TECHNICAL SUPPORT FOR
ROCKY MOUNTAIN ARSENAL

FINAL
INTEGRATED ENDANGERMENT ASSESSMENT/ RISK CHARACTERIZATION
VERSION 4.2

VOLUME I OF IV

Executive Summary, Section 1-7
Appendix A, and Appendix B (Sections B.1 and B.2)

JULY 1994
CONTRACT NO. DAAA05-92-D-0002, Delivery Order 0004

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LIST OF ACRONYMS AND ABBREVIATIONS

$\mu g/m^3$	micrograms per meters cubed
ARARs	Applicable or Relevant and Appropriate Requirements
Army	U.S. Army
BAF	bioaccumulation factor
BCHPD	bicycloheptadiene
BCRL	below certified reporting limit
BEMA	Bald Eagle Management Area
BMF	biomagnification factor
CAR	contamination assessment report
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
C_{max}	maximum site concentration
CMP	Comprehensive Monitoring Program
COC	contaminant of concern
C_{ow}	chemical concentration in overlying water
CPMS	chlorophenylmethylsulfide
$CPMSO_2$	chlorophenylmethylsulfone
C_{rep}	arithmetic mean of contaminant concentration
CRL	certified reporting limit
C_{sed}	mean sediment chemical concentration
CSF	cancer slope factor
DBCP	dibromochloropropane
DCPD	dicyclopentadiene
DDE	dichlorodiphenyldichloroethene
DDT	dichlorodiphenyltrichloroethane
DT	critical toxicity value
EA	endangerment assessment
EI	exposure index
EPA	U.S. Environmental Protection Agency
ERC	Ecological Risk Characterization
ESC	estimated exposure area soil concentration
FFA	Federal Facility Agreement
F_{oc}	fraction of organic carbon in sediment
FR	dietary fraction
ft	foot
GIS	Geographical Information System
ha	hectare
HCCPD	hexachlorocyclopentadiene
HHEA	Human Health Exposure Assessment
HHRC	Human Health Risk Characterization

HI	hazard index
HQ	hazard quotient
Hyman	Julius Hyman and Company
IEA	Integrated Endangerment Assessment
IL	indicator level
IRA	interim response action
ISCLT	Industrial Source Complex—Long Term
K_{oc}	soil water partition coefficients normalized to organic carbon
LCL	lower confidence limit
LHS	Latin Hypercube sampling
MATC	maximum allowable tissue concentration
mg/cm^2	milligrams per centimeters squared
mg/cm^3	milligrams per centimeters cubed
mg/kg/day	milligrams per kilogram per day
mg/kg/bw	milligrams per kilogram of body weight
MLE	most likely estimate
NAAQS	National Ambient Air Quality Standard
NCP	National Contingency Plan
NOAEL	no observed adverse effects level
OAS	Organization and State
OCP	organochlorine pesticide
PCC	partial correlation coefficient
PPLV	preliminary pollutant limit value
ppm	parts per million
PRG	preliminary remediation goal
Q	ratio of pore water to overlying concentration
R	feeding rate coefficient
RAF	relative absorption factor
RC	Risk Characterization
RfD	reference dose
RI/FS	remedial investigation/feasibility study
RISR	Remedial Investigation Summary Report
RMA	Rocky Mountain Arsenal
RME	reasonable maximum exposure
RSD	risk-specific dose
SAR	study area report
Shell	Shell Oil Company
SPPPLV	single pathway preliminary pollutant limit value
SRC	standardized regression coefficient
TBCs	nonpromulgated or technical data issued by the federal or state government

TC	tissue concentration
TDV	time-dependent variable
TIC	tentatively identified compound
TRV	toxicity reference value
UCL	upper confidence limit
UF	uncertainty factor
UNK	unknown
UST	underground storage tank
UXO	unexploded ordnance
WASP4	Water Quality Analysis Simulation Program, Version 4.3.1

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EXECUTIVE SUMMARY

1.0 INTRODUCTION

The Rocky Mountain Arsenal (RMA) Endangerment Assessment (EA) was performed in accordance with Environmental Protection Agency (EPA) guidance to characterize potential threats to human health and the environment from contaminants released as a result of historical operations and past waste disposal practices at RMA. This assessment was completed as part of the Remedial Investigation/Feasibility Study (RI/FS) for the On-Post Operable Unit, consistent with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), and the Federal Facility Agreement (FFA) for RMA.

This report, the IEA/RC, describes the results of one component and one subproduct of the EA at RMA, the Integrated Endangerment Assessment and the Risk Characterization, respectively. The IEA/RC report is based on a progressive series of human health and ecological endangerment analyses initiated by the Biota RI, completed in 1989 (ESE 1989); the Human Health Exposure Assessment (HHEA), completed in 1990 (EBASCO 1990); and the HHEA Addendum, completed in 1992 (EBASCO 1992). These initial endangerment evaluations were screening assessments for human health and environmental protection and provided the basic information and conceptual approaches for the IEA/RC report.

The IEA/RC report presents the results of the baseline risk assessment, which identifies potential risks to human and animal receptors on the basis of current and historical contamination levels. The baseline risk assessment identifies the following: receptors most likely to be affected by potential risks, the chemicals that contribute significantly to the overall potential risks (i.e., those that "drive" the estimates of potential risk), the primary areas or locations of potential risk, and the uncertainty associated with the potential risk estimations. The intent of the baseline risk assessment is not to identify actual adverse health effects, but to identify potential risks based on a set of clearly specified exposure assumptions. The results of the baseline risk assessment,

as presented in the IEA/RC report, will also provide useful information for risk management decisions guiding the selection of appropriate remedies (e.g., cleanup methods).

2.0 CHARACTERIZATION OF POTENTIAL HUMAN HEALTH RISKS

Potential risks (carcinogenic and noncarcinogenic health effects) from exposure to contaminated soils were quantified for receptor populations representing biological workers (e.g., wildlife biologists), visitors, commercial workers and industrial workers. The receptor populations were selected on the basis of current and potential land use. To ensure that risks would not be underestimated, risks were characterized for a subpopulation of visitors and wildlife refuge workers (i.e., biological workers) assumed to have a high potential for exposure to the contaminants.

The cancer risks are expressed as a probability (e.g., 1 in 10,000) and represent excess lifetime cancer risks, i.e., the likelihood of an individual developing cancer in "excess" of the normal cancer rate of approximately one in three. Noncarcinogenic risks are expressed as a hazard index (HI), the sum of chemical-specific hazard quotients (HQs) that represent the degree to which benchmark concentrations for each receptor population are exceeded by RMA concentrations. The results of the human health risk assessment summarized herein are based on long-term exposure (i.e., chronic, greater than 7 years in duration) and short-term exposures (i.e., acute, less than 1 day, and subchronic, more than 1 day but less than 7 years) at each of 178 specified sites on RMA and at individual borings. The potential risks were also estimated on the basis of site-specific exposures (e.g., chemical agent storage areas) for an estimate of risk on an area-wide basis and point exposures (individual soil borings) for an estimate of risk representing a more extreme exposure scenario. A qualitative risk assessment was performed to address potential risks associated with areas that were not evaluated in the quantitative risk assessment.

The results of the human health risk assessment indicate the following:

- The biological worker has the highest potential risk on the basis of the open space land-use option. Of the 178 sites studied, 149 fall within the EPA acceptable cancer risk range of 1 in 1,000,000 (10^{-6}) to 1 in 10,000 (10^{-4}). Twelve of the sites studied exceed

a 10^{-4} cancer risk level. For noncarcinogenic effects, 24 of the sites have HIs exceeding 1.0 (HIs greater than 1.0 indicate a potential for health effects occurring).

- The industrial worker has the highest potential risk on the basis of the economic development land-use option. Sixteen of the 178 sites studied exceed the 10^{-4} cancer risk level, and 70 sites are within the EPA acceptable risk range. For noncarcinogenic effects, 49 of the sites have HIs exceeding 1.0.

The distribution of risks depicted in Figures E.S.1 and E.S.2 (for site-specific and individual soil borings, respectively) shows that potential risks for chronic exposure are highest for those sites located in the central portions of RMA, i.e., South Plants, the area including the evaporative basins, and North Plants.

The site-specific evaluation (Figure E.S.1) of biological worker exposures to contamination measured at a soil depth of 0 to 10 feet (ft) indicates exceedances of the 10^{-4} cancer risk level are generally limited to the following areas: Chemical Sewers (site SP10); Lime Basins, (sites SP1E [Buried M-1 Pits] and NC1B [Section 36 Lime Basins]); South Plants, with sites SP3A, SP1A, and SP3B (ditch), SP1A (Central Processing Area), and SP3B (concrete salt storage pad) exhibiting the highest risks; Former Basin F (site NC3); sanitary/process water sewers (site NC8A); Basin A (site NC1A); and Shell Trenches (site C1A).

Similar patterns were observed for noncarcinogenic effects (HIs). In addition, the general trends exhibited for the biological worker were similar to those shown for the industrial worker and essentially all other potential receptors.

The soil boring (boring-by-boring) evaluations (Figure E.S.2) basically parallel those described for the biological worker site-specific analysis in that exceedances of 10^{-4} cancer risk level or an HI of 1.0 at individual borings are generally limited to the central portions of RMA (South Plants, Sewer Systems, Lime Basins, Basin A, Former Basin F, and Shell Trenches). Isolated exceedances of the 10^{-4} cancer risk level also occur at borings located in Basin C, the Sand Creek Lateral, North Plants Agent Storage Areas, and the sanitary landfill near the Rail Classification/Maintenance Yard.

The contaminants contributing most to potential carcinogenic risks are aldrin, dibromochloropropane (DBCP), arsenic, and dieldrin. Aldrin, DBCP, and arsenic are the major contributors to the noncarcinogenic HIs.

Potential human health risks from acute and subchronic exposures were also evaluated. These short-term cumulative risks were, with few exceptions, substantially lower than the estimated chronic risks by up to four orders of magnitude (i.e., 10,000 times lower). The contaminants contributing most to these short-term risks are identical to those listed for the chronic effects.

The qualitative risk assessment performed for those sites not addressed in the quantitative assessment (e.g., areas containing unexploded ordnance, or UXO) did not identify any sites having potential risks that are not currently being addressed in the FS process.

3.0 CHARACTERIZATION OF POTENTIAL ECOLOGICAL RISKS

The quantitative ecological risk assessment was developed for the IEA/RC to evaluate potential health impacts to biota (plants, wildlife, and aquatic organisms) at RMA. Potential ecological risks at RMA were evaluated in consideration of and consistent with the requirements of Section 44 of the FFA (EPA 1989), which states that biological habitat(s) must be preserved and managed to protect endangered species of wildlife as required by the Endangered Species Act; migratory birds, as required by the Migratory Bird Treaty Act; and bald and golden eagles, as required by the Bald Eagle Protection Act. The ecological risk assessment provides useful information to consider when selecting environmental remedies for the future management of RMA as a National Wildlife Refuge as authorized by the Rocky Mountain Arsenal National Wildlife Refuge Act of 1992.

The primary ecological receptors for which risks were estimated were the bald eagle, great horned owl, American kestrel, great blue heron, shorebirds (which includes killdeer), small bird (which includes mourning dove, vesper sparrow, and western meadowlark), water bird (which includes the mallard, blue-winged teal, and American coot), small mammal (which includes the deer mouse and thirteen-lined ground squirrel), and medium mammal (which includes the black-tailed

prairie dog and desert cottontail). These species or species groups are representative of predators (bald eagle, great horned owl, American kestrel, and great blue heron), species with special feeding niches (shorebird), and prey on RMA.

The potential risks were estimated by integrating a food-web model with a geographic information system (GIS) program. The potential risks for the ecological receptors are characterized as a tissue concentration exceedance of a maximum allowable tissue concentration (MATC) or a dose exceedance of a toxicity reference value (TRV). The exceedances, calculated using average concentrations over exposure areas, are represented as an HQ for each chemical of concern (COC) and receptor evaluated, and an HI is represented as the sum of all chemical-specific HQs for a particular receptor. The MATCs and TRVs are toxicological threshold values derived specifically for the IEA/RC. Potential ecological risk was evaluated for 14 COCs.

Biomagnification factors (BMFs), an essential component of the food-web model when estimating potential risks from chemicals that bioaccumulate (e.g., dieldrin, DDT), were derived for the bioaccumulative chemicals evaluated according to three approaches (U.S. Army, EPA, and Shell Oil Company). Because these three approaches result in a range of BMF values, a range of potential risks (HQs and HIs) is presented, in map format, for each specific bioaccumulative contaminant and receptor being evaluated. The maps were generated to depict the areas and magnitude of potential risks.

The results of the ecological risk assessment are best understood by examining Figures E.S.3 and E.S.4; note that the areas depicted on the maps reflect areas of potential risk and do not represent areas delineating the extent of contamination nor areas requiring cleanup. Figure E.S.3 shows that, based on the Shell approach (used because it is, in this case, the intermediate result relative to areal extent of risk) most of RMA presents a potential risk (HI greater than 1.0) from the combined COCs to two to four trophic boxes (receptors). Figure E.S.4 shows that one trophic box is almost always at a potential risk (HI greater than 1.0) from aldrin/dieldrin, DDT/DDE, and endrin at any point at RMA.

The HI from the combined COCs to the bald eagle exceeds 1.0 for all three approaches throughout the entire eagle exposure area. The HI from the combined COCs also exceeded 1.0 over most of RMA, regardless of approach, for the great horned owl and the American kestrel. Sizable areas of potential risk are created for these two raptors by averaging very high contaminant concentrations in hot spots around the manufacturing plants and basins over their large exposure areas. The HI from all COCs combined exceeds 1.0 over most of RMA, regardless of approach, for the medium mammal as represented by the prairie dog. Because the exposure area for the prairie dog is relatively small, the vast areas of potential risk are probably due to significant contributions to the HI value from several different COCs and the medium mammal's relatively high BMFs for some of the COCs. The prairie dog is the main prey item in the diet of bald and golden eagles at RMA. Potential risk to some predators from aquatic food chains is present; however, HIs are of relatively low magnitude (i.e., HI less than 2.0) for all trophic boxes having an aquatic food chain, except the great blue heron (HI equals 13).

The contaminants contributing most to the potential ecological effects are aldrin, dieldrin, DDT, DDE, and mercury. The potential risk attributable to mercury is overestimated because it was conservatively assumed that all detected mercury concentrations were in the more bioavailable and toxic form, methylmercury. A less toxic and less bioavailable form of mercury (i.e., inorganic) is the form most likely present in soil at RMA.

Areas of increased overall potential risk to biota occur primarily in the interior sections of RMA including South Plants; Basins A, B, C, D, and F; the Toxic Storage Yard; and the northernmost terrestrial areas adjacent to Lake Mary, Lake Ladora, Upper Derby Lake, and Lower Derby Lake. These are areas where all of the trophic boxes have HIs greater than 1.0. The areas of high ecological risk located in the central portion of RMA correspond to the areas exhibiting the highest risks to potential human receptors (Figures E.S.1 and E.S.2).

The results of the ecological risk assessment indicate that potential risk occurs in areas of RMA having elevated concentrations of contaminants; and the presence of risks to wildlife resources has been supported by ecological studies on some individual species (e.g., mallards at Lower

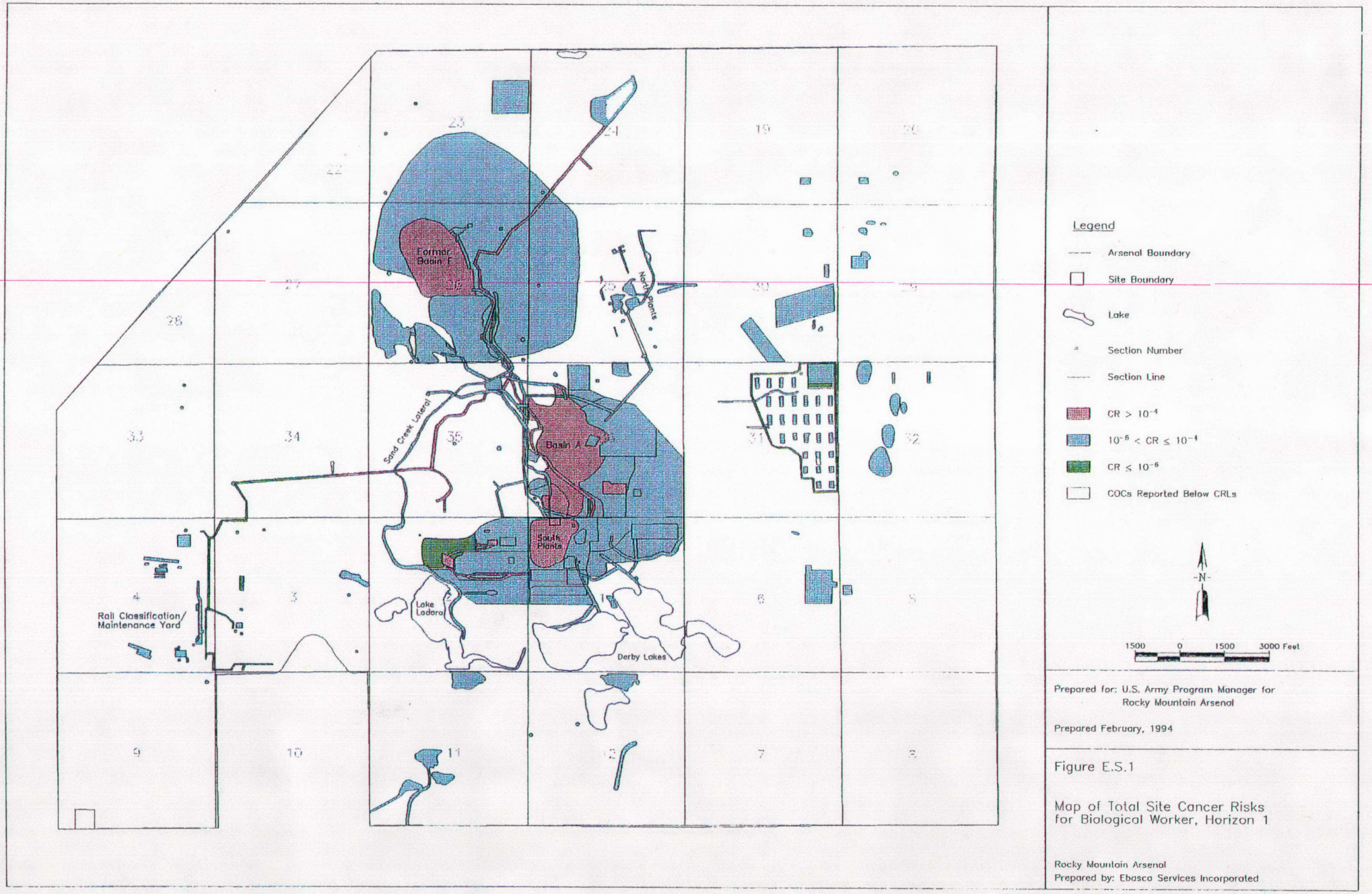
Derby Lake in 1986, kestrels during 1982 to 1983, and pheasants in 1987). The weight of evidence from ecological measurement endpoints studies does not generally indicate the wildlife diversity has been adversely affected at RMA. Species expected to occur in the region are present and some species maintain high population densities at RMA. Population-level studies generally indicate a lack of adverse reproductive effects for birds and mammals, and most individuals observed on RMA appear healthy. It should be noted that although there are uncertainties associated with both the calculation of potential risk and the data on ecological endpoints, these uncertainties should be read and understood as the context for interpreting these two types of results, each of which is generally consistent with the other (i.e., estimated potential risks in areas of RMA where field studies have documented effects in the past).

4.0 INTEGRATED RISK ASSESSMENT RESULTS

Both the human health and the ecological risk assessment results are based on probabilistic methodologies. The probabilistic methods account for the variability in literature and field data for the various parameters used to quantify exposure and risk and at least partially reflect the uncertainty associated with these parameters. The use of this methodology and the discussions of uncertainty increase confidence in the risk characterization by clarifying the uncertainties associated with input values and their implications on estimated risks.

The results of the baseline risk assessment, as presented in the IEA/RC, indicate that potential risks exist for both human and ecological receptors. The contaminants that are the major contributors to overall potential risks are similar for both receptor groups; namely, the organochlorine pesticides. Likewise, the areas that pose the greatest potential risks to both receptor groups are in the central core region of RMA. It is very important to remember that the potential risks presented in this report are baseline (i.e., they are based on current and historical contamination evaluated under present or future land-use scenarios). However, data from some of the areas on RMA that have undergone interim remediation (e.g., capping to eliminate possible exposure pathways for receptors) were not revised to reflect the remediation; the actual risks are, thus, likely to be lower than the baseline risks presented in the IEA/RC. Risk maps that reflect all existing (and future) areas of remediation would depict potential risk over a smaller area.

Figure E.S.5 depicts a soil remediation scenario, based on the Army approach, that would eliminate the potential risk (i.e., result in HQ less than or equal to 1.0 everywhere at RMA) to the great horned owl from aldrin/dieldrin. Risk maps that reflect all existing (and future) areas of remediation would result in lower levels of potential risk, and any residual potential risk would be associated with a substantially smaller area. The Army approach is presented because it is, in this case, the intermediate result regarding areal extent of risk.



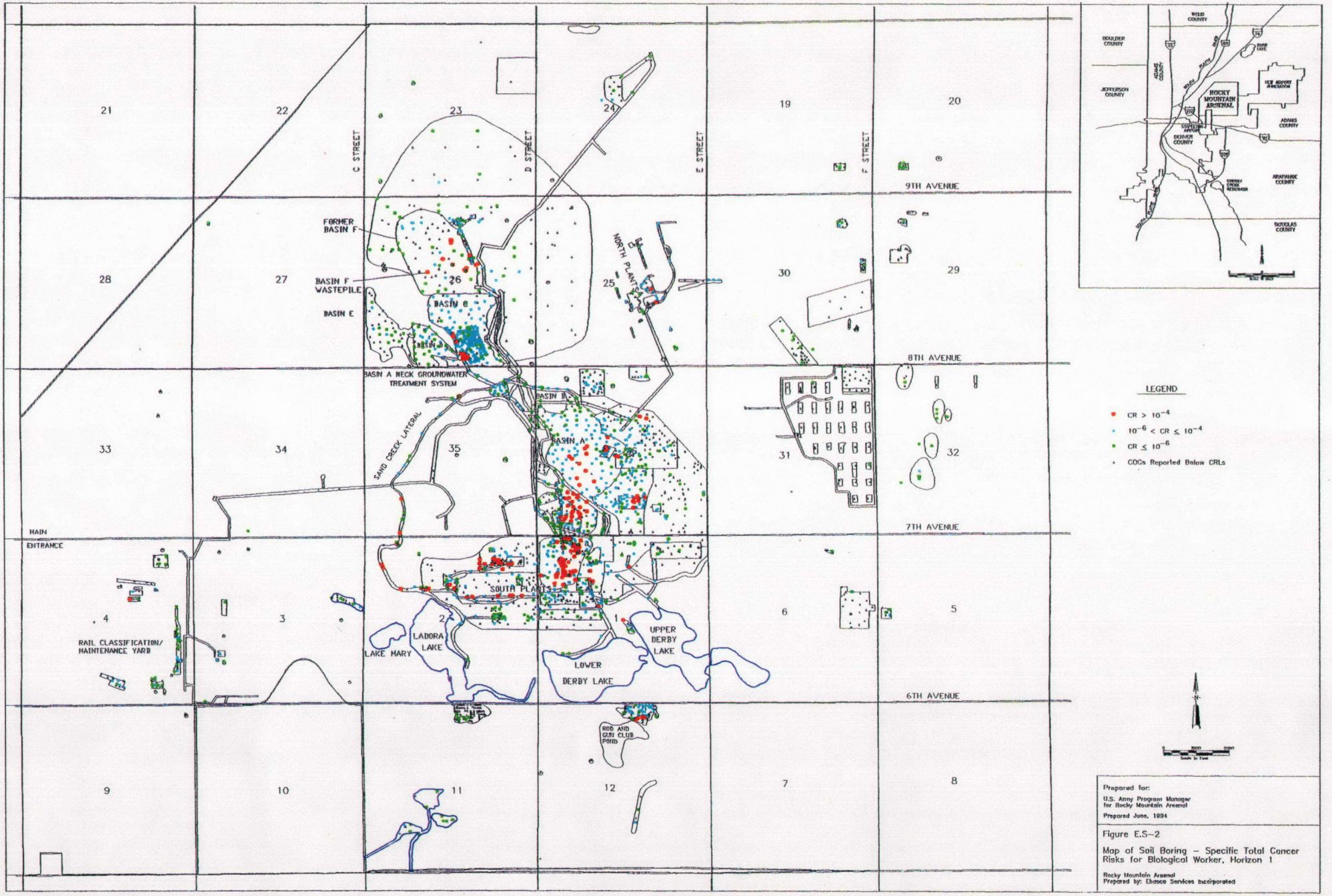
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

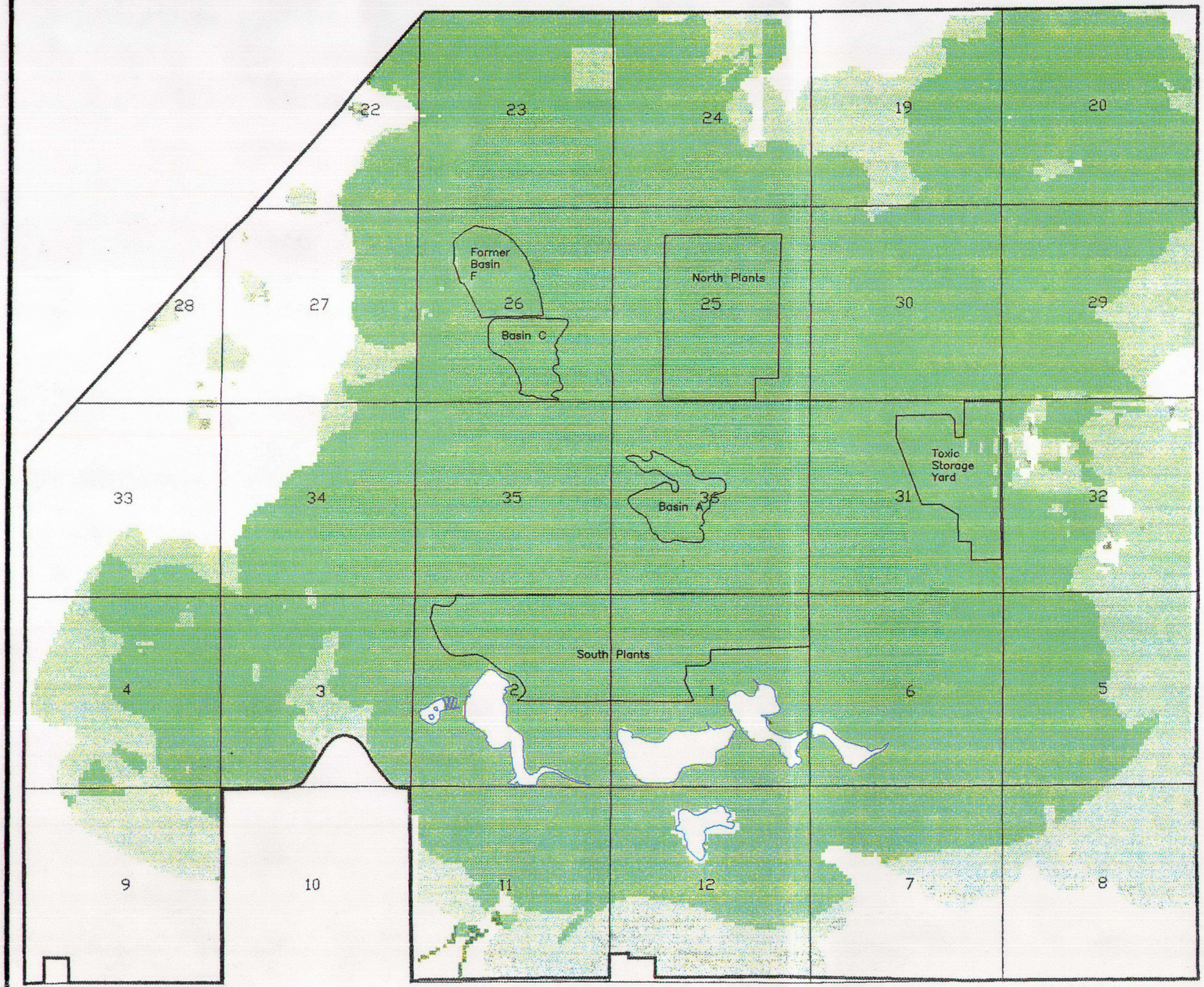
Prepared February, 1994

Figure E.S.1

Map of Total Site Cancer Risks for Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated


21
22
23
24
19
20
C STREET
D STREET
E STREET
F STREET
9TH AVENUE
FORMER BASIN F
BASIN F WASTEPILE
BASIN E
BASIN G
BASIN D
NORTH PLANTS
28
27
26
25
30
29
8TH AVENUE
BASIN A NECK GROUNDWATER TREATMENT SYSTEM
BASIN B
BASIN A
SAND CREEK LATERAL
33
34
35
31
32
7TH AVENUE
MAIN ENTRANCE
SOUTH PLANTS
4
3
2
1
6
5
RAIL CLASSIFICATION/ MAINTENANCE YARD
LADORA LAKE
LAKE MARY
UPPER DERBY LAKE
LOWER DERBY LAKE
6TH AVENUE
ROD AND GUN CLUB POND
9
10
11
12
7
8
LEGEND
CR > 10-4
10-6 < CR ≤ 10-4
CR ≤ 10-6
COCs Reported Below CRLs
WELD COUNTY
BOULDER COUNTY
ADAMS COUNTY
JEFFERSON COUNTY
DENVER COUNTY
ARAPAHOE COUNTY
DOUGLAS COUNTY
ROCKY MOUNTAIN ARSENAL
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared June, 1994
Figure E.S-2
Map of Soil Boring - Specific Total Cancer Risks for Biological Worker, Horizon 1
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend

- 1 trophic box with HI > 1
- 2-4 trophic boxes with HI > 1
- 5-7 trophic boxes with HI > 1

Lake

31 Section Number

Section Line

N

0 2000 4000

Scale in Feet

Prepared for:

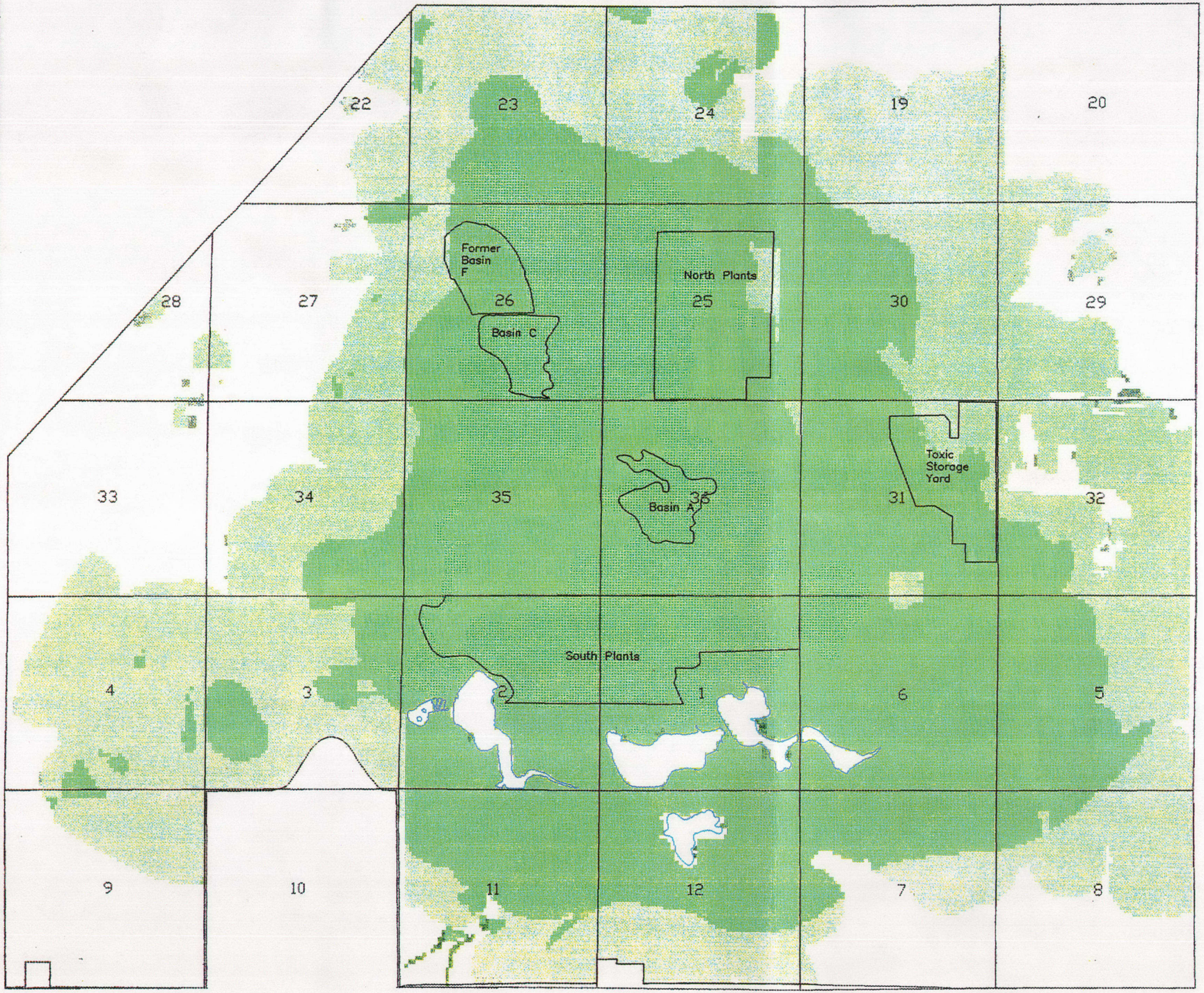
U.S. Army Program Manager
for Rocky Mountain Arsenal

January 1994

Figure E.S.3

Number of Trophic Boxes with Soil Hazard Indices Greater than 1.0 for COCs Combined Based on the Shell Approach

Rocky Mountain Arsenal
Prepared by: ENSERCH Environmental Corp



Legend

- 1 trophic box with HI > 1
- 2-4 trophic boxes with HI > 1
- 5-7 trophic boxes with HI > 1
- Lake
- 31 Section Number
- Section Line

N

0 2000 4000

Scale in Feet

Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

February 1994

Figure E.S.4
Number of Trophic Boxes with Soil Hazard Indices Greater than 1.0 for Aldrin/Dieldrin, DDT/DDE, and Endrin Combined Based on the Shell Approach
Rocky Mountain Arsenal
Prepared by: ENSERCH Environmental Corp

Legend

Potential Soil Remediation Area

Lake

31 Section Number

Section Line

N

0 2000 4000

Scale in Feet

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

February 1994

Figure E.S.5
Potential Areas of Soil Remediation
Necessary to Reduce Aldrin/Dieldrin Hazard
Quotient to 1.0 for the Great Horned Owl
Based on the Army Approach
Rocky Mountain Arsenal
Prepared by: ENSERCH Environmental Corp

1.0 INTRODUCTION

Site investigations conducted under the National Contingency Plan (NCP) are required to include a site-specific endangerment assessment (EA) as part of a remedial investigation/feasibility study (RI/FS) (40 CFR 300.430 (d)(1)). The EA is intended to characterize potential threats to human health and the environment posed by contaminants released to site environmental media (40 CFR 300.430 (d)(4)) and to provide risk managers with an understanding of the risks to human health and the environment posed by the site and any uncertainties associated with the estimation of these potential risks. This information is used to determine whether there is a potential risk to human and ecological health at a site that warrants remedial action.

