater level is limited for calculation purposes (only) to no more than 20 times the casing ID. If the depth to groundwater is less than 20 times the casing ID, the true depth is used in the calculations. However, where the depth to groundwater exceeds this criterion, it is considered to be at this 20-diameter depth in the calculations. This limitation is derived by 3-dimensional analogy with the two-dimensional "effective radius" of a well. The volumetric effects of temperature are accounted for using a corrected final head, replacing (H_2) by (H_2'), where:

$$H_2' = H_2 - c \tag{3.5-2}$$

where: c = Increase in TEG standpipe water level during time period from t_1 to t_2

If the TEG standpipe water level goes up between readings, (c) is positive and ($H_2' < H_2$). Conversely, (c) is negative and ($H_2' > H_2$) if the TEG standpipe level drops between readings. This step is not theoretically precise, but is close enough for test purposes. The theoretical solution yields a complex implicit equation in which the true permeability is a function of its own logarithm. However, for the geometry of the test setups and the observed magnitudes of increases/decreases, the apparent permeabilities calculated in this manner differ from the true permeabilities by no more than 2 to 5 percent. The net result is to "smooth" the apparent permeabilities. This smoothing is most apparent (and most useful) when the soil's apparent permeability is less than about 2 to 5x10(-7) cm/sec and especially for small-diameter standpipes.

The kinematic viscosity factor (R_T) used in the calculation is that for the average test water temperature during the period from (t_1) to (t_2).

3.5.1 Stage 1. The nomenclature for the various terms of the Stage 1 calculations is illustrated on Figure 5. The proper equation is given below; it is the solution for (k_v) for an isotropic medium ($k_h/k_v = 1$).

$$K1 = R_T(\pi d^2/11D_1)[1+a(D_1/4b_1)]Ln(H_1/H_2')/(t_2-t_1) \tag{3.5-3}$$

where:

	d	=	ID of Standpipe
	D_1	=	Effective diameter of Stage 1 (Casing ID or OD)
	b_1	=	Depth of tested medium below bottom of casing
	a	=	+1 for impervious lower boundary
	a	=	0 for infinite depth of tested medium ($b_1 = \infty$)
	a	=	-1 for pervious lower boundary

And the other terms are as defined above. For field use, the geometric terms are combined into a single constant:

$$K1 = R_T\, G1\, Ln(H_1/H_2')/(t_2-t_1) \tag{3.5-4}$$

where: $G1 = (\pi d^2/11D_1)[1+a(D_1/4b_1)]$

A complete example is given in the Sample Calculations, Appendix A.

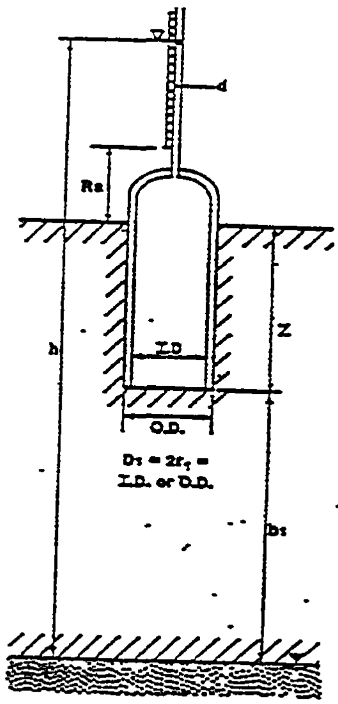


FIGURE 5
STAGE 1 NOMENCLATURE

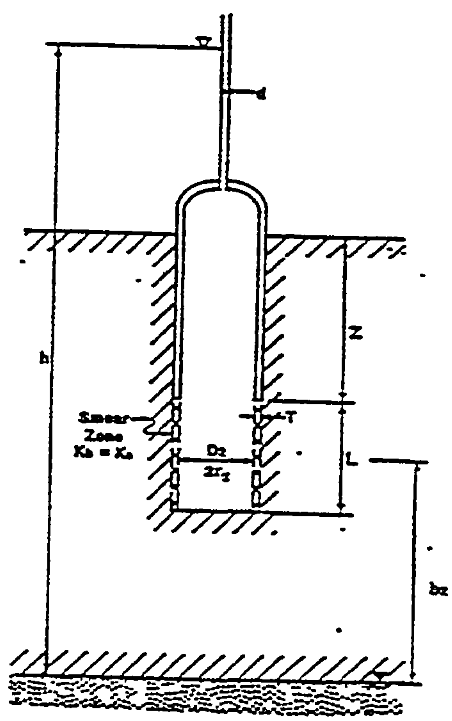


FIGURE 6
STAGE 2 NOMENCLATURE

3.5.2 Stage 2. The nomenclature for the various terms of the Stage 2 calculations is illustrated on Figure 6. The proper equation is that given below; it is the solution for (k_v) with the assumption that ($k_h/k_v=1$).

$$K2 = R_T\,(d^2/16Lf)\,\{Ln[u(1,r_o,o)] + a\,Ln[u(1,r_o,2b_2)]\}\,Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}5)$$

where:	f	=	1-0.5623 Exp(-1.566 L/D)
	L	=	Length of Stage 2 cylinder below casing
	$u(1,r_o,o)$	=	$\{L/D_2 + \sqrt{1+(L/D_2)^2}\}^2$
	$u(1,r_o,2b_2)$	=	$\dfrac{4b_2/D_2+L/D_2+\sqrt{1+(4b_2/D_2+L/D_2)^2}}{4b_2/D_2-L/D_2+\sqrt{1+(4b_2/D_2-L/D_2)^2}}$
	D_2	=	Diameter of Stage 2 extension (normally casing ID)
	b_2	=	Distance from center of Stage 2 extension to underlying boundary

And the other terms are as defined previously. The factor (f) was introduced to account for the non-convergence of the Hvorslev equations as ($L \rightarrow 0$). For field use, the geometric terms are combined into a single constant:

$$K2 = R_T\,G2\,Ln(H_1/H_2')/(t_2-t_1) \qquad (3.5\text{-}6)$$

where: $G2 = (d^2/16Lf)\,\{Ln[u(1,r_o,o)] + a\,Ln[u(1,r_o,2b_2)]\}$

A complete example is given in the Sample Calculation, Appendix A.

3.5.3 Time-Weighted Averaging. Whether one uses the Laplacian or the Green-Ampt model for groundwater flow, there are still transient effects at the beginning of every type of field or laboratory permeability test. The observed effect is to indicate a high permeability, gradually decreasing to some relatively constant value corresponding to a steady-state flow condition. Such an effect is usually noted in the TSB. Therefore, the test must be conducted "long enough" to achieve virtually the steady-state condition or the results will be not only too high but also erratic. In addition, a single value each of (K1) and (K2) must be used in the final data reduction (Section IV).

There is no reliable method for pre-calculating the length of time required to achieve steady-state. Rather, the observational method is used. The appropriate apparent permeability (K1 or K2) is calculated for each time increment, and/or over longer periods of time; when these appear to be stable, they are checked using arithmetic time - weighted averages, e.g.,

$$K' = \Sigma\ (TiKi)/\Sigma\ (Ti) \tag{3.5-7}$$

where: K' = Arithmetic Time-Weighted Average (ATWA) Permeability
Ti = Time Duration of Test Increment (i)
Ki = Permeability Measured during Test Increment (i)

This is theoretically exact for a single run (between refills). Time - weighted averaging also provides a rational basis for smoothing the (often) slightly erratic individual (K1,K2) values from the various time increments. An example of time-weighted averaging is given in the Sample Calculations, Appendix A.

<u>3.5.4 Termination Criteria.</u> Infiltration theory indicates that the apparent permeabilities (K1,K2) should forever decrease at an ever-and-ever decreasing rate. Observations in over 200 of these tests show that a steady-state condition or a close approximation of it is achieved in reasonable testing periods. A log-log plot of apparent permeability versus time is useful in determining when steady-state is achieved. Eventually, the (K1,K2) plots fluctuate about stable values. An example of such a plot is given in the Sample Calculation, Appendix A. This plot illustrates the importance of fairly closely spaced readings at the beginning of each stage, which allow separating the long-term behavior from the short-term fluctuations, i.e., enhance the "signal-to-noise" ratio.

In most tests, time-weighted averages become quite stable, often to within 1 to 5%. A reasonable set of criteria for terminating a stage is as follows:

* The time-weighted averages do not show an upwards or downwards trend with time,

and

* Do not fluctuate more than 10 to 20% among themselves,

and

* Maintain this behavior over a "sufficiently long" time, 12 - 72 hours depending on permeability.

IV. DATA REDUCTION

4.1 Basic Procedure. In some cases, the (K1') or (K2') values may be adequate for the purpose of the test. More generally, the test is performed to determine the actual (k_h,k_v). This section outlines how to convert the (K1',K2') values calculated as outlined in Paragraphs (3.5.1) and (3.5.2) into the real permeabilities (k_h,k_v). Details for the common case are covered below.

4.1.1 Simultaneous Equations. The equations presented earlier for determining (K1,K2) are special cases of more general relationships. These more general equations define the degree of anisotropy by the parameter:

$$m = \sqrt{k_h/k_v} \tag{4.1-1}$$

This parameter affects the geometric terms of the various equations. Each stage has its own equation with a different effect of (m). In a general sense, these can be written as:

Stage 1: $k_v = G1_m \, Ln(H_1/H_2')(t_2\text{-}t_1)$
$K1 = G1 \, Ln(H_1/H_2')(t_2\text{-}t_1)$

$$\text{or} \quad k_v = K1\,(G1_m/G1) \tag{4.1-2}$$

where: $G1_m$ = Geometric factor including (m)

Similarly, for Stage 2,

$$k_v = K2'\,(G2_m/G2) \tag{4.1-3}$$

If the soil medium being tested is homogeneous (although cross-anisotropic and possibly bounded), the vertical permeability (k_v) must be the same in both stages. Hence, (4.1-2) and (4.1-3) provide two equations in the two unknowns ($m = \sqrt{k_h/k_v}$) and (k_v). The resulting equation is:

$$K1'(G1_m/G1) = k_v = K2'(G2_m/G2)$$

$$\text{or} \quad K2'/K1' = (G1_m/G1)(G2/G2_m) \tag{4.1-4}$$

The standpipe area (A_p) cancels for each individual stage in (4.1-2 and 4.1-3), even though different (A_p) values may have been used for Stage 1 and Stage 2, and even for different portions of either stage. The actual equations for the geometric constants involving (m) are given in Paragraph (4.2).

The ratio (K2'/K1') is known from the test; the actual values introduced are the long-term time-weighted averages, (K1' and K2'). The geometric terms are also known. Therefore, Equation (4.1-4) is satisfied only for one value of (m). Due to the complex nature of (4.1-4), trial-and-error or graphical solution works best for specific problems.

4.1.2 Calculating (k_h) and (k_v). The value for (m) is obtained as outlined above in Paragraph (4.1.1). When (m) is known, (k_v) can be calculated directly from Equation (4.1-2), and, by the definition of (m) in Equation (4.1-1).

$$k_h = m^2 k_v \tag{4.1-5}$$

4.1.3 Stage 1 Only Method. In some individual tests, the ratio (K2'/K1') is so low that Equation (4.1-4) fails to converge. Others may have so large a (K2'/K1') ratio that the permeability values are obviously in error: (k_v) is far too low and (k_h) is far too high. This is usually due to inhomogeneity of the tested material. Advancing Stage 2 into a zone of lower permeability will cause a low (K2'/K1'). Conversely, advancing into a zone of higher permeability (such as a poor lift joint in fill or a silt/sand seam in natural materials) yields a very high (K2'/K1').

These events are handled by using a conservative (m) from the best-behaved tests and introducing that value into Equation (4.1-2).

4.2 Image Equation with Smear. The basic Hvorslev equations apply most directly to masses of infinite depth and below the groundwater level. Neither test pads nor liners often meet these criteria. Therefore, results calculated by using the Hvorslev equations directly for such cases will not be correct. For a given permeability, both proximity to a drainage zone and the vertical gradient due to gravity cause the flow to be greater than the basic Hvorslev equations would predict. The basic Hvorslev equations therefore predict a higher permeability than the material really has. The vertical gradient effect can be overcome by using the head as from the top of the standpipe to the groundwater level. A method for accounting for the proximity effect and proving the previous assertion was needed.

The method of image wells has been used in geohydrology for years. The classic example is the solution for a well near a river, found in many textbooks. However, the method is not limited to two-dimensional situations such as this illustration. Any solution for an infinite or semi-infinite medium which describes the potential field (head distribution) can be converted to a solution for a finite medium bounded by a plane by using the Image Potential technique (Carslaw & Jaeger, 1959).

The basic idea is that halfway between a source and a sink of equal but opposite strength will be a plane of zero potential. So, if there is a plane of zero potential (head), its effect can be replaced by an "image" source/sink located twice as far away from the sink/source as is the midway plane. If the test (source) is set a distance (b) above the drainage blanket, the flow field will be the same as if there were no blanket but there was an image test (sink) with negative head at a distance of (2b) below the real test. Since the drainage blanket is at zero head, the head at the test is taken as the total head lost: (b) plus the excess pressure (ht) applied at the infiltration point of the test.

Consider also the case where both the real and image sources have equal strengths and both are sources (positive head) or both are sinks (negative head). By the same logic as given above, the midway plane will be a no-flow boundary, corresponding to an impermeable bottom boundary located at a depth (b) below the real test.

4.2.1 Stage 1. The Hvorslev-Image equation (Case "C") for the flush-bottomed portion of the test is given by:

$$k_v = (\pi d^2/11mD_1)[1+a(D_1/4mb_1)]Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}1)$$

where:

- d = ID of Standpipe
- D_1 = Test diameter for Stage 1
- b_1 = Thickness of test medium below base of casing
- H_1 = Initial head ($t=t_1$)
- H_2' = Corrected final head = H_2-c (see Paragraph 3.5)
- t_2 = Final time
- t_1 - Initial time
- a = -1 for permeable bottom boundary
- a = 0 for infinite depth to bottom boundary
- a = +1 for impermeable bottom boundary

Equation (4.2-1) can also be written as:

$$k_v = G1_m\, Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}2)$$
$$G1_m = (\pi d^2/11mD_1)[1+a(D_1/4mb_1)]$$

4.2.2 Stage 2. Similarly, for the cylindrical case (Hvorslev "G"), the Image equation (with sidewall smear) is that given by:

$$k_v = (d^2/16Lfm^2)\ \{Ln[u(m,r_o+T,o)] + a\ Ln[u(m,r_o,2b_2)] + p\ Ln[u(m,r_\infty,o)/u(m,r_o+T,o)]\}\ Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}3)$$

where: L	=	Length of Stage 2 extension
f	=	1-0.5623 Exp(-1.566 L/D)
$u(m,r_o,o)$	=	$[mL/D_2 + \sqrt{1+(mL/D_2)^2}]^2$
$u(m,r_o,2b_2)$	=	$\frac{4mb_2/D_2+mL/D_2+\sqrt{1+(4mb_2/D_2+mL/D_2)^2}}{4mb_2/D_2-mL/D_2+\sqrt{1+(4mb_2/D_2-mL/D_2)^2}}$
$u(m,r_o+T,o)$	=	$\{mL/(D_2+2T) + \sqrt{1+[mL/(D_2+2T)]^2}\}^2$
p	=	k_h/k_s
k_s	=	Permeability of smeared zone
T	=	Thickness of smeared zone (0.6cm=0.25in)
D_2	=	Diameter of Stage 2 extension
b_2	=	Distance from <u>center</u> of Stage 2 cylinder to underlying boundary

And the other terms are as defined above for Stage 1. Equation (4.2-3) can be written in the generic format as:

$$k_v = G2S\ Ln(H_1/H_2')/(t_2-t_1) \qquad (4.2\text{-}4)$$

where:

$$G2S = (d^2/16Lfm^2)\{Ln[u(m,r_o+T,o)] + a\ Ln[u(m,r_o,2b_2) + p\ Ln[u(m,r_o,o)/u(m,r_o+T,o)]]\}$$

The generic expression for (K2'/K1') as a function of the test geometry is Equation (4.1-4). Following the steps outlined in Paragraph (4.1.1),

$$K2'/K1' = (G1_m/G1) \cdot (G2/G2S) \qquad (4.2\text{-}5)$$

where:

$$(G1_m/G1) = (1/m)\ [1+a(D_1/4mb_1)]/[1+a(D_1/4b_1)]$$

$$(G2/G2S) = \frac{m^2\{Ln[u(1,r_o,o)]+aLn[u(1,r_o,2b_2)]\}}{Ln[u(m,r_o+T,o)]+aLn[u(m,r_o,2b_2)]+pLn[u(m,r_o,o)/u(m,r_o+T,o)]}$$

Equation (4.2-5) is solved by taking an appropriate (p) and determining (m) by trial-and-error or by a graphical solution such as Figure 7.

The value of (p) is not determined in the test. The normal range of (p) is from 2 to 20; (p=1) indicates no smear. The following values for (p) have yielded satisfactory results, consistent with apparently non-smeared tests on the same tested units:

K2'/K1'	p
>1.1	1
0.9 - 1.1	1,2
0.8 - 0.9	2,5
0.7 - 0.8	5,10
0.6 - 0.7	10,20
0.4 - 0.6	15,20
0.4>	*

* Use Stage 1 Only Approach - Paragraph (4.1.3).

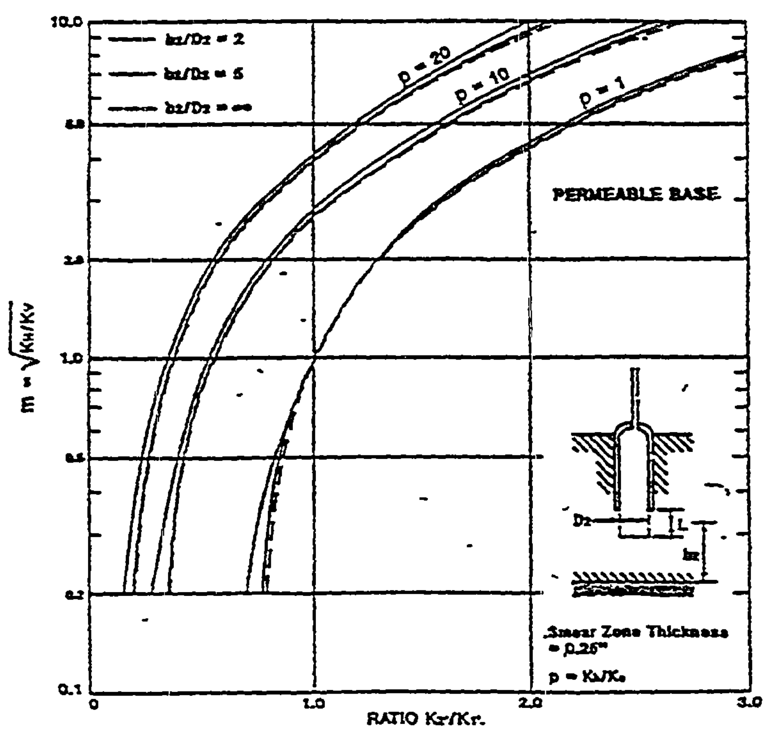


FIGURE 7
GRAPH FOR (m) - (L/D=1.5)

4.3 Non-Saturated Media. Field permeability tests are frequently performed on materials which are not fully saturated. Such materials affect the tests in two ways:

* The hydraulic head is dissipated over the (changing) distance from the point of inflow into the soil to the "wetting front", where the soil is considered fully saturated (Green-Ampt Model).

* Unsaturated clays exhibit "soil suction", which effectively adds to the hydraulic head.

In the Two-Stage test, infiltration into the soil is three-dimensional. The majority of the head loss occurs close to the inflow surface, even in a fully saturated material. About 50% of the loss occurs within one test radius of the inflow surface. For a typical Two-Stage test, disregarding wetting front distance theoretically yields a permeability 10 to 50% too high.

The effect of soil suction is roughly proportional to the ratio of suction to applied head. The effect of suction alone on a permeability test can be expressed as:

$$k_a/k_t = (1 + S/h_o) \qquad (4.3\text{-}1)$$

where:
k_a = Observed permeability
k_t = True saturated permeability
S = Soil suction
h_o = Applied head

The Two-Stage test normally operates with heads 3 to 6 times those of other test methods, minimizing the relative effect of suction.

These two effects can be handled using the graph presented on Figure 8. That figure is based on numerical solutions for the equipotential surfaces in an infinite medium (a=0). However, for the typical real test, the dimensionless flow volume is such that the equipotentials do not vary significantly from the ellipsoids in either the permeable-base (a=-1) or impermeable-base (a=+1) cases. The actual volume, which includes an allowance for the impermeable casing, has been included on Figure 8.

When using Figure 8, the initial volume (V_o) is taken as:

* Stage 1 - The volume of a hemi-ellipsoid having the diameter (D_1) and height ($D_1/4$).

$$V_{o1} = (\pi/24)\, D_1^3 \qquad (4.3\text{-}2)$$

* Stage 2 - The volume of the Stage 2 cylinder.

$$V_{o2} = (\pi/4)\, D_2^3\, (L/D_2) \qquad (4.3\text{-}3)$$

The term (V_w) is the total volume of water which has infiltrated into the soil through the end of each stage, allowing for that removed in the Stage 2 extension. The (n_a) term is the soil's air porosity.

Figure 8 is applied first to the individual (K1) values from Stage 1:

$$K1_t = K1/[R(1+s/H_o)] \quad (4.3\text{-}4)$$

where: $K1_t$ = K1 corrected for suction and wetting front
R = Permeability ratio from Figure 8

Then, Figure 8 is similarly applied to the individual (K2) values from Stage 2:

$$K2_t = K2/[R(1+s/H_o)] \quad (4.3\text{-}5)$$

where: $K2_t$ = K2 corrected for suction and wetting front

Thereafter, ($K1_t$,$K2_t$) are used in Equation (3.5-7) for the average values ($K1'_t$,$K2'_t$). These are then introduced into Equations (4.2-5) for (m) then (4.1-2) for (k_v), and finally (4.1-5) for (k_h).

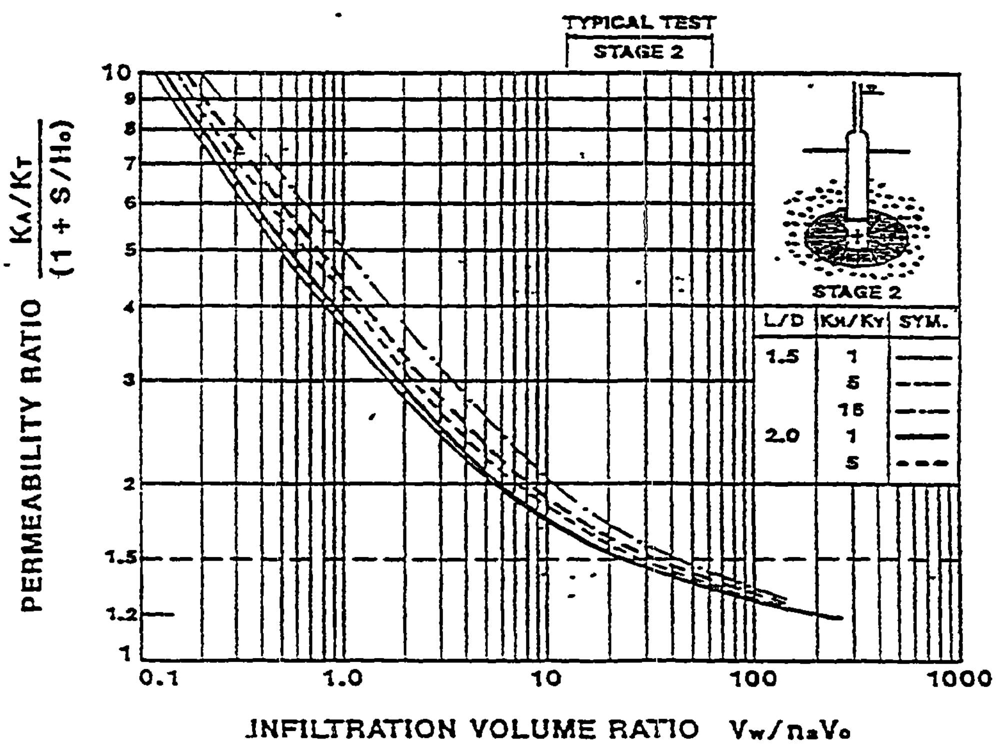


FIGURE 8
NON-SATURATION EFFECTS

V. EXPERIENCE WITH TSB TESTS

As of January, 1992, STEI alone has been involved in some 200 tests (40+ projects) on recompacted materials and 90 tests (6 projects) in natural materials. These have generally been of relatively low permeability [10(-6) to 10(-9) cm/sec]. Some conclusions from this experience are given below.