At Rocky Mountain Arsenal (RMA), the EA is being conducted consistent with the Federal Facility Agreement (FFA). In this instance, the EA for the On-Post Operable Unit consists of three major components (products): Contaminant Identification and Identification of Applicable or Relevant and Appropriate Requirements (ARARs) (hereafter referred to as Contaminant Identification); Exposure/Toxicity Assessment, and Integrated Endangerment Assessment (IEA). A fourth subproduct—the Risk Characterization (RC)—is designated under the EA. The Contaminant Identification and Exposure/Toxicity Assessment reports were completed in 1988 and 1990, respectively (EBASCO 1988b, 1990; ESE 1989). This report incorporates both the IEA and RC for the On-Post Operable Unit as specified in Sections 24.30 and 24.32, respectively, of the FFA. Hereafter, this report is referred to as the IEA/RC.

The IEA/RC report builds upon previous endangerment evaluations—including the Human Health Exposure Assessment (HHEA) (EBASCO 1990), the HHEA Addendum (EBASCO 1992a,c), and the Biota RI (ESE 1989)—as well as several other programs that characterized site conditions (Figure 1.0-1). The RC portion of the report represents an expanded analysis of the potential human health risks posed by specific contaminants of concern (COCs) that were originally presented in the HHEA and HHEA Addendum reports. The RC portion of the report also develops an expanded analysis of risk-based criteria for ecological receptors for soil, sediment,

and surface water exposure pathways originally presented in the Biota RI. The expanded analysis presented in the IEA/RC report uses updated models and model parameters to provide a quantitative, probabilistic assessment of risks for both human and ecological receptors and an evaluation of ecological endpoints.

The Human Health Risk Characterization (HHRC) quantified potential risks for 27 COCs to five groups of potential receptors (populations/subpopulations). Risks were quantified for three direct soil exposure pathways (soil ingestion, dermal contact, and particulate inhalation) and two indirect soil exposure pathways (inhalation of soil vapors in open and enclosed spaces). Potential human health risks were computed using probabilistic risk-based criteria referred to as preliminary pollutant limit values (PPLVs). Risks were not quantified for groundwater or surface water exposures or for soil exposures through consumptive pathways (e.g., through vegetables) because their use is prohibited by the FFA in paragraph 44.2(a), (b), (c). In characterizing potential human health risks for the IEA/RC, the following endpoints were evaluated: chronic risks on a site-specific and boring-by-boring basis (using probabilistic PPLVs), acute/subchronic risks (using deterministic PPLVs developed in the HHEA and the HHEA Addendum), and qualitative risks.

The Ecological Risk Characterization (ERC) quantified potential risks to ecological receptors through a comparison of dose or tissue concentrations based on site-specific contaminant concentrations in soil, sediment, and surface water to toxicological criteria (i.e., toxicity reference values, or TRVs, and maximum allowable tissue concentrations, or MATCs). Potential risks were estimated for the six bioaccumulative COCs (aldrin, dieldrin, dichlorodiphenyltrichloroethane [DDT], dichlorodiphenyldichloroethene [DDE], endrin, and mercury), and eight other chemicals (arsenic, cadmium, copper, chlordane, chlorophenylmethylsulfide [CPMS], chlorophenylmethylsulfone [$CPMSO_2$], dicyclopentadiene [DCPD], and dibromochloropropane [DBCP]). Potential risks were estimated for five representative food webs designed to simulate food webs occurring at RMA. The structure of the biomagnification model was based on these

five representative food webs. The biomagnification model used data from literature and from RMA soil and biota samples to calculate potential risk. An alternative means of characterizing risk—comparing measured tissue concentrations to MATCs or tissue concentrations in prey combined to approximate daily food intake to TRVs—was used in aquatic food chains where measured tissue concentrations were adequately representative of the aquatic system. In addition, information from model analyses, contaminant analyses, and ecological effects investigations were used to evaluate ecological endpoints.

1.1 SPECIFIC OBJECTIVES OF THE IEA/RC REPORT

The specific objectives of the IEA/RC report are to accomplish the following:

- Estimate the magnitude and spatial extent of potential health risks to human receptors to identify geographic areas to be considered for remediation in the FS.
- Estimate potential adverse effects of contamination at the individual, population, and community levels of ecological organization.
- Estimate the magnitude and spatial extent of areas where average tissue concentrations or contaminant doses exceed toxicological threshold limits.
- Update the site-specific, quantitative computational framework for RMA and provide a more comprehensive risk characterization than previous human health evaluations (which served only as screening assessments) and provide ecological evaluations that are consistent with current guidance.
- Characterize the uncertainty inherent in exposure parameters and assumptions for the human health PPLV equations using the literature and site-specific information (as available).

The IEA/RC report identifies potential risks to be considered in the development of preliminary remediation goals (PRGs) during the FS. Also, to be considered in developing PRGs are technology-based treatment or quantification limits, such as certified reporting limits (CRLs), ambient concentrations of naturally occurring or anthropogenic chemicals, ARARs, and to-be-considered (TBC) information (i.e., nonpromulgated health or risk-based information or technical

data issued by the federal or state government). The risk management decisions regarding the selection of criteria to achieve remedial action objectives will be documented as part of the FS process.

1.2 HISTORICAL PERSPECTIVE

RMA is a 27-square-mile U.S. Army (Army) facility located northeast of Denver, Colorado (Figure 1.2-1). RMA was established in 1942 to manufacture chemical warfare agents and agent-filled munitions and to produce incendiary munitions for use in World War II. From December 1942 to May 1943, the Army manufactured a chemical warfare agent, Levinstein mustard, in the South Plants manufacturing complex (Figure 1.2-2). Additionally, a chemical warfare agent, Lewisite, was manufactured at RMA between April and November 1943.

Incendiary munitions were produced at RMA both during and after World War II. Five types of incendiary bombs were either filled or produced at RMA from 1942 to 1946. Once filled, the bombs were stored in open storage areas and in bunkers in sections of RMA east and southeast of South Plants. Military activities continued at the South Plants after the end of World War II, but parts of the South Plants complex were leased to private industry, primarily for the production of pesticides. During the 1950s and into the 1960s, obsolete and deteriorating World War II ordnance was demilitarized on post either by neutralizing the contents and burning the remains or by controlled detonation or open burning.

Additionally, RMA served as a production center for the nerve agent Sarin, as a demilitarization center, and as a rocket fuel production and storage area. Between 1950 and 1952, the Army designed and constructed the North Plants complex (Figure 1.2-2) to manufacture Sarin, which was manufactured there between 1953 and 1957. Sarin was filled into munitions intermittently between 1953 and 1969. From the 1950s through the 1980s, a wide variety of items were demilitarized at RMA, including agent-filled munitions. Rocket fuel was prepared and stored at RMA between 1961 and May 1982.

Portions of RMA were leased to private industry, primarily for the production of pesticides, following World War II. Records indicate that nine companies conducted manufacturing or processing operations in South Plants between 1946 and 1982, when all manufacturing and processing operations in South Plants ceased. The two major lessees of facilities in South Plants were Julius Hyman and Company (Hyman) (1947–54) and Shell Chemical Company (Shell), a division of Shell Oil Company (1954–87).

Hyman manufactured the chlorinated pesticides aldrin, dieldrin, and chlordane, and also manufactured or brought to RMA feedstock chemicals used in manufacturing its commercial products. These included hexachlorocyclopentadiene (HCCPD), bicycloheptadiene (BCHPD), DCPD, cyclopentadiene, hydrogen peroxide, acetylene, and chlorine. In 1952, Shell acquired the stock of Hyman, which continued as a lessor until 1954 when it was merged into Shell Chemical Company. Following the merger, Shell leased and constructed additional facilities in South Plants, producing chlorinated hydrocarbon insecticides, organophosphate insecticides, carbamate insecticides, herbicides, and soil fumigants.

Chemical byproducts from these various activities were introduced into RMA environmental media primarily through the burial or surface disposal of solid wastes, discharge of wastewater to unlined or asphalt-lined basins, and leakage of wastewater and industrial effluents from chemical and sanitary sewer systems. Contaminants were additionally introduced through demilitarization activities, routine application of pesticides, and accidental chemical spills and releases. A more detailed account of the historical activities occurring on RMA is presented in the Remedial Investigation Summary Report (RISR) (EBASCO 1992b).

1.3 REPORT ORGANIZATION

Following a brief discussion of background information (Section 2.0), this report presents the HHRC (Section 3.0) and the ERC (Section 4.0) evaluations independently. These sections discuss the conceptual framework used in evaluating human health and ecological risks and

present the results of the respective risk characterizations. Section 5.0 describes the factors influencing the characterization of potential risks at RMA for both human health and ecological receptors including the limitations, assumptions, and uncertainties affecting the evaluation process. Section 6.0 summarizes the criteria and major findings of the EA process and provides auxiliary information for consideration during the completion of the FS. Section 7.0 lists the references cited in the report.

For ease of reference, tables and figures have been appended to the text sections that they support. In addition, six appendices are included that provide supplemental technical information. Appendix A presents a brief summary of previous investigations and evaluations contributing to the IEA/RC. Appendices B and C present detailed information supporting the human health and ecological risk characterizations, respectively. Appendix D describes the databases, equations, spreadsheets, and software programs used to characterize risks at RMA, and Appendix E elaborates on the application of uncertainty factors. Appendix F provides responses to the Organization and State (OAS) comments on the August 1993 Proposed Final IEA/RC.

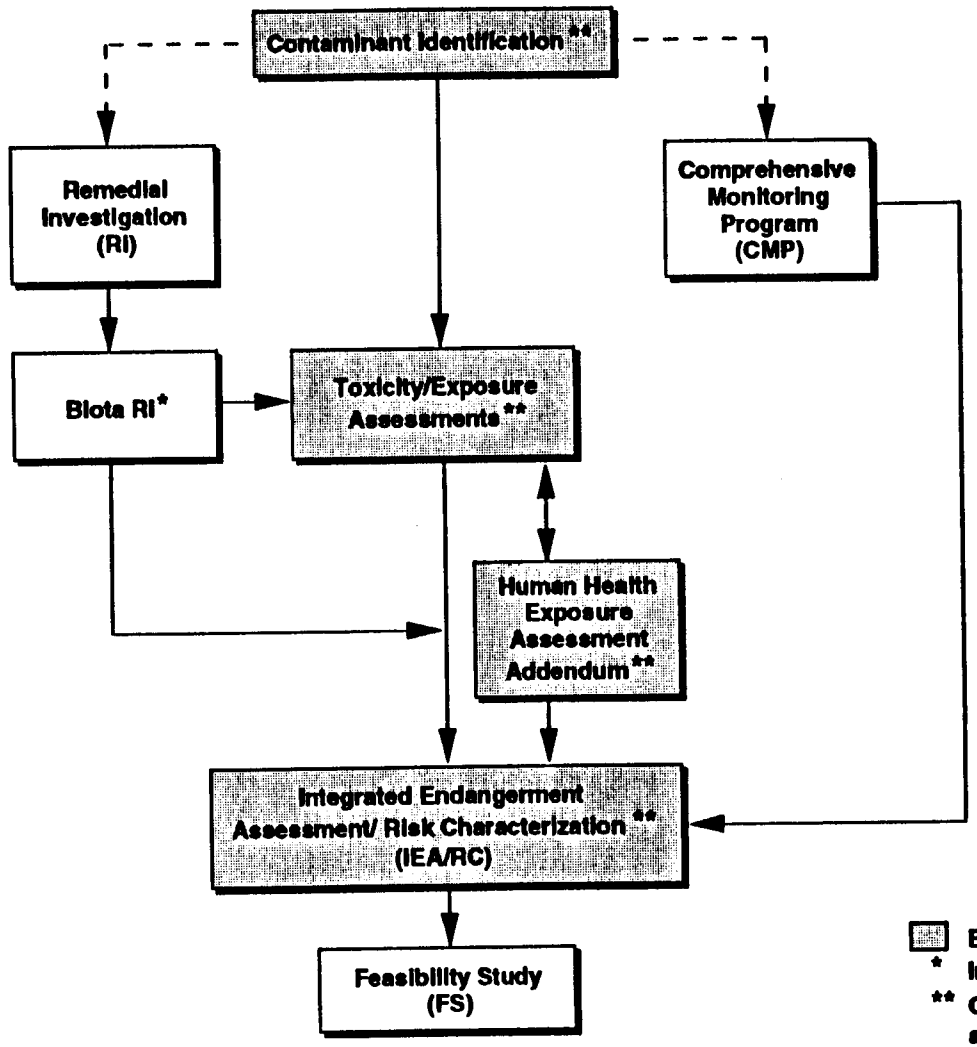


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Figure 1.0-1
Endangerment Assessment Flow Diagram

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

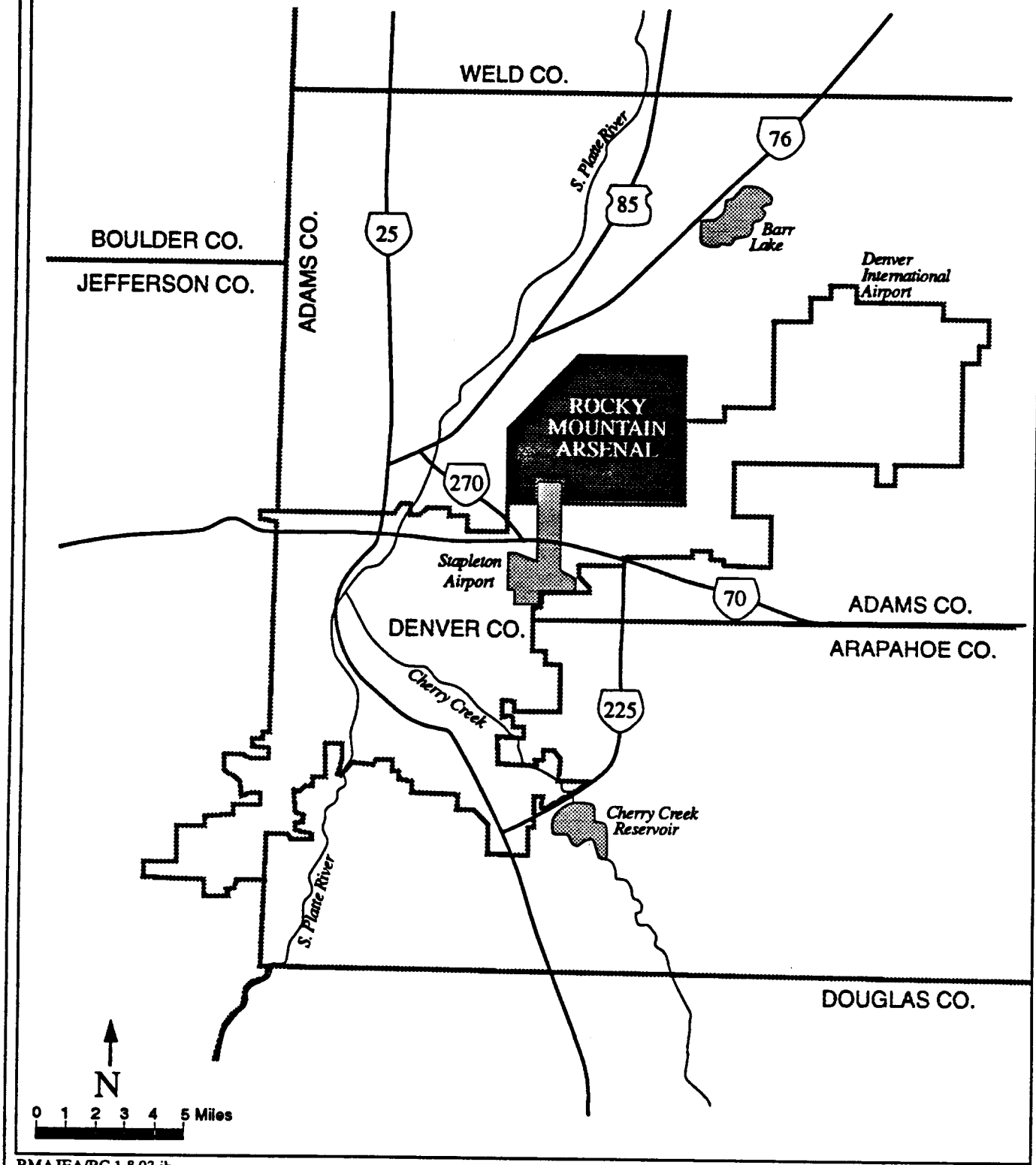

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Figure 1.2-1

Location of Rocky Mountain Arsenal

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

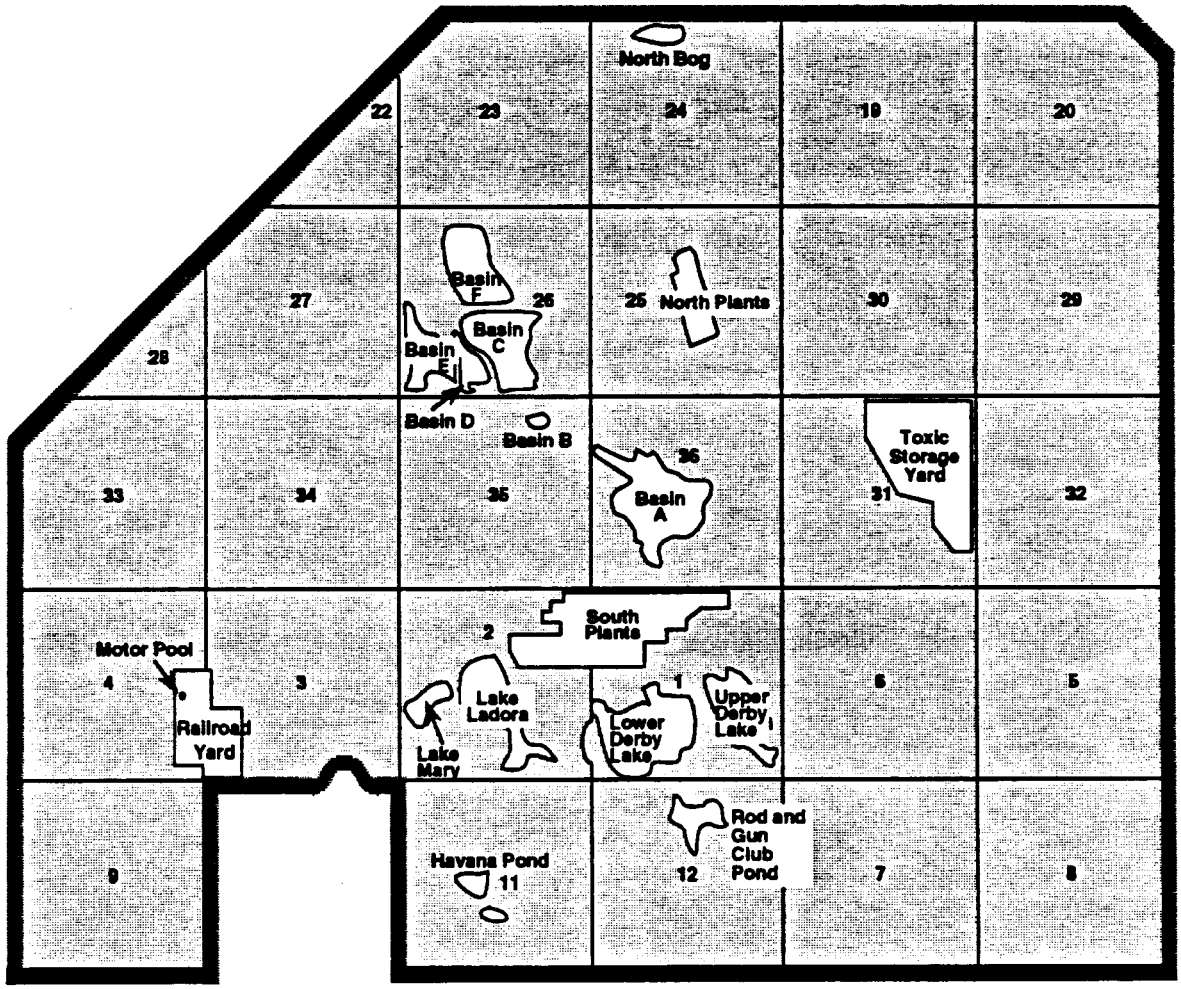

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Figure 1.2-2

Major Areas of Reference on Rocky Mountain Arsenal

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

2.0 BACKGROUND

This section describes the general environmental setting at RMA (Section 2.1) and provides an overview of the contamination trends on post (Section 2.2). It then briefly summarizes the previous investigations and analyses that contribute to the IEA/RC report (Section 2.3), and describes how the data from these programs are used in the HHRC and the ERC (Section 2.4). Finally, this section describes the overall conceptual model used to characterize potential risk at RMA for both human and biological receptors (Section 2.5) and points out important differences and similarities between the human health and ecological approaches to evaluate risk for these two receptor groups. Sections 3.0 and 4.0 describe in more detail the conceptual model for the HHRC and the ERC, respectively.

2.1 GENERAL ENVIRONMENTAL SETTING

To provide a context for consideration of potential risk, ecological data were used to characterize the plant communities, the wildlife habitats these communities provide, and the wildlife species that are present in these communities. This section briefly describes the ecosystems at RMA; Appendix Section C.5.2 provides this information in more detail.

2.1.1 Plant Communities and Animal Habitats at Rocky Mountain Arsenal

The structure of RMA plant communities and the wildlife habitats they provide result from interactions between native and introduced species of plants and animals, historical and current land-use practices, and abiotic factors such as climate, geology, and topography. RMA is situated within a temperate grassland region and is part of a broad ecotone (i.e., transition zone) between mountain and plains habitats. Native vegetation of the region consists primarily of open semiarid grasslands, with some areas of yucca, shrubland, woodland, and riparian habitats. Human societal changes in the region have altered the landscape to a mosaic of agricultural, developed (industrial facilities, residential areas, and successional parcels), and native habitats.

Currently, 88 percent of the RMA land surface is vegetated. Out of this total, 41 percent supports early successional plant communities, and 19 percent crested wheatgrass, which was used in the 1930s and 1940s to stabilize land susceptible to erosion (MKE 1989b). The remaining 28 percent supports shrubland, patches of yucca, riparian woodlands, cattail marshes and other wetland types, locust and wild plum thickets, upland groves of deciduous trees, and ornamental plantings. Each of these varied plant groups provides potential wildlife habitat.

2.1.2 Animals at Rocky Mountain Arsenal

Formal ecological inventories of the animals at RMA began in the mid-1970s (RLSA 1988a). These studies documented a diversity of species that may require specific habitat types (e.g., the Brewer's sparrow requires sagebrush shrubland), or inhabit a range of habitat types (e.g., the black-billed magpie and coyote can be found in all terrestrial habitats at RMA). For RMA fish communities, management history also plays a particularly important role in determining the species present and their population dynamics.

Twenty-six species of mammals have been observed at RMA (Appendix Attachment C.5-1), a number that includes all of the common mammals that inhabit the prairie grasslands of the Colorado Front Range (Armstrong 1972; Bissel and Dillon 1982).

One hundred seventy-six species of birds have been observed at RMA (Appendix Attachment C.5-1), which is approximately 40 percent of all bird species recorded in the State of Colorado (Bailey and Niedrach 1965; Chase et al. 1982). The species richness of RMA avifauna is high relative to that of the region. A variety of ground-nesting songbirds and other birds preferring open habitat are common in the primary RMA habitats of open grassland and weedy plains. At least two regionally rare or declining species (Cassin's sparrow and Brewer's sparrow) are relatively common breeding birds at RMA (Webb et al. 1991). Raptor population density and species diversity are comparable with those at other sites in the region (MKE 1989a). Winter

raptor populations, particularly that of the bald eagle, are a primary attraction for the 20,000 to 30,000 visitors that come to RMA during this season (USFWS 1992).

Several species of reptiles and amphibians may be encountered in nearly every habitat type at RMA. Incidental observation has recorded 61 percent or 17 of the 28 species of reptiles and amphibians that could potentially occur on RMA (Appendix Attachment C.5-1).

The four southern lakes (i.e., Lake Mary, Lake Ladora, Lower Derby Lake, and Upper Derby Lake; Figure 1.2-2) are the primary bodies of water at RMA. Studies indicate these lakes support viable aquatic communities (Appendix Attachment C.5-1), although macrobenthic organisms appear to be largely absent. Differences among lakes in fish species content and in relative numbers within species are primarily attributable to differences in stocking and management (e.g., catch-and-release fishing).

2.1.3 Historical Effects of Contamination

Adverse effects of contamination on RMA were severe in the past, as is indicated by documentation of water bird die offs and fish kills in the lakes associated with contaminant releases (RLSA 1988a). The weight of evidence from ecological observations during the past decade indicate however, that the overall ecosystems and animal communities have retained their integrity and most wildlife populations appear healthy. RMA populations that perform (i.e., reproduce, survive, grow, etc.) as well as or better than general populations in the region are considered to be healthy, without evidence to the contrary. Nonetheless, it is acknowledged that RMA populations are not subject to many modern-day wildlife impacts (e.g., hunting and agricultural practices), so comparisons to populations that are subject to such impacts must be qualified. Furthermore, there is inherent uncertainty as to the properties that constitute population health.

Currently, adverse effects to individual organisms continue to be observed. Although broods of American coots and mallards or blue-winged teal were documented in 1988 through 1990, reduced reproductive success of mallards in RMA lakes was documented in 1986 (ESE 1989), when the last RMA waterfowl reproduction study was conducted. These observations, along with continuing, but occasional, observations of dead and dying raptors, suggest some adverse effects of contamination may still be occurring. This conclusion is supported by tissue concentration data (RLSA 1992; Appendix Attachment C.5-2) and food-web model results. These adverse effects on individuals, however, are not apparent at the population level given the available data on localized populations of sedentary species and on RMA-wide populations of more mobile species (Appendix Section C.5). Recently, interim response actions (IRAs) have been completed in an effort to reduce localized sources of high contamination. Some of the IRAs (i.e., those conducted at Basin F, the Shell Trenches, and the Lime Basins) were completed between May 1989 and October 1993. These activities may have decreased wildlife exposure to contaminants in these areas of RMA.

2.2 OVERVIEW OF CONTAMINATION AT RMA

Contaminants were initially introduced into the RMA environment via liquid waste disposal in open basins, solid waste burial in trenches, accidental spills of feedstock and product chemicals, leakage from sewer and process water systems, emissions from permitted air stacks, and use of commercial chemical products during normal facility operation. As discussed above in Section 1.2 and in Appendix A, significant contamination is generally limited to the manufacturing complexes, solid waste disposal areas, and liquid waste disposal basins. Other contaminated sites include storage areas, maintenance areas, and sewer lines.

Four environmental media (soil, groundwater, sediment, and biota) were found to be impacted. The contaminants of greatest concern to humans or wildlife included organochlorine pesticides (OCPs), arsenic, mercury, volatile halogenated organics, volatile aromatic organics, volatile hydrocarbons, semivolatile halogenated organics, and DBCP.

Infiltration of contaminated water and liquid wastes from source areas transported contaminants into subsurface environments, including the unsaturated zone of soil and the unconfined groundwater flow system. The resultant contaminant plumes are currently moving toward the north and northwest boundaries of RMA, where they are intercepted by boundary containment systems designed to prevent further migration of contaminated groundwater off post. Although local volatilization and wind have introduced contaminants into the air, RI and Comprehensive Monitoring Program (CMP) data show the RMA air quality to be superior to that of nearby urban areas with respect to criteria National Ambient Air Quality Standard (NAAQS) pollutants. Detections of OCPs (e.g., aldrin, dieldrin, DDT, DDE, and endrin) in surficial soils indicate that wind-borne transport of soil particles has caused the redistribution of these contaminants. Elevated concentrations of OCPs, arsenic, and mercury in biota samples collected (particularly those in the central portions of RMA) indicate that these contaminants have entered food chains via contaminated soil and water. Sections 3.2 and 4.5 discuss the spatial distributions of these contaminants in greater detail.

2.3 PROGRAMS CONTRIBUTING TO THE IEA/RC

The IEA/RC report builds on information provided in three previous major programs: the RI program, the CMP, and the EA program. Relevant data from all RMA programs available in the RMA Environmental Database (DP Associates 1993) as of March 1993 were used in the IEA/RC evaluations of ecological risk; data used in evaluations of potential human health risk were updated in December 1993. The summary of the major programs that is provided below emphasizes those tasks and data contributing most to the risk characterizations presented in this report (Sections 3 and 4). Appendix A provides a more complete overview of these programs, as well as references to specific reports providing results of all corresponding investigations.

2.3.1 Remedial Investigation Program

The RI program involved a detailed study of chemical contamination of several environmental media within the On-Post Operable Unit that included 9,692 soil and sediment samples from

4,015 borings, 1,982 groundwater samples from 619 wells, 297 surface water samples from 27 locations, 886 air samples from 13 stations, and 494 biological samples.

The RI investigated more than 320 areas of suspected contamination and, based on historical knowledge and the results of the sampling programs listed above, identified 178 contaminated soil sites at RMA. Figure 2.3-1 shows the locations of the types of sites evaluated in the IEA/RC report, and Figures 2.3-2 and A.2-3 (Appendix A) show the locations of individual sites. Contamination at RMA is generally concentrated in sites located within and around manufacturing complexes, solid waste disposal areas, liquid waste disposal basins, and areas including storage areas, maintenance areas, and sewer lines. As shown in Figure 2.3-1, most of these sites are located in the central sections of RMA.

The Biota RI (ESE 1989) characterized the nature and extent of contamination in biota through tissue analyses, toxicity assessments, and food-web modeling. In addition, ecological endpoints were evaluated at the individual, population, and community level of ecological organization. Sampling design involved on-post and off-post (reference) sites for assessing contaminant concentrations in biological tissues and associated effects. This information was used in the ERC. The on-post tissue data were used to quantify COC concentrations in target receptors; the toxicity assessments and food-web model provided a foundation for risk assessment that was updated, revised, and expanded in the ERC; and the ecological endpoint evaluations were important contributors to the ERC assessment of ecological status and health at RMA.