5.1 Types of Projects. The test has been successful in many types of soils:

5.1.1 Test Pads and Liners. It has been used in such conditions for test units from 20 to 60 inches thick. Materials have ranged from CH-OH (Liquid Limit 100+, clay content 70%+) to SC/GC (Liquid Limit 30-, gravel content up to 30%, clay content 12%). Vertical permeabilities have been successfully measured from the mid 10(-7)'s to the low 10(-9)'s (values in cm/sec).

5.1.2 "Natural" Deposits. It has been very successful in clays to depths of 10 to 15 feet. Where the clay does not make water, it has also been successful to about 20 to 25 feet. The test was moderately successful in soft, highly layered mine tailings clay at depths up to 30 feet. It has been used up to 7 feet deep in shales. Measured vertical permeabilities have been in the same ranges mentioned above.

5.2 Comparisons with Other Methods. The accuracy and lack of false negatives of the TSB can be evaluated by the comparisons with SDRI data shown on Figure 9 and with laboratory data from undisturbed samples given on Figure 10. Of the 11 known cases where both field methods were used on the same test pads/liners the mean ratio of their conductivities was 1.1 (TSB higher). In three known cases, the TSB proved failure defects in test pads that laboratory tests did not show, indicating the TSB avoids false positives. Experience to date can be summarized as:

5.2.1 Recompacted Clays. The vertical permeability (k_v) as obtained from laboratory tests, the TSB, and the SDRI generally agree quite well on test pads/liners (11 cases) which have had proper CQA. The laboratory tests tend to underestimate the horizontal permeability.

5.2.2 Natural Clays. Comparisons have only been made with small-scale laboratory tests. In general, there is good agreement with the TSB for vertical permeability, while laboratory tests again underestimate the horizontal permeability.

5.3 Speed. As soon as the test begins, so does the question from the client, "Does it Pass?" It is usual that (k_v) must be less than some specified value (Spec), or that (k_h) must be greater than a different (Spec). Since the maximum possible value for (k_v) is (K1), as soon as (K1<Spec), one knows the test for (k_v) must pass. Likewise, since (K2) is the minimum possible value for (k_h), if the long-term (K2) is greater than (Spec), the test for (k_h) must pass.

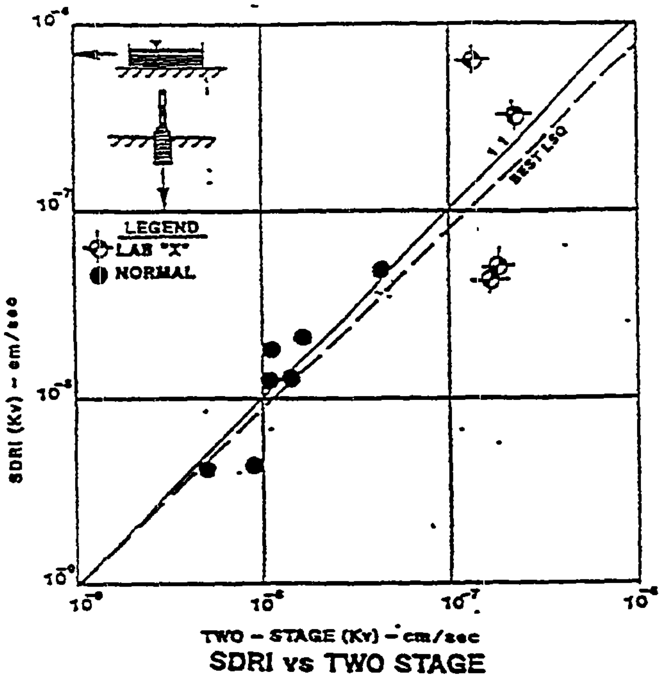


FIGURE 9
TSB AND SDRI RESULTS
(Tests on Same Liners/Test Pads)

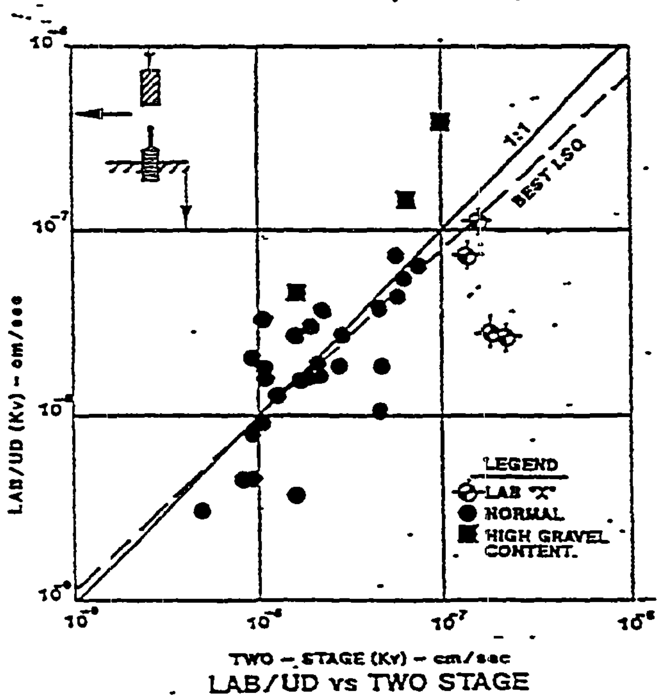


FIGURE 10
TSB AND LAB (k_v) RESULTS
(Tests on Same Liners/Test Pads)

Most of the TSB tests to date in test pads/liners have been for (k_v). The better the pad, i.e., the higher the (Spec/k_v) ratio, the sooner (K1<Spec). In 90% of the tests where (Spec/k_v>1.7), passing was indicated in 24 hours or less. Some 75% of all tests have indicated passing within 72 hours. A marginal test unit, whose (k_v) is just below (Spec), will require completing Stage 2. In general, each Stage lasts 4 to 14 days, the longer times being required to complete a test in lower permeability materials.

5.4 Volume Tested. A single typical TSB test permeates a volume around 0.6 to 1.1 cubic feet, or 60 to 200 times the volume of a typical plug tested in the laboratory (3 inch diameter, 3 inch height). The usual 5-test program thus tests about 10 to 20% the volume of an SDRI, yet yields about the same values. The TSB has a good balance of soil volume tested and speed.

REFERENCES

Benson, C.H. (1991) - personal communication.

Boutwell, G.P., and C.N. Tsai (1992), "The Two-Stage Test - Measuring Field Hydraulic Conductivity Rapidly", Geotechnical News, June, 1992 (in press).

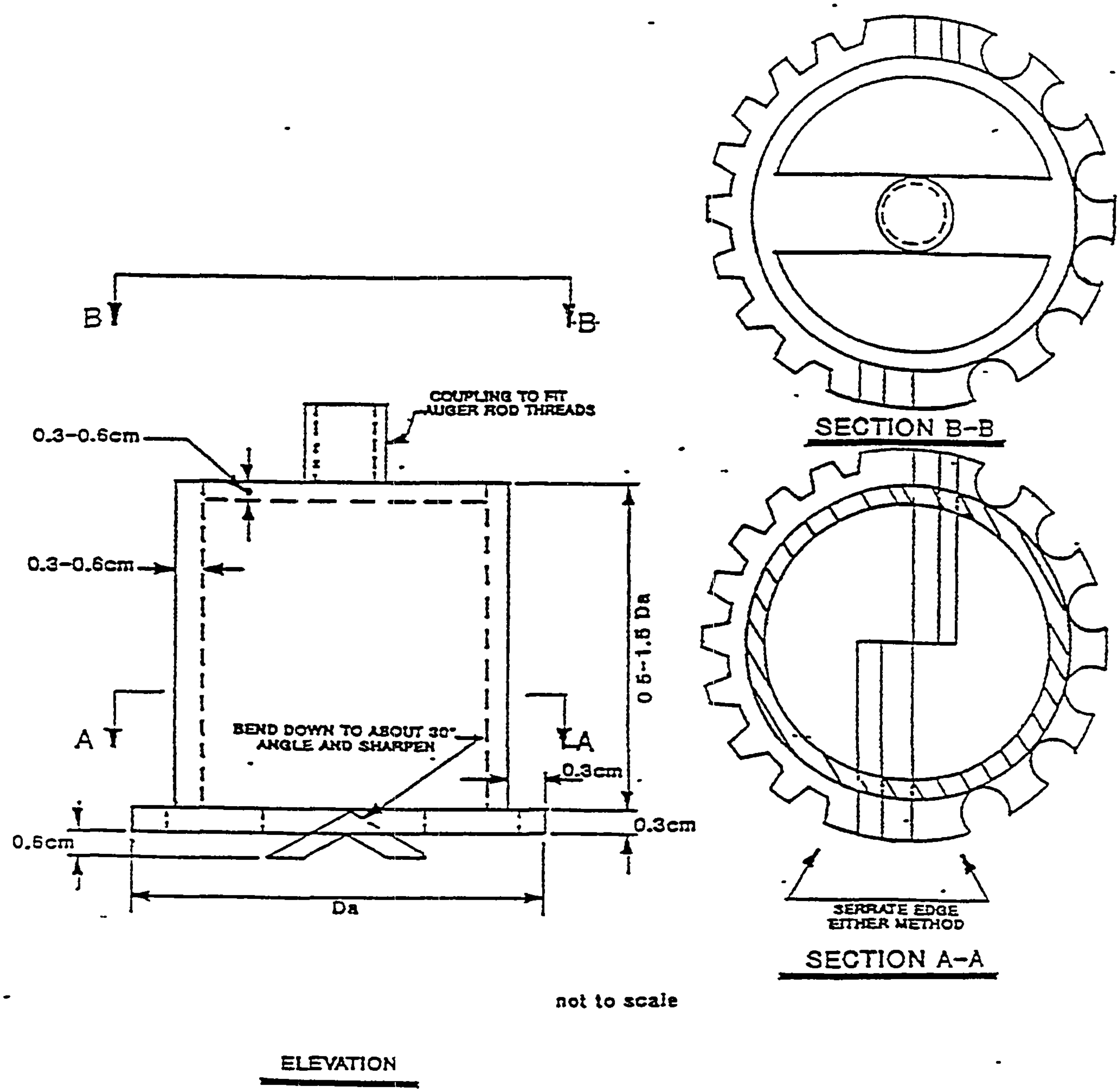
Carslaw, H.S. and J.C. Jaeger (1959), Conduction of Heat in Solids, 2nd. Ed., Oxford University Press, London, UK.