2.3.2 Comprehensive Monitoring Program

The objectives of the 3-year CMP were to collect baseline and long-term monitoring data for air, biota, groundwater, and surface water in order to identify baseline patterns of variability and changes in these patterns associated with remediation, and to collect specific data to supplement the Biota RI information. The CMP, which was conducted between 1988 and 1990, was a detailed study of chemical contamination of several environmental media that included

approximately 4,000 air samples (RLSA 1988b, 1990c,1991c), 1,400 biological samples (RLSA 1989c, 1990d, 1991d), approximately 3,200 groundwater samples (RLSA 1989b, 1990b, 1991b), and 390 surface water samples (RLSA 1989a, 1990a, 1991a). The air, biota, groundwater, and surface water data were used to identify changes in contaminant levels and migration patterns as well as to evaluate the success of, and any impacts resulting from, IRAs. The Air and Groundwater CMPs are ongoing programs. The ERC used CMP data on surface water and biota to quantify COC concentrations in source media and target receptors, respectively. The use of biota and surface water CMP data in the ERC is consistent with the CMP objectives.

The Biota CMP (RLSA 1992) provided additional site-specific information on COC concentrations in biota at RMA for comparison to control sites, as well as information regarding the pathways of COC movement in biota, the extent of accumulation or magnification of COCs that occurs in these pathways, and changes in the concentrations of COCs in receptor tissue relative to time and increasing distance from identified contaminant sources. The Biota CMP resulted in the collection of more than 1,400 biological samples that were analyzed for COCs. A comparison of the RMA samples to off-post reference samples showed higher tissue concentrations of COCs in on-post samples, especially for dieldrin. The Biota CMP data also confirmed Biota RI findings that the central portion of RMA is the most contaminated area. Results of these biota evaluations and the RI data described above were used to characterize potential ecological risks at RMA, by direct comparison with toxicological threshold values, or as the basis for quantifying a biomagnification factor (BMF) that could be used to predict tissue concentrations or doses for comparison with toxicological threshold values.

2.3.3 Endangerment Assessment Program

As described in Section 1, the EA program consists of three major components that are designated as products under the FFA: Contaminant Identification and Identification of ARARs

(hereafter referred to as Contaminant Identification), Exposure/Toxicity Assessment, and the IEA. In addition, a fourth subproduct of the EA, the RC, is designated under the FFA.

The Contaminant Identification component was the subject of a three-volume report (EBASCO 1988b) that addressed the following: 1) the selection of a subset of target analytes for evaluation in the RI and EA programs from an initial listing of more than 650 chemicals, 2) the evaluation of nontarget (i.e., tentatively identified) analytes in soils and groundwater for potential inclusion as target analytes in the RI and EA programs, and 3) a determination of potential chemical-specific ARARs. The Exposure/Toxicity Assessment component was completed for human receptors in the HHEA and HHEA Addendum reports (EBASCO 1990, 1992c). Only the toxicity assessment portion was completed for ecological receptors in the final Biota RI report; the IEA/RC report provides the exposure assessment component for ecological receptors.

Appendix A describes the Contaminant Identification and the Exposure/Toxicity Assessment components, as well as the HHEA Addendum report, in detail. This report describes the final two components, the IEA and RC.

2.4 USE OF SAMPLING DATA TO CHARACTERIZE RISKS TO HUMAN AND ECOLOGICAL RECEPTORS

The following sections describe how RMA sampling data were used in the HHRC and ERC. Figure 2.4-1 shows the locations of all soil borings used in the IEA/RC evaluations, and Figure 2.4-2 the surficial soil sampling locations.

2.4.1 Use of Sampling Data in the Human Health Risk Characterization

The RI program identified 178 sites to be evaluated under the EA program (Appendix Figure A.2-3) on the basis of historical information (i.e., prior uses and disposal practices and initial findings as to the nature and extent of contamination). Human health risks estimated for these sites were characterized on the basis of soil data only. Consequently, sediment data from lake sites were not used in the quantitative evaluation with the exception of site S1A (Eastern Upper

Derby Lake), which is typically dry. The exclusion of sampling results from other media is consistent with the use restrictions specified in the FFA.

The HHRC used data from soil borings drilled inside the boundaries of designated sites, as well as data from surficial soil samples (i.e., 0- to 2-inch soil depth interval) collected outside the defined boundaries of sites (Figures 2.4-1 and 2.4-2). Section 3.1 describes the specific soil boring depths and horizons sampled in detail.

Potential human health risks at RMA were characterized on both a site-specific and a boring-by-boring basis. For the site-specific analysis, human health risks were estimated using representative contaminant concentrations calculated for each of the 178 sites evaluated in the IEA/RC. In accordance with U.S. Environmental Protection Agency (EPA) guidance (EPA 1992a), the concentration term in the intake equations, arithmetic mean of contaminant concentration (C_{rep}), was calculated as the sample arithmetic mean, and was considered to represent the average contaminant concentration that would be contacted at a site over time (see Section 3.1).

The purpose of the boring-by-boring analysis, which was developed to supplement the site-specific evaluation, was to better reflect the spatial distribution of contaminant-specific risks within sites. Although useful in characterizing contaminant variability and identifying hot spots, the results of this analysis have limited usefulness for describing potential risks because the person is assumed to be exposed continuously and solely at the one location of the boring and at the specified depth horizon. As such, the risks thus identified do not reflect potential chronic human exposures or risks.

2.4.2 Use of Sampling Data in the Ecological Risk Characterization

Data from the RI and CMP on contaminant concentrations in biota tissue and abiotic media samples (i.e., soil, sediment, and surface water), as well as additional data described in Appendix

Section C.4, were used directly and with a food-web model to provide a site-specific basis for estimating potential risks to biota. Specifically, these data included the 0- to 1-foot (ft) depth interval soil boring data and surficial soil data (i.e., the 0- to 2-inch depth interval) collected irrespective of site boundaries (Figures 2.4-1 and 2.4-2). In addition, subsurface soil data from the 1- to 20-ft depth interval were also used for evaluating the potential risk to prairie dogs.

Ecological exposure evaluations (comparable to the HHRC term C_{rep}) were computed to reflect exposure within animal activity areas (i.e., exposure ranges) that were defined for representative species of the trophic boxes in the food-web model. To calculate average exposure area concentrations, soil data were interpolated to estimate concentrations at grid points located 100 ft apart across RMA. Interpolated grid data were then averaged within the trophic-box-specific exposure range to estimate the potential exposure to biota in the individual food-web components. Thus, for ecological exposure evaluations, the concentration term for use in the intake equations was defined quite differently than for human health exposure evaluations, and varied among trophic boxes in the food-web model (EPA 1989b). Moreover, boring-by-boring analyses were not performed for biota.

Data were also collected on ecological measurement endpoints including species diversity (i.e., species richness), mortality, reproductive success, population density, and physiological factors to evaluate potential adverse effects. These results and the results of tissue analyses and pathways modeling to characterize ecological risk were compared to see if they were consistent. Uncertainties present in both types of results were identified and considered in the comparison, and both types of results were then presented to characterize ecological risk and to be considered in the feasibility study decision process.

2.5 CONTEXT FOR REVIEWING HUMAN HEALTH AND ECOLOGICAL RISK CHARACTERIZATIONS

The following paragraphs briefly discuss differences in the methods used in each analysis (e.g., spatial averaging), the endpoints evaluated, and the presentation of findings, to facilitate interpretation of the findings of the human health and ecological risk characterizations developed for the IEA/RC. These comparisons are discussed to provide a context for interpreting conclusions regarding the areas of risk identified for human and ecological receptors (Figures 2.5-1 and 2.5-2, respectively).

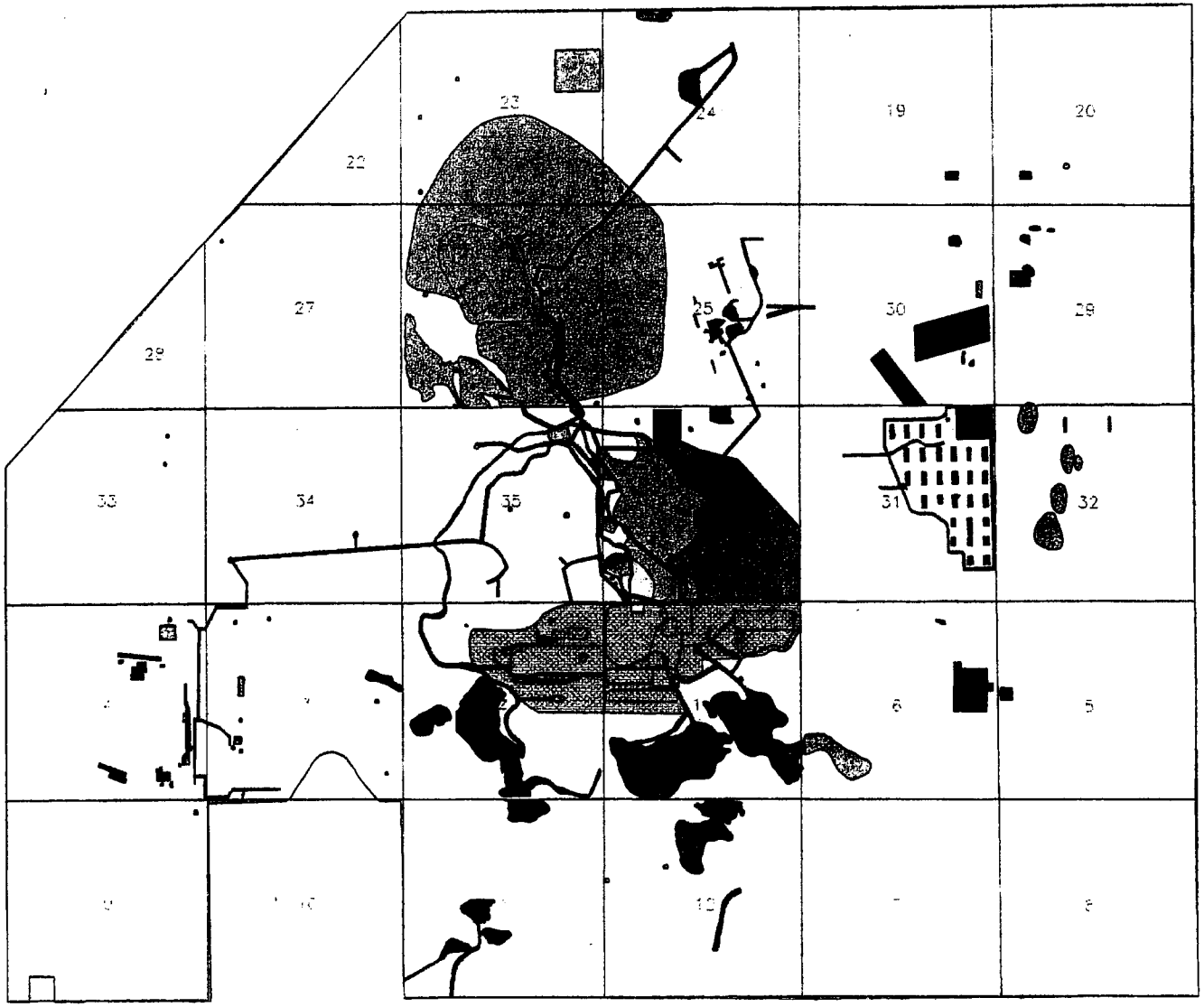
Human health risks were quantified on both a site-specific (C_{rep}) and a boring-by-boring basis using probabilistic risk-based criteria (PPLVs). Potential ecological risks were estimated by comparing environmental media concentrations to trophic box and chemical-specific criteria to compute HQs and HIs. As discussed in Section 2.2, the methods used to estimate average exposure point concentrations for the HHRC were very different from those applied in the ecological risk evaluation, for which soil contaminant data were interpolated using a 100-ft grid spacing. The interpolated grid data were then averaged to estimate exposures for individual food-web components (trophic boxes).

Cumulative carcinogenic risks (representing all exposure pathways and COCs) for the human health evaluation were compared to an acceptable risk range of 10^{-6} to 10^{-4} (NCP, 40 CFR 300). For carcinogens causing health effects in addition to cancer, and for noncarcinogens, potential adverse health effects were identified where HI values exceeded 1.0, which is considered the acceptable, or benchmark, level. Analogous guidance specifying an acceptable risk level for ecological receptors has yet to be developed.

However, the results of the ERC and identification of areas of potential risk can be evaluated by comparing them with what is known about the status and health of ecological receptors at RMA (based on field observations and biota/tissue sampling) to see whether they are consistent. Such

a "reality check" is not achievable for the human health evaluation, however, given the hypothetical nature of the exposure scenarios evaluated (i.e., receptors are defined for projected future land-use scenarios) and the absence of a human tissue sampling program.

Given the issues discussed above, the risk maps developed for the human health and ecological risk evaluations can be directly compared only in terms of overall trends (e.g., the identification of RMA areas exhibiting the highest risks). As discussed in Section 6, the HHRC and ERC do reveal similar findings regarding the spatial distribution of risks at RMA.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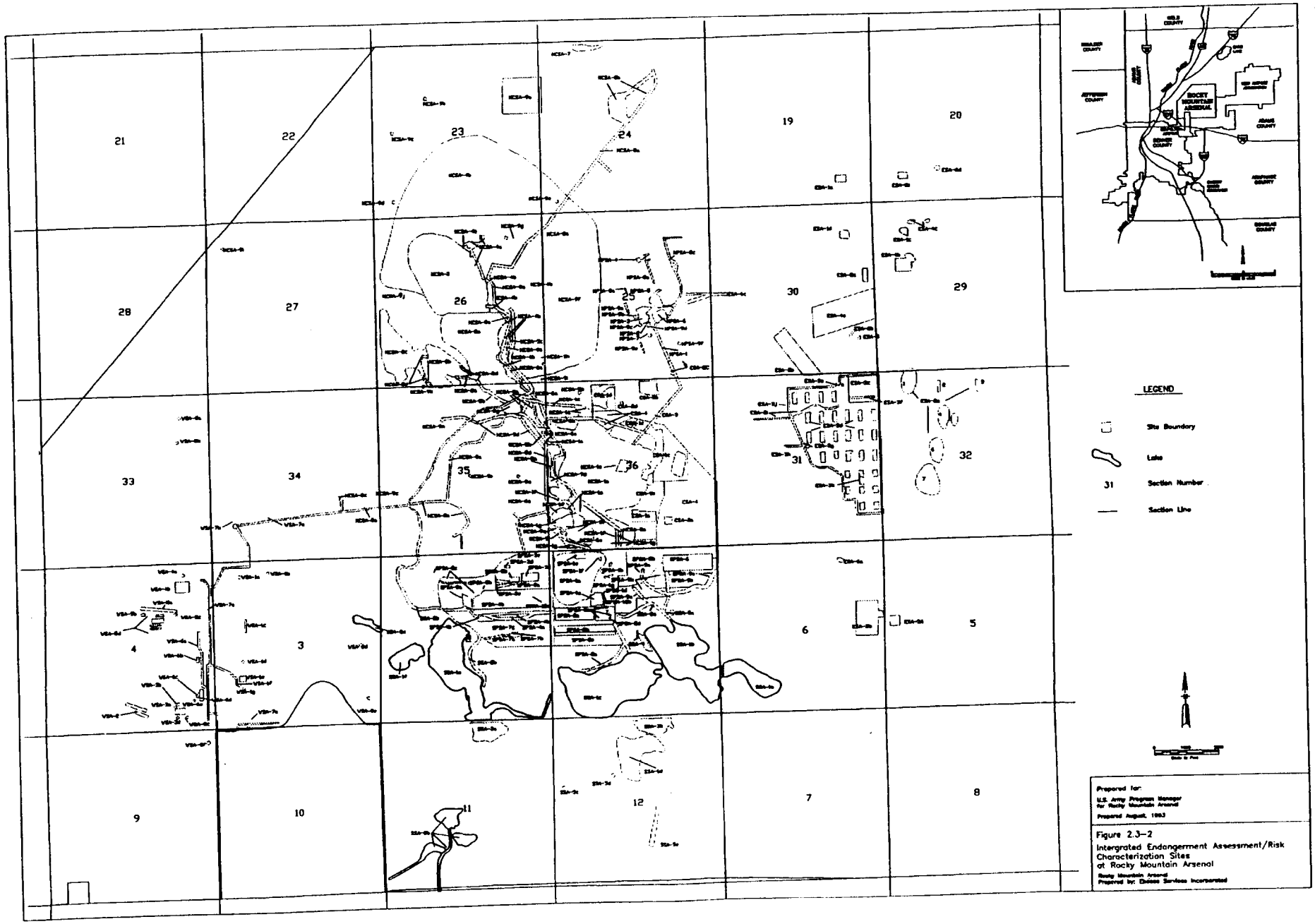
Munitions Testing
Agent Storage
Lake Sediments
Ditches/Drainage Areas
Basins (A–F)
Sewer Systems
Disposal Trenches
Sanitary Landfills
Lime Basins
South Plants
Buried Sediments/Ditches
Section 36 Balance of Areas
Burial Trenches
RMA Balance of Areas[1]
5 Section Number
[1]RMA Balance of Areas site designation includes all Arsenal areas not shaded
N
1500 0 1500 3000 Feet
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared: February 1994
Figure 2.3–1
RMA Site Designations
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated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Site Boundary
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Section Number
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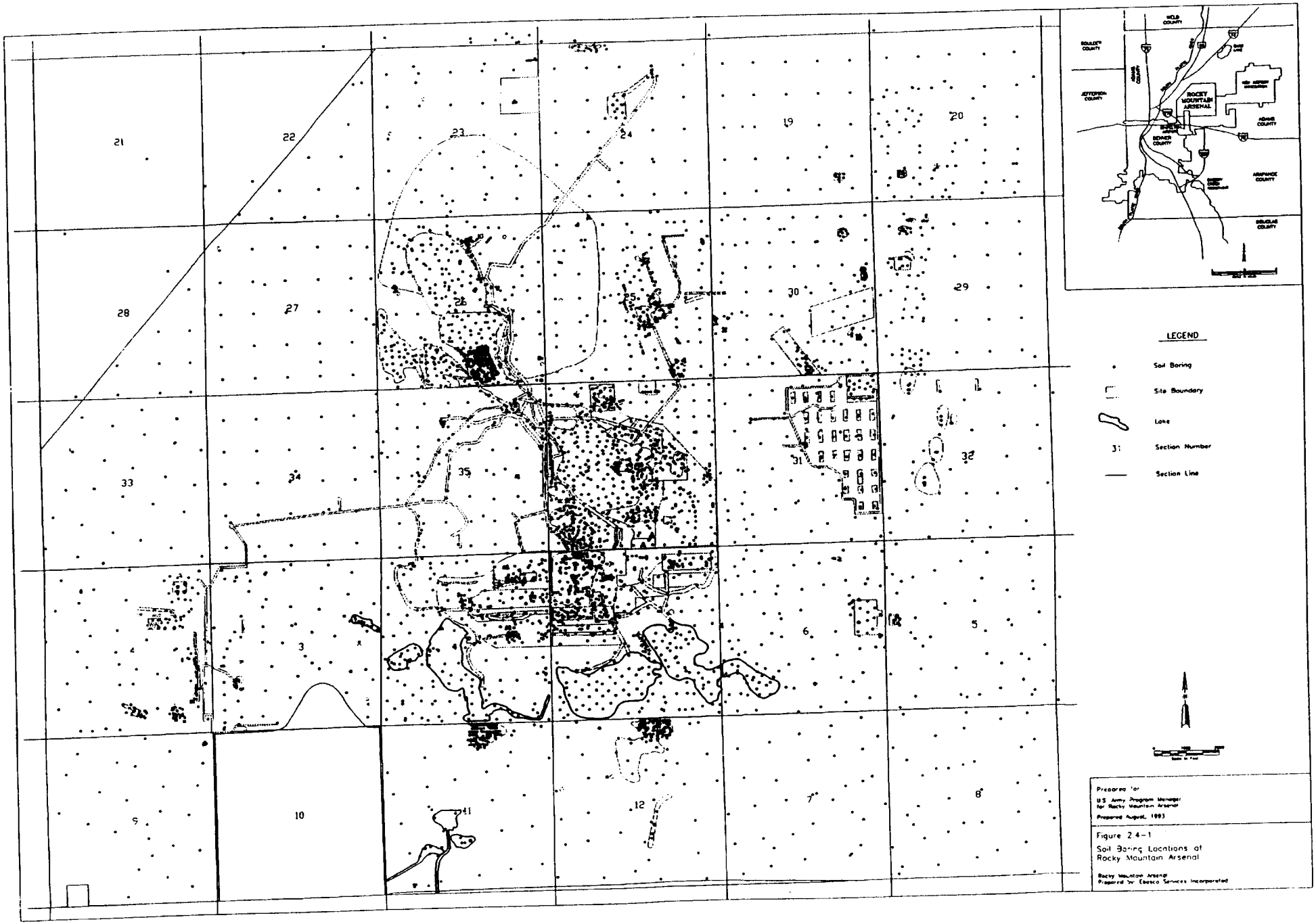
ADAMS COUNTY
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal
Prepared August, 1983
Figure 2.3-2
Intergrated Endangerment Assessment/Risk
Characterization Sites
at Rocky Mountain Arsenal
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated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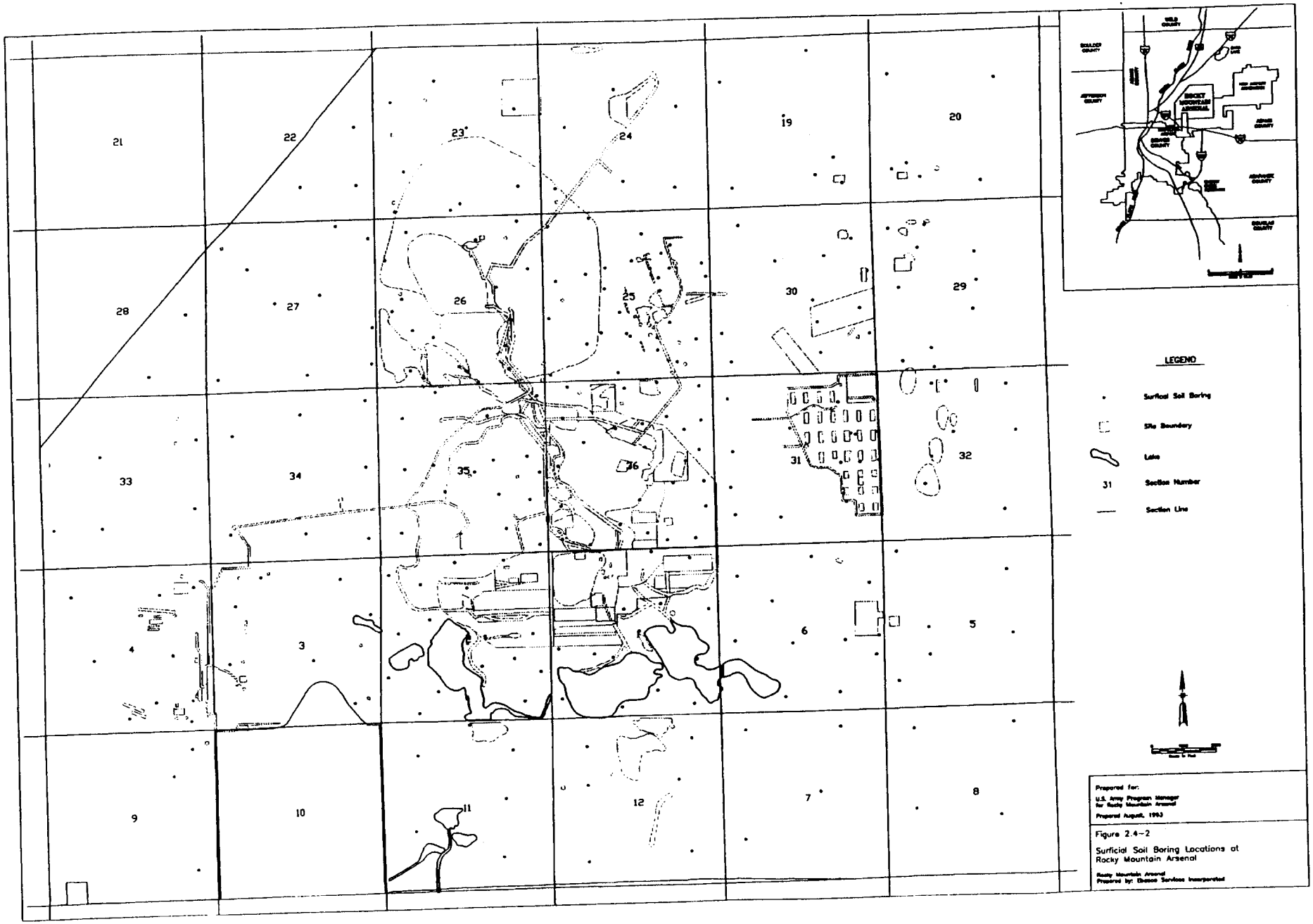
ROCKY MOUNTAIN ARSENAL
Prepared for
US Army Program Manager
for Rocky Mountain Arsenal
Prepared August, 1993
Figure 2.4-1
Soil Boring Locations at
Rocky Mountain Arsenal
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated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Surficial Soil Boring
Site Boundary
Lake
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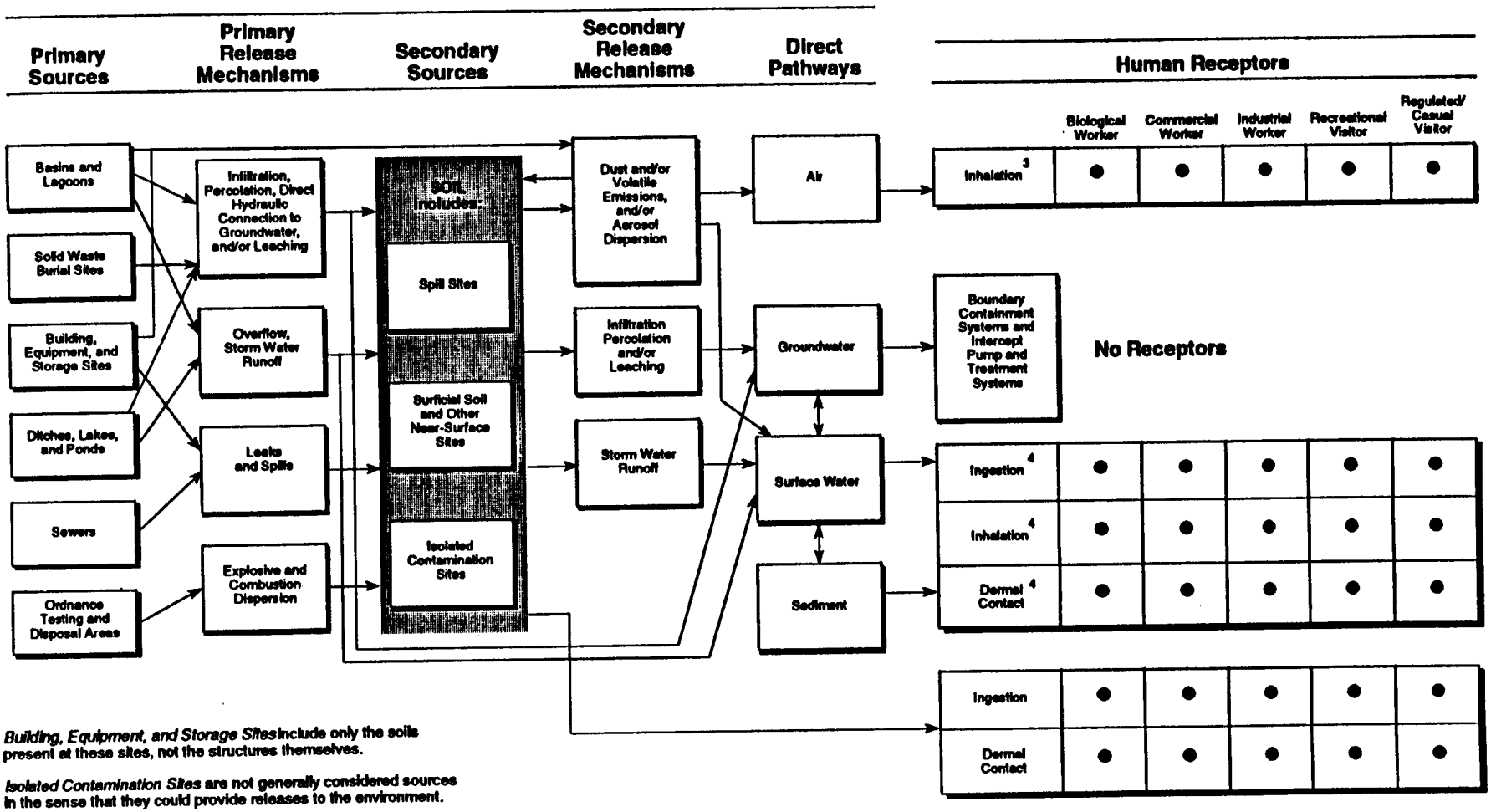
Section Line
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared August, 1993
Figure 2.4-2
Surficial Soil Boring Locations at Rocky Mountain Arsenal
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



1 *Building, Equipment, and Storage Sites* include only the soils present at these sites, not the structures themselves.

2 *Isolated Contamination Sites* are not generally considered sources in the sense that they could provide releases to the environment.

3 Enclosed space soil vapor inhalation evaluated for commercial and industrial populations only. Open space soil vapor inhalation evaluated for all populations except commercial workers.

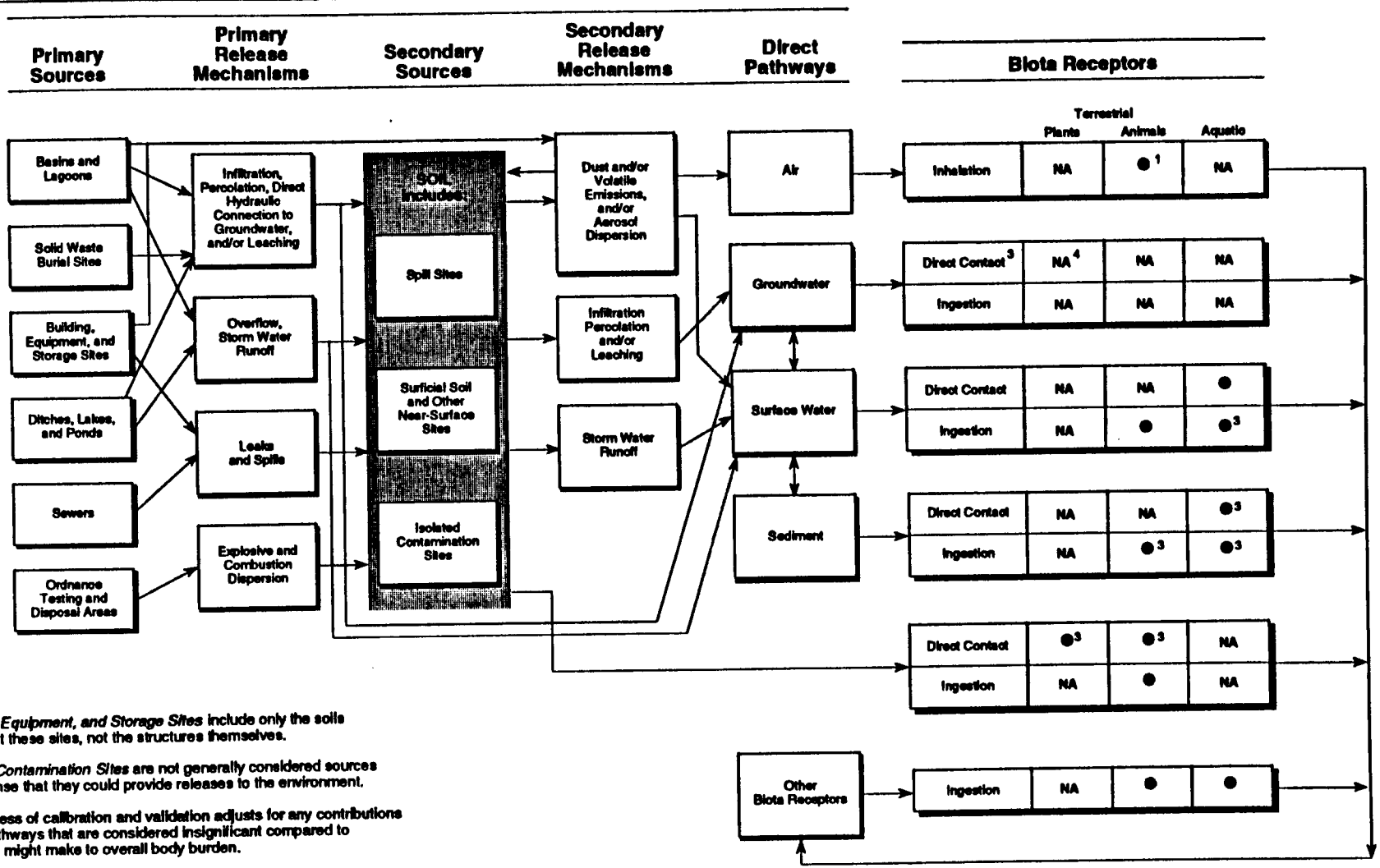
4 Only ephemeral lake sediments were evaluated.