Daniel, D.E. (1989), "In-Situ Hydraulic Conductivity Tests for Compacted Clay", Journal of Geotechnical Engineering, ASCE, Vol. 115, No. 9, Sept. 1989, pp. 1205-1226.

Day, S.R., and D.E. Daniel (1985), "Hydraulic Conductivity of Two Prototype Clay Liners", Journal of Geotechnical Engineering, ASCE, Vol. 111, No. 8, pp. 957-970.

Hvorslev, M.J. (1951), Time Lag and Soil Permeability in Ground-Water Observations, Bulletin No. 36, USA/COE WES Vicksburg, MS.

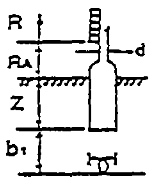
U.S Bureau of Reclamation, The Earth Manual, Second Edition, 1974, pp. 573-578.



NOTE: FOR FLAT AUGER, Da=D+5cm
FOR REAMER, Da=D −0.1 cm

FLAT BOTTOM REAMING AUGER

STAGE 1 CALCULATIONS



d = 1.27 cm
D = 11.43 cm
Z = 61.0 cm
R_A = 22.9 cm
b_1 = 61.0 cm

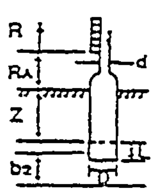
ΔV = 1.27 Δhc
H = 144.8 +R
$K1 = 0.0384 / \frac{\ln (H_1/H_2)}{t_2 - t_1}$

Ground Elev.________
TOC Elev.________ (before)
________ (after)
Site Coords: ________
____

Project ________
File No.:________
Test No.:________
Page.________

Date	Time	Δt (hrs)	Δt (sec.)	R (cm)	H1 (cm)	H2 (cm)	K1 (cm/sec)	C (cm)	H2' (cm)	K1' (cm/sec)	Temp. (°C)	R_t Factor	K1'$_t$ (cm/sec)	Cum Vol. (cc)	Cum. Hrs.	Remarks
8/01	0800	–	–	64 8	–	209 6	–	0.0	–	–	21	–	–	0.0	0.0	START
	0830	0.50	1800	47.8	209.6	192.6	1.80E-06	0.0	192.6	1.80E-06	21	0 97	1.76E-06	21.5	0.5	
	0900	0.50	1800	36.3	192.6	181 1	1.31E-06	0.0	181.1	1.31E-06	21	0 97	1.27E-06	36.0	1.0	
	1000	1.00	3600	19.7	181.1	164.5	1.03E-06	0.2	164.3	1.04E-06	22	0.96	9.99E-07	57.1	2.0	END RUN
	1001	–	–	66.7	–	211.5	–	0.0	–	–	22	–	–	–	2.0	REFILL
	1200	1h+59m	7140	47.0	211.5	191.8	5.26E-07	0.6	191.2	5.44E-07	23	0.94	5.09E-07	82.0	4.0	
								etc.								
8/05	1700			50 0		194.8					26				105.0	
8/06	0800	15.00	54000	38.1	194.8	182.9	4 49E-08	-2.8	185 7	3.39E-08	19	0.94	3.20E-08	205.5	120 0	STOP

STAGE 2 CALCULATIONS



d = 1.27 cm
D = 10.16 cm
Z = 61.0 cm
R_A = 22 9 cm
b_2 = 53.3 cm

L = 152 cm
ΔV = 1.27 Δhc
H = 144.8 +R
$K2 = 0.01570 \frac{\ln (H_1/H_2)}{t_2 - t_1}$

Ground Elev.:________
TOC Elev.:________ (before)
________ (after)
Site Coords: ________
____

Project:________
File No.:________
Test No.:________
Page:________

Date	Time	Δt (hrs.)	Δt (sec.)	R (cm)	H1 (cm)	H2 (cm)	K2 (cm/sec)	C (cm)	H2' (cm)	K2' (cm/sec)	Temp. (°C)	R_t Factor	K2'$_t$ (cm/sec)	Cum Vol (cc)	Cum. Hrs.	Remarks
8/06	0930	–	–	65.4	–	210 2	–	–	–	–	20	–	–	0.0	0 0	START
	1000	0.5	1800	59.4	210.2	204.2	2 52E-07	0 0	204.2	2.52E-07	21	0 99	2 49E-07	7.6	0.5	
	1030	0 5	1800	54.3	204 2	199 1	2 21E-07	+0.2	198.9	2.28E-07	22	0 96	2.19E-07	14 1	1.0	
	1130	1 0	3600	45 7	199.1	190.5	1 92E-07	+0.3	190 2	2.00E-07	23	0.94	1 87E-07	24 9	2.0	
	1330	2 0	7200	33 3	190.5	178.1	1.47E-07	+1 3	176.8	1.62E-07	24	0.91	1 48E-07	40 6	4.0	
							etc									
8/09	0730			21.3		166 1					16			-	70.0	
	1600	8.5	30600	9 2	166 1	154.0	3 88E-08	+1 1	152 9	4.25E-08	19	1 07	4 56E-08	267.9	78.5	STOP

FIGURE 3

APPENDIX A

SAMPLE CALCULATION
FOR
2-STAGE FIELD PERMEABILITY TEST

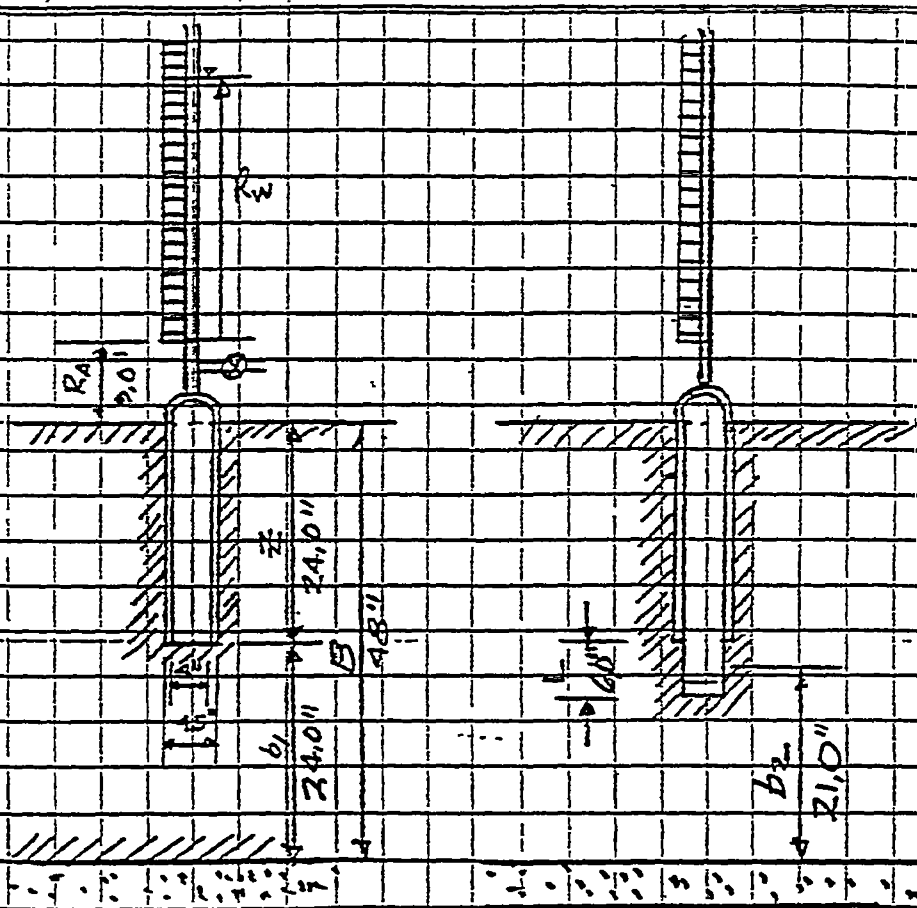
NOTE: This is an idealized case exhibiting virtually perfect behavior, and is not to be considered representative of field behavior.

SOIL TESTING ENGINEERS, INC.
316 Highlandia Drive
P.O Box 83710
BATON ROUGE, LOUISIANA 70884
(504) 752-4790

JOB SAMPLE – "A"
SHEET NO. 1 OF
CALCULATED BY DATE 08 A
CHECKED BY DATE
SCALE

SAMPLE 2-STAGE CALCULATION – HYPOTHETICAL TEST "A"

1. TEST SETUP



STAGE 1

STAGE 2

Note: Water seeped into casing during bentonite sealing. Therefore, use casing OD = 4.5" for Stage 1 Only.

TO AVOID HYDRAULIC FRACTURING:

HEAD < 1.25 × OVERBURDEN AT CASING BOTTOM

$62.4 \frac{LB}{FT^3} H^{FT} < 1.25 \times 2.0^{FT} \times 124.8 \; ^{LB}/_{FT^3}$

$H^{FT} < 5.0 \, FT$

OR $R_W < 5.0 - 2.0 - 0.75 = 2.25 \, FT = 27.0^{IN}$

STEI 16A

SOIL TESTING ENGINEERS, INC.
316 Highlandia Drive
P.O. Box 83710
BATON ROUGE, LOUISIANA 70884
(504) 752-4790

JOB SAMPLE - A
SHEET NO. 2 OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

2. TEST DATA

STAGE 1 DATA

Date	Time	RW (in.)	ΦC (in.)	Temp. (°F)	TEG (in.)
8/01	08:00	25.50	–	70	13.00
	0830	18.81	0	70	13.00
	0900	14.31	0	70	13.00
	1000	7.75	+0.06	72	13.06
Rf.	1001	26.25	–	72	13.06
	1200	18.50	+0.25	74	13.31
	1600	13.88	+1.00	80	14.31
Rf.	1601	26.00	–	80	14.31
8/02	0800	15.81	-1.50	65	12.81
	1700	14.06	+1.31	74	14.12
8/03	0800	9.06	-1.25	68	12.87
	1600	8.38	+1.06	76	13.93
8/04	0800	3.75	-1.44	62	12.49
Rf.	0801	26.50	–	62	12.49
	1701	24.88	+0.50	71	13.00
8/05	0700	20.88	-0.62	66	12.37
	1700	19.69	+1.25	78	13.62
8/06	0800	15.00	-1.12	67	12.50

CALCULATED FROM TEG LEVELS

READ FROM TEG

STAGE 2 DATA

Date	Time	RW (in.)	ΦC (in.)	Temp. (°F)	TEG (in.)
8/06	0930	25.75	–	68	12.56
	1000	23.39	0.00	70	12.56
	1030	21.38	+0.06	72	12.62
	1130	18.00	+0.13	74	12.75
	1330	13.12	+0.50	76	13.25
	1700	7.12	+0.69	80	13.94
R	1701	26.56	–	80	13.94
8/07	0700	6.06	-1.12	70	12.82
R	0701	25.25	–	70	12.82
	1200	19.88	+0.31	74	13.03
	1700	15.94	+0.56	78	13.59
8/08	0800	3.81	-1.50	62	12.09
R	0802	26.31	–	62	12.09
	1700	20.56	+1.69	74	13.78
8/09	0730	8.38	-1.56	60	12.22
	1600	3.62	+0.44	66	12.66

READ FROM TEG

Calculate from TEG Levels

SOIL TESTING ENGINEERS, INC.
316 Highlandia Drive
P.O. Box 83710
BATON ROUGE, LOUISIANA 70884
(504) 752-4790

JOB SAMPLE – A
SHEET NO 3 OF
CALCULATED BY DATE
CHECKED BY DATE
SCALE

3. STAGE 1

A. CALCULATE FACTOR [Eq. 3.5-4]

$$K1 = F_1 \frac{L_N(H_1/H_2')}{t_2 - t_1} \quad \text{where } F_1 = \frac{\pi d^2}{11 D}(1 - D/4b_1)$$

$d = 0.50'' = 1.27\ cm$ (See sketch on p. 1)
$D = 4.50'' = 11.43\ cm$ (See note on p. 1)
$b_1 = 24.0'' = 60.96\ cm$ (See sketch on p. 1)

$$F_1 = \frac{\pi (1.27)^2}{11 \times 11.43}\left(1 - \frac{11.43}{4 \times 60.96}\right)$$

$$\boxed{F_1 = 0.03841\ cm}$$

B. CALCULATIONS:

$K1$ $H1 = B + R_A + R_{W1}$ $= 48.00 + 9.00 + R_{W1} = 57.00 + R_{W1}$
$H2' = B + R_A + R_{W2} - C = 48.00 + 9.00 + (R_{W2} - C) = 57.00 + (R_{W2}$

i. Period 1700 08/02 – 0800 08/03

$$K1 = .03841 \frac{L_N[(57.00 + R_{W1}) / (57.00 + R_{W2} + C)]}{\Delta T\ (sec)}$$

$H1 = 57.00 + 14.06 = 71.06$
$H2' = 57.00 + 9.06 + 1.25 = 67.31$

Note: TEG fell 1.25" in this period, ∴ 1.25" of the test drop is purely temp.