RMA IEA/RC A.2 2.94.jb

Figure 2.5-1

Rocky Mountain Arsenal Site Conceptual Model for Human Receptors

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



RMA IEA/RC A.2 2.94.jb

Figure 2.5-2

Rocky Mountain Arsenal Site Conceptual Model for Biota Receptors

Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated

3.0 HUMAN HEALTH RISK CHARACTERIZATION

The objectives of the HHRC developed for RMA were to accomplish the following: (1) to develop probabilistic risk-based criteria for contaminants in site soils to protect target human receptors, (2) to quantify the uncertainty associated with these criteria, (3) to characterize the potential risks to projected human populations posed by the existing contamination at RMA, and (4) to evaluate the spatial distribution of calculated risks to provide a realistic basis for future cleanup decisions.

The data and literature bases used to characterize risks to human health were extensive. These factors, when combined with the probabilistic method used to quantify potential risks, resulted in the generation of a complex array of results that reflected the numerous site locations/areas, receptor populations, and exposure settings evaluated in the analysis. Therefore, to facilitate interpretation of the findings of the risk characterization, this section focuses on results obtained for the maximally exposed receptor population (i.e., that population/subpopulation for which estimated risks were highest for a given land-use scenario, thereby driving remediation). This section also limits the discussion to those chemicals contributing most to the estimated risks. Appendix B presents a detailed description of the methods used and the results obtained for all five maximally exposed receptor populations/subpopulations.

The HHRC drew heavily upon results presented in the HHEA report (EBASCO 1990), which identified COCs, preliminary land-use scenarios, and target receptors, and defined parameters to be used in the exposure and toxicity (dose-response) assessments. Based on these initial evaluations, Section 3.1 of this document describes the conceptual framework used to quantitatively evaluate exposures and risks for the potential human receptor populations at RMA. Section 3.2 presents the risk-based criteria developed for the projected exposure settings and summarizes the results of the HHRC, which quantifies risk on both a site-specific and a boring-by-boring basis. In addition to evaluating chronic-risk endpoints using probabilistic PPLVs, Section 3.2 also summarizes the results of the acute/subchronic risk evaluation presented in the HHEA, which was developed using deterministic PPLVs. Section 3.3 presents the results of the

qualitative risk assessment, which was developed to identify potential areas of concern that could not be quantitatively addressed in the HHRC due to the lack of sampling or the nature of sampling conducted during the RI. (Areas of concern include sites with the potential presence of unexploded ordnance, or UXO, or agent, drum disposal sites, underground storage tanks, and other potential hazards.) Section 3.4 summarizes the results of the human health risk assessment.

3.1 CONCEPTUAL FRAMEWORK

This section summarizes the conceptual approach used to characterize the risks associated with potential human exposure to COCs at RMA. The conceptual approach (Figure 3.1-1) is briefly described in this section in a sequence paralleling the more detailed description of methods and equations provided in Appendix Section B.1. Section 3.1.1 describes the selection of COCs. Section 3.1.2 identifies target human receptors reflecting both existing and potential future land uses at RMA and defines the associated exposure pathways. Section 3.1.3 summarizes the approach used to estimate exposure point concentrations. Sections 3.1.4 and 3.1.5 identify the exposure and toxicity parameters used in the HHRC analysis, respectively. Section 3.1.6 describes the approach used to compute PPLVs, the risk-based soil criteria that form the basis for all human health risk calculations. This section also discusses the role of quantitative uncertainty analysis in the risk evaluation process. Finally, Section 3.1.7 describes the methods used to quantify and characterize potential cancer risks and noncancer health effects.

3.1.1 Selection of Contaminants of Concern

Twenty-seven COCs, selected after a series of preliminary and screening evaluations conducted as part of the HHEA, were evaluated in the HHRC. These chemicals are listed in the results tables provided in Section 3.2. Appendix A and Appendix Section B.1.2 detail the criteria used to select the COCs.

3.1.2 Identification of Target Receptors and Definition of Exposure Pathways

The identification of potentially exposed populations at RMA requires consideration of potential site land uses. The FFA indicates that significant portions of RMA will be available for open

space for public benefit (including, but not limited to, wildlife habitat(s) and park(s)). Through the introduction of the Rocky Mountain Arsenal National Wildlife Act of 1992, hereafter referred to as the Refuge Act, this has come to mean that future land-use options will involve an open space scenario dominated by the formation of a nature preserve and wildlife refuge that includes parks and recreational areas. Limited areas at RMA may also be developed for light commercial and industrial uses.

Given the land-use projections identified above and the lack of specific information regarding future land-use distribution within the RMA boundaries, two land-use options were identified that formed the basis for defining target receptor populations: (1) open space, which includes nature preserve, wildlife refuge, and recreational park scenarios, and (2) economic development, which includes commercial and industrial scenarios. Based on the open space land-use projection, three receptor populations were evaluated in the HHRC: refuge workers, regulated/casual visitors, and recreational visitors. For each of these potentially exposed populations, several subpopulations can be identified. The subpopulations with the potential for highest exposure at RMA were chosen for evaluation in the HHRC. Specifically, for the refuge worker population, the biological worker subpopulation was selected for evaluation. For the regulated/casual and recreational visitor populations, the subpopulations of regulated/casual and recreational visitors living in the local neighborhood were selected for evaluation.

Based on the economic development land-use projection, two worker populations, industrial and commercial workers, were selected for evaluation. Figure 3.1-2 is a diagram showing the land-use scenarios and potentially exposed populations and subpopulations associated with them.

The potentially exposed populations and subpopulations at RMA are further defined in Sections 3.1.2.1 and 3.1.2.2. These sections also identify the potential routes of exposure and the soil depths (referred to as "soil horizons") evaluated for each receptor group. Table 3.1-1 provides a summary of the soil horizons and specific exposure pathways evaluated for each potentially

exposed population. Section 3.1.2.3 discusses the pathways that are not quantitatively evaluated in the HHRC.

For both open space and economic development land-use options, risks were calculated assuming that exposure would occur at a given site (see Figure 3.1-2) or, in the case of the boring-by-boring analysis, at an individual soil boring. The context for evaluating these results, and their applicability to the potential land uses at RMA, is discussed further in Section 3.1.3, which describes the methods used to determine exposure point concentrations.

3.1.2.1 Open Space Land-Use Option

As shown in Figure 3.1-2, the future land-uses and potentially exposed populations identified under the open space land-use option include a nature preserve and wildlife refuge, which would be used by refuge workers, regulated visitors, and casual visitors. A recreational park, which would be used by recreational visitors, was also evaluated. For each of these three populations, a maximally exposed subpopulation was evaluated as follows: (1) the biological worker subpopulation (of the refuge worker population); (2) the local neighborhood subpopulation of the regulated/casual visitor population; and (3) the local neighborhood subpopulation of the recreational visitor population. Under the open space option, there may be refuge workers at the site who perform a variety of work activities, ranging from working indoors to groundskeeping. The biological worker represents a subpopulation of workers who have the highest potential for extensive soil exposure because of the type of work they perform. Similarly, while the visitor population could draw from the greater Denver area, it is assumed that the local neighborhood subpopulation of visitors would use the site more frequently and thus would be exposed to RMA soils more frequently than individuals comprising the general visitor population. The exposure pathways evaluated for each of these exposed subpopulations are described below.

Biological Worker

Under the future open space land-use scenarios shown in Figure 3.1-2, there is likely to be a population of workers engaged in a diverse range of indoor and outdoor activities associated with the preservation of wildlife. A recent study of wildlife refuges with open space development patterns similar to those projected for RMA (once remedial activities are complete) assessed the activities of a refuge worker population (Appendix Section B.2). Based on the results of this activity survey, biological workers were selected for evaluation in the risk characterization, given that site-use intensity is expected to be highest (of the refuge workers interviewed) for these receptors.

As shown in Table 3.1-1, direct soil exposure pathways and an indirect open space soil vapor inhalation pathway were evaluated for the biological worker. The direct pathways include soil ingestion, dermal contact, and particulate inhalation. For the site-specific analysis, these direct pathways were evaluated for two soil depth intervals: Horizon 0 (0 to 1 ft) and Horizon 1 (0 to 10 ft). For the boring-by-boring analysis, the direct pathways were evaluated only for surficial soils (0 to 2 inches) and Horizon 0 borings. These depths were considered because they represent the most likely soil exposure depths for a biological worker, who, by definition, would be engaged in extensive soil intrusive activities. Because biological workers are assumed to spend most of the work day outdoors, indirect exposures to soil contaminants resulting from outdoor (open space) contaminant vapor inhalation were also evaluated for this subpopulation for Horizon 1 and Horizon 2 (from 10 ft below ground surface to groundwater). However, this analysis focuses on results for Horizon 1, which was considered most applicable to the biological worker exposure setting. Indirect exposure pathways are not considered for surficial soils or for Horizon 0 due to the lower concentration of contaminants in these depth profiles relative to Horizons 1 and 2.

Regulated/Casual Visitor

Under the nature preserve and wildlife refuge future land-use scenarios (Figure 3.1-2), human activities such as wildlife observation, picnicking, hiking, nature walks, and nature photography

would be allowed (EBASCO 1990). The predominant exposed population would therefore be the general public, i.e., adults and children visiting the refuge or nature preserve. Two separate visitor populations were initially defined in the HHEA report (EBASCO 1990): the regulated visitor and the casual visitor. However, because the activities (and thus exposure magnitudes) projected for these populations were determined to be similar, these populations were combined into a single regulated/casual visitor population for the HHRC. In addition, because proximity to RMA would likely influence visitation frequency and activity participation frequency, local neighborhood visitors were identified as having a potential for greater exposure to soil contaminants at RMA. This subpopulation—the local neighborhood regulated/casual visitor—was therefore selected for quantitative evaluation in the HHRC.

Table 3.1-1 summarizes the direct and indirect exposure pathways quantified for the local neighborhood regulated/casual visitor subpopulation. These pathways are the same as those identified for the biological worker, except that open space soil vapor inhalation is evaluated for Horizon 1 (0 to 10 ft) only.

Recreational Visitor

Under the recreational park land-use scenario, the development of recreational facilities for public use would be emphasized (EBASCO 1990). Based on initial analyses conducted for the HHEA, the following recreational park land uses were considered: a visitor center with adjoining picnic grounds and parking areas; an extensive network of trails for hiking, jogging, bicycling, wildlife observation, or cross-country skiing; and athletic fields (EBASCO 1990). The maximally exposed subpopulation for this land-use scenario was assumed to consist of local neighborhood visitors who would have a potential for greater exposure to soil contaminants at RMA. The exposure pathways quantified for the local neighborhood recreational visitor subpopulation are shown in Table 3.1-1 and are the same as those assumed for the regulated/casual visitor.

3.1.2.2 Economic Development Land-Use Option

Two potentially exposed populations were evaluated for RMA under the economic development land-use option industrial workers and commercial workers. The following sections describe the activities and expected soil exposures for these populations, which are summarized in Figure 3.1-2 and Table 3.1-1.

Industrial Worker

The future industrial land-use scenario assumes light industrial use of areas at RMA. Under this scenario, the exposed population would consist of adults engaged in activities associated with light manufacturing (e.g., assembly, finishing, and packaging). The industrial worker population has also been defined to include individuals engaged in groundskeeping and maintenance activities at RMA, although it would not include individuals who are engaged in remedial activities associated with the RMA cleanup.

As shown in Table 3.1-1, direct and indirect soil exposure pathways were selected for industrial workers. Similar to the biological worker evaluation, the direct pathways (soil ingestion, dermal contact, and particulate inhalation) were evaluated for surficial soils and Horizons 0 (0 to 1 ft) and 1 (0 to 10 ft). Additionally, because industrial workers may spend time both indoors and outdoors, indirect soil exposure pathways consisting of open and enclosed space soil-vapor inhalation were selected for this population for Horizons 1 and 2 (>10 ft to groundwater) depth intervals. The open space vapor inhalation pathway was evaluated to estimate inhalation risks to industrial workers while they are outdoors, and the enclosed space vapor inhalation pathway was evaluated to estimate inhalation risks to industrial workers when they are in enclosed basement structures.

Commercial Worker

Under the future commercial land-use scenario, the predominantly exposed population would consist of adult employees in office and retail buildings. As summarized in Table 3.1-1, direct and indirect pathways were also analyzed for this potentially exposed population. Direct soil

exposure pathways (soil ingestion, dermal contact, and particulate inhalation) were quantified for surficial soils and Horizons 0 and 1, despite the predominantly indoor activities associated with this receptor population, under the assumption that indoor dust originates from outdoor soils. Because commercial workers are assumed to spend the majority of their time indoors, the enclosed space soil vapor inhalation pathway (soil vapor inhalation from transport into enclosed basement structures) for Horizons 1 and 2 was evaluated.

3.1.2.3 Exposure Pathways Not Quantitatively Evaluated in the HHRC

Several exposure pathways were not quantified in the HHRC due to land-use restrictions and/or limitations on the uses of environmental media specified in the FFA. As described in the HHEA (EBASCO 1990), these pathways include ingestion of groundwater, exposures to surface water or sediments, ingestion of fish (from RMA), and (for future land-use scenarios only) ingestion of vegetable, meat, and dairy products produced at RMA. Additionally, dermal contact with metals in soils was not evaluated for any receptor population due to negligible contaminant absorption through this exposure route.

3.1.3 Exposure Point Concentrations

The chemical concentration to which an individual could be exposed is known as the exposure point concentration. Exposure point concentrations used in the PPLV and risk equations were derived using the methods described in Appendix Section B.1 and are summarized below.

To characterize potential chronic (long-term risk, i.e., 7 to 70 years) human health risks at RMA, both site-specific risks and boring-by-boring risks were quantified. For the site-specific analysis, human health risks were estimated using representative contaminant concentrations calculated for each of the 178 sites quantitatively evaluated in the HHRC. In accordance with EPA guidance (EPA 1992a), the concentration term in the intake equations, C_{rep}, was calculated as the sample arithmetic mean, and is considered to represent the contaminant concentration that would be contacted at a site over time (i.e., the chronic exposure). In addition to C_{rep}, the 95th percentile upper and lower confidence intervals (UCL and LCL, respectively) of the site sample mean

concentration were also derived. Appendix Section B.1.4 details the methods used to calculate C_{rep}, including assumptions used in assigning values to data reported as below CRLs.

The limitation of the site-specific analysis described above is that site boundaries (shown in Figure 2.3-1) were defined on the basis of historical operations or, in some cases, defined arbitrarily (e.g., during initial sampling programs). Consequently, these sites may not represent appropriate averaging zones for potential future exposures. For example, if specific information were available regarding future land use at RMA, averaging zones would likely differ according to the receptor group evaluated (e.g., biological worker vs. industrial worker). However, in the absence of detailed information regarding the distribution of projected future land uses at RMA, appropriate averaging zones for potential human exposures cannot be determined at this time.

For the boring-by-boring analysis, potential risks were calculated using the maximum contaminant concentration at a given boring for a specific depth interval (C_{max}). However, since a person is not likely to be exposed solely to soil at one boring location for the entire exposure period (let alone at the specific depths where the contaminant maximum occurred), the results do not reflect average human exposures or risks. The results of the analysis are provided to offer insight into the contaminant variability at RMA and facilitate the identification of contaminant hot spots.

3.1.4 Exposure Parameters

Exposure parameters are combined with chemical-specific exposure point concentrations and toxicity data to characterize each of the five potential routes of human exposure to COCs at RMA. Some exposure parameters, such as body weight and frequency of exposure, are applicable to all exposure pathways. Other parameters, however, such as soil ingestion rate and molecular diffusivity, are used only for specific exposure routes. The probabilistic analysis developed for the IEA/RC, discussed in Sections 3.2.1 through 3.2.3, assumes chronic exposures (greater than 7 years). However, potential risks associated with shorter term exposures (i.e., acute exposures occurring on a single day, or subchronic exposures lasting more than 1 day but less

than 7 years) were calculated for the HHEA using deterministic methods (i.e., using fixed exposure parameters). Results of this analysis are discussed briefly in Section 3.2.4.

The exposure parameters used in this evaluation are fixed or probabilistic. Probabilistic parameters are characterized by a distribution of values, while the fixed parameters are represented by a single value. Probability distributions and the fixed numerical estimates were defined based on an extensive literature search and data review. Appendix Sections B.3.1 through B.3.10 provide a detailed description of the individual exposure parameters and the development of their specific distributions.

3.1.5 Toxicity Parameters

Toxicity criteria used to calculate PPLVs are fixed at established EPA values, consistent with EPA risk assessment guidance (1989a). Reference doses (RfDs) were used to estimate noncarcinogenic toxicity, while cancer slope factors (CSFs) were used to estimate cancer risks. In the PPLV equations, the RfDs and CSFs are embodied in the term "DT." Because RfDs represent doses at which no adverse noncancer health effects are expected, the RfD equals DT. However, because CSFs are based on the dose-response curve of a carcinogen and do not represent a "safe" dose, a 10^{-6} risk level is divided by the CSF. This quotient is referred to as the risk-specific dose (RSD), which is equivalent to DT for carcinogens. Appendix Section B.1.6 provides a review of the methods used in assigning EPA toxicity values to carcinogenic and noncarcinogenic COCs.

3.1.6 PPLV Calculations and Probabilistic Approach

Use of the PPLV method was initiated prior to the publication of the EPA Risk Assessment Guidance for Superfund (1989a). Although this method was not formally acknowledged in the most recent EPA guidance, it does incorporate many of the exposure and toxicity assessment methodologies specified in these guidelines. As noted previously, due to the magnitude of the EA at RMA and the extensive documentation supporting the HHRC, several elements documented within standard risk assessments are not reproduced in this report. This documentation is

customarily incorporated to provide reviewers with an understanding of the critical aspects of the site investigation and their bearing on the projection of health risks (see Exhibit 9-1 in EPA 1989a). The specific elements contained in EPA's Suggested Outline for a Baseline Risk Assessment Report, listed in Appendix Table B.1-1, are cross-referenced either to specific sections in the IEA/RC report or to sections in other published reports where such information can be found.

The PPLVs were computed based on a computational framework originally established by Rosenblatt et al. (1982), Dacre et al. (1980), Rosenblatt et al. (1986), and Small (1984). The methodology, adapted to RMA, enhances the work of Rosenblatt et al., and is consistent with EPA risk assessment guidance (1988, 1989a). The following paragraphs summarize the PPLV approach, which is described in detail in Appendix Section B.1.

PPLVs are defined as soil concentrations unlikely to pose adverse noncarcinogenic health effects (e.g., as indicated by a hazard index (HI) less than or equal to 1.0), or as soil concentrations unlikely to pose a cancer risk greater than a specified risk level (e.g., 10^{-4} or 10^{-6}). Probabilistic soil PPLVs, computed for each of five potentially exposed populations as a function of exposure parameters and toxicological parameters, are calculated using standard exposure pathway models that are generally consistent with those described in EPA risk assessment guidance (1989a). By setting the site contaminant intake—computed using a pathway exposure model—to an established health-based guideline (i.e., the critical toxicity value, or DT), a rearrangement of the exposure pathway models permits the computation of a soil concentration corresponding to the target HI or cancer risk value. These steps are expressed mathematically in equations (1) through (3):

Contaminant Intake Rate = Soil Intake or Contact Rate * Soil Concentration/BW (1)

Substituting the critical toxicity value, or DT, for contaminant intake rate and solving for soil concentration yields:

$$\textbf{Soil Concentration} = \textbf{DT} * \textbf{BW/Soil Intake or Contact Rate} \quad (2)$$

Defining the single pathway PPLV as this limiting soil concentration yields:

$$\textbf{SPPPLV} = \textbf{DT} * \textbf{BW / Soil Intake or Contact Rate} \quad (3)$$

where: SPPPLV = Single pathway preliminary pollutant limit value for soil (milligrams per kilogram [mg/kg])

DT = Critical toxicity value (i.e., allowable dose) that is without adverse effect to human health or that does not pose a cancer risk greater than a predetermined risk level (mg/kg-day)

BW = Body weight (kg)

Because exposure to contaminants may occur from a number of exposure routes, a cumulative PPLV is calculated over all of the single pathway PPLVs (SPPPLVs). For the soil exposure evaluations at RMA, there are five possible soil exposure SPPPLVs: ingestion, dermal contact, particulate inhalation, open space soil vapor inhalation, and enclosed space soil vapor inhalation. A cumulative probabilistic PPLV that incorporates all of these exposures is calculated using the formula recommended by Rosenblatt et al. (1982):

$$\textbf{PPLV} = \textbf{1/(1/SPPPLV}_{\textbf{ING}} \textbf{+ 1/SPPPLV}_{\textbf{DRM}} \textbf{+ 1/SPPPLV}_{\textbf{INH}} \textbf{+ 1/SPPPLV}_{\textbf{openspace}} \textbf{+ 1/SPPPLV}_{\textbf{enclosedspace}}\textbf{)} \quad (4)$$

In this equation, the PPLV represents a cumulative PPLV computed over all five applicable soil exposure pathways. The cumulative PPLV is lower than any of the SPPPLVs. Appendix Section B.1 details the direct and indirect SPPPLV equations, including the open and enclosed space soil vapor inhalation models.

3.1.6.1 Use of Quantitative Uncertainty Analysis

Current EPA guidance for conducting human health risk assessments (1989a, 1991) acknowledges the importance of considering uncertainty in risk assessments. Though generally approached in a qualitative fashion for the majority of risk assessments, uncertainty analysis can be conducted in a quantitative fashion by developing probabilistic distributions using available techniques such as first-order Taylor series approximation, Monte Carlo simulation, or Latin Hypercube sampling. Latin Hypercube sampling is a constrained Monte Carlo sampling technique, and was used in the exposure and risk evaluations for RMA.

Both the 5th and 50th percentile PPLVs were used to compute potential health risks and provide a perspective on how the risks may vary. The 5th percentile statistically defines the cumulative reasonable maximum exposure (RME) PPLV (i.e., there is 95 percent confidence that the cumulative PPLV will be protective at the specified risk level), and the 50th percentile represents the median PPLV estimate (i.e., there is 50 percent confidence that the cumulative PPLV will not exceed the specified risk level). Because risk is inversely proportional to the PPLV, a higher PPLV (e.g., representing the 50th percentile) would equate to lower estimated site risks, while a lower PPLV (e.g., that based on the 5th percentile) would result in higher estimated site risks. As discussed previously, this analysis focuses on results for the 5th percentile PPLV, which corresponds to a reasonable maximum exposure (and risk) evaluation.

3.1.7 Risk Evaluations for Carcinogenic and Noncarcinogenic Endpoints

Once PPLVs were calculated, they were then combined with exposure point concentrations to calculate carcinogenic risks and noncarcinogenic HIs. For carcinogens, cumulative risks (representing all exposure pathways and COCs) were compared to an acceptable risk range of 10^{-6} to 10^{-4}, (NCP 40 CFR 300). For carcinogens causing health effects in addition to cancer and for noncarcinogens, potential adverse health effects were identified where HI values exceeded 1.0, which is considered the safe, or benchmark, level. As stated by EPA (1991), where the cumulative site risk to an individual based on the RME for both current and future land-use

scenarios is less than 10^{-4}, and the noncarcinogenic hazard quotient (HQ) is less than 1.0, action generally is not warranted.

As discussed in Section 3.1.3, cancer risks and HIs were quantified for both the site-specific and boring-by-boring risk evaluations (Sections 3.2.2 and 3.2.3, respectively). To characterize potential exposures for subchronic and acute durations, risks were estimated using deterministic (i.e., nonprobabilistic) methods derived from the HHEA Addendum report (EBASCO 1992c). The acute and subchronic risks are summarized in this report in Section 3.2.4 and Appendix Section B.6.

Carcinogenic Risk

Carcinogenic risks were estimated using probabilistic PPLVs (defined above) in a manner analogous to that used for the estimation of chronic daily intakes in EPA (1989a). This methodology can be summarized in the following basic equation:

$$Risk_{site,i} = \frac{C_{s,i}}{PPLV_i} * RL \qquad (5)$$

where:

$Risk_{site,i}$ = Site risk for contaminant i

$C_{s,i}$ = Soil contaminant concentration of contaminant i (e.g., C_{rep} or C_{max})

RL = Reference cancer risk level specified for contaminant i (e.g., 10^{-6} or 10^{-4}) used in the calculation of DT (an input parameter for the PPLV equation)

$PPLV_i$ = Preliminary pollutant limit value for contaminant i at the specified cancer risk level (defined in equations (1) through (4))

The quotient of $C_{s,i}$ and $PPLV_i$ is defined as an exposure index (EI). As described in Appendix Section B.1., EIs were computed as the ratio of the site (or boring) concentration to either the direct cumulative PPLV, the indirect cumulative PPLV, or the sum of the cumulative direct and

indirect EIs. For boring-by-boring analyses, the risk ($risk_{boring,i}$) is calculated using boring-specific data.

Noncarcinogenic Risk

Noncarcinogenic risks were calculated based on the computation of HQ values consistent with EPA risk assessment guidance (EPA 1989a). The HQ for a contaminant is defined as follows:

$$HQ = \frac{C_{s,i}}{PPLV_i} \tag{6}$$

The potential for noncancer risk resulting from exposure to multiple contaminants is estimated by calculating the HI as follows:

$$HI_{site} = \sum HQ_i = \sum \frac{C_{s,i}}{PPLV_i} \tag{7}$$

where:

HI_{site} = Site hazard index

HQ_i = Hazard quotient for contaminant i

$C_{s,i}$ = Soil contaminant concentration of contaminant i (e.g., C_{rep})

For boring-by-boring analyses, the HI (HI_{boring}) is calculated using boring-specific data.

Interpretation of Cancer Risks and Hazard Indices

The context within which to judge potential risks estimated for each of the pathways/receptor populations evaluated in the IEA/RC has been established by the EPA for the federal Superfund program (NCP, 40 CFR 300). For carcinogens, the target risk range is a 10^{-6} to 10^{-4} cancer risk, where risk is the unitless probability of an individual developing cancer attributable to the

assumed exposure setting. A risk of 10^{-6} corresponds to a risk of one additional cancer (i.e., that in excess of the rate attributable to other causes) per 1 million individuals, and a 10^{-4} cancer risk corresponds to a risk of one additional cancer per 10,000 individuals. Recent EPA guidance directs that sites not exceeding a 10^{-4} cancer risk generally do not require further evaluation (1991). For noncarcinogens, where the HI exceeds unity (1.0), expressed in scientific notation as 1.0E+00, the assumed exposure may present a health hazard and therefore warrants further evaluation.

3.2 RESULTS AND INTERPRETATIONS

This section presents the results of the HHRC. The results focus on the biological worker, because the PPLVs that were calculated were lowest for this subpopulation, and thus would be expected to drive remediation. Appendix Section B.4 presents results for all five populations, as do the results from the HHRC computer program described in Appendix D.

3.2.1 Criteria for Exposure and Risk Evaluations

As discussed in Section 3.1.6, the cumulative PPLV serves as the basis for quantifying potential risks at RMA and reflects both direct (soil ingestion, dermal contact, and particulate inhalation) and indirect (open and enclosed space soil vapor inhalation) exposure pathways. Sections 3.2.1.1 and 3.2.1.2 describe the direct and indirect PPLVs, respectively.

3.2.1.1 Cumulative Direct PPLVs

Tables 3.2-1 and 3.2-2 list the cumulative direct soil PPLVs representing the 5th and 50th percentiles of the cumulative distribution function curve described in Appendix Section B.1. Comparison of these values indicates that 50th percentile PPLVs are generally 3 to 8 times higher (less than an order of magnitude) than the more conservative 5th percentile PPLVs. In accordance with EPA risk assessment guidance requiring the evaluation of RMEs, 5th percentile PPLVs were used as the basis for characterizing potential human health risks at RMA, and thus are the focus of the following discussion.

PPLVs were derived for each of the five potentially exposed populations/subpopulations evaluated in the risk characterization. As shown in Tables 3.2-1 and 3.2-2, the lowest (driver) PPLVs were generally derived for the biological worker. The only exceptions were certain volatile organic chemicals (benzene, carbon tetrachloride, chloroacetic acid, chlorobenzene, and toluene), whose PPLVs were lowest for the industrial worker. Appendix Tables B.4.1-1 through B.4.1-5 summarize the dominant exposure pathways contributing to the 5th percentile cumulative direct PPLVs. As shown in these tables, the majority of the direct PPLVs were derived based on a carcinogenic endpoint. Additionally, for most of the organic COCs, the cumulative direct PPLV is dominated by the dermal absorption pathway (i.e., the dermal absorption pathway accounts for the majority of the cumulative risk). The only exceptions are aldrin, dieldrin, DDE, endrin, and isodrin, for which soil ingestion is the dominant exposure pathway (biological worker only), and DCPD and HCCPD, for which the particulate inhalation pathway is the driver. For metals, soil ingestion and particulate inhalation are the dominant pathways; dermal uptake was not quantified for metals (see Section 3.1). Soil ingestion represents the driver pathway for arsenic, lead, and mercury, whereas particulate inhalation is dominant for cadmium and chromium. As shown in Appendix Tables B.4.4-1 through B.4.4-5, the driver pathway for individual chemicals varies depending on the receptor evaluated.

Tables 3.2-3, 3.2-4, and 3.2-5 list the number of site $C_{rep,mean}$ values exceeding the corresponding PPLV for Horizons 0 (0 to 1 ft), 1 (0 to 10 ft), and 2 (>10 ft to groundwater), respectively. For carcinogens, the number of exceedances is noted for both 10^{-6} and 10^{-4} risk levels. Appendix Section B.4.2 tables, which list the site-specific $C_{rep,mean}$ values estimated for each chemical of concern, provide supporting data. As shown in these tables, only five carcinogenic contaminants have C_{rep} estimates exceeding a 10^{-4} cancer risk PPLV: aldrin, dieldrin, arsenic, chlordane, and DBCP. For noncarcinogens, only chloroacetic acid and mercury have C_{rep} values exceeding the corresponding PPLV (assuming an HI of 1.0 as the target criterion).

It should be noted that the results summarized in Tables 3.2-3 through 3.2-5 are shown primarily to highlight those chemicals driving the site risks at RMA (discussed in greater detail in

Section 3.2.2.4) and to provide an overview of their prevalence and magnitude. These summaries do not necessarily reflect the distribution of individual contaminants, which can only be evaluated by examining results of the boring-by-boring analysis (Section 3.2.3), and so may mask localized exceedances (i.e., hot spots within a given site). The uncertainties associated with C_{rep} estimates are reflected in the lower confidence limit (LCL) and upper confidence limit (UCL) values, which are discussed in Section 3.2.2.6 and summarized in Appendix Section B.4.5 for selected chemicals.

3.2.1.2 Cumulative Indirect PPLVs

Cumulative indirect PPLVs reflect both open space (all receptors) and enclosed space (economic development option receptors only) soil vapor inhalation pathways. These values were calculated using the contaminant vapor flux from soil to air, which is governed by the configuration of the contaminated layer exhibited at each site (i.e., the vertical extent of COCs) and the surface area of the site (open space model only). Table 3.2-6 presents the range of cumulative indirect 5th percentile PPLVs determined for biological and industrial workers. Site-specific indirect PPLVs are listed along with corresponding C_{rep} estimates in Appendix Section B.4.2 chemical data tables.

As shown in these tables, cumulative indirect PPLVs vary depending on the receptor and the contaminant. For the biological worker, minimum and maximum values typically differ by four to five orders of magnitude. The widest ranges (spanning approximately six to seven orders of magnitude) are reported for aldrin, chlordane, and dieldrin. The ranges of indirect PPLVs derived for economic development receptors, however, are much smaller. With the exception of endrin, these ranges generally span less than one order of magnitude. The wide range in indirect PPLVs exhibited for the biological worker reflects the use of the Industrial Source Complex—Long Term (ISCLT) transport model used to estimate open space soil vapor inhalation exposures. The ISCLT model incorporated site-specific input that varied widely, including meteorological parameters, vapor flux estimates, and receptor placement. The narrower range in indirect PPLVs obtained for the industrial worker reflects the dominance of the enclosed space soil vapor inhalation pathway, which was not modeled using ISCLT methods.

3.2.2 Chronic Risk Evaluation: Site-Specific Results

Site risks were calculated based on estimated representative (C_{rep}) contaminant concentrations determined over all soil borings within each designated site boundary. As discussed in Section 3.2.1, cancer risks and noncancer HIs for all evaluations were calculated using 5th percentile PPLVs. Both total risks and incremental risks were evaluated for metals; incremental risk is defined as the total risk minus the risk attributable to concentrations at or below the indicator (assumed background) levels shown in Table 3.2-1. In evaluating total risks, risks were not quantified for those sites for which all borings had organic contaminant levels below CRLs. For the incremental risk evaluation, risks were not quantified for sites to which either of the following conditions applied: (1) all borings located at the site had organic contaminant levels below CRLs and/or had metals concentrations below indicator levels; or (2) all borings located at the site borings were analyzed for metals only and levels were below indicator levels.

Appendix Section B.4.3 (Tables 1 and 2) provide a summary of the sites evaluated in the HHRC *vis a vis* their location/functional groupings; Figures 2.3-1 and 2.3-2 show the RMA site designations and individual site locations, respectively. The information provided in Appendix Section B.4.3 is intended for use as a cross-reference for the more detailed results presented in Appendix Section B.4.4 tables, which present site-specific (total and incremental) cancer risks and HIs for all receptors and all applicable soil horizons. To facilitate identification of those sites exhibiting the highest risks, results are listed in order of descending incremental risks. The extent to which background levels of metals contribute to the total site risk is also noted in these tables.

3.2.2.1 Summary of Receptor-Specific Site Risks and Hazard Indices

Figure 3.2-1 shows the percentage of sites exceeding specified cancer risk reference levels (e.g., 10^{-4} and 10^{-6}) for each receptor based on site-specific (C_{rep}) total and incremental risk results. This figure shows results for Horizon 1 (0 to 10 ft) only since this soil depth interval reflects pathways common to all receptors (facilitating comparisons) and since this interval also reflects the trends exhibited for Horizon 0 (0 to 1 ft). The box plots in Figure 3.2-2 show the actual

distribution of receptor-specific risks, and thus better characterize the magnitude of exceedances reflected in the preceding bar charts (Figure 3.2-1). Figures 3.2-3 and 3.2-4 present HI results in a similar fashion, comparing the percentage of sites exceeding specified HI levels among the different receptors (Figure 3.2-3) as well as the distribution of site-specific HI results (Figure 3.2-4).

The results summarized in Figures 3.2-1 through 3.2-4 indicate the following:

- Among the open space land-use option receptors, the number of exceedances and the magnitude of estimated risks is greatest for the biological worker. Of the total site cancer risks calculated for this receptor, 6.7 percent (12 sites) exceed 10^{-4}, and 83.7 percent (149 sites) fall within the EPA target risk range of 10^{-6} to 10^{-4}, (NCP, 40 CFR 300). The differences in total and incremental risks, for the 10^{-6} to 10^{-4} cancer risk range in particular, reflect the influence of background concentrations of arsenic, cadmium, and chromium on the total risk. Similar trends are exhibited for noncarcinogenic endpoints (Figure 3.2-3). For the biological worker (the maximally exposed population), 13.4 percent (24) of sites have total HIs exceeding 1.0 (EPA's target HI criterion) (NCP, 40 CFR 300).

- Among the economic development land-use option receptors, the number of exceedances and the magnitude of estimated risks is greatest for the industrial worker. As shown in Figure 3.2-1, of the total site cancer risks, 9.0 percent (16 sites) exceed 10^{-4}, and 39.3 percent (70 sites) fall within the EPA target risk range (10^{-6} to 10^{-4}). For noncarcinogenic endpoints, 27.5 percent (49) of the sites evaluated have total HIs exceeding 1.0.

- The number of site exceedances and the magnitude of site risks for the industrial worker (economic development land-use option are comparable to, although slightly larger, than those determined for the biological worker (open space land-use scenario). This finding probably reflects the greater magnitude of indirect exposures assumed for the industrial worker, as well as inclusion of the enclosed space soil vapor inhalation pathway, which was not evaluated for the biological worker.

Given the findings discussed above, the following section focuses only on results obtained for those populations exhibiting the highest risks for a given land-use scenario at RMA: the biological worker (open space option) and the industrial worker (economic development option).

3.2.2.2 Summary of Horizon-Specific Results for Biological and Industrial Workers

Figures 3.2-5 and 3.2-6 summarize horizon-specific exceedances for cancer risk and HI endpoints, respectively. As shown in these figures, for both cancer risk and HI endpoints, Horizon 1 (0 to 10 ft) evaluations show the greatest number of site exceedances. Those exhibited at Horizon 0 (0 to 1 ft) are slightly lower, probably due to the fact that indirect soil vapor inhalation pathways were not evaluated for shallow soil depth intervals. Horizon 2 (>10 ft to groundwater) evaluations revealed far fewer site exceedances (relative to results for Horizons 0 and 1): no site exceedances of a 10^{-4} cancer risk level were identified for either the biological or industrial workers. Only 2.2 percent (4 sites) of Horizon 2 site cancer risks calculated for the industrial worker exceed 10^{-6}; similar trends are exhibited for HI endpoints.

Of note is that the number of exceedances shown for Horizon 0 is larger for the biological worker than for the industrial worker. This finding is expected, given that the cumulative direct PPLVs (summarized in Table 3.2-1) are generally lowest (and are thus drivers) for the biological worker.

Given the trends identified above and discussed in Section 3.2.2.1, the following sections focus on results obtained for the biological worker based on the 5th-percentile PPLV and on Horizon 1. Horizon 2 evaluations are also addressed based on results obtained for the industrial worker, but are summarized only briefly due to the relatively small number of site exceedances observed for this soil depth interval (>10 ft to groundwater) (Figure 3.2-5).

3.2.2.3 Distribution of Site Risks by Location, Biological Worker (Horizon 1)

The biological worker PPLVs are generally the lowest compared with the other receptor populations. Because remediation is expected to focus on the maximally exposed receptor group, the results in this section are provided for the biological worker only. Risk results for the other receptor populations are summarized in Appendix Section B.4 and can also be accessed through the HHRC computer program.

Figures 3.2-7 and 3.2-8 show site cancer risks and HIs estimated for the biological worker at Horizon 1 (0 to 10 ft). These figures illustrate that risks are highest for those sites located in the central portions of RMA, namely South Plants, Sewer Systems, Lime Basins, Former Basin F, Basin A, and the Complex Trenches located in Section 36. Figures 3.2-9 and 3.2-10 plot site-specific incremental cancer risks and HIs by location, providing more detailed information regarding the magnitude and distribution of estimated risks. The location groupings used in these figures reflect the categories summarized in Appendix A and Appendix B, Table B.4.3-1, including the following:

- South Plants
- Lime Basins
- Basins (A, B, C, D, E, and F)
- Disposal Trenches
- Buried Sediments/Ditches
- Burial Trenches
- Sanitary Landfills
- Sewer Systems
- Agent Storage Areas
- Section 36: Balance of Areas (sites C1B, C2A, and C4)
- Ditches/Drainage Areas
- Munitions Testing
- Balance of Areas

As shown in Figure 2.3-1, some of the groupings listed above reflect a functional component rather than a spatial component (e.g., ditches/drainage areas). Despite the lack of spatial correlation, these groupings were used to characterize HHRC results because potential exposures are expected to be similar in these areas. Additionally, they correspond (in general) to the medium groups currently being considered in the FS.

The results shown in Figures 3.2-7 and 3.2-9 for the biological worker at Horizon 1 indicate that exceedances of 10^{-4} total cancer risk levels are limited to the following areas:

- Chemical Sewers (site SP10)
- Lime Basins (sites SP1E, or Buried M-1 Pits, and NC1B or Section 36 Lime Basins)

- South Plants, with sites SP3A (ditch), SP1A (Central Processing Area), and SP3B (concrete salt storage pad) exhibiting the highest risks
- Former Basin F (site NC3)
- Sanitary/Process Water Sewers (site NC8A)
- Basin A (site NC1A)
- Shell Trenches (site C1A)

The results for HIs shown in Figures 3.2-8 and 3.2-10 show similar trends in that exceedances of 1.0 occur in the following areas:

- All sites specified above for cancer risk exceedances
- South Plants sites SP2A and SP2B (South Tank Farm), SP4A (ditch), SP3C, SP1G, and SP12B (Balance of Areas)
- Sanitary Landfills (site W5D)
- Section 36 sites C1B (Balance of Areas) and C1C (Complex Trenches)
- Sites NP4 (Sand Creek Lateral) and NP5 (North Plants Agent Storage)
- Sites NC1E (located in Basin A) and S2B (Sand Creek Lateral)

Additionally, the general trends shown in Figures 3.2-7 through 3.2-10 for the biological worker are similar to those identified for the industrial worker and, essentially, all other receptors.

3.2.2.4 Chemicals Contributing Most to Estimated Risks

Figures 3.2-11 and 3.2-12 show the chemicals contributing most to total estimated risks and HIs for the biological worker at Horizon 1 (0 to 10 ft). The sites shown in these figures are the top 20, ranked based on total cancer risk and HI (respectively). For cancer risk endpoints, DBCP, aldrin, arsenic, and dieldrin are the major contributors to the total estimated risks. It should be noted, however, that the apparent major contribution of DBCP shown in Figures 3.2-11 and 3.2-

12 stems in large part from the elevated observation at the Chemical Sewers, site SP10, where the DBCP cancer risk was 7.6 x 10^{-3}, and the HI was 1.6 x 10^{-2}. The influence of arsenic on total cancer risks for site SP1E (Buried M-1 Pits) and sites NP5 and NP6 (agent storage sites) is expected, given that arsenic is a component of the agent compounds that were stored or disposed in these areas. For noncancer risk endpoints (Figure 3.2-12), DBCP, aldrin, and arsenic account for the majority of the total estimated HIs.

Figures 3.2-13 and 3.2-14 show the chemicals contributing most to total indirect risks and HIs at selected sites for the industrial worker, Horizon 2 (>10 ft to groundwater) evaluation. No cancer risk estimates exceed 10^{-4} for this receptor at Horizon 2. However, for those sites with Horizon 2 cancer risks exceeding 10^{-6}, chloroform and benzene are the major contributors to the total estimated risks. For those sites with HIs exceeding 1.0, DBCP, DCPD and HCCPD account for the majority of the total estimated HIs.

The trends shown in Figures 3.2-11 through 3.2-14 generally reflect those exhibited for other sites with higher cancer risks and HIs, but may not adequately reflect the chemicals contributing to total risks at remaining sites (e.g., those not exceeding target risk criteria). Detailed data regarding the contribution of individual chemicals to total site risks and HIs are provided in the additivity reports, which can be accessed using the HHRC software provided in Appendix D.

Volumes II and III of the HHEA report (EBASCO 1990) provide toxicity profiles for the driver COCs, as well as all other COCs, and Appendix Section B.1 provides a summary of the toxicity criteria used in the HHRC. The weight-of-evidence classifications for the driver carcinogenic COCs identified above are as follows: aldrin (Group B2), DBCP (Group B2), arsenic (Group A), dieldrin (Group B2), and chlordane (Group B2). Appendix Section B.1 further defines these classifications. Appendix Section E.6, which summarizes the potential carcinogenic and systemic effects projected for each driver COC, discusses the uncertainties associated with the toxicity estimates. Section 5.5.1 also summarizes these uncertainties.

3.2.2.5 Dominant Exposure Pathways and the Driver Parameters

Cancer and noncancer risks estimated for the biological worker and other open space land-use option receptors were attributed primarily to the direct soil exposure pathways (soil ingestion and dermal absorption; see Appendix Tables B.4.1-1 through B.4.1-5). In contrast to trends identified for the biological worker, the soil vapor inhalation pathway was the dominant exposure pathway for the driver COCs identified for industrial (and commercial) workers.

A sensitivity analysis was conducted for the HHRC to rank the influence of several distributed input parameters on the variability of the cumulative direct PPLVs for aldrin, dieldrin, DBCP, arsenic, and chlordane. These chemicals were chosen because of their strong contributions to overall risk at RMA (Section 3.2.2.4). The sensitivity analysis considered both biological and industrial worker receptors (representing open space and economic development land-use options respectively) for both cancer risk and HI endpoints. As outlined in Appendix Section B.5, standardized regression coefficients (SRCs) and full-model partial correlation coefficients (PCCs) were computed for each input parameter to provide two separate measures of a parameter's influence on the variability of the direct exposure pathway PPLVs.

The eight distributed input parameters for direct PPLV calculations are as follows:

TE	Exposure duration (years) (for carcinogens only)
DW	Annual frequency of exposure (days/year)
TM	Daily exposure rate (hours/day)
RAF_{dermal}	Relative absorption factor for dermal absorption (unitless)
$RAF_{ingestion}$	Relative absorption factor for ingestion (unitless)
CSS	Dust loading factor ($\mu g/m^3$)
SC	Skin soil covering (mg/cm^3)
SI	Soil ingestion (mg/day)

The results of this analysis indicate that variability in exposure duration is consistently the dominant contributor to variability in the direct carcinogenic PPLV, followed by soil ingestion. Soil ingestion is also a dominant contributor to variability in the direct noncarcinogenic PPLV. Other influential parameters include RAF_{dermal}, $RAF_{ingestion}$, and soil covering. These results are described in greater detail in Appendix Section B.5.

3.2.2.6 Uncertainties in C_{rep} Estimates

As discussed above, the HHRC focused on C_{rep} values, i.e., the 5th percentile PPLVs. To illustrate the uncertainties that the $C_{rep,mean}$ estimates (calculated based on the sample mean) contribute to the risk results, Figure 3.2-15 plots total cancer risks calculated for the biological worker (Horizon 1, 0 to 10 ft) using $C_{rep,\ mean}$, $C_{rep,95th,upper}$, and $C_{rep,95th,lower}$ contaminant concentrations. This figure shows data for those sites for which C_{rep} estimates are most uncertain (i.e., those instances in which UCL and LCL values differ by greater than two orders of magnitude). Figure 3.2-15 also illustrates the conservatism inherent in use of $C_{rep,mean}$: C_{rep} values often approach the UCL. More detailed information is provided in Appendix Section B.4.5, which lists the site-specific C_{rep}, LCL, and UCL values estimated for total cancer risks (biological worker, Horizon 1) as well as those derived for the driver chemicals (aldrin, dieldrin, DBCP, and arsenic).

3.2.3 Chronic Risk Evaluation: Boring-by-Boring Results

The site definitions used as the basis for the site-specific risk estimation discussed in Section 3.2.2 were not originally established with land-use and exposure considerations in mind. In addition, site boundaries, which were based on historical knowledge of known or potential contamination, do not reflect current knowledge of contamination. In the absence of meaningfully defined exposure areas, a boring-by-boring analysis was undertaken to supplement the site-specific results. This type of evaluation is considered to be very conservative (i.e., worst case) because it assumes that cumulative chronic exposures would occur at any individual boring location (i.e., average exposure over the exposure period was not considered). Additional conservatism stems from the assumption that an individual would be exposed to the maximum contaminant concentration detected in the specified depth interval (e.g., 0 to 10 ft).

Risks for the boring-by-boring analysis were characterized using the following sampling data:

- Surficial soil results (samples collected from a 0- to 2-inch soil-depth interval in areas outside of designated sites)

- Boring-by-boring results (maximum contaminant concentrations detected in each soil-depth interval for individual borings located within designated sites)

The following analysis is limited to a discussion of boring-by-boring results for the biological worker at Horizon 1 (0 to 10 ft) for three reasons: (1) cumulative direct PPLVs are generally lowest (and are thus drivers) for the biological worker receptor, (2) similar spatial trends were observed for risks estimated for all receptors (given that all receptor evaluations used the same chemical data), and (3) indirect exposure risks cannot be estimated on a boring-by-boring basis since these pathways require spatial averaging of exposures, which cannot be achieved for a single boring. Appendix Section B.4.7 details the results of the boring-by-boring analyses, which is briefly summarized below. The tables in this appendix present site-specific cancer risk and HI results for the biological worker only (for the reasons described above), and only list data for those site borings exceeding 10^{-4} cancer risk levels (or 10^{-6} cancer risk levels for surficial soils) or an HI of 1.0.

Figure 3.2-16 shows the incremental cancer risks estimated for the biological worker using surficial soil (0 to 2 inches) results. This map indicates only four surficial soil locations with incremental cancer risks exceeding 10^{-4}. Two occur just east of Basin F, one occurs near the northern boundary of Basin C, and one occurs in the southern portion of Section 36. Similar trends are apparent for HIs; of the 493 non-zero observations, only three surficial soil locations have incremental HIs exceeding 1.0 (see Appendix Section B.4.7 tables). These results are not meaningful when examined independently due to the low density of surficial soil samples (Figure 3.2-16) relative to that of soil borings (Figure 3.2-17). (In general, the grid spacing for surficial soils was approximately 1,000 ft.) However, the surficial soil results do supplement the subsurface boring evaluation discussed below, and may be more relevant to the evaluation of direct contact exposure risks for open space land-use option receptors than corresponding results for deeper soil intervals (in particular, the recreational and regulated/casual visitor subpopulations).

Figure 3.2-17 shows the cancer risks estimated for the biological worker at Horizon 1 (0 to 10 ft) borings. The trends shown in this map basically parallel those described for the site analysis presented in Section 3.2.2 in that exceedances of a 10^{-4} cancer risk level at individual borings are generally limited to the following areas located in the central portions of RMA: South Plants, the Lime Basins, Basins A and C, Former Basin F, Buried Sediments/Ditches, and the Sand Creek Lateral. Isolated exceedances of a 10^{-4} cancer risk also occur at borings located in North Plants agent storage areas and the sanitary landfill near the Rail Classification/Maintenance Yard (located in the western portion of RMA). The boring-specific HI results shown in Figure 3.2-18 for noncarcinogenic risk endpoints exhibit similar trends.

As discussed above, the boring-by-boring results shown in Figures 3.2-16 through 3.2-18 should be interpreted with caution because they do not incorporate a realistic spatial or temporal averaging component (i.e., they do not represent chronic exposures). However, these maps do provide more detailed information reflecting the variability of risks in certain areas, and also highlight the number of site borings showing risks or HIs less than (as well as exceeding) reference risk levels.

3.2.4 Summary of Acute and Subchronic PPLVs Calculated for the HHEA

In the probabilistic evaluation, PPLVs were calculated to be protective of chronic (long-term) exposures. However, it is possible that exposures to COCs at RMA could be short term, such as exposures occurring only on a single day (acute), or exposures lasting more than 1 day but less than 7 years (subchronic). This section presents the cumulative direct acute and subchronic PPLVs that are protective of exposure via three pathways, soil ingestion, particulate inhalation, and dermal contact with soil. These PPLVs are the same as those originally calculated for the HHEA Addendum (EBASCO 1992c), with two exceptions. PPLVs for aldrin and dieldrin were recalculated for the IEA/RC to reflect updated toxicity criteria and revisions of the dermal relative absorption factor (all receptor scenarios) and soil covering factor (visitor populations only).

The potentially exposed populations evaluated in the HHEA Addendum are the same as those evaluated in the IEA/RC, except that the biological worker is included in the industrial worker population and the analysis of visitor populations addresses only child receptors. This approach differs from the chronic risk evaluation developed for the IEA/RC, for which biological worker and industrial worker receptors were evaluated independently and visitor populations include both adults and children. (In addition, the exposure assumptions used in the acute/subchronic analyses are deterministic RME estimates, whereas those used in the chronic analyses were probabilistic.)

The HHEA Addendum evaluated two exposure concentration methods: the MLE and the RME. In accordance with EPA guidance, the RME analysis was developed to represent a reasonable upperbound estimate of acute/subchronic hazards, and thus is the focus of the following discussion. Results of the MLE evaluation are provided in the HHEA Addendum.

Tables 3.2-7 and 3.2-8 list the cumulative deterministic RME PPLVs developed for acute and subchronic exposures, respectively. The exposure parameters used to calculate these values are summarized in Appendix Tables B.6-1 and B.6-2. Appendix Table B.6-3 lists the toxicity estimates used to compute acute and subchronic PPLVs. This table reflects an update of the acute/subchronic RfD for aldrin and dieldrin, 1×10^{-4} mg/kg-day, which was specifically developed by EPA's Office of Research and Development (December 1992). This criterion supersedes the (5×10^{-5} mg/kg-day) subchronic RfD used in the HHEA Addendum. Appendix Figure B.6-1 presents a map of soil boring-specific HQs for aldrin/dieldrin reflecting the revised criteria. HQs shown in this map correspond to the driver receptor scenario (i.e., the scenario for which PPLVs were lowest—recreational visitor, acute exposures).

As shown in Tables 3.2-7 and 3.2-8, the lowest (driver) acute and subchronic PPLVs were derived for regulated/casual and recreational visitors. The only exception is chromium, for which the biological/industrial worker is the dominant receptor in the subchronic evaluation. The reason that the acute/subchronic PPLVs derived for the two visitor populations are identical is that the assumptions used to estimate exposures for these two populations were generally the same (see

Appendix Tables B.6-1 and B.6-2). Exposure assumptions differed only for the inhalation pathway, which was not a major contributor to PPLV and HI calculations.

In general, and in particular for the biological and industrial worker populations, the acute and subchronic PPLVs shown in Tables 3.2-7 and 3.2-8 are higher than the corresponding chronic noncarcinogenic 5th percentile PPLVs (see Appendix Tables B.4.1-1 through B.4.1-5). This finding is expected since the body can generally tolerate a higher contaminant dose over a short (e.g., acute) duration than over a long (chronic) duration for a given dose rate. However, for the recreational and regulated/casual visitor exposure settings, acute/subchronic PPLVs for some chemicals are lower than corresponding chronic noncarcinogenic 5th percentile PPLVs.

Table 3.2-9 summarizes the acute (deterministic), subchronic (deterministic), and chronic (probabilistic) noncarcinogenic PPLVs calculated for visitor populations. Two factors should be considered when evaluating these results and, in particular, when comparing acute/subchronic deterministic PPLVs with corresponding chronic probabilistic PPLVs. First, the exposure assumptions used in the acute and subchronic evaluations are fixed (RME) estimates, whereas the range of values used in the chronic evaluations were probabilistic. For some parameters (e.g., oral and dermal absorption factors), the assumptions used in the acute/subchronic analysis are different from those used in the chronic risk evaluation. Second, the applicability of toxicity criteria may influence the acute/subchronic and chronic PPLV comparison (e.g., the use of RfDs developed from long-term (i.e., chronic) toxicity studies to evaluate potential acute effects). These two factors, the differences in exposure assumptions and the applicability of toxicity criteria, are also discussed in Appendix Section B.6.

3.3 QUALITATIVE RISK ASSESSMENT

3.3.1 Introduction

3.3.1.1 Objectives

The qualitative risk assessment was developed to identify areas of concern that could not be quantitatively addressed in the IEA/RC due to lack of sampling or the nature of sampling during the RI. Specific objectives of this qualitative evaluation are the following:

- Evaluate FS no action sites to identify any potential qualitative risk not considered in the determination of the no action designation
- Document qualitative risk for sites included in the current FS process
- Evaluate current FS sites to ensure all potential risk areas are included in the remediation areas

Qualitative assessment based on these objectives is used to recommend inclusion of potential risk sites in the FS process.

3.3.1.2 Methodology

The qualitative risk assessment was conducted by reviewing 227 contamination assessment reports (CARs), study area reports (SARs), data presentation reports, and media reports with respect to areas sampled; chemical results; historical operations; and physical anomalies. These reports were completed during the RI portion of the RI/FS. As each report was reviewed, a summary form was completed to document the information for the site. Areas of concern that are included in the qualitative risk assessment summary include areas with potential presence of UXO or agent, drum disposal sites, underground storage tanks (USTs), past or present structures, spill sites, tentatively identified compounds/unknowns, and other chemicals not quantitatively addressed in the risk assessment, and any physically anomalous occurrences that could lead to a potential risk. The summary information was entered into an electronic database for use in storing, sorting, and searching for particular information. Each summary point was evaluated to determine potential risk and to support or recommend inclusion of the site in the FS.

3.3.2 Potential Risks from Agent/Unexploded Ordnance

3.3.2.1 Potential Agent Presence

As reported in the CARs, potential presence of agent or agent-contaminated materials is indicated through historical records or the detection of agent breakdown products during RI/FS sampling. Appendix Tables B.7-1 and B.7-2 present information on the potential for the presence of agent in each site reviewed. As part of the RI, an extensive review of all CARs, SARs, database information, and individual interviews was conducted to determine which sites had potential agent presence (EBASCO 1992c). As a result, 23 SAR sites (Figure 3.2-19) are currently identified in the FS process as areas with potential agent presence, and treatment or containment alternatives are currently being evaluated for possible implementation (EBASCO 1993).

3.3.2.2 Potential Presence of Unexploded Ordnance

The potential presence of UXO is indicated in the CARs through historical records or from physical observation during RI/FS sampling. UXO discovered during the geophysical portions of sampling efforts were removed by the Army for future detonation. Appendix Tables B.7-1 and B.7-2 present information regarding the potential for UXO presence at each site. Fifteen sites identified as having potential UXO presence are currently being considered in the FS as potential UXO presence areas, and treatment alternatives are currently being evaluated for possible implementation (EBASCO 1993). These sites are primarily former munitions testing and disposal areas. CAR sites within Section 6 identified as former munitions storage areas are excluded from the FS Munitions Testing Medium Group based on documentation in the report that UXO was removed. CAR site 35-6 (NCSA-9m, possible munitions test area) was used as a firing site for munitions testing. No evidence of existing UXO was discovered at this site during the RI.

3.3.3 Potential Risks Associated with Chemicals not Evaluated as COCs in the IEA/RC

COCs were selected based on the methodology presented in the HHEA report (EBASCO 1990). On a chemical-by-chemical basis, maximum contaminant concentrations detected in soils on a site-by-site, RMA-wide basis were compared to contaminant-specific PPLVs for each potentially exposed population. If the resulting value exceeded 0.1, the chemical was designated "priority

1" and selected as a COC. If the resulting value for a chemical did not exceed 0.1, the chemical was designated as "priority 2" and not considered a COC. Selected COCs were carried into the IEA/RC process if they exceeded the PPLVs for the maximally exposed population.

3.3.4 Potential Risks Associated with Factors not Quantitatively Evaluated

3.3.4.1 Physical Anomalies

The presence of certain physical anomalies—drums, USTs, and structures—presents a potential risk that cannot be quantified. Each site was evaluated based on the potential for past or present drum disposal or storage, and the presence or past presence of USTs. The presence of drums or USTs represents a potential risk from the possibility of leaks or spills of the contents, so all sites identified as containing drums or USTs are currently FS action sites. Appendix Tables B.7-1 and B.7-2 list the number of drums and USTs found at each site. More detailed information concerning each occurrence can be found in the individual CARs.

Sites were also evaluated for the presence of structures, past or present. Structures include all buildings, storage sheds, pads, aboveground tanks, and towers located within each site. Structures present a potential risk since soils beneath structures were not included in RI/FS sampling and therefore not included in the quantitative assessment of soil contamination at a site. Risk from an existing structure cannot be quantified due to limited sampling and a lack of accepted standards for interpreting sampling data. All structures are being evaluated for remediation in the FS, and soil sampling is planned to investigate possible contamination in soils beneath structures with a history of agent production or storage. Appendix Tables B.7-1 and B.7-2 list the number of structures identified at each site. More detailed information concerning the location and use of each structure can be found in the individual CARs.

3.3.4.2 Physical Site Types

In addition to physical anomalies, certain site types pose a potential risk due to the nature of the site. Site types identified in this category include landfills, trenches, burn pits, and spill areas. These sites were identified based on historical information or visual evidence indicating activity

at the site. There are 34 SAR sites (from 22 CARs) that have potential risk based on site type, most of which are currently being considered as action sites in the FS. Ten sites located in the western portion of RMA, mainly in the Motor Pool/Railyard Area, are identified as isolated detections and are considered no action sites. In addition, a portion of site ESA-2a (pits 1, 2, and 3) is considered as a no action site. Analytical data from samples taken in these pits revealed metals concentrations within indicator levels. Phase I sampling produced three samples from one boring with benzene concentrations less than 1 part per million (ppm). However, Phase II sampling did not encounter any organic compounds in the same area.

3.3.5 Basin F Wastepile

Potential risks associated with the Basin F Wastepile were not quantified because of the difficulty in determining a meaningful exposure point concentration. It is known that materials with concentrations that would exceed 10^{-3} carcinogenic risk or an HI of 1,000 are in the Basin F Wastepile; the quantities and locations of these materials are not known. Therefore, given the difficulty in determining exposure point concentrations, the Basin F Wastepile is referred to the FS for consideration in final remediation. Risks identified for the Basin F Wastepile on Figures 3.2-17 and 3.2-18 are based on a qualitative assessment of samples collected from the original wastes.

3.3.6 Conclusions of the Qualitative Risk Assessment

The qualitative assessment identified potential areas of agent and UXO presence, as well as other areas at RMA which could not be quantitatively addressed in the HHRC due to lack of sampling. This evaluation did not identify any sites (i.e., those sites with no action designations) indicating potential risks that are not currently being addressed in the FS process. References to the no-action sites are only intended to facilitate review of the risk assessment and to provide a link to the FS where risk management decisions are made.

3.4 SUMMARY OF THE HUMAN HEALTH RISK CHARACTERIZATION

3.4.1 Summary of the Quantitative Chronic Risk Evaluation

3.4.1.1 Site-Specific Evaluation

Site-specific cancer risks and HIs estimated for the HHRC were highest for the Horizon 1 (0 to 10 ft) evaluation of biological worker (open space option) and industrial worker (economic development land-use option) receptors. Given these findings, and the fact that the biological worker exposure setting is most reflective of anticipated future land uses at RMA, the following summary is based on results obtained for the biological worker, Horizon 1 evaluation. These results indicate that potential cancer risks are highest in the following areas, which are generally located in the central portions of RMA:

- Chemical Sewers (site SP10)
- Lime Basins with sites SP1E (Buried M-1 Pits) and NC1B (Section 36 Lime Basins)
- South Plants, with sites SP3A (ditch), SP1A (Central Processing Area), and SP3B (concrete salt storage pad) exhibiting the highest risks
- Former Basin F (site NC3)
- Sanitary/Process Water Sewers (site NC8A)
- Basin A (NC1A)
- Shell Trenches (site C1A)

Exceedances of 10^{-4} cancer risk levels are limited to the sites/areas listed above. The results for noncarcinogenic endpoints (HIs) exhibit similar trends; however, more sites exceed an HI of 1.0 than those identified above (e.g., the sanitary landfill and additional sites in South Plants).

3.4.1.2 Boring-by-Boring Evaluation

The findings of the boring-specific evaluation basically parallel those described for the site analysis summarized above in that exceedances of a 10^{-4} cancer risk level or an HI of 1.0 at individual borings are generally limited to the following areas located in the central portions of

RMA: South Plants, Sewer Systems, Lime Basins, Former Basin F, Basin A, and the Complex Trenches located in Section 36. Isolated exceedances of a 10^{-4} cancer risk were also identified at borings located in Basin C, Sand Creek Lateral, the North Plants Agent Storage Areas, and the sanitary landfill near the Rail Classification/Maintenance Yard (located in the western portion of RMA). The boring-specific HI results exhibit similar trends.

The boring-specific analysis should be interpreted with caution because it does not incorporate a realistic spatial or temporal averaging component (i.e., they do not represent chronic long-term exposures). However, the maps supporting the evaluation do provide more detailed information reflecting the variability of risks in certain areas and also highlight the number of site borings showing risks or HIs less than, or greater than, reference risk levels.

3.4.1.3 Driver Chemicals and Exposure Parameters

For all receptors evaluated in the HHRC, the major contaminants contributing to potential cancer risks were aldrin, DBCP, arsenic, and dieldrin. For noncancer risk endpoints, DBCP, aldrin, and arsenic account for the majority of the total estimated HIs.

A sensitivity analysis was conducted for the HHRC to rank the influence of several distributed input parameters on the variability of the cumulative direct PPLVs for aldrin, dieldrin, DBCP, arsenic, and chlordane. These chemicals were chosen because of their strong contributions to estimated risks. The analysis evaluated both biological and industrial worker receptors (representing open space and economic development land-use options, respectively) for both cancer risk and hazard index endpoints. The results indicate the following: (1) that the variability in exposure duration is consistently the most influential contributor to variability in the direct carcinogenic PPLV, and (2) that the variation in the soil ingestion rate, the relative oral and dermal absorption factors, and skin soil covering is an influential contributor to variability in the direct PPLVs for both biological worker and industrial worker receptors.