$\Delta t = 15 hrs \times 3600\ s/hr = 54000\ sec.$

$$K1 = 0.03841\ cm \frac{L_N(71.06/67.31)}{54000\ sec} = 3.86 \times 10(-8)$$

Now, apply viscosity correction
$\overline{Temp} = \frac{1}{2}(74 + 68) = 71°$
From chart, Viscosity Factor $= 0.96 = R_T$

$$K1_i' = R_T \cdot K1_i = 0.96 \times [3.86 \times 10(-8)] = 3.71 \times 10(-8)\ \frac{cm}{sec}$$

See p. 6 for tabulation of all points

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4. STAGE 2

4.1 CALCULATE FACTOR [Eq. 3.5-5, with a = −1]

$$K2 = F\ \frac{\ln(H_1/H_2)}{t_2 - t_1}$$

where: $F = \left(\frac{1}{f}\right)\left(\frac{d^2}{16L}\right) \ln\left[\frac{U(D, 0)}{U(D, 2b_2)}\right]$

$f = 1 - 0.5623\, e^{-1.566(L/D)}$

L = Extension below Casing (6 inches = 15.24 cm)

D = Borehole diameter = ID of Casing (4 inches)

$r_0 = D/2$

$b_2 = B - Z + L/2 = 48.00'' - 24.00'' - 6.00''/2 = 21.00''$

$$u(1, D, z) = \frac{(2z/D + L/D) + \sqrt{1 + [2z/D + L/D]^2}}{2z/D - L/D + \sqrt{1 + [2z/D - L/D]^2}}$$

$\therefore\ f = 1 - 0.5623\, e^{-1.566(1.5)}$ ... $L/D = 6''/4'' = 1.5$

$= 0.9463$

$$U(1, r_0, 0) = U(1, D, 0) = \frac{(0+1.5) + \sqrt{1 + [0+1.5]^2}}{(0-1.5) + \sqrt{1 + [0-1.5]^2}} = \frac{1.5 + \sqrt{1+1.5^2}}{-1.5 + \sqrt{1+1.5^2}}$$ [U(1, r0, 0) Eq. 3.5-5]

$= 10.9083$ $= [1.5 + \sqrt{1+1.5^2}]^2$

$2b_2 = 2 \times 21 = 42''$

$$U(1, r_0, 2b_2) = U(1, D, 42) = \frac{(84/4 + 1.5) + \sqrt{1 + [84/4 + 1.5]^2}}{(84/4 - 1.5) + \sqrt{1 + [84/4 - 1.5]^2}} = \frac{22.5 + \sqrt{1+22.5^2}}{19.5 + \sqrt{1+19.5^2}}$$

$= 1.1537$ [U(1, r0, 2b2) Eq. 3.5-5]

$\therefore\ F = \frac{1}{0.9463} \times \frac{12.7^2\ cm^2}{16 \times 15.24\ cm} \ln(10.9083/1.1537)$

$$\boxed{F = 0.01570\ cm}$$

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= 57.00 + R_{w1} , H_2' = 57.00 + (R_{w2} − c)

17:00 8/08

.31 = 83.31 in

1.69 = 75.87"

Note: During this period the level rose 1.69", due only to temp. ∴ subtract 1.69" to get corrected head on test

= 8(3600) + 58(60) = 32280 sec.

LN (83.31 / 75.87) / 32280 sec

(4.55 × 10(−8)) cm/sec

(62+74) = 68.0°F

viscosity factor = 1.00 = R_T

= 1.00 [4.55 × 10(−8) cm/sec] = 4.55 × 10(−8) cm/sec.

for Tabulation of all data points

SAMPLE - A
STAGE 1

DATE	TIME	READING (In)	TIME (sec)	H1 (In)	H2 (In)	K1 (cm/sec)	TC (In)	H2' (In)	K1c (cm/sec)	Temp	Temp Factor	K1tc (cm/sec)	Cum. Hrs.	Cum. Volume (cu. cm.)	Remarks
8/1	8 00	25 50	-	-	82 50	-	0 00	82 50	-	70	-	-	0 0	0 0	START
	8 30	18 81	1800	82 50	75 81	1 80E-06	0,00	75,81	1,80E-06	70	0,97	1,76E-06	0,5	21 5	
	9 00	14 31	1800	75 81	71 31	1,31E 06	0 00	71 31	1 31E-06	70	0 97	1 27E-06	1 0	36 0	
	10 00	7 75	3600	71 31	64 75	1 03E-06	-0 06	64 69	1 04E 06	72	0 96	9 99E-07	2 0	57 1	end run
	10 01	28 25	60	64 75	83 25	-	0 00	83 25	-	72	-	-	2 0	57 1	Refill
	12 00	18 50	7140	83 25	75 50	5 26E 07	-0 25	75 25	5 44E-07	74	0 94	5 09E 07	4 0	82 0	
	16 00	13 88	14400	75 50	70 88	1 68E-07	-1 00	69 88	2 06E-07	80	0,89	1 84E 07	8 0	96 9	end run
	16 01	26 00	60	70 88	83 00	-	0 00	83 00	-	80	-	-	8 0	96 9	Refill
8/2	8 00	15 81	57540	83 00	72 81	8 74E-08	1 50	74 31	7 38E-08	65	0 94	6 96E 08	24 0	129 7	
	17 00	14 06	32400	72 81	71 06	2 88E-08	-1 31	69 75	5 09E-08	74	0 98	4 99E-08	33 0	135 3	
8/3	8 00	9 06	54000	71 06	66 06	5 19E-08	1,25	67,31	3 86E-08	68	0 96	3 71E-08	48 0	151,4	
	16 00	8 38	28800	66 06	65 38	1,38E-08	-1,06	64 32	3 56E-08	76	0 95	3 38E-08	56 0	153 6	
8/4	8 00	3 75	57600	65 38	60 75	4 90E-08	1 44	62 19	3 34E-08	62	0,99	3 29E-08	72 0	168,5	end run
	8 01	26 50	60	60,75	83,50	-	0 00	83 50	-	62	-	-	72 0	168 5	Refill
	17 01	24 88	32400	83 50	81 88	2 32E-08	-0,50	81 38	3 05E-08	71	1 02	3 11E-08	81 0	173,7	
8/5	7·00	20,88	50340	81,88	77 88	3 82E 08	0,62	78 50	3 22E-08	66	0 99	3 20E-08	95 0	186 6	
	17·00	19 69	36000	77 88	76 69	1 84E-08	-1,25	75 44	3 40E 08	78	0 95	3 22E-08	105 0	190 4	
8/6	8 00	15 00	54000	76 69	72 00	4 49E-08	1,12	73 12	3 39E-08	67	0 94	3 20E 08	120 0	205 5	STOP

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5.B. Calculation for $K2'_c$ - (See p. 7 for the data points)

This is virtually the same calculation as on p. 8

Period (hrs)	Calculation			$K2'_c$
0.0 – 2.0	$\frac{24.9\times1.80 + 21.9\times1.80 + 18.1\times3.60}{1.80 + 1.80 + 3.60}$	$= \frac{151.56}{7.20}$	$= 21.05\times10(-8)$	$2.11\times10(-7)$
2.0 – 21.5	$\frac{14.8\times7.20 + 11.0\times12.60 + 7.52\times50.34}{7.20 + 12.60 + 50.34}$	$= \frac{623.72}{70.14}$	$= 8.89\times10(-8)$	$8.89\times10(-8)$
21.5 – 31.5	$\frac{5.94\times17.94 + 4.74\times18.00}{17.94 + 18.00}$	$= \frac{191.88}{35.94}$	$= 5.34\times10(-8)$	$5.34\times10(-8)$
31.5 – 55.5	$\frac{4.46\times54.00 + 4.55\times32.28}{54.00 + 32.28}$	$= \frac{387.71}{86.28}$	$= 4.49\times10(-8)$	$4.49\times10(-8)$
55.5 – 78.5	$\frac{4.49\times52.20 + 4.56\times30.60}{52.20 + 30.60}$	$= \frac{373.91}{82.80}$	$= 4.52\times10(-8)$	$4.52\times10(-8)$

The last two periods are virtually identical and last some 24 hours each (appropriate for this permeability level)

$$\text{ie } K2' = \frac{387.71 + 373.91}{86.28 + 82.80} = \frac{761.62}{169.08} = 4.50\times10(-8)$$

$$\boxed{K2' = 4.50\times10^{-8}\ \text{cm/sec}}$$

6.0 Calculate Kv and Kh

A. Smear

Check by K2/K1 ratio needed for next step

$$K2'/K1' = \frac{4.50\times10(-8)}{3.21\times10(-8)} = 1.40$$

Probably no smear since > 1:1

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B. EQUATION (FOR SHORTCUT, see p. 12)

$$K2'/K1' = \left(\frac{G1m}{G1}\right)\left(\frac{G2}{G2S}\right) \quad [\text{Eq. 4.2-5}]$$

where $G1m/G1 = (1/m)\,[1 + a(D_1/4mb_1)]\,/\,[1 + a(D_1/4b_1)]$

but, $D_1 = 11.43$ cm (p. 3) $a = -1$ (Perm. Base)

$b_1 = 20.96$ cm (p. 3)

$$G1m/G1 = (1/m)\left[1 - \frac{11.43}{4(m)(20.96)}\right] \Big/ \left[1 - \frac{11.43}{4(20.96)}\right]$$

$$= (1/m)\left(\frac{1}{.8636}\right)\left(1 - \frac{1}{21.33m}\right)$$

$$G2/G2S = \frac{m^2\{Ln[v(1,r_0,0)] + a\,Ln[v(1,r_0,2b_2)]\}}{Ln[v(m,r_0+?,0)] + a\,Ln[v(m,r_0,2b_2)] + p\,Ln[v(m,r_0,0)/v(m,\ldots]}$$

$a = -1$

$p = 1$

$$\text{Thus } G2/G2S = \frac{m^2\,Ln[v(1,r_0,0)/v(1,r_0,2b_2)]}{Ln[v(m,r_0,0)/v(m,r_0,2b_2)]}$$

$$v(1,r_0,0) = [L/D + \sqrt{1+(L/D)^2}]^2 = [1.5 + \sqrt{1+1.5^2}]^2 = 10.90833$$

$$v(1,r_0,2b_2) = \frac{4b_2/D_2 + L/D_2 + \sqrt{1+(4b_2/D_2+L/D_2)^2}}{4b_2/D_2 - L/D_2 + \sqrt{1+(4b_2/D_2-L/D_2)^2}}$$

$b_2 = 21''$ (See p. 1)

$D_2 = 4.0'$ (See p. 1)

$$= \frac{4(21/4) + 6/4 + \sqrt{1+(4\times21/4+6/4)^2}}{4(21/4) - 6/4 + \sqrt{1+(4\times21/4-6/4)^2}} = \frac{45.0222}{39.0256}$$

$v(1,r_0,2b_2) = 1.15366$

$$G2/G2S = \frac{m^2\,Ln[10.90833/1.15366]}{Ln[v(m,r_0,0)/v(m,r_0,2b_2)]} = \frac{2.24659\,m^2}{Ln[v(m,r_0,0)/v(m,r_0,2b_2)]}$$

$$K2'/K1' = \frac{1}{m\,.8636}\left(1 - \frac{1}{21.33m}\right) \cdot \frac{2.24659\,m^2}{Ln[v(m,r_0,0)/v(m,r_0,2b_2)]}$$

$$= 2.3738\,m\left(1 - \frac{1}{21.33m}\right)\frac{1}{Ln[v(m,r_0,0)/v(m,r_0,2b_2)]}$$

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(i) Try $m = 2.0$

$$u(m,r_0,0) = [mL/D_2 + \sqrt{1+(mL/D_2)^2}]^2$$
$$= [1.5m + \sqrt{1+(1.5m)^2}]^2$$
$$u(2,r_0,0) = [1.5\times2 + \sqrt{1+(1.5\times2)^2}]^2 = 6.1623^2$$
$$= 37.9737$$

$$u(m,r_0,2b_2) = \frac{4mb_2/D_2 + mL/D + \sqrt{1+(4mb_2/D_2 + mL/D_2)^2}}{4mb_2/D_2 - mL/D + \sqrt{1+(4mb_2/D_2 - mL/D_2)^2}}$$
$$= \frac{4m\,21/4 + m\,6/4 + \sqrt{1+(4m\,21/4 + m\,6/4)^2}}{4m\,21/4 - m\,6/4 + \sqrt{1+(4m\,21/4 - m\,6/4)^2}}$$
$$= \frac{22.5m + \sqrt{1+(22.5m)^2}}{19.5m + \sqrt{1+(19.5m)^2}}$$

$$u(2,r_0,2b_2) = \frac{22.5\times2 + \sqrt{1+(22.5\times2)^2}}{19.5\times2 + \sqrt{1+(19.5\times2)^2}} = \frac{90.0111}{78.0128} = 1.1538$$

$$K_2'/K_1' = 1.40 \stackrel{?}{=} 2.3738(2.0)\left(1 - \frac{1}{21.33\times2}\right)\frac{1}{\ln[37.9737/1.1538]}$$
$$\stackrel{?}{=} 4.7476\,(.9766)\,\frac{1}{3.4938}$$
$$1.40 > 1.327$$

∴ need larger m.

ii. Try $m = 2.4$

$$u(2.4,r_0,0) = [1.5\times2.4 + \sqrt{1+(1.5\times2.4)^2}]^2 = 53.8214$$

$$u(2,r_0,2b_2) = \frac{22.5\times2.4 + \sqrt{1+(22.5\times2.4)^2}}{19.5\times2.4 + \sqrt{1+(19.5\times2.4)^2}} = 1.1538$$

$$K_2'/K_1' = 1.40 \stackrel{?}{=} 2.3738(2.4)\left[1 - \frac{1}{21.33\times2.4}\right]\frac{1}{\ln[53.8214/1.1538]}$$
$$\stackrel{?}{=} 5.6971\,(.9805)\,(1/3.8426)$$
$$1.40 < 1.454$$

∴ need smaller m

Successive trial-and-error yields $m = 2.27$

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C. CALCULATE Kv, Kh

Note: ONE CAN AVOID THE CALCULATIONS of pp. 10 and 11 by BY USING THE ATTACHED NOMOGRAPH (Fig. 7-Text)

The easiest calculation is using the STAGE 1 EQUATION:

$$K_v = \frac{G_{1m}}{G_{11}} K1' = \quad [Eq. 41-2]$$

$$= \frac{1}{m}\left[\frac{1 - D_1/4mb_1}{1 - D_1/4b_1}\right] K1'$$

with $D_1 = 4.50''$
$b_1 = 24.0''$
$m = 2.27$

$$K_v = \frac{1}{2.27}\left[\frac{1-\frac{4.5}{4(2.27)(24)}}{1-\frac{4.5}{4(24)}}\right]\left[3.21 \times 10(-8)\right]$$

$$= \frac{1}{2.27}\left[\frac{.9793}{.9531}\right] 3.21 \times 10(-8)$$

$$\boxed{K_v = 1.45 \times 10(-8) \text{ cm/sec}}$$

$$K_h = m^2 K_v \quad [Eq. 41-5]$$

$$= 2.27^2 \left[1.45 \times 10(-8)\right]$$

$$\boxed{K_h = 7.47 \times 10(-8)}$$

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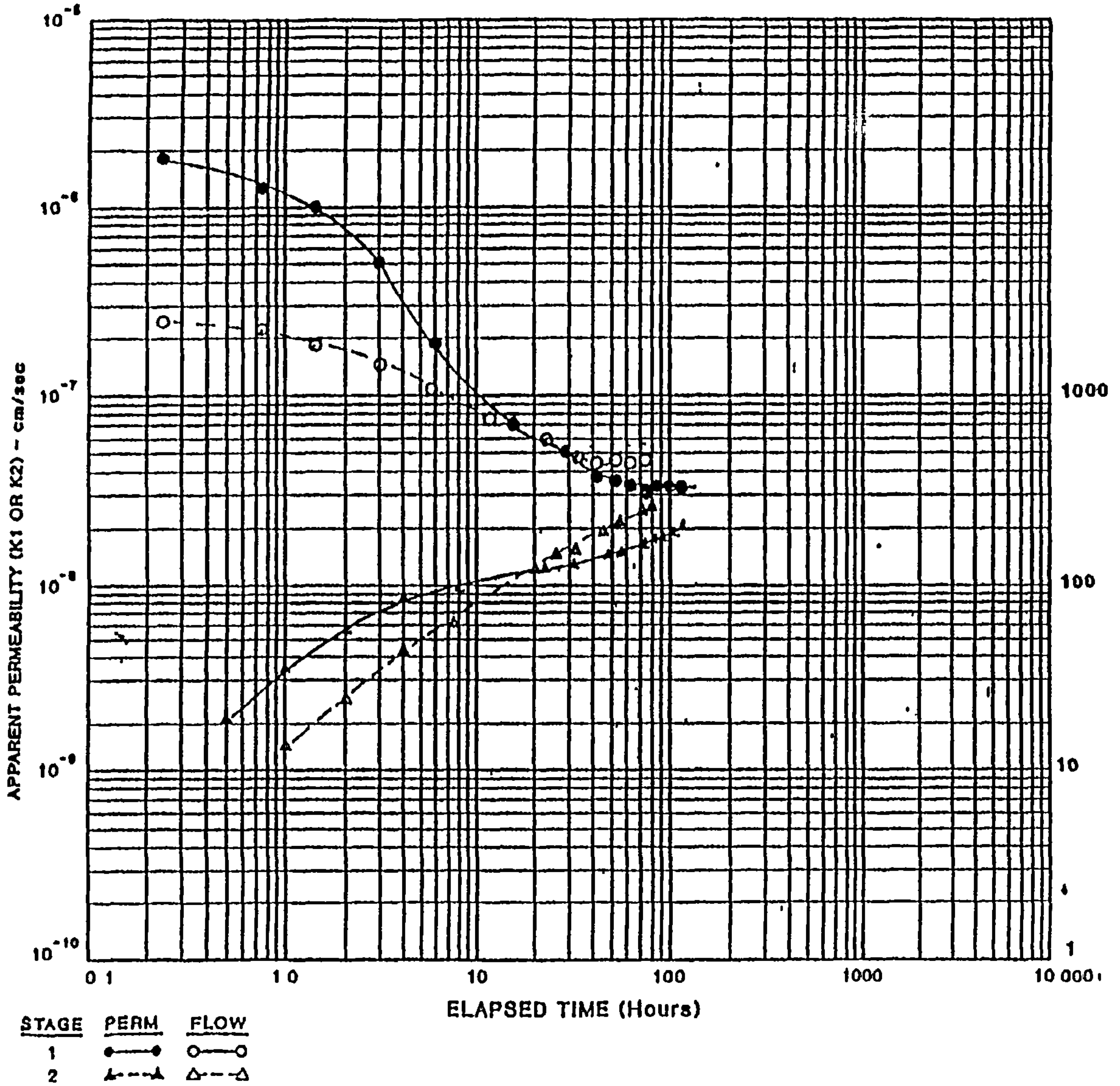
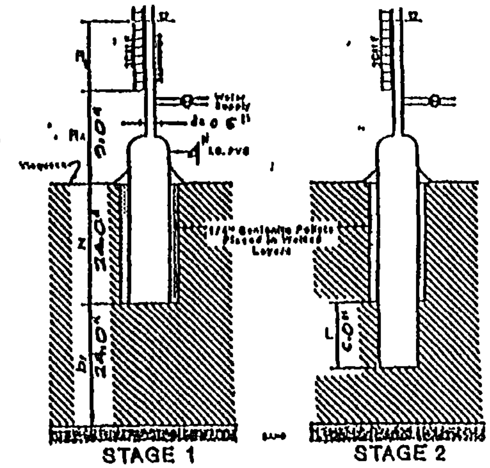




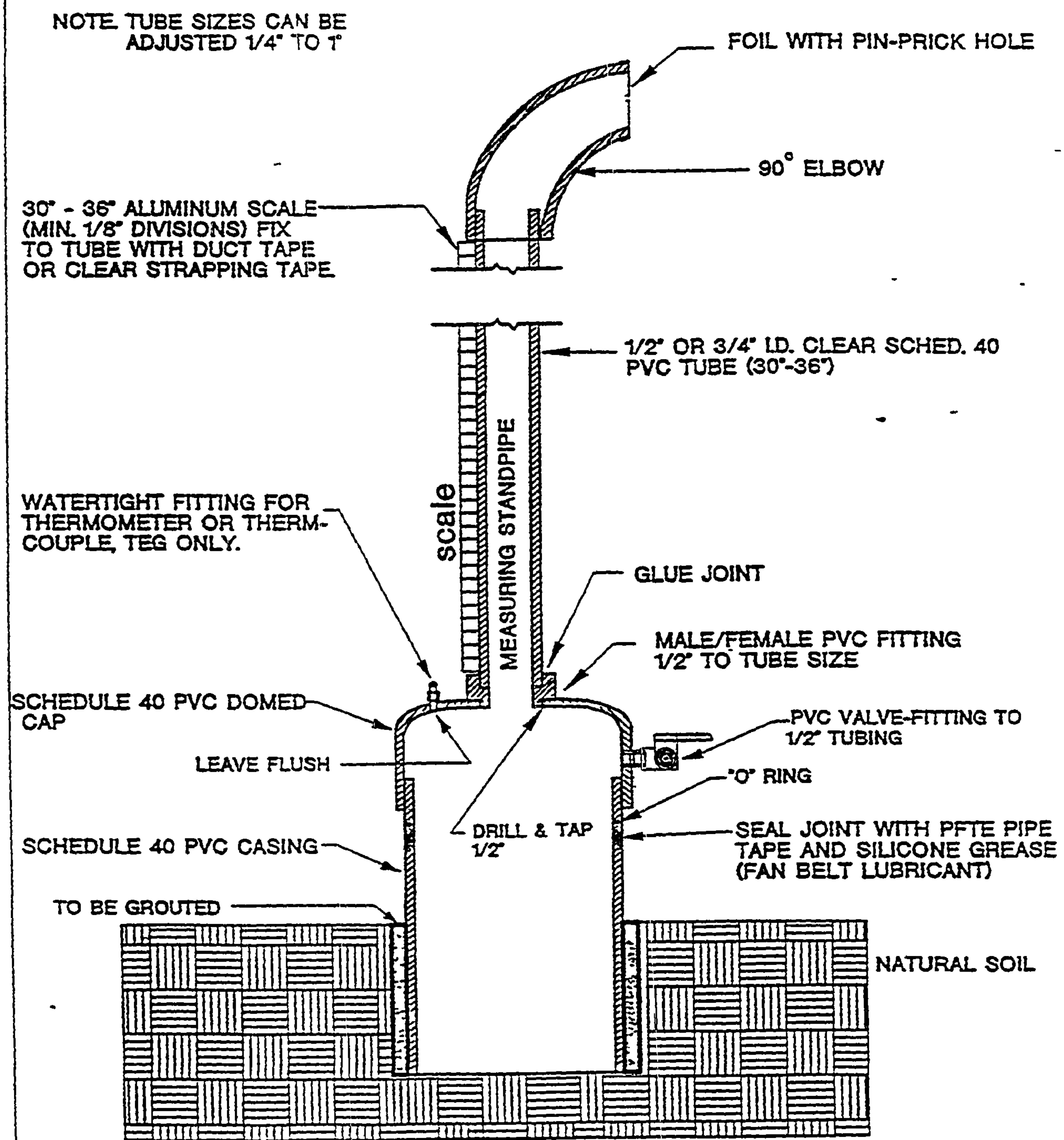
TWO – STAGE
FIELD PERMEABILITY TEST
SUBBASE TEST PAD