3.4.2 Summary of the Acute and Subchronic Risk Evaluation Conducted for the HHEA

The chronic risk evaluation summarized above was the focus of the HHRC. However, it is possible that exposures to COCs at RMA could be short term, such as exposures occurring only on a single day (acute), or exposures lasting more than 1 day but less than 7 years (subchronic). Cumulative direct PPLVs for acute and subchronic exposures were calculated as part of the HHEA Addendum (EBASCO 1992c). The results of the acute/subchronic evaluation for the RME method indicated that the lowest (driver) acute and subchronic PPLVs were derived for regulated/casual and recreational visitor receptors. The only exception is chromium, for which the biological/industrial worker is the dominant receptor in the subchronic evaluation.

Two factors should be considered when evaluating the results of the acute/subchronic analysis and, in particular, when comparing acute/subchronic deterministic PPLVs with corresponding chronic probabilistic PPLVs. First, for some parameters (e.g., oral and dermal absorption factors), the exposure assumptions used in the deterministic (fixed) acute/subchronic evaluation are different from those used in the probabilistic chronic analysis. Second, the applicability of toxicity criteria may influence the acute/subchronic and chronic PPLV comparison (e.g., the use of RfDs developed from long-term (i.e., chronic) toxicity studies to evaluate potential acute effects).

3.4.3 Summary of the Qualitative Risk Assessment

The qualitative assessment identified both areas of agent and UXO presence as well as other areas at RMA that could not be quantitatively addressed in the HHRC due to lack of sampling. This evaluation did not identify any sites (i.e, those sites with no action designations) indicating potential risks that are not currently being addressed in the FS process.

Table 3.1-1 Soil Horizons and Exposure Pathways Evaluated for the Human Health Risk Characterization

Soil Horizon	Depth Interval	Open Space Option Receptor		Economic Development Option Receptor	
		Biological Worker	Local Neighborhood Regulated/Casual and Recreational Visitor	Industrial Worker	Commercial Worker
Surficial Soil	0 - 2 inches[1]	Dir	Dir	Dir	Dir
Horizon 0	0 - 1 feet[2]	Dir	Dir	Dir	Dir
Horizon 1	0 - 10 feet[2]	Dir, Ind (Open Space)	Dir, Ind (Open Space)	Dir, Ind (Open and Enc. Space)	Dir, Ind (Enc. Space)
Horizon 2	>10 feet - GW[2]	Ind (Open Space)	Not Evaluated	Ind (Open and Enc. Space)	Ind (Enc. Space)

1 Risks for this depth horizon were calculated on a boring-by-boring basis using results of surficial soil samples collected in areas peripheral to designated sites. The surficial soil interval (0-2") is not a subset of Horizon 0 (0-1').

2 Cumulative risks for these soil horizons were calculated on a site-specific basis (representing both direct and indirect pathway exposures), as well as a boring-by-boring evaluation (representing direct exposure pathways only).

Dir Denotes direct soil exposure pathway evaluation (soil ingestion, dermal contact, and particulate inhalation). Dermal contact with metals in soils was not evaluated for any receptors due to negligible contaminant absorption from this exposure route.

Ind Denotes indirect vapor inhalation pathway evaluation for open space and/or enclosed space (e.g., enclosed basement structures). Both open and enclosed space soil vapor inhalation exposures were not considered to be significant for shallower depth intervals due to volatilization loss, and therefore were not evaluated for surficial soils and Horizon 0.

GW Groundwater

Table 3.2-1 Summary of Cumulative Direct Soil PPLVs for the 5th Percentile [1,2]

Chemical	Receptor-Specific Soil PPLVs (Units: mg/kg)				
	Open Space Populations			Economic Development Populations	
	Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker
Aldrin	**7.16E-01**	1.16E+01	3.29E+00	3.02E+00	4.71E+00
Benzene	1.18E+01	5.76E+01	1.30E+01	**1.04E+01**	2.26E+02
Carbon Tetrachloride	2.51E+00	1.32E+01	2.69E+00	**2.33E+00**	5.14E+01
Chlordane	**3.72E+00**	5.39E+01	1.09E+01	7.58E+00	2.66E+01
Chloroacetic Acid*	1.01E+02	8.13E+02	2.34E+02	**7.71E+01**	1.88E+03
Chlorobenzene*	9.66E+02	6.95E+03	2.55E+03	**8.45E+02**	1.68E+04
Chloroform	**4.82E+01**	3.23E+02	8.91E+01	4.84E+01	1.11E+03
DDE	**1.25E+01**	1.77E+02	3.05E+01	1.87E+01	1.26E+02
DDT	**1.35E+01**	1.51E+02	3.60E+01	3.61E+01	9.58E+01
DBCP	**2.01E-01**	1.17E+00	2.52E-01	2.36E-01	4.51E+00
1,2-Dichloroethane	**3.23E+00**	1.74E+01	3.75E+00	3.39E+00	7.07E+01
1,1-Dichloroethylene	**5.16E-01**	2.82E+00	7.33E-01	5.21E-01	1.02E+01
DCPD*	**3.69E+03**	6.11E+04	2.91E+04	6.65E+03	5.83E+04
Dieldrin	**4.14E-01**	6.45E+00	1.96E+00	1.40E+00	2.54E+00
Endrin*	**2.32E+02**	2.99E+03	8.65E+02	3.18E+02	1.12E+03
HCCPD*	**1.06E+03**	1.47E+04	6.16E+03	1.78E+03	1.67E+04
Isodrin*	**5.24E+01**	6.43E+02	2.15E+02	7.39E+01	2.51E+02
Methylene Chloride	**3.53E+01**	2.06E+02	4.58E+01	4.43E+01	7.78E+02
1,1,2,2-Tetrachloroethane	**1.45E+00**	1.94E+00	9.61E+00	1.49E+00	3.31E+01
Tetrachloroethylene	**5.43E+00**	3.57E+01	6.26E+00	5.87E+00	1.30E+02
Toluene*	9.46E+03	6.48E+04	2.11E+04	**7.22E+03**	1.38E+05
Trichloroethylene	**2.84E+01**	1.78E+02	3.98E+01	2.90E+01	6.27E+02
Metals (Indicator Level [3])					
Arsenic (IL = 10 ppm, >driving PPLV)	**4.17E+00**	7.91E+01	3.68E+01	2.60E+01	2.60E+01
Cadmium (IL = 2.0 ppm)	**5.01E+01**	8.55E+02	2.17E+02	2.12E+02	1.87E+03
Chromium (IL = 40 ppm, >driving PPLV)	**7.52E+00**	1.29E+02	3.28E+01	3.23E+01	3.26E+02
Lead* (IL = 40 ppm)	**2.17E+03**	4.77E+04	2.65E+04	4.46E+03	7.06E+03
Mercury* (IL = 0.1 ppm)	**5.74E+02**	9.85E+03	5.49E+03	1.24E+03	1.35E+03

Note:

Bolded values indicate that PPLV for corresponding receptor population is driving for that chemical.

* Denotes a noncarcinogen. No asterisk denotes PPLV based on carcinogenic slope factors for both oral and inhalation pathways.

[1] Cumulative direct PPLVs represent a cancer risk level of 10^{-6} for carcinogens; the PPLV at a 10^{-4} cancer risk is 100 times higher than the values shown in this table.

[2] Summaries of dominant exposure pathways comprising the cumulative (5th percentile) direct PPLV are provided in Appendix Section B.4.1 for each receptor population evaluated (Appendix Tables B.4.1-1 through B.4.1-5). As shown in these tables, the majority of PPLVs listed above reflect the carcinogenic endpoint. Also, for most chemicals, dermal absorption was the driver exposure pathway. The only exceptions were certain OCPs (aldrin, DDE, endrin and isodrin), for which soil ingestion was the driver pathway, and metals, for which ingestion or inhalation pathways were drivers.

[3] Indicator level is the assumed background concentration for the inorganic chemicals of concern.

Table 3.2-2 Summary of Cumulative Direct Soil PPLVs for the 50th Percentile [1]

Chemical	Receptor-Specific Soil PPLVs (Units: mg/kg)				
	Open Space Populations			Economic Development Populations	
	Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker
Aldrin	**4.27E+00**	1.10E+02	9.43E+01	1.52E+01	3.89E+01
Benzene	**3.43E+01**	6.21E+02	3.26E+02	1.04E+02	1.53E+03
Carbon Tetrachloride	**7.69E+00**	1.28E+02	6.75E+01	1.94E+01	3.05E+02
Chlordane	**1.97E+01**	3.30E+02	2.35E+02	5.03E+01	2.53E+02
Chloroacetic Acid*	2.19E+02	2.84E+03	1.31E+03	**1.67E+02**	2.60E+03
Chlorobenzene*	2.19E+03	2.88E+04	1.28E+04	**1.61E+03**	2.50E+04
Chloroform	**1.91E+02**	3.08E+03	1.66E+03	4.58E+02	7.48E+03
DDE	**7.13E+01**	1.28E+03	8.10E+02	1.95E+02	8.22E+02
DDT	**6.49E+01**	1.29E+03	1.01E+03	2.20E+02	9.01E+02
DBCP	**7.24E-01**	1.24E+01	6.21E+00	1.89E+00	2.89E+01
1,2-Dichloroethane	**1.07E+01**	1.88E+02	9.14E+01	2.99E+01	3.99E+02
1,1-Dichloroethylene	**1.57E+00**	2.94E+01	1.52E+01	4.53E+00	6.83E+01
DCPD*	**8.12E+03**	2.17E+05	2.09E+05	1.66E+04	1.33E+05
Dieldrin	**2.45E+00**	5.73E+01	4.81E+01	8.42E+00	2.27E+01
Endrin*	**6.42E+02**	1.28E+04	6.72E+03	6.81E+02	3.41E+03
HCCPD*	**2.22E+03**	6.12E+04	4.05E+04	3.80E+03	3.32E+04
Isodrin*	**1.48E+02**	2.67E+03	1.56E+03	1.55E+02	7.76E+02
Methylene Chloride	**1.27E+02**	2.04E+03	1.19E+03	3.51E+02	5.32E+03
1,1,2,2-Tetrachloroethane	**5.16E+00**	9.04E+01	4.55E+01	1.32E+01	1.97E+02
Tetrachloroethylene	**1.92E+01**	3.64E+02	1.86E+02	5.33E+01	7.51E+02
Toluene*	2.04E+04	1.74E+05	9.02E+04	**1.46E+04**	1.76E+05
Trichloroethylene	**1.03E+02**	1.84E+03	8.83E+02	2.79E+02	4.62E+03
Metals (Indicator Level) [2]					
Arsenic (IL = 10 ppm, >driving PPLV)	**2.64E+01**	9.38E+02	9.02E+02	1.38E+02	2.44E+02
Cadmium (IL = 2.0 ppm)	**3.10E+02**	1.24E+04	1.36E+04	2.34E+03	2.19E+04
Chromium (IL = 40 ppm, >driving PPLV)	**4.72E+01**	1.89E+03	2.16E+03	3.56E+02	4.21E+03
Lead* (IL = 40 ppm)	7.22E+03	2.37E+05	2.18E+05	1.68E+04	2.40E+04
Mercury* (IL = 0.1 ppm)	**1.80E+03**	6.82E+04	6.81E+04	4.35E+03	5.96E+03

Note:

Bolded values indicate that PPLV for corresponding receptor population is the driver for that chemical.

* Denotes a noncarcinogen. No asterisk denotes PPLV based on carcinogenic slope factors for both oral and inhalation pathways.

[1] Cumulative direct PPLVs represent a cancer risk level of 10^{-6} for carcinogens; the PPLV at a 10^{-4} cancer risk is 100 times higher than the values shown in this table.

[2] Indicator level is the assumed background concentration for the inorganic chemicals of concern.

Table 3.2-3 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 0

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 10^{-4} and 10^{-6} risk levels are noted (e.g., as 8,34). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Aldrin	64	6,28*	1,13	2,19	2,21	2,16	Sites exceeding 10^{-4} PPLV: SP3A (all receptors); SP3B (all except Reg); SP4A, NC8A, SP8A, and SP1A (Bio).
Benzene	4	0,0	0,0	0,0	0,0*	0,0	---
Carbon Tetrachloride	0	--	--	--	--	--	---
Chlordane	38	2,9*	0,3	0,7	0,7	0,4	SP3A (C_{rep}=402 ppm) and SP1E (380 ppm) exceed 10^{-4} PPLV (Bio only).
Chloroacetic Acid	6	1	0	0	1*	0	Only site NP4 (C_{rep}=147 ppm) exceeds noncarc PPLV (Bio and Ind).
Chlorobenzene	3	0	0	0	0*	0	---
Chloroform	0	--	--	--	--	--	---
DDE	50	0,1*	0,0	0,0	0,1	0,0	Only site SP1E (C_{rep}=41.4 ppm) exceeds10^{-6} PPLV (Bio and Ind).
DDT	56	0,1*	0,0	0,1	0,1	0,0	Only site SP1E exceeds 10^{-6} PPLV (Bio, Rec, and Ind only).
DBCP	15	1,6*	0,2	1,4	1,5	0,1	C_{rep} for site SP1A (94.2 ppm) exceeds 10^{-4} PPLV for Bio, Rec, and Ind receptors.
1,2-Dichloroethane	0	--	--	--	--	--	---
1,1-Dichloroethylene	0	--	--	--	--	--	---
DCPD	6	0*	0	0	0	0	---

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 10^{-4} and 10^{-6} risk levels are noted (e.g., as 8,34). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Dieldrin	78	5,47*	0,17	2,27	3,32	1,26	Sites exceeding 10^{-4} PPLV: SP3A (all except Reg and CW); SP8A and SP3B (Bio and Ind); SP1A (Bio); SP8A (Rec); NC8A (Ind and CW)
Endrin	58	1*	0	0	0	0	NC8A (260 ppm) exceeds noncarc PPLV
HCCPD	34	0*	0	0	0	0	---
Isodrin	49	0*	0	0	0	0	---
Methylene Chloride	4	0,0*	0,0	0,0	0,0	0,0	---
1,1,2,2-Tetrachloroethane	0	--	--	--	--	--	---
Tetrachloroethylene	2	0,0*	0,0	0,0	0,0	0,0	---
Toluene	5	0	0	0	0*	0	---
Trichloroethylene	2	0,0*	0,0	0,0	0,0	0,0	---
Arsenic	82	4,36*	0,6	0,8	1,12	1,12	Sites exceeding 10^{-4} PPLV: SP1E (C_{rep} = 2,930 ppm) for Bio, CW, and Ind; NP5, NC1A and NP6 for Bio only. C_{rep} values for 16 sites exceed arsenic indicator (background) level of 10 ppm.
Cadmium	64	0,1*	0,0	0,0	0,0	0,0	Only site W3C (868 ppm) exceeds 10^{-6} PPLV (Bio only). C_{rep} values for 19 sites exceed cadmium indicator (background) level of 2.0 ppm.
Chromium	145	0,132*	0,1	0,5	0,5	0,0	Sites with chromium C_{rep} values exceeding 40 ppm indicator (background) level: SP1G (160 ppm), C1C (81.9 ppm), NP9B (57.1 ppm) and W6A (52.9 ppm)

Table 3.2-3 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 0

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 10^{-4} and 10^{-6} risk levels are noted (e.g., as 8,34). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Lead	130	0*	0	0	0	0	Crep values for 31 sites exceed lead indicator (background) level of 40 ppm. The highest lead C_{rep} concentration was 880 ppm at site E2A6.
Mercury	78	0	0	0	0	0	

Note:

[1] Site-specific C_{rep} and PPLV values for individual chemicals are provided in Appendix Tables B.4.2-1 through B.4.2-27.

[2] In summarizing site exceedances, sites are discussed in order of decreasing C_{rep} values. Exceedances for COCs for which both carcinogenic and noncarcinogenic risk endpoints were evaluated reflect the carcinogenic PPLV only. For noncarcinogens, only one exceedance value is listed (i.e., that exceeding an HI of 1.0).

*PPLV is the driver for the corresponding receptor population.

**Shaded cells indicate exceedances of 10^{-4} cancer risk or hazard indices of 1.0.

Bio=Biological Worker; Reg=Regulated/Casual Visitor; Rec=Recreational Visitor; Ind=Industrial Worker; CW=Commercial Worker

Table 3.2-4 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 1

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 1 x 10^{-4} and 1 x 10^{-6} risk levels are noted (e.g., as 9,35). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Aldrin	74	6,29*	1,14	4,17	4,19	3,16	Sites exceeding 10^{-4} PPLV: SP1A (Bio, Ind, and Rec); SP4A and NC3 (Bio); SP3A and SP3B (All but Reg); SP10 (all receptors)
Benzene	28	0,0	0,0	0,0	0,0*	0,0	---
Carbon Tetrachloride	5	0,1	0,0	0,1	0,1*	0,0	Only site SP10 (C_{rep}=6.15 ppm) exceeds 10^{-6} PPLV (Bio, Ind, and Rec)
Chlordane	43	0,8*	0,2	0,6	0,7	0,3	Sites exceeding 10^{-6} PPLV: SP3A and SP1E (all receptors); SP3B (Bio and Rec); SP1A (All but Reg); SP8A, NC1A and NC8A (Bio, Rec, and Ind); NC1B (Ind)
Chloroacetic Acid	12	1	0	1	2*	0	NC3 (C_{rep} = 337 ppm) exceeds noncarc PPLV (Bio, Rec, and Ind only); NP4 (Ind)
Chlorobenzene	10	0	0	0	0*	0	
Chloroform	12	0,1*	0,0	0,1	0,1	0,0	Only site SP1A (Crep=240 ppm) exceeds 10^{-6} PPLV (Ind, Bio, and Rec only)
DDE	53	0,0*	0,0	0,0	0,0	0,0	---
DDT	60	0,2*	0,0	0,0	0,0	0,0	Sites exceeding 10^{-6} PPLV: SP1E and SP10 (Bio only)
DBCP	21	2,9*	1,3	2,8	2,8	1,3	Sites exceeding 10^{-4} PPLV: SP10 (C_{rep}=1,540 ppm) for all receptors; SP1A (C_{rep}=59.3 ppm) for Bio, Ind, and Rec only
1,2-Dichloroethane	4	0,0*	0,0	0,0	0,0	0,0	---
1,1-Dichloroethylene	1	0,0*	0,0	0,0	0,0	0,0	---

Table 3.2-4 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 1

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 1 x 10^{-4} and 1 x 10^{-6} risk levels are noted (e.g., as 9,35). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
DCPD	13	0*	0	0	0	0	---
Dieldrin	84	6,43*	0,16	0,26	0,29	0,25	Sites exceeding 10^{-4} PPLV: SP3A, SP8A, SP3B and NC3 (Bio); SP1A (Bio and Ind only)
Endrin	64	0*	0	0	0	0	---
HCCPD	37	0*	0	0	0	0	---
Isodrin	58	1*	0	0	1	0	Only site NC3 (C_{rep}=152 ppm) exceeds noncarc PPLV (Bio and Ind only),
Methylene Chloride	47	0,0*	0,0	0,0	0,0	0,0	---
1,1,2,2-Tetrachloroethane	2	0,0*	0,0	0,0	0,0	0,0	---
Tetrachloroethylene	26	0,1*	0,0	0,0	0,0	0,0	Only site SP10 (5.61 ppm) exceeds 10^{-6} PPLV (Bio only)
Toluene	19	0	0	0	0*	0	---
Trichloroethylene	11	0,0*	0,0	0,0	0,0	0,0	---
Arsenic	108	1,37*	1,6	1,9	1,11	1,11	Site SP1E (C_{rep} = 15,400 ppm) exceeds 10^{-4} PPLV (all receptors). C_{rep} values for 15 sites exceed arsenic indicator (background) level of 10 ppm.
Cadmium	76	0,1*	0,0	0,0	0,0	0,0	Only site SP1E (C_{rep} = 219 ppm) exceeds 10^{-6} PPLV (Bio only). C_{rep} values for 12 sites exceed cadmium indicator (background) level of 2.0 ppm.

Table 3.2-4 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 1

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 1 x 10^{-4} and 1 x 10^{-6} risk levels are noted (e.g., as 9,35). For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Chromium	166	0,146*	0,1	0,4	0,4	0,0	Sites with C_{rep} values exceeding 40 ppm indicator (background) level include: W5D (202 ppm), SP1G (76.7 ppm) and C1C (42.3 ppm).
Lead	143	0*	0	0	0	0	Crep values for 21 sites exceed indicator (background) level of 40 ppm. The highest lead C_{rep} concentration was 458 ppm at site E2A6.
Mercury	90	1*	0	0	1	1	Only site SP1E (C_{rep} = 2,850 ppm) exceeds noncarc PPLV for mercury (Bio, Ind, and CW only). C_{rep} values for 34 sites exceed mercury indicator (background) level of 0.1 ppm.

Note:

[1] Site-specific C_{rep} and PPLV values for individual chemicals are provided in Appendix Tables B.4.2-1 through B.4.2-27.

[2] In summarizing site exceedances, sites are discussed in order of decreasing C_{rep} values. Exceedances for COCs for which both carcinogenic and noncarcinogenicrisk endpoints were evaluated reflect the carcinogenic PPLV only. For noncarcinogens, only one exceedance value is listed (i.e., that exceeding an HI of 1.0).

*PPLV is the driver for the corresponding receptor population.

**Shaded cells indicate exceedances of 10^{-4} cancer risk or hazard indices of 1.0.

Bio=Biological Worker; Reg=Regulated/Casual Visitor; Rec=Recreational Visitor; Ind=Industrial Worker; CW=Commercial Worker

Table 3.2-5 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 2

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific C_{rep} (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 1 x 10^{-4} and 1 x 10^{-6} risk levels are noted (e.g., as 4,7) For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Aldrin	14	3,6*	0,4	1,5	2,5	1,5	Sites exceeding 10^{-4} PPLV: SP10 (all receptors but Reg); NC3 (Bio); C1A and SP1A (Bio and Ind only)
Benzene	13	0,0	0,0	0,0	0,0*	0,0	---
Carbon Tetrachloride	1	0,0	0,0	0,0	0,0*	0,0	---
Chlordane	0	--	--	--	--	--	---
Chloroacetic Acid	1	0	0	0	0*	0	---
Chlorobenzene	3	0	0	0	0*	0	---
Chloroform	11	0,0*	0,0	0,0	0,0	0,0	---
DDE	3	0,0*	0,0	0,0	0,0	0,0	---
DDT	3	0,0*	0,0	0,0	0,0	0,0	---
DBCP	5	1,3*	1,3	1,3	1,3	1,1	C_{rep} for site SP10 (512 ppm) exceeds 10-4 PPLV for all receptors.
1,2-Dichloroethane	1	0,0*	0,0	0,0	0,0	0,0	---
1,1-Dichloroethylene	0	--	--	--	--	--	---
DCPD	7	0*	0	0	0	0	---
Dieldrin	20	0,8*	0,3	0,3	0,4	0,3	
Endrin	11	0*	0	0	0	0	---
HCCPD	5	0*	0	0	0	0	---
Isodrin	10	1*	0	0	1	0	Site C1A (C_{rep}=97.4 ppm) exceeds noncarc PPLV (Bio and Ind only).
Methylene Chloride	22	0,0*	0,0	0,0	0,0	0,0	---
1,1,2,2-Tetrachloroethane	0	--	--	--	--	--	---

Table 3.2-5 Summary of Sites with C_{rep} Values Exceeding 5th Percentile PPLVs, Horizon 2

Chemical [1]	No. of Sites for which Risks were Quantified (N=178 Sites)	Number of Sites w/ Chemical-Specific Crep (Mean) Concentrations Exceeding 5th Percentile PPLVs [For carcinogens, exceedances of both 1 x 10^{-4} and 1 x 10^{-6} risk levels are noted (e.g., as 4,7) For noncarcinogens, exceedances of a target HI of 1.0 are given.]					Comments [2]
		Biological Worker	Regulated/ Casual Visitor	Recreational Visitor	Industrial Worker	Commercial Worker	
Tetrachloroethylene	12	0,0*	0,0	0,0	0,0	0,0	---
Toluene	8	0	0	0	0*	0	---
Trichloroethylene	4	0,0*	0,0	0,0	0,0	0,0	---
Arsenic	0	--	--	--	--	--	---
Cadmium	0	--	--	--	--	--	---
Chromium	0	--	--	--	--	--	---
Lead	0	--	--	--	--	--	---
Mercury	0	--	--	--	--	--	---

Note:

[1] Site-specific C_{rep} and PPLV values for individual chemicals are provided in Appendix Tables B.4.2-1 through B.4.2-27.

[2] In summarizing site exceedances, sites are discussed in order of decreasing C_{rep} values. Exceedances for COCs for which both carcinogenic and noncarcinogenicrisk endpoints were evaluated reflect the carcinogenic PPLV only. For noncarcinogens, only one exceedance value is listed (i.e., that exceeding an HI of 1.0).

*PPLV is the driver for the corresponding receptor population.

** Shaded cells indicate exceedances of 10^{-4} cancer risk or hazard indices of 1.0.

Bio=Biological Worker; Reg=Regulated/Casual Visitor; Rec=Recreational Visitor; Ind=Industrial Worker; CW=Commercial Worker

Table 3.2-6 Range of Cumulative Indirect PPLVs for the 5th Percentile for Horizon 1 [1,2]

Chemical Name	Number of 178 Total Sites with Non-zero Indirect PPLVs	Biological Worker		Industrial Worker	
		Minimum	Maximum	Minimum	Maximum
Aldrin	74	5.86E-01	1.00E+06	1.14E-01	1.44E-01
Benzene	28	1.28E+01	2.76E+04	2.09E+00	3.28E+00
Carbon Tetrachloride	5	1.87E+01	6.53E+04	1.07E+00	5.42E+00
Chlordane	43	4.24E+00	1.00E+06	1.89E+00	1.15E+01
Chlorobenzene	10	7.90E+01	8.34E+05	5.82E+00	8.02E+00
Chloroform	12	1.77E+00	1.06E+04	6.40E-01	9.53E-01
DDE	53	1.42E+01	1.00E+06	7.79E+00	1.07E+01
DDT	60	2.44E+02	1.00E+06	5.04E+01	5.35E+01
DBCP	21	1.13E+02	1.00E+06	3.60E+01	1.40E+02
1,2-Dichloroethane	4	1.06E+01	2.83E+04	9.43E-01	1.14E+00
1,1-Dichloroethylene	1	--	1.29E+04	--	2.37E+00
DCPD	13	1.98E+00	1.23E+05	1.74E-01	2.14E-01
Dieldrin	84	1.89E+00	1.00E+06	6.49E-01	6.78E-01
Endrin	64	3.26E+02	1.00E+06	4.32E+02	3.93E+04
HCCPD	37	2.48E-01	1.09E+05	5.76E-02	8.58E-02
Isodrin	58	2.44E+01	1.00E+06	5.92E+00	8.71E+00
Methylene Chloride	47	8.83E+01	1.00E+06	6.20E+01	2.46E+02
1,1,2,2-Tetrachloroethane	2	1.31E+01	5.04E+04	3.50E-01	3.57E-01
Tetrachloroethylene	26	3.68E+02	1.00E+06	9.54E+01	1.78E+02
Toluene	19	1.03E+03	1.00E+06	1.25E+02	1.72E+02
Trichloroethylene	11	1.01E+02	1.92E+05	1.14E+01	3.38E+01

[1] Values reported as mg/kg.

[2] This table provides the range of cumulative indirect PPLVs determined for each site and contaminants for which risks were calculated. The first column lists the number of non-zero values on which the range was based and reflects the overall prevalence of contaminants at RMA. Site-specific indirect PPLVs (Horizons 1 and 2) are provided in Appendix Section B.4.2 for biological worker and industrial worker receptors. Cumulative indirect pathways are not applicable to metals, so metal COCs are not listed here.

Table 3.2-7 Summary of Acute Reasonable Maximum Exposure (RME) PPLVs for Cumulative Direct Soil Exposure Pathway[1]

Chemical	Receptor-Specific Soil PPLVs (Units: mg/kg)			
	Biological/ Industrial Worker	Regulated/ Casual Visitor	Recreational Visitor	Commercial Visitor
Aldrin[2]	5.6E+01	**3.8E+00**	**3.8E+00**	6.9E+01
Benzene	ND	ND	ND	ND
Carbon Tetrachloride	4.8E+04	**1.1E+04**	**1.1E+04**	2.5E+05
Chlordane	7.2E+02	**1.7E+02**	**1.7E+02**	3.7E+03
Chloroacetic Acid	ND	ND	ND	ND
Chlorobenzene	2.4E+04	**5.6E+03**	**5.6E+03**	1.2E+05
Chloroform	2.2E+04	**5.0E+03**	**5.0E+03**	1.1E+05
DDE	ND	ND	ND	ND
DDT	6.0E+01	**1.4E+01**	**1.4E+01**	3.1E+02
Dibromochloropropane (DBCP)	6.0E+02	**1.4E+02**	**1.4E+02**	3.1E+03
1,2-Dichloroethane	ND	ND	ND	ND
1,1-Dichloroethylene	2.4E+04	**5.6E+03**	**5.6E+03**	1.2E+05
Dicyclopentadiene	ND	ND	ND	ND
Dieldrin[2]	4.7E+01	**3.7E+00**	**3.7E+00**	6.9E+01
Endrin	2.4E+02	**5.6E+01**	**5.6E+01**	1.2E+03
Hexachlorocyclopentadiene	ND	ND	ND	ND
Isodrin	ND	ND	ND	ND
Methylene Chloride	1.2E+05	**2.8E+04**	**2.8E+04**	6.2E+05
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND
Tetrachloroethylene	2.4E+04	**5.6E+03**	**5.6E+03**	1.2E+05
Toluene	2.4E+05	**5.6E+04**	**5.6E+04**	[3]
Trichloroethylene	2.9E+05	**6.7E+04**	**6.7E+04**	[3]
Metals				
Arsenic	3.4E+03	**3.0E+02**	**3.0E+02**	5.4E+03
Cadmium	1.9E+03	**1.5E+02**	**1.5E+02**	2.8E+03
Chromium	4.7E+04	**3.8E+03**	**3.8E+03**	6.9E+04
Lead	ND	ND	ND	ND
Mercury	9.4E+04	**7.7E+03**	**7.7E+03**	1.4E+05

[1] Based on an HI of 1.0, and using the exposure assumptions listed in Appendix Table B.6-1.

[2] RME PPLVs for aldrin and dieldrin were recalculated using an RfD recently updated by the EPA (1992b)(1.0×10^{-4} mg/kg-day; see Appendix Table B.6-3); this criterion supersedes the value used in the HHEA Addendum. These recalculated PPLVs also reflect the following: (1) dermal RAFs for aldrin and dieldrin were revised to equal 0.0052 and 0.1, respectively, consistent with the assumptions used in the IEA/RC; and (2) concomitant with this revision of the aldrin/dieldrin dermal RAFs, the soil covering assumed for recreational and regulated/casual visitor populations was revised to equal 1.0 mg/cm^2, consistent with recent EPA dermal exposure assessment guidance.

[3] PPLV is greater than 1×10^6 mg/kg, indicating that the allowable soil concentrations are equivalent to exposure to pure compound over all direct soil pathways at the soil intake rates assumed for this analysis.

ND Not Developed; EPA dose-response information not available.

Bolded values indicate the driver receptor scenario for that particular chemical.