SAMPLE TEST "A"
EREWHON, CALIVANIA

GEOTECHNICAL SERVICES BY
SOIL TESTING ENGINEERS, INC.
Baton Rouge LA Lake Charles LA

Project Engineer:	Drawn by:	Checked by:
G P BOUTWELL	SJT	C N TSAI
File No.: 91-061	Date:	Figure No.:

Title: BEHAVIOR OF TEST FP- "A"



TYPICAL PERMEAMETER

Attachment 1

STATE COMMENTS ON THE FINAL LANDFILL SITE FEASIBILITY REPORT

STATE OF COLORADO

Roy Romer, Governor
Patti Shwayder, Acting Executive Director
Dedicated to protecting and improving the health and environment of the people of Colorado
HAZARDOUS MATERIALS AND WASTE MANAGEMENT DIVISION

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Colorado Department of Public Health and Environment

August 30, 1995

Mr. Charlie Scharmann
Office of the Program Manager
AMXRM-PM, Building 111
Rocky Mountain Arsenal
Commerce City, CO 80022-2180

Dear Mr. Scharmann

The state has reviewed the Final Landfill Site Feasibility Report for the Feasibility Study Soils Support Program. The report was generally well done. Enclosed please find comments on both the technical aspects of this report and the state's analysis of the regulatory aspects that need to be addressed in the CAMU Designation process for the hazardous waste landfill.

Now that a Conceptual Remedy exists for RMA, the Army can become very specific with respect to configuration and design of the landfill. The CAMU regulations require compliance with Part 264, Subparts B, C, D, E, and N as well as the siting requirements contained in 6 CCR 1007-2, Part 2 The CAMU must also meet regulatory requirements for applicable design, operation and closure requirements including ground water monitoring. The specific requirements needed for the CAMU Designation Document can be discussed at our meeting tomorrow; some items should be described in detail by the Army in its proposed designation document, while other items could be outlined with a corresponding schedule for future submittals of the required information.

The state would like to request a copy of the HELP inputs used by the Army for the Feasibility Study in a digital format If you have any questions, please feel free to call.

Sincerely,

Barbara Nabors

for Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

cc:	Connally Mears, EPA	Ken Conright, TCHD	Eduardo Quintana, EPA
	William Adcock, Shell	Ronel Finley, USF&W	Craig Tessmer, Adams County
	Robert Foster, DOJ	Edward McGrath, HRO	Ronel Finley, USF&W
	Jonathan Potter, JAG	Vicky Peters, AGO	Ira Star, GT

CDPHE Review of Landfill Siting Criteria

Siting Criteria	Adequately Addressed by Site Feasibility Report?
Faults (1,000 year)	Yes
Floodplain (100 year)	Yes, but provide more info on source of map
Salt Formations	Yes
Surface Water/Ground Water	Yes
Airport Safety	Yes, please provide a map for ease of public review showing location of landfill with surrounding land uses including DIA
Wetlands	Yes
Seismic Impact Area	No, please provide citation for source
Unstable Area (onsite soil conditions)	No, no discussion provided
Topography (protection against winds and minimize precip catchment)	No, not discussed
Isolation (isolate wastes)	No, but seems like more of a design issue
Hydrogeology/Geology 1,000 siting criteria	No, have questions
Location (controlled by operator)	Yes
Buffer Zone (noise)	Yes

Proposed RMA Landfill CAMU Designation Time Line
CDPHE - August 30, 1995

Dec 31, 1995	Jan. 30, 1996	Jan 31- March 1	March 29		
Army submits CAMU Designation Document (CDD)	CDPHE Reviews & Revises CDD As Needed	Minimum of 30-day Public Comment	CDPHE Issues Corrective Action Order incorporating revised CDD and public comment. Could also request additional landfill design, operation, etc information from Army with corresponding submittal schedule.	Army continues detailed design process and/or site characterization study submittals to meet substantive requirements of landfill permitting process	Construction

* Corrective Action Order needs to be issued in advance of the Record of Decision

Colorado Department of Public Health and Environment
Comments on Final Landfill Site Feasibility Report and Requirements
for the CAMU Designation
August 30, 1995

Summary:

CAMU regulations specifically dictate compliance with Subpart B, C, D, E and N of Part 264 of the state's Hazardous Waste Regulations and compliance with the state's regulations for siting of hazardous waste disposal sites, 6 CCR 1007-2, Part 2. CAMU regulations (264.552E) also specify requirements that address design, operation, closure, post-closure, and ground-water monitoring. Prior to the issuance of the CAMU Designation Document (CDD), the Army should provide information necessary to satisfy the state siting criteria (particularly the 1,000 year protection criterion), identify and technically support a preliminary liner and cover design, and submit a Construction Quality Assurance document and specifications that are consistent with the construction methods used in the test fill Other regulatory requirements should be addressed directly in the proposed CDD or by schedule and provided for state approval during development of the landfill design.

The discussion below indicates some of the preliminary technical concerns of the state and indicate appropriate regulations. Reference is also made to the July 1995 Site Feasibility Report (Report) Regulatory citations are noted in *italics*.

Part 264, Subpart B -- General Facility Standards

Section 264 13, General waste analysis

Addressed in the Report but not fully developede Chemical and physical analyses of hazardous waste and hazardous debris must contain all information which must be known to treat, store, or dispose of wastes properly in accordance with Part 264 A waste analysis plan is required. This plan can take into account the sampling that has occurred at most sites during the Remedial Investigation This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 14 Security

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 15, General inspection requirements

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 16, Personnel training

Addressed in the Report but not fully developed This information should be provided or addressed in a schedule by issuance of the CDD

Section 264 17, General requirements for ignitable, reactive, or incompatible wastes

Not addressed in the Report. This information should be provided or addressed in a schedule by issuance of the CDD. This plan will interface with the waste analysis plan This issue is important considering UXO debris and Basin F materials

Section 264 18, Installation standards, were addressed by the Army in the Report in Section 4-- Area Feasibility Study. Additional information is needed with respect to the flood plain analysis, which was based on an Army Corps reference The groundwater protection regulation is further developed in the state's siting regulations

Section 264.19, Construction quality assurance program, is a requirement of the state for construction of foundations, dikes, liners, leachate collection and detection and cover systems A formal written CQA plan is required. The plan should be completed in conjunction with the final designs

<u>Test Fill</u>
The Army has already undertaken a major step in the CQA program by developing specifications and constructing a test fill. The general concern of the state is that specifications for the full-scale liner construction be consistent with the findings of the field program or with the original specifications-- whichever is more conservative

The test fill did not meet several technical specifications (e g., the contractor did not use the equipment specified) Specific concerns are noted below

Lift Thickness --

The specifications (Appendix A) state that loose lifts of 9" of soil will be placed on the pad in order to achieve 6'' of compacted material In the final results, as recorded in Figure 3.2, both test pads only achieved 3" and 4" of compacted soil This may suffice for a test pad attempting to prove only low permeability, but it is not the most optimum lift thickness for future construction, which was one of the objectives of this part of the report, as stated in Section 2.1 of the Material Feasibility Study The full-scale construction specification should be revised to reflect that smaller lift thickness was obtained in the field.

Clod size --

A 3" maximum size was specified in the contract specifications (Appendix A, page 11-4 of the Report) This is a large clod size and the state reserves the right to review this potential criterion based current state-of-the-art practice The number of moisture failures observed during the test fill may have resulted from inadequate soil conditioning Specifications should be written on equipment and methods to condition soil moisture and clod size The specifications as written did not specify the equipment to achieve this end. A pulvamixer was ultimately used on the test fill and should be so-specified for full-scale.

Moisture and Curing --

In Appendix I, Section 2.2 4, there is a statement regarding the soil processing function. It states that there is a need to "allow adequate time for clod reduction, moisture addition, blending, curing and testing to verify the optimal moisture content range has been achieved" There is further EPA QA/QC guidance (Sept 93) recommending at least 24 - 48 hours curing time for uniform absorption and hydration of soil particles when the moisture variance is increased by more than 3 percentage points. It is also recommended in guidance that if this moisture variance is observed during the test pad construction, test soil should be removed from the test pad and brought back to the soil processing area for reworking The removing and reprocessing of the soil is also required in the specifications of Appendix A, page 11-5. However, as evidenced by the soils test reports in Tables 3.2 and 3.3 of this document, soils failing moisture tests by much greater variances than those discussed above, were neither allowed adequate time to absorb added moisture nor were they removed from the test pad to be re-processed in a separate processing area, or at least no details were provided to verify such. No such variation from the specifications should be allowed in the full-scale specifications

Depth of compaction and type of compactor --

The depth of compaction is measured by the length of the compactor's foot. EPA QC/QA guidance makes it clear that the minimum length of the roller foot should be the length of the loose lift of soil. The specifications, however, (Appendix A, pg 11-4) state that the foot is to be as long as the compacted lift thickness (6"). This is short of the desired length resulting in lack of bonding between lifts This is critical for adequate mixing and kneading of the soil to insure proper homogeneity and even moisture control The shorter feet on this test fill may have resulted in problems with achieving compaction, as evidenced in the test results shown in Tables 3.2 and 3.3

The type of compactor is also very important, as noted in the Work Plan for this project in Section 2 2.6, of Appendix I. It states a "Caterpillar Model 825 or equal" is to be used for this project. The actual model used was an 815B, per Section 3.22 of the Material Feasibility Study This compactor is nearly one half the size of the 825 Model and definitely not the most desirable piece of equipment for construction of this large of a landfill (see Appendix C for details)

Recompaction and Moisture Adjustment --

Significant moisture adjustments in the test fills were required, as reported in Tables 3.2 and 3.3 Most results appeared to have been corrected on the same day, without adequate saturation time, and repaired on the test pad itself, without moving the failing soil back to the processing area. Both of these conditions violate the specifications written for this project in Appendix A For example, Appendix A, Section 11, Part 3.02 -H, page 11-5, states "No more than 2 percent moisture may be added to the test fill during construction. If the moisture content is greater than 2 percent.., the test fill soil shall be removed from the test fill..." No evidence of the correct procedure was recorded or so stated in the document when moisture tests failed on the test pad by this margin

Test fill #2 recorded a moisture test, Test Number 34, of 6 percentage points above optimum moisture On the <u>same day</u>, a second passing test was recorded (Test Number 37), that stated in the comments, "Retest of No. 34, after *wetting* of dry areas pulverizing and compacting"

This would not be significant if not for the fact that in two test fills containing 55 and 70 tests each, a failure rate of 20% - 30% was experienced. Also, there were soil moisture variations on the test fills of 5 points below to 6 points above optimum moisture Both observations lead to the acceptability and reliability of the test fill construction program methods The full-scale specifications should concur with the original test fill specifications with regard to reconditioning failed lifts

Part 264, Subpart C -- Preparedness and Prevention

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD.