Table 3.2-8 Summary of Subchronic Reasonable Maximum Exposure (RME) PPLVs for Cumulative Direct Soil Exposure Pathway[1]

Chemical	Receptor-Specific Soil PPLVs (Units: mg/kg)			
	Biological/ Industrial Worker	Regulated/ Casual Visitor	Recreational Visitor	Commercial Visitor
Aldrin[2]	8.0E+01	**2.7E+01**	**2.7E+01**	1.0E+02
Benzene	ND	ND	ND	ND
Carbon Tetrachloride	1.2E+03	**1.4E+03**	**1.4E+03**	6.3E+03
Chlordane	1.0E+01	**1.2E+01**	**1.2E+01**	5.4E+01
Chloroacetic Acid	3.5E+03	**3.9E+03**	**3.9E+03**	1.8E+04
Chlorobenzene	3.5E+04	**3.9E+04**	**3.9E+04**	1.8E+05
Chloroform	1.7E+03	**2.0E+03**	**2.0E+03**	9.0E+03
DDE	ND	ND	ND	ND
DDT	8.7E+01	**9.8E+01**	**9.8E+01**	4.5E+02
Dibromochloropropane (DBCP)	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND
1,1-Dichloroethylene	1.6E+03	**1.8E+03**	**1.8E+03**	8.1E+03
Dicyclopentadiene	3.4E+04	**5.4E+04**	**5.4E+04**	2.0E+05
Dieldrin[2]	6.8E+01	**2.6E+01**	**2.6E+01**	1.0E+02
Endrin	8.7E+01	**9.8E+01**	**9.8E+01**	4.5E+02
Hexachlorocyclopentadiene	8.8E+03	**1.3E+04**	**1.3E+04**	5.1E+04
Isodrin	ND	ND	ND	ND
Methylene Chloride	1.0E+04	**1.2E+04**	**1.2E+04**	5.4E+04
1,1,2,2-Tetrachloroethane	ND	ND	ND	ND
Tetrachloroethylene	1.7E+04	**2.0E+04**	**2.0E+04**	9.0E+04
Toluene	3.5E+05	**3.9E+05**	**3.9E+05**	[3]
Trichloroethylene	4.3E+05	**4.9E+05**	**4.9E+05**	[3]
Metals				
Arsenic	6.7E+02	**2.7E+02**	**2.7E+02**	9.9E+02
Cadmium	3.4E+02	**1.4E+02**	**1.4E+02**	5.0E+02
Chromium	**7.2E+02**	2.4E+03	2.4E+03	5.3E+03
Lead	ND	ND	ND	ND
Mercury	2.0E+02	**8.2E+01**	**8.2E+01**	3.0E+02

1 Based on an HI of 1.0.

2 RME PPLVs for aldrin and dieldrin were recalculated using an RfD recently updated by the EPA (1992b) (1.0×10^{-4} mg/kg-day; see Appendix Table B.6-3); this criterion supersedes the value used in the HHEA Addendum. These recalculated PPLVs also reflect the following: (1) dermal RAFs for aldrin and dieldrin were revised to equal 0.0052 and 0.1, respectively, consistent with the assumptions used in the IEA/RC; and (2) concomitant with this revision of the aldrin/dieldrin dermal RAFs, the soil covering assumed for recreational and regulated/casual visitor populations was revised to equal 1.0 mg/cm^2, consistent with recent EPA dermal exposure assessment guidance.

3 PPLV is greater than 1×10^6 mg/kg, indicating that the allowable soil concentrations are equivalent to exposure to pure compound over all direct soil pathways at the soil intake rates assumed for this analysis.

ND Not Developed; EPA dose-response information not available.

Bolded values indicate the driver receptor scenario for that particular chemical.

Table 3.2-9 Comparison of Acute, Subchronic and Chronic Noncarcinogenic PPLVs for Visitor Populations

Chemical	Soil PPLVs for Noncarcinogenic Endpoints (Units: mg/kg)					
	Recreational Visitor			Regulated/Casual Visitor		
	Acute Deterministic RME PPLV	Subchronic Deterministic RME PPLV	Chronic Probabilistic Noncarcinogenic PPLV (5th Percentile)	Acute Deterministic RME PPLV	Subchronic Deterministic RME PPLV	Chronic Probabilistic Noncarcinogenic PPLV (5th Percentile)
Aldrin*	**3.8E+00**	2.7E+01	1.2E+02	**3.8E+00**	2.7E+01	4.2E+02
Arsenic*	3.0E+02	**2.7E+02**	5.8E+03	3.0E+02	**2.7E+02**	1.0E+04
Cadmium**	1.5E+02	**1.4E+02**	6.5E+03	1.5E+02	**1.4E+02**	1.3E+04
Carbon Tetrachloride	1.1E+04	1.4E+03	**8.7E+01**	1.1E+04	1.4E+03	**2.9E+02**
Chlordane**	1.7E+02	**1.2E+01**	1.4E+02	1.7E+02	**1.2E+01**	5.3E+02
Chloroacetic Acid	ND	3.9E+03	**2.3E+02**	ND	3.9E+03	**8.1E+02**
Chlorobenzene	5.6E+03	3.9E+04	**2.6E+03**	**5.6E+03**	3.9E+04	7.0E+03
Chloroform**	5.0E+03	2.0E+03	**1.2E+03**	5.0E+03	**2.0E+03**	4.4E+03
Chromium	3.8E+03	2.4E+03	**3.6E+02**	3.8E+03	2.4E+03	**7.4E+02**
DDT***	**1.4E+01**	9.8E+01	1.6E+03	**1.4E+01**	9.8E+01	5.9E+03
DBCP	1.4E+02	ND	**2.3E+01**	1.4E+02	ND	7.8E+01
1,1-Dichloroethylene**	5.6E+03	1.8E+03	**1.1E+03**	5.6E+03	**1.8E+03**	3.5E+03
DCPD	ND	5.4E+04	**2.9E+04**	ND	**5.4E+04**	6.1E+04
Dieldrin*	**3.7E+00**	2.6E+01	2.2E+02	**3.7E+00**	2.6E+01	4.6E+02
Endrin	**5.6E+01**	9.8E+01	8.7E+02	**5.6E+01**	9.8E+01	3.0E+03
HCCPD	ND	1.3E+04	**6.2E+03**	ND	**1.3E+04**	1.5E+04
Mercury**	7.7E+03	**8.2E+01**	5.5E+03	7.7E+03	**8.2E+01**	9.9E+03
Methylene Chloride**	2.8E+04	1.2E+04	**7.3E+03**	2.8E+04	**1.2E+04**	2.4E+04
Tetrachloroethylene	5.6E+03	2.0E+04	**1.3E+03**	5.6E+03	2.0E+04	**3.8E+03**
Trichloroethylene	**6.7E+04**	4.9E+05	ND	**6.7E+04**	4.9E+05	ND
Toluene*	5.6E+04	3.9E+05	**2.1E+04**	**5.6E+04**	3.9E+05	6.5E+04

* Chemical for which acute and subchronic deterministic PPLVs were calculated using the same oral and/or inhalation reference dose (RfD); toxicity criteria used in the acute and subchronic risk evaluations are listed in Appendix Table B.6-3.

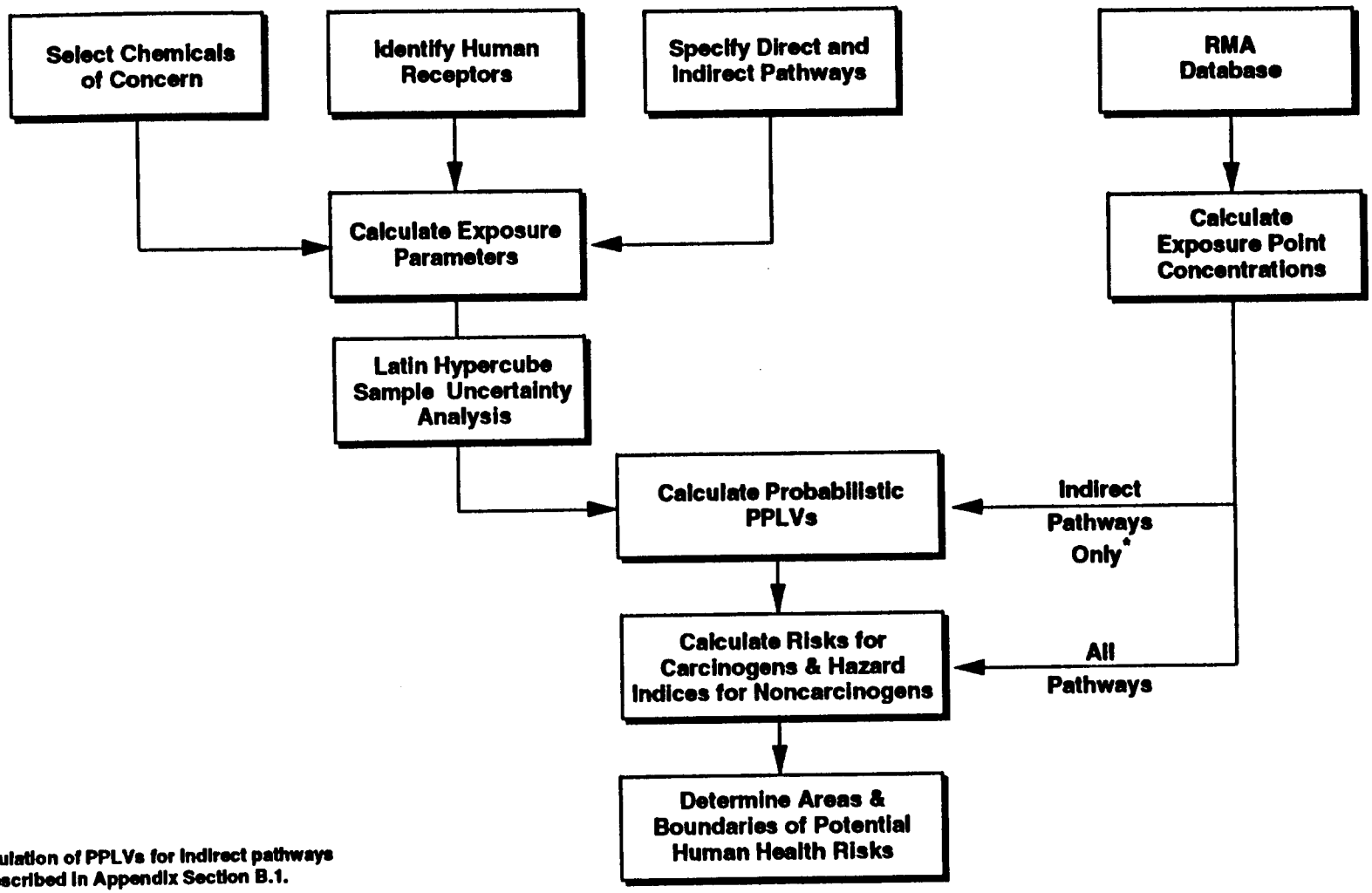
** Chemical for which subchronic deterministic PPLVs and noncarcinogenic chronic probabilistic PPLVs were calculated using the same oral and/or inhalation RfD.

*** Chemical for which all (acute, subchronic and chronic) noncarcinogenic PPLVs were calculated using the same oral and/or inhalation RfD.

For each receptor population, **bolded** and shaded values represent the lowest PPLV derived for the acute, subchronic, and chronic endpoints evaluated.

RME Reasonable Maximum Exposure Scenario; ND = Not Determined

Noncarcinogenic toxicity criteria are not available for benzene, DDE, 1,2-dichloroethane, and 1,1,2,2-tetrachloroethane; these compounds are therefore not listed above. Isodrin and lead are also not listed, because PPLVs for these constituents were not determined in the acute and subchronic deterministic risk evaluations. Chronic probabilistic PPLVs are summarized in Tables 3.2-1 and 3.2-2 and in Appendix Tables B.4.1-1 through B.4.1-5.

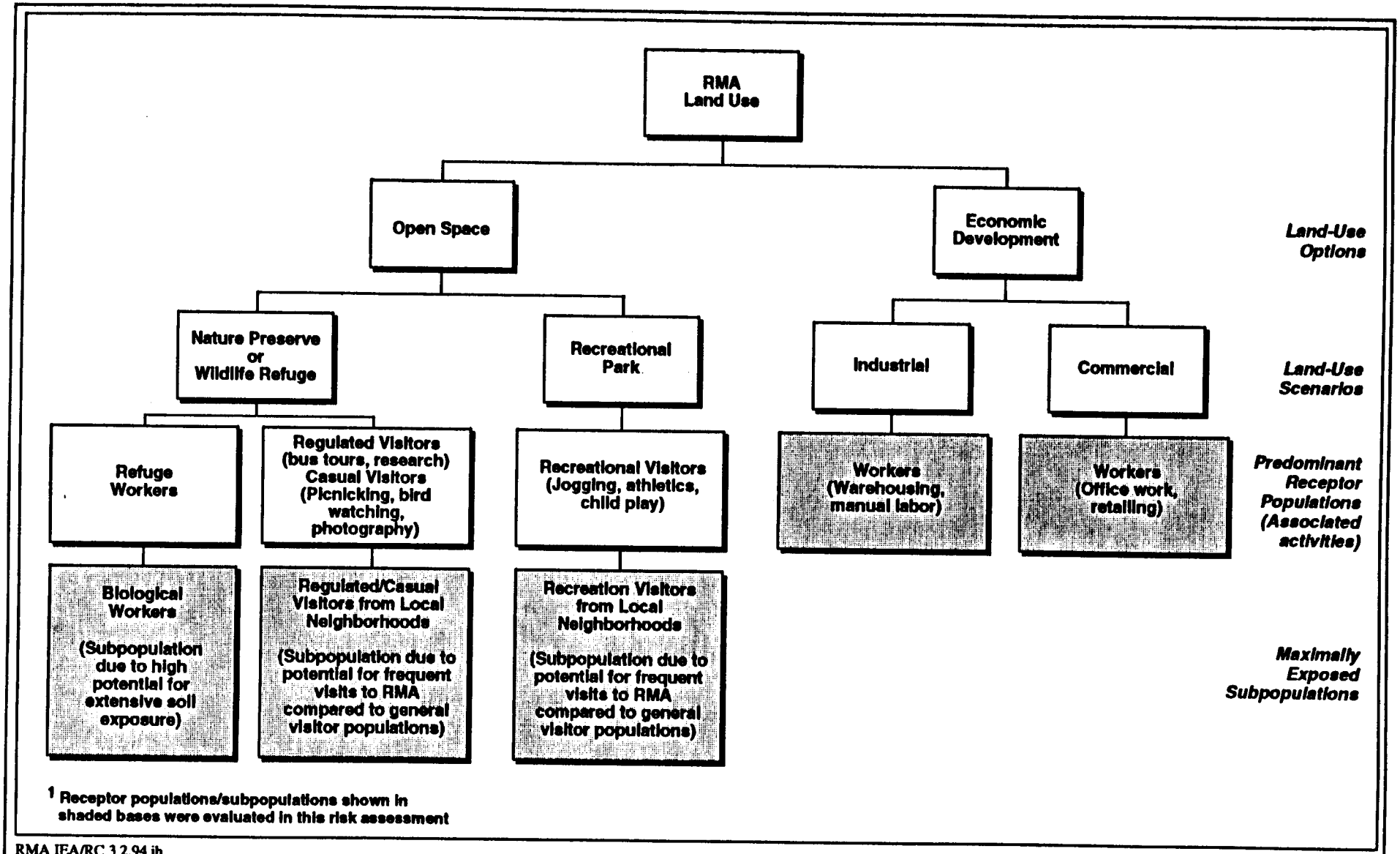


RMA IEA/RC 3 2.94.jb

Figure 3.1-1

Conceptual Approach for Human Health Risk Characterization

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



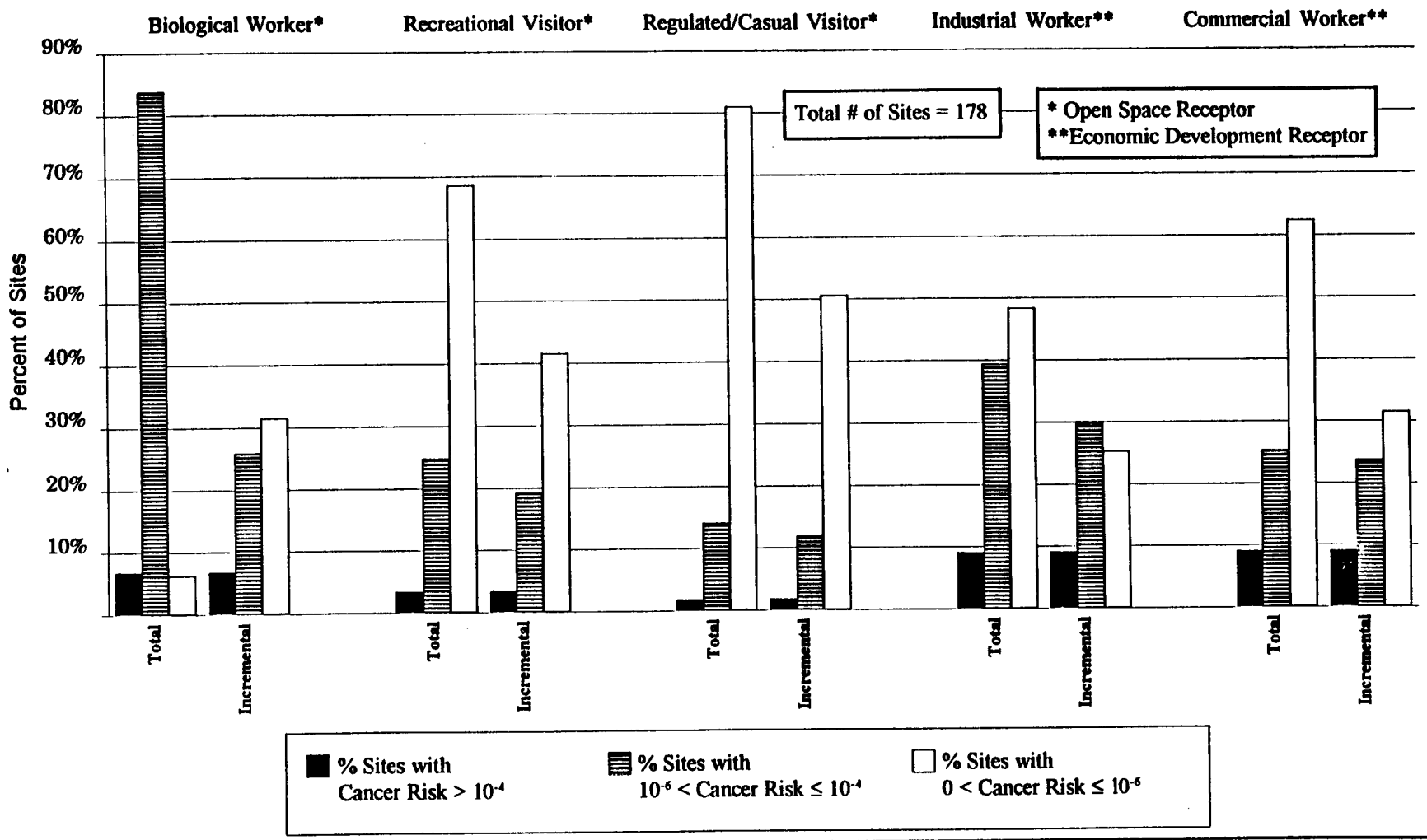
[1] Receptor populations/subpopulations shown in shaded bases were evaluated in this risk assessment

RMA IEA/RC 3 2.94.jb

Figure 3.1-2

Projected Land-Use Scenarios for Rocky Mountain Arsenal [1]

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

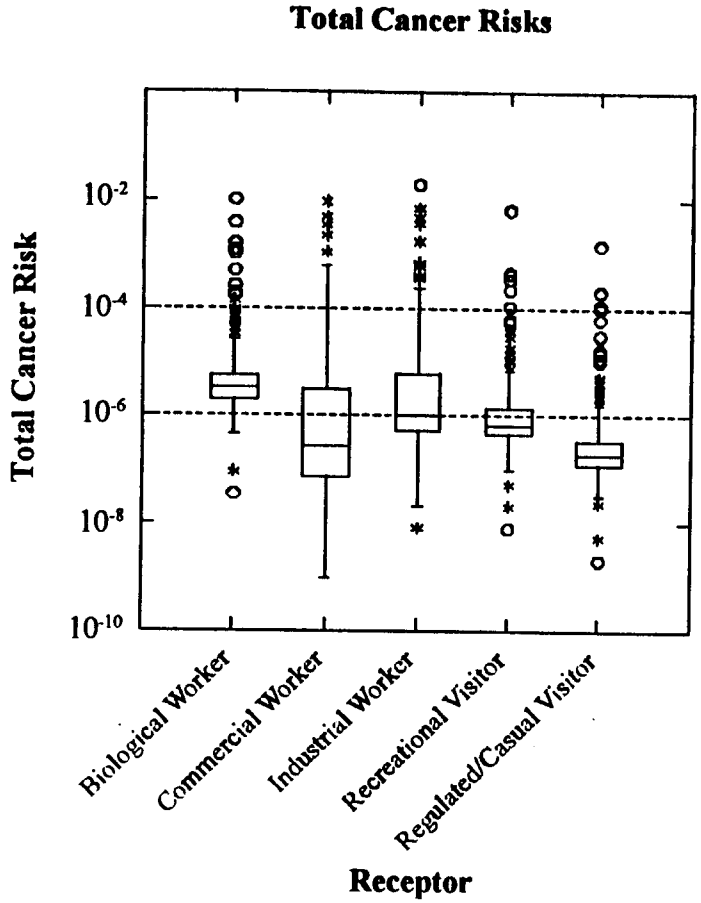


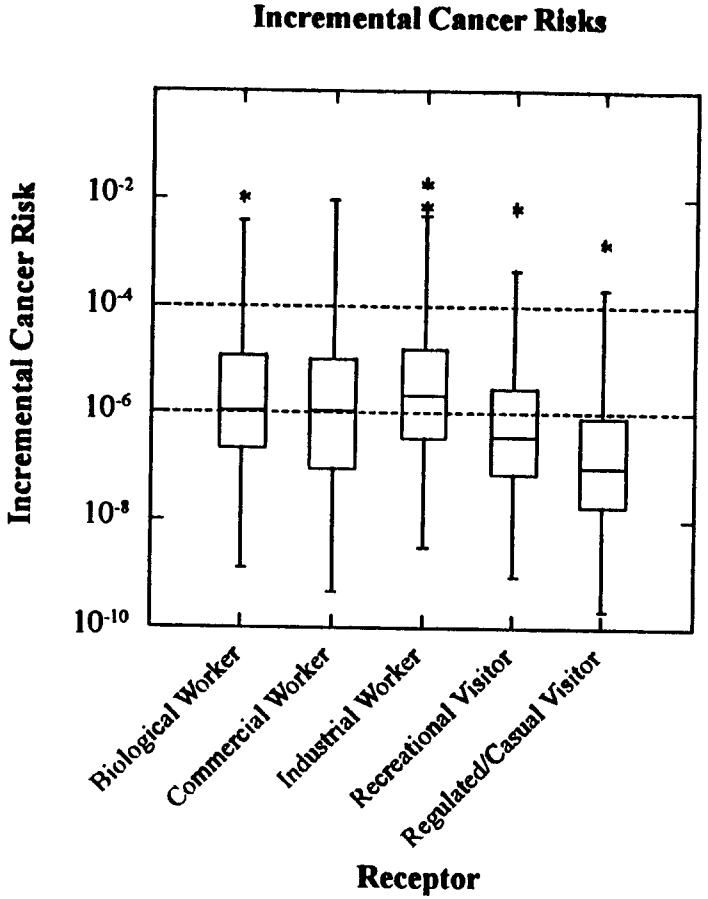
Note: Incremental risk is equal to the total risk minus the risk attributable to indicator (background) levels of metal COCs.

Figure 3.2-1

Cancer Risk Exceedance Summary for All Receptors Based on Site-Specific (C_{rep}) Results, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated





----: Limits denote acceptable risk range (NCP 1990); see text section 3.1.7

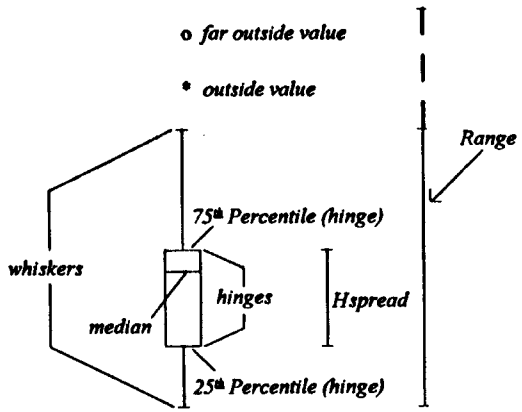
Note: Guidance for interpreting the box plots shown above is provided in the attached legend.

Figure 3.2-2 1 of 2

Distribution of Site Cancer Risks by Receptor, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Box plots provide a simple graphical summary of a data set, identifying the median and outside values in a batch. For the HHRC, box plots are used to illustrate the distributions of site-specific cancer risks and HIs calculated for each receptor population/subpopulation evaluated. The following diagram illustrates the information provided in the box plot.



The center line marks the ***median***, the value above (or below) which half the data (risk or HI) values fall.

The lower and upper ***hinges*** mark the lower and upper quartiles (25th and 75th percentiles) of the data, i.e., 25 percent of the values are at or below the bottom hinge value, and 25 percent of the values equal or exceed the upper hinge value.

The ***whiskers*** mark the minimum and maximum data values except the outliers (outside and far outside values) defined below.

* Marks the ***outside values***, the values outside the inner fences, which are defined as follows:

lower inner fence = lower hinge - 1.5 x Hspread
upper inner fence = upper hinge + 1.5 x Hspread

where: ***Hspread*** represents the interquartile range or mid-range, which is the absolute value of the difference between the value of the two hinges.

o Marks the ***far outside values***, the values outside the outer fences, defined as follows:

lower outer fence = lower hinge - 3.0 x Hspread
upper outer fence = upper hinge + 3.0 x Hspread

For additional information about box (schematic) plots, consult Morgan and Henrion (1990).

Figure 3.2-2 **2 of 2**

Distribution of Site Cancer Risks by Receptor, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

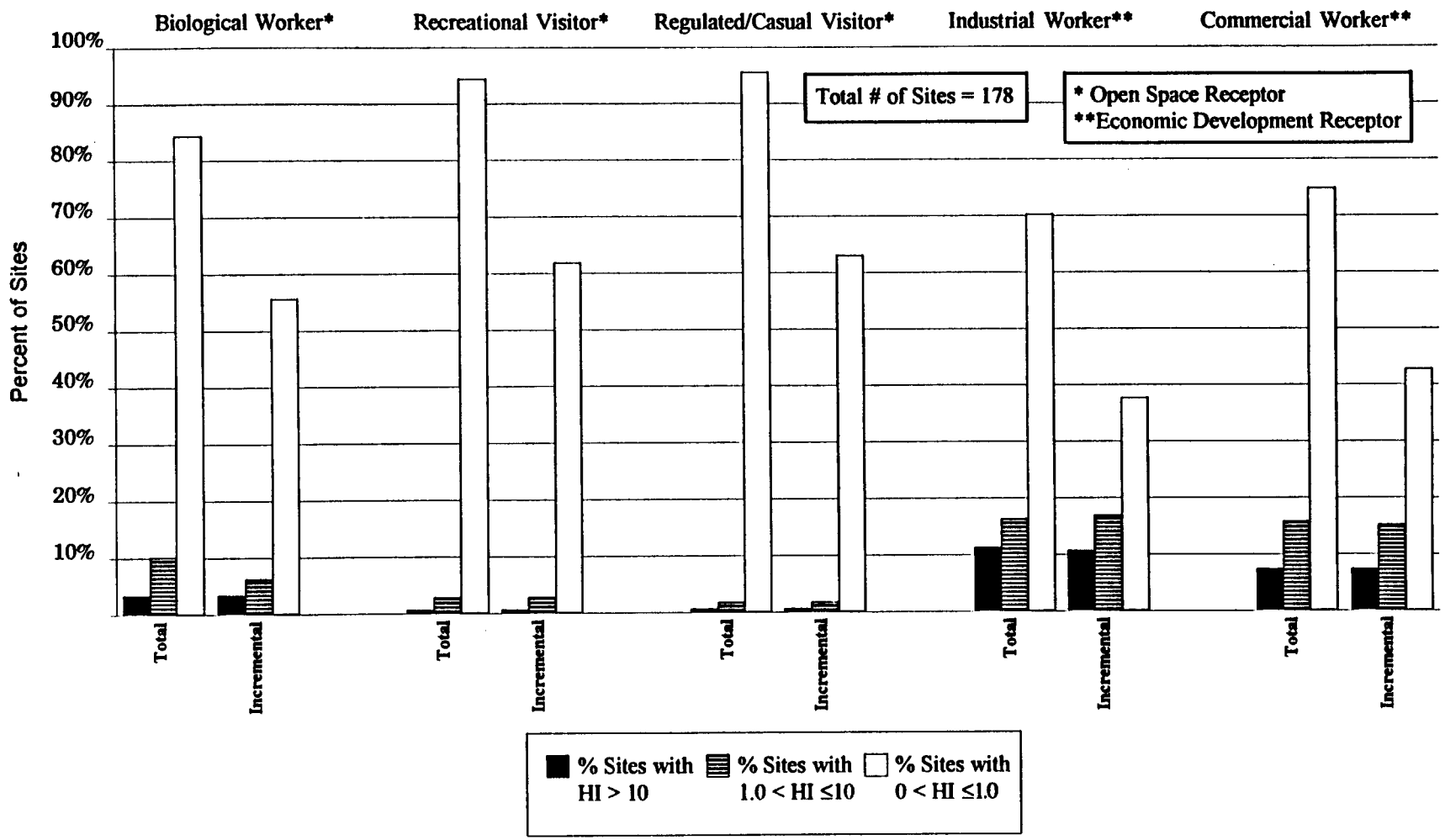
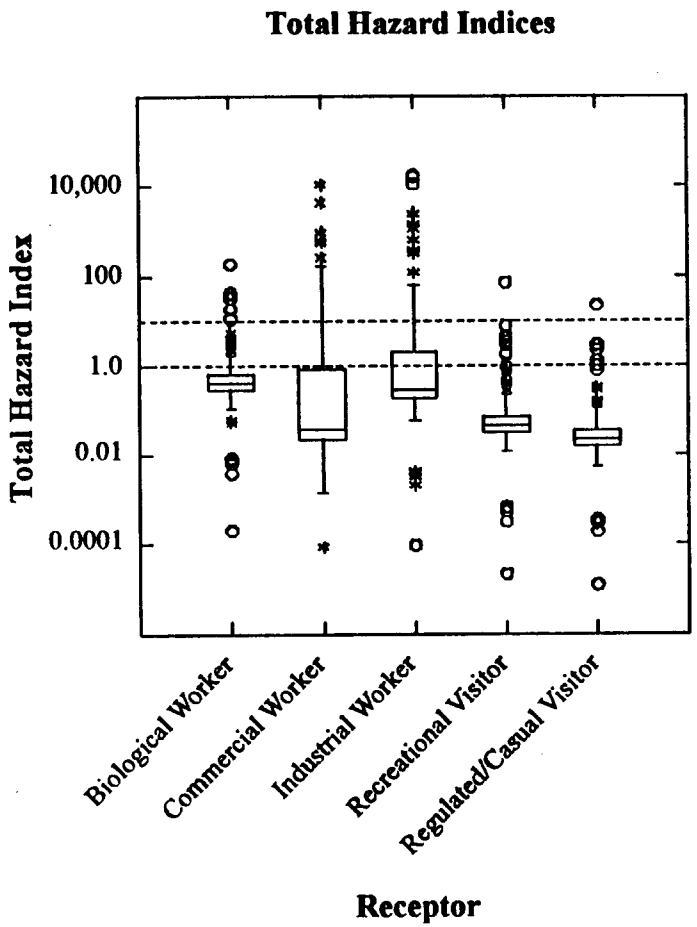
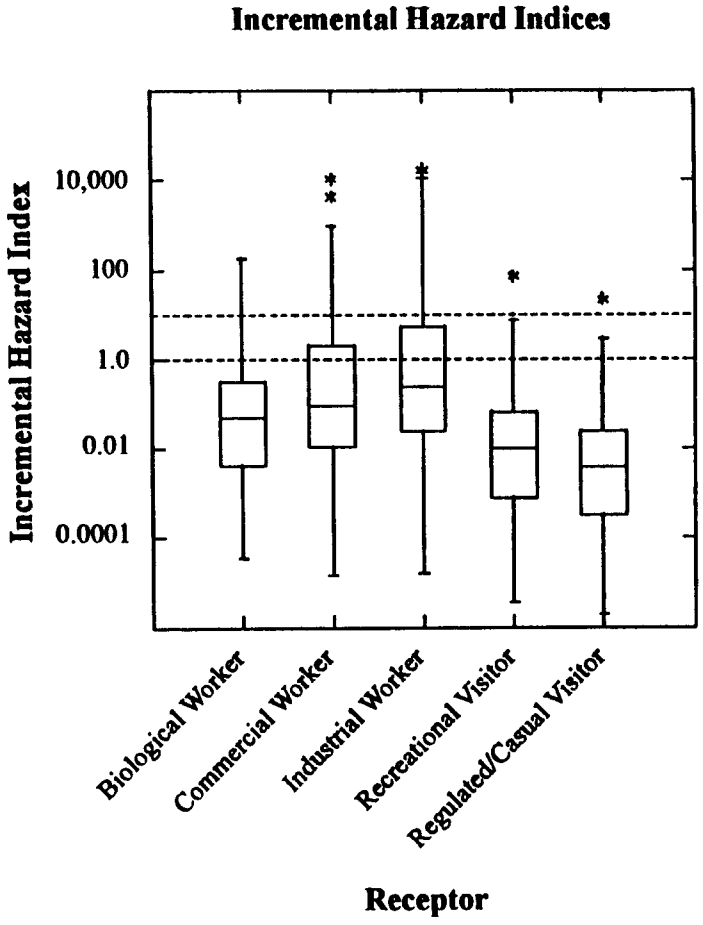


Figure 3.2-3

Hazard Index Exceedance Summary for All Receptors Based on Site-Specific (C_{rep}) Results, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