Part 264, Subpart D -- Contingency Plan and Emergency Procedures

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD

Part 264, Subpart E -- Manifest System, Record keeping and Reporting

Addressed in the Report but not fully developed. This information should be provided or addressed in a schedule by issuance of the CDD (State agrees that manifest system is not applicable).

Part 264, Subpart F -- Ground Water Protection

Development of a ground water monitoring plan is needed for the CDD and not addressed in the Report.

Part 264, Subpart G -- Closure and Post-Closure

Part 264, Subpart S, (d)(4) addresses in general terms the closure and post-closure requirements for CAMUs Substantive sections of Subpart G will be applicable.

Part 264, Subpart N -- Landfills

Development of landfill design, specifications, construction, response actions, record keeping, and closure and post closure care, will be consistent with this Subpart.

Rules and Regulations pertaining to Solid Waste Disposal Sites and Facilities 6 CCR 1007-2

CAMU Regulations specifically address siting of hazardous waste disposal sites, 6 CCR 1007-2, Part 2 The Army also considered the solid waste regulations. The state's regulations governing solid waste disposal sites were addressed in the Report and adopted as criteria, specifically *Location Restrictions and Site Standards, Section 3 1* The demonstration that these criteria are met is lacking in some instances, as noted by the Army (e.g., topographic protection and hydrogeologic isolation, Page 4-15) The isolation criteria is actually more fully developed under the Part 2 rules. below

Rules and Regulations pertaining to Solid and Hazardous Wastes 6 CCR 1007-2, Part 2 Requirements for Siting of Hazardous Waste Disposal Sites

These regulations are adopted under the CAMU regulations *Section 264 552*

6 CCR 1007-2, Part 2, Section 2 4, Minimum Design Performance Criteria

These regulations consider: 2 4 1, Protection of human health and the environment, 2 4 2, Protection of groundwater quality, 2 4.3, Protection of surface water quality, 2 4.4, Protection of Air Quality, 2 4.5, Long-term impact to public health and the environment, 2 4.6, Liner integrity, 2 4 7, Leachate and runoff control, 2 4 8, Closure, 2 4 9, Surface and groundwater water monitoring; and 2.4 10, Post-construction certification, 2.5 Requirements for Siting and Design. General comments follow

The Army should provide cross-reference to these regulations for agency reviewers, as many of these requirements are partially addressed in various sections of the Report.

A major design consideration, the potential for migration through liners (and impact to groundwater) should be addressed using mass transport modeling, not just by HELP The Army used RITZ for unsaturated flow estimates. The estimate of travel time to demonstrate the 1,000 year protectiveness criterion requires additional evaluation

The Army should consider other liner performance criterion besides cost and constructability, such as mass transport considerations, before selecting a liner design. The state is particularly concerned with the use of GCL in the primary liner The state is also concerned with using sand in the leachate collection layers (See page 5-10, second paragraph of the Report) Coarse granular material or geogrid is more effective than sand (coarse granular is preferred over geogrid) The state would like to discuss the use of 80-mil geomembrane versus 60-mil

The prevention of impacts to air and surface-water quality should be addressed at the issuance of the CDD

6 CCR 1007-2, Part 2, Section 2 5, Requirements for Siting amd Design
Sections 2 5 1,2
These sections consider conformance with the minimum design criteria, odor-threshold levels, safety and contingency issues, materials for liners and covers, and resources necessary to guarantee long-term protection of the environment. The Army should address these issues directly, referencing the appropriate regulation. Odor, in particular, has not been addressed in the Report Material availability for liners and covers has been addressed in this report and the Final Feasibility Study Soils Support Program Report.

Section 2 5 3, addresses the 1,000 year criterion for exposure of waste to the public This criterion was addressed in previous RMA studies using a time of travel argument to show that a depth to groundwater greater than 40 feet below the liner system was adequate to prevent impact to groundwater for close to 1,000 years. The current Report approaches the issue in Section 4-- Area Feasibility by citing the requirements directly from the regulations (see page 4-16, first complete paragraph) without evaluating how the criterion is met. The selected depth criterion (ground surface to groundwater) ranges from 40 to 70 feet (See Page 4-21, First Paragraph)

In Section 5-- Site Feasibility Study, the Army notes that the effective depth to groundwater from the bottom of the liner can be as shallow as 10 feet (Page 5-37, First Complete Paragraph) This shallow depth is presumed to provide in excess of 1,000 years travel time to groundwater. Thus the current report reduces the minimum depth to groundwater significantly below the 40 foot depth presumed in earlier siting documents

The model runs, including HELP and RITZ should be further documented to justify not only the cover and liner designs, but to justify the Army's conclusion that soil water movement through the vadose zone could require 1,000 to 1,200 years to travel one foot. This rate is over 50 times slower than previous calculations shown in the 1988 Ebasco report. Mass transport modeling, in lieu of HELP modeling may be more appropriate to account for diffusion of volatiles

The report figures showing geologic cross-sections and sites should be modified to show groundwater elevations (Figures 5 6 to 5.8). The state infers that an excavated landfill in the Army's model would have a depth to groundwater much less than the 40 to 70 foot range discussed in the Report (page 4-21, second complete paragraph)

Sections 2.5 4,5 states that designs are to be consistent with requirements of section 2.4 in order to be sited.

Section 2 5 6 of the regulations addresses the location of a facility with respect to acceptable means to prevent adverse effects on public health in the event of discharges of hazardous waste (See page 4-16, last paragraph of the Report). The Army should note the appropriate plans (e g , contingency, operations) which will address this regulation

Part A requirements of 6 CCR 1007-3, Section 100.40 (See Appendix A)

This section of a state permit for siting a hazardous waste disposal facility, *Permit Requirements and Conditions*, covers thirteen items of general information, status of other environmental permits and approvals, and some specific information on the processes and wastes to be handled A formal permitting process will not be required for the landfill since the CAMU process is being used. However, substantive technical information that should be provided by the Army, are noted below (appropriate sections are italicized)

> *Section 100 40 (a), (8)* requires a "description of the processes to be used for treating, storing, and disposing of hazardous waste, and the design capacity of these items"
>
> *Section (a), (9)* requires a specification of the hazardous wastes listed. quantities, and processes to be used for such wastes
>
> *Section (a), (13)* covers hazardous debris and the categories

The Final Landfill Site Feasibility Report (Report) defines only general waste categories, e g., contaminated soils, treated soil, structural debris Additional detail on the hazardous waste sources and character, list category, and their respective volumes. based on the conceptual remedy, will be needed with the CAMU Designation Document (CDD) Detail on any processes and material handling at the landfill are also required. The waste generation rates and schedule in the Report are broad enough to cover a range of potential remedial alternatives; however, these should be refined to reflect the current conceptual agreement and the new version of the DAA.

Part B requirements of 6 CCR 1007-3, Section 100.41 (See Appendix A)

Part B requirements are used to demonstrate compliance with standards promulgated in Part 264. Additional substantive technical information should be provided by the Army, as noted below

Section 100.41 (a) (2,3) Chemical and physical analyses of hazardous waste and hazardous debris must contain all information which must be known to treat, store, or dispose of wastes properly in accordance with Part 264. A waste analysis plan is required.

This information, which was not included in the Report, is needed to support a liner design compatible with the wastes to be disposed (See 264 301) This information should be provided or addressed in a schedule by issuance of the CDD. The issue of waste analysis was briefly discussed in the Report. Further detail is needed.

Sections (a) (4), (5), (6), (7), (8)

These reports have been briefly addressed in the Report. These plans should be developed in detail and submitted or addressed in the schedule at the time of the CDD.

Section (a), (11)

This section, which relates to facility location information has been addressed, in part, in the Report. The following additional information is required

Section (a) (11) (B) (iii) The Army provides a 100-year flood plain map with a vague citation to a 1983 Army Corps study Please elaborate on this source of floodplain information.

Section (a), (18) A detailed topographic map showing a distance of 1,000 feet around the facility at a scale of one inch equal to not more than 200 feet is required. Inadequate topographics for the conceptual landfill footprints were provided in the Report.

Section 100 41 (b) (7) consists of additional detailed information requirements for landfills to illustrate compliance with Part 264, Subpart N

Appendix S

COLORADO DEPARTMENT OF HEALTH AND ENVIRONMENT'S MODIFICATIONS TO DRAFT FINAL CORRECTIVE ACTION MANAGEMENT UNIT DESIGNATION DOCUMENT

Colorado Department of Health and Environment's
Modifications to

Draft Final Corrective Action Management Unit
Designation Document
Rocky Mountain Arsenal
Commerce City, Colorado

The following modifications and/or additions are to be included in the Final Corrective Action Management Unit Designation Document, Rocky Mountain Arsenal

Text, Section 2.1, Facilitation of the Remedy

In the fourth paragraph, third bullet, replace "toxicity" with "mobility."

Text, Table 2 1, Description of Preferred Sitewide Soil Remedy

Toxic Storage Yards - The cubic yardage should be **2,700 BCY** instead of 2,600 BCY.

Chemical Sewers - The cubic yardage should be **64,000 BCY** instead of 62,000 BCY

Hex Pit - The cubic yardage listed under the 'Components of the Preferred Remedy' should be in bold type to indicate that remediation waste from that unit may go into the landfill.

Buried M-1 Pits - The cubic yardage (**26,000 BCY**) should be in bold type to indicate the volume of remediation waste that will be placed into the landfill

South Plants Balance of Areas - The cubic yardage should be **135,000 BCY** instead of 130,000 BCY

Section 36 Balance of Areas - The cubic yardage should be **142,000 BCY** instead of 140,000 BCY

'Principal' is misspelled through the table as 'principle '

Text, Table 4 2, Cross-References of Regulatory Requirements

Include Subpart N in the Table's title

Text, Figure 3. Schedule of CAMU Activities

Revise the table to indicate actual dates, i e

- 30-Day Public Comment period dates should be March 16, 1996 through April 19, 1996;
- Add - **30-Day Extension to Public Comment Period, starting April 20, 1996, finishing May 20, 1996.**
- CDPHE Issues CDD Designating CAMU - **June 11, 1996**

Appendix B, Section 3.1 2. Site Investigation and Laboratory Testing

In the last sentence of the section, replace "should" with "will "

Appendix B, Section 4 2.3. Vegetation

Delete "CERCLA" from the first sentence of the first paragraph

4

Appendix D, Section 4 ~~2~~. Compatibility Screening Analysis

Add "Observable reactivity with liner components" to the list of exhibited waste characteristics which may entail segregation and/or pretreatment based on screening results.

Appendix D, Section 8 0. Acronyms

Define S^{2-} as Sulfide

Appendix K, Section 3.1.3. Monitoring Well Installation

Add a reference to ASTM D 5092 in item number 3. of this section

Appendix K, Section 8 1. Data Evaluation Including Statistical Analysis of Results

To be consistent with the text in Section 2.1, modify the first sentence of the second paragraph of Section 8 1 to read

> Groundwater analytical data collected as part of the pre-operational monitoring program will be reviewed initially to identify the background water quality conditions within the landfill CAMU areal configuration, including the CFS and the UFS.

Appendix L, Section 3.0, Closure Procedures

In the last sentence of the second paragraph, replace "may" with "will." The sentence will read

> Specific procedures for closure of these facilities will be developed during design and will include confirmation sampling and verification of decontamination.

Appendix P, Section 02721, Compacted Clay Liner

Section 3 02, A. - Revise the third sentence to read "The compacted clay liner shall be a minimum of three (3) feet thick over the bottom and perpendicular to sideslopes of the landfill cell "

Figures B1, K1, and L2

The label in the upper left corner should read Facilities within Corrective Action Management Unit (CAMU) areal configuration.