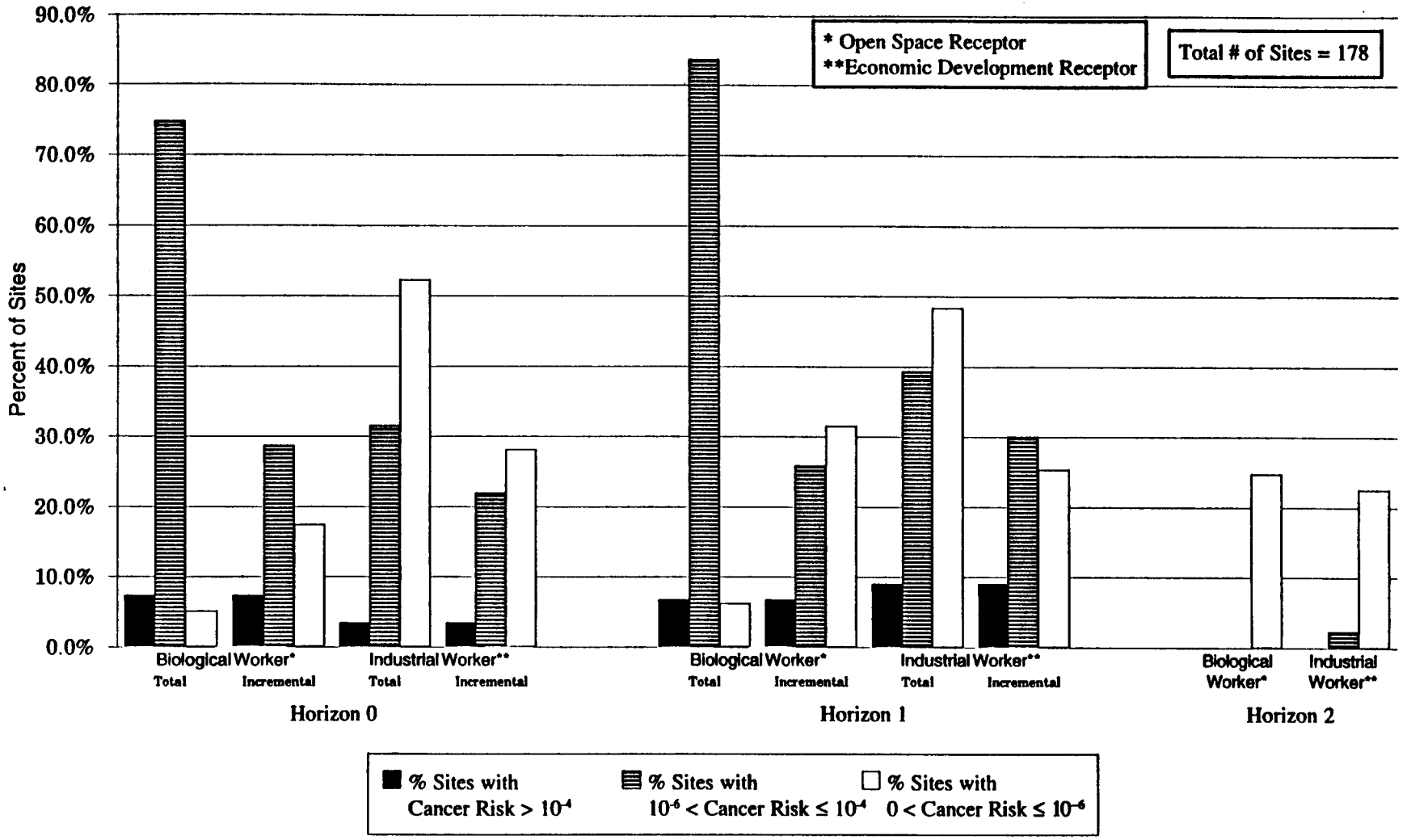


----: Denotes HI of 1.0 (target HI criterion) and 10; see text section 3.1.7

Figure 3.2-4

Distribution of Site Hazard Indices by Receptor, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

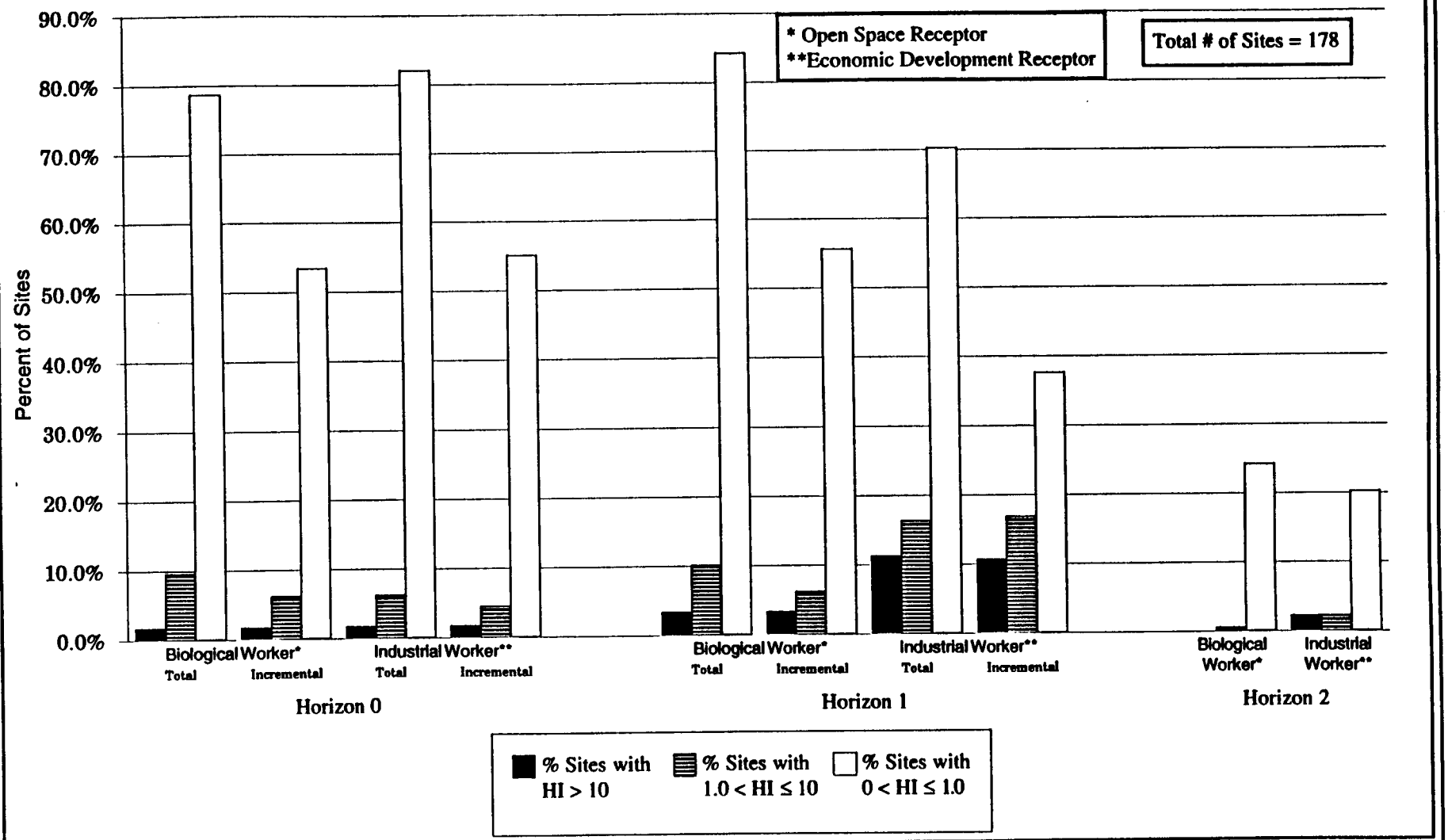


Horizon 0 = 0 to 1 ft
Horizon 1 = 0 to 10 ft
Horizon 2 = > 10 ft to Groundwater

Figure 3.2-5

Horizon-Specific Cancer Risk Exceedance Summary for Biological and Industrial Work Receptors

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

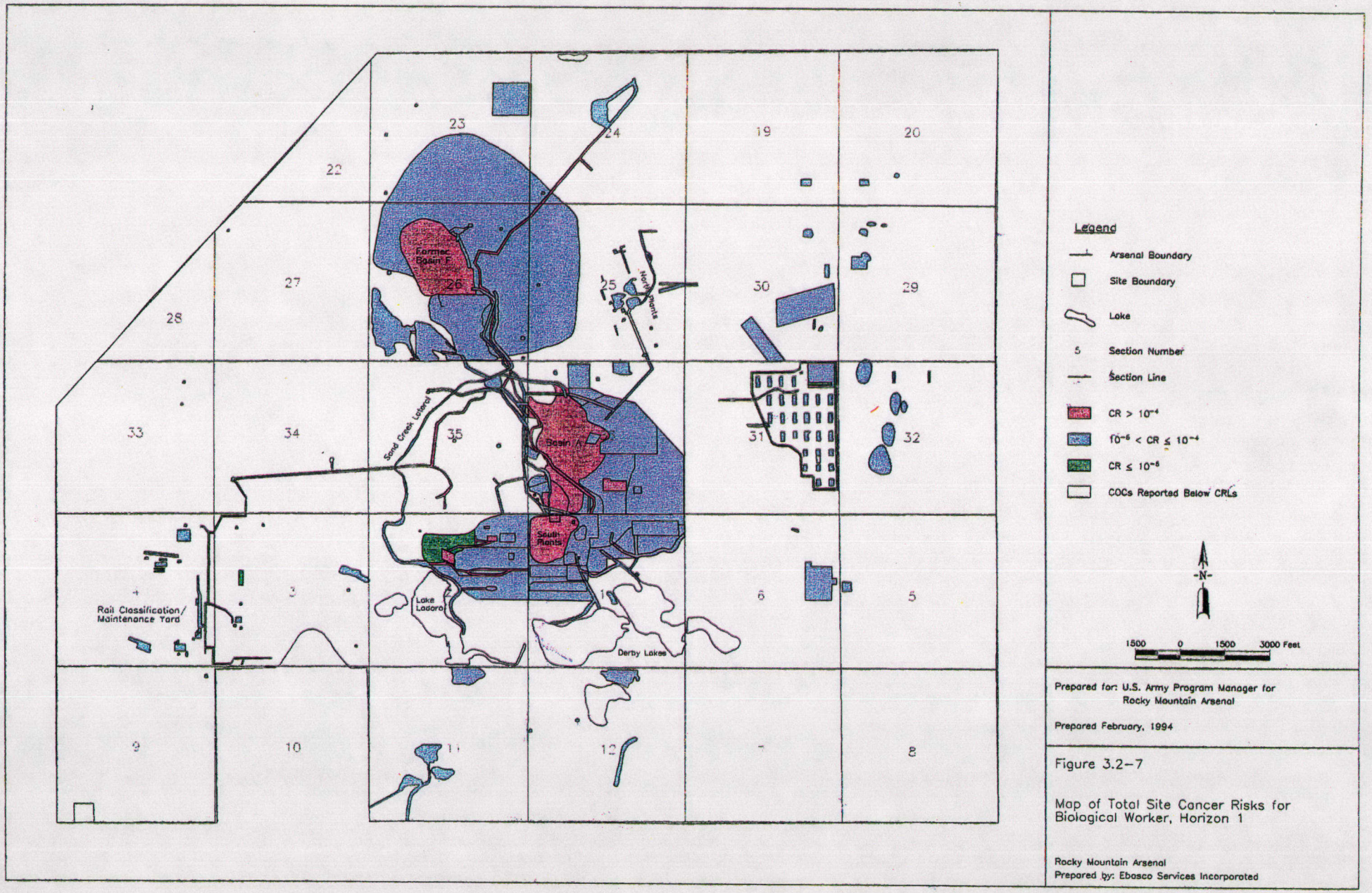


Horizon 0 = 0 to 1 ft
Horizon 1 = 0 to 10 ft
Horizon 2 = > 10 ft to Groundwater

Figure 3.2-6

Horizon-Specific Hazard Index Exceedance Summary for Biological and Industrial Work Receptors

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



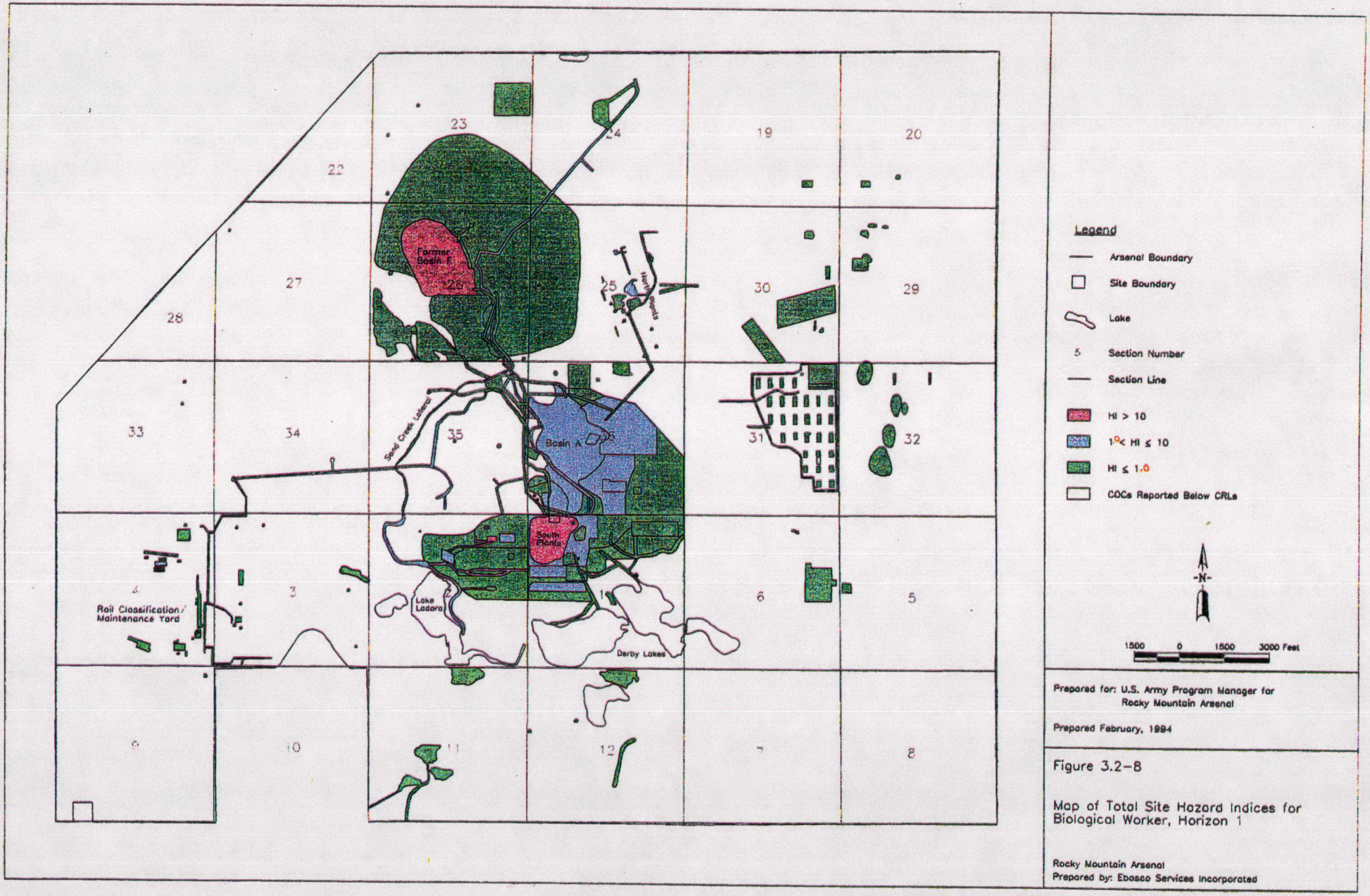
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Prepared February, 1994

Figure 3.2–7

Map of Total Site Cancer Risks for Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal

Prepared February, 1994

Figure 3.2-8

Map of Total Site Hazard Indices for Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

***Each point represents the (Crep mean) incremental cancer risk estimated for an individual site according to the location groupings shown below. HHRC site designations are summarized in Figure 2.3-1 and Appendix B.4.3; detailed site risk results are listed in Table B.4.4-2.*

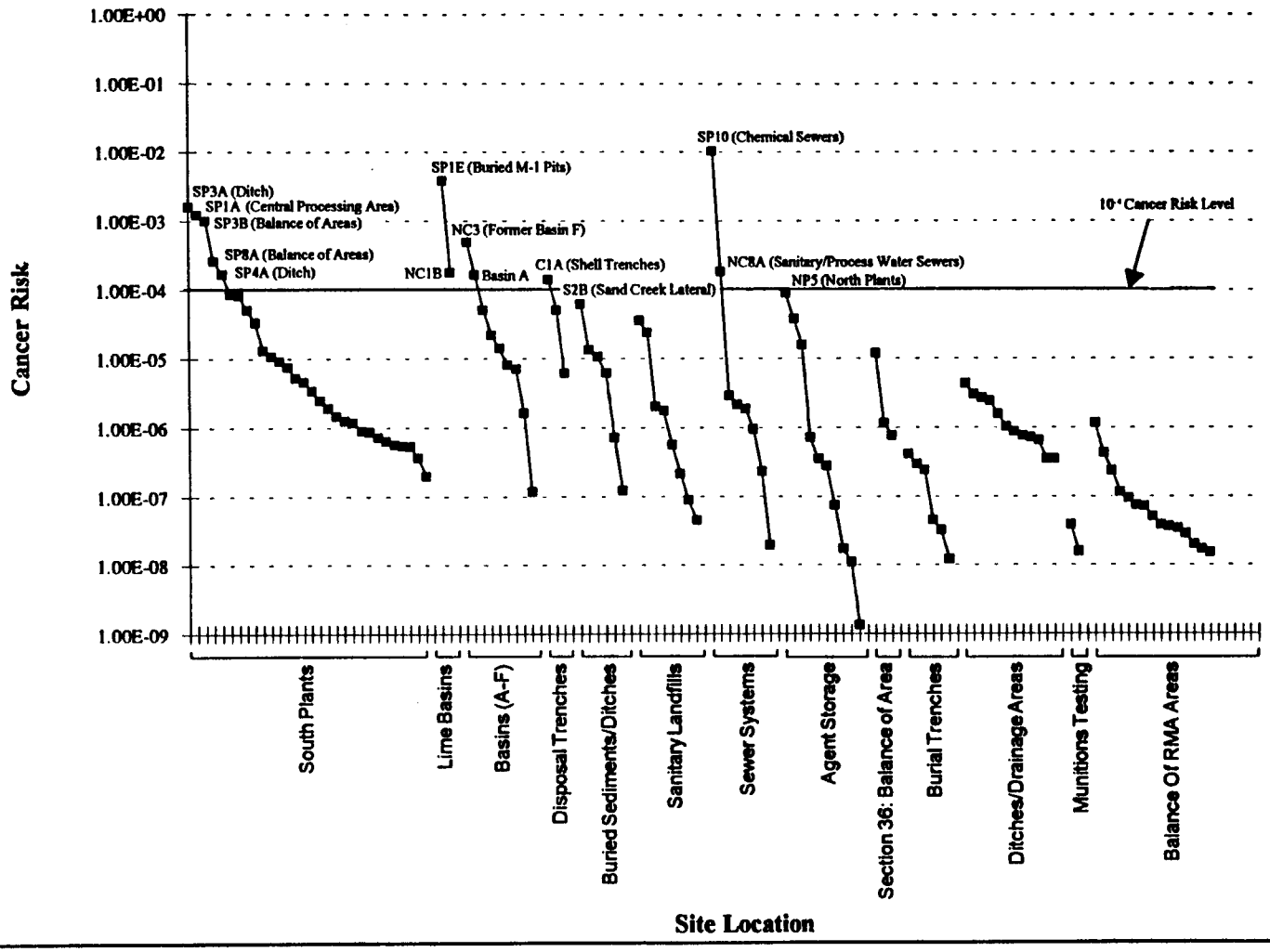


Figure 3.2-9

Plot of Site-Specific Incremental Cancer Risks by Location: Biological Worker, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

***Each point represents the (Crep mean) incremental hazard index (HI) estimated for an individual site; only non-zero HIs are plotted.*
Site designations are summarized in Figure 2.3-1 and Appendix B.4.3; detailed HI results are listed in Table B.4.4-5.

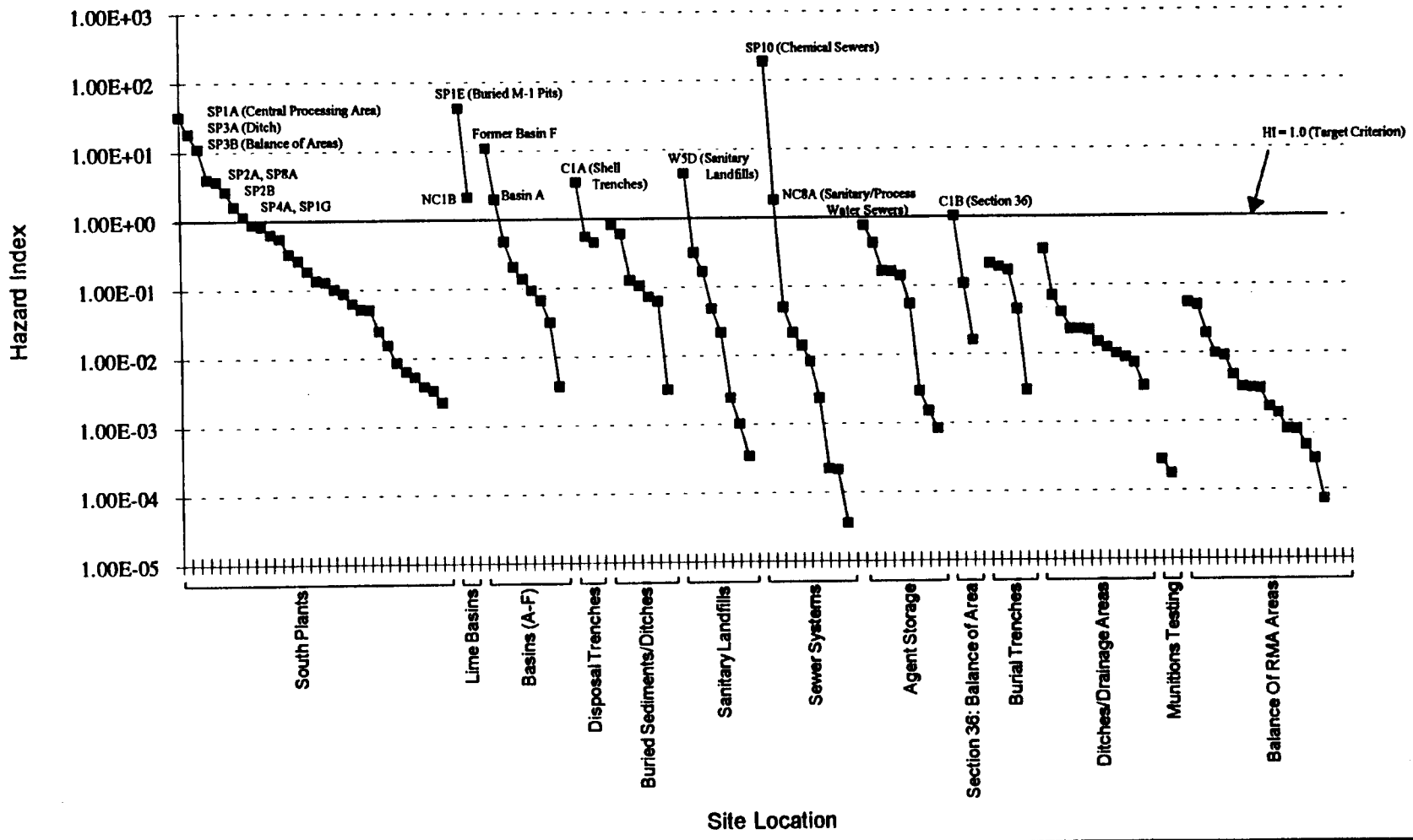
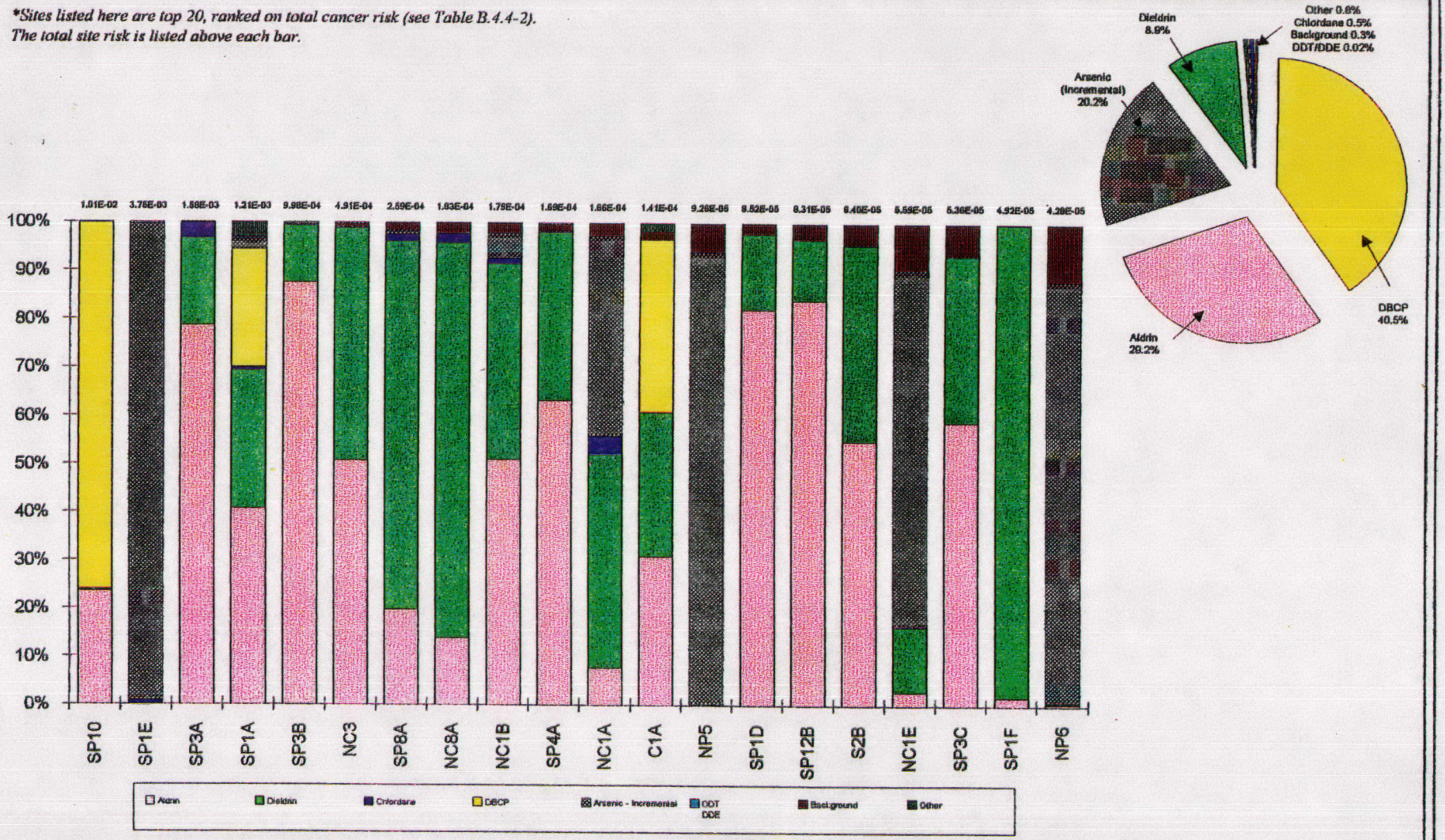


Figure 3.2-10

Plot of Site-Specific Incremental Hazard Indices by Location: Biological Worker, Horizon 1(0 - 10ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

**Sites listed here are top 20, ranked on total cancer risk (see Table B.4.4-2).*
The total site risk is listed above each bar.



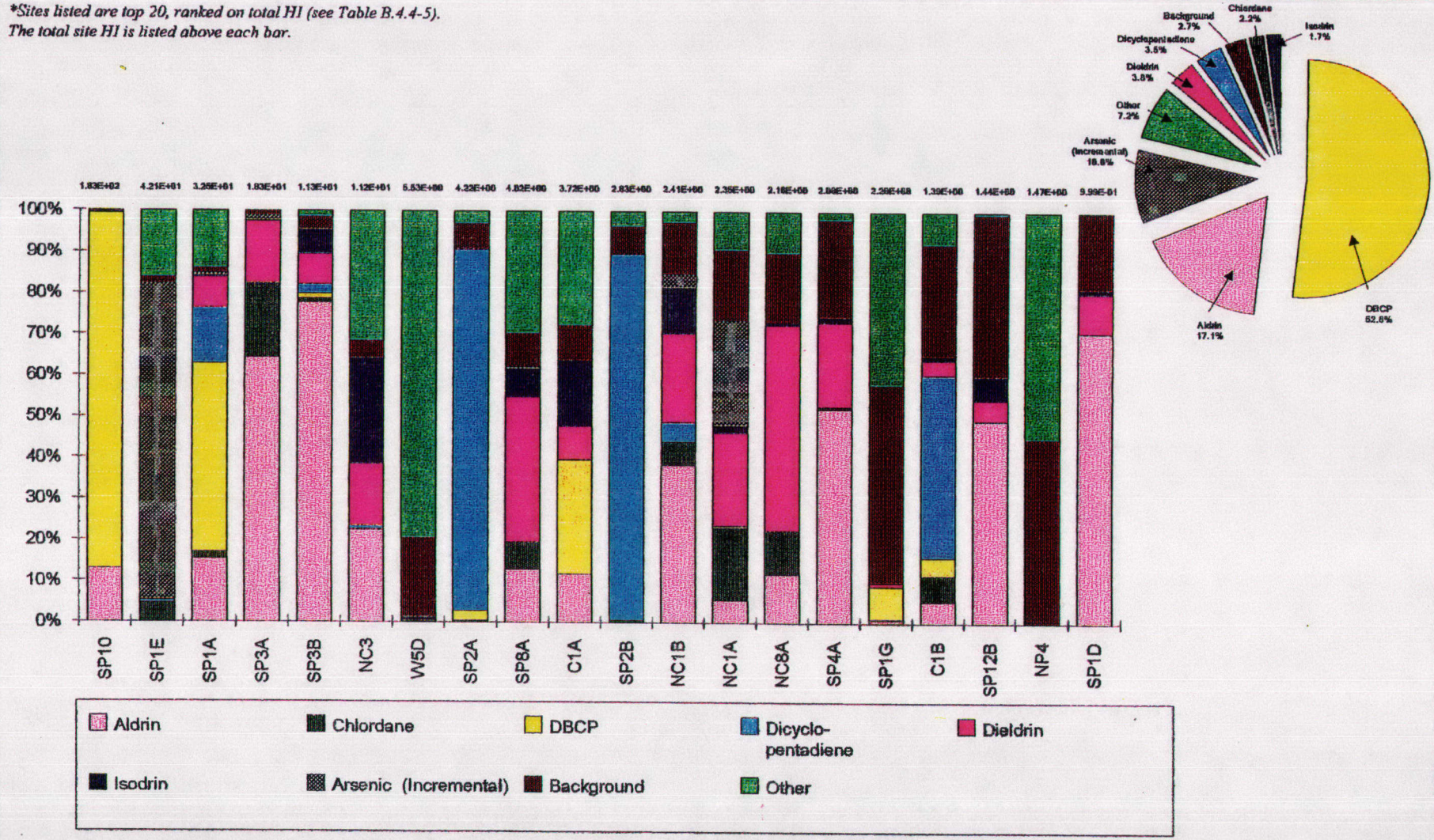
Note: The pie chart reflects the overall contribution of chemicals to the total risk at only those (top 20 ranked) sites shown on this figure. Supporting data are provided in Appendix B, Table B.4.6-1.

Figure 3.2-11

Chemicals Contributing to Total Cancer Risks at Selected Sites, Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

**Sites listed are top 20, ranked on total HI (see Table B.4.4-5).*
The total site HI is listed above each bar.



Note: The pie chart reflects the overall contribution of chemicals to the total HIs at only those (top 20 ranked) sites shown on this figure. Supporting data are provided in Appendix B, Table B.4.6-2.

Figure 3.2-12

Chemicals Contributing to Hazard Indices at Selected Sites, Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

** Sites listed are top 20, ranked on total indirect cancer risk (see Appendix B.4.4 tables).*
The total site risk is listed above each bar; supporting data are provided in Appendix B, Table B.4.6-3.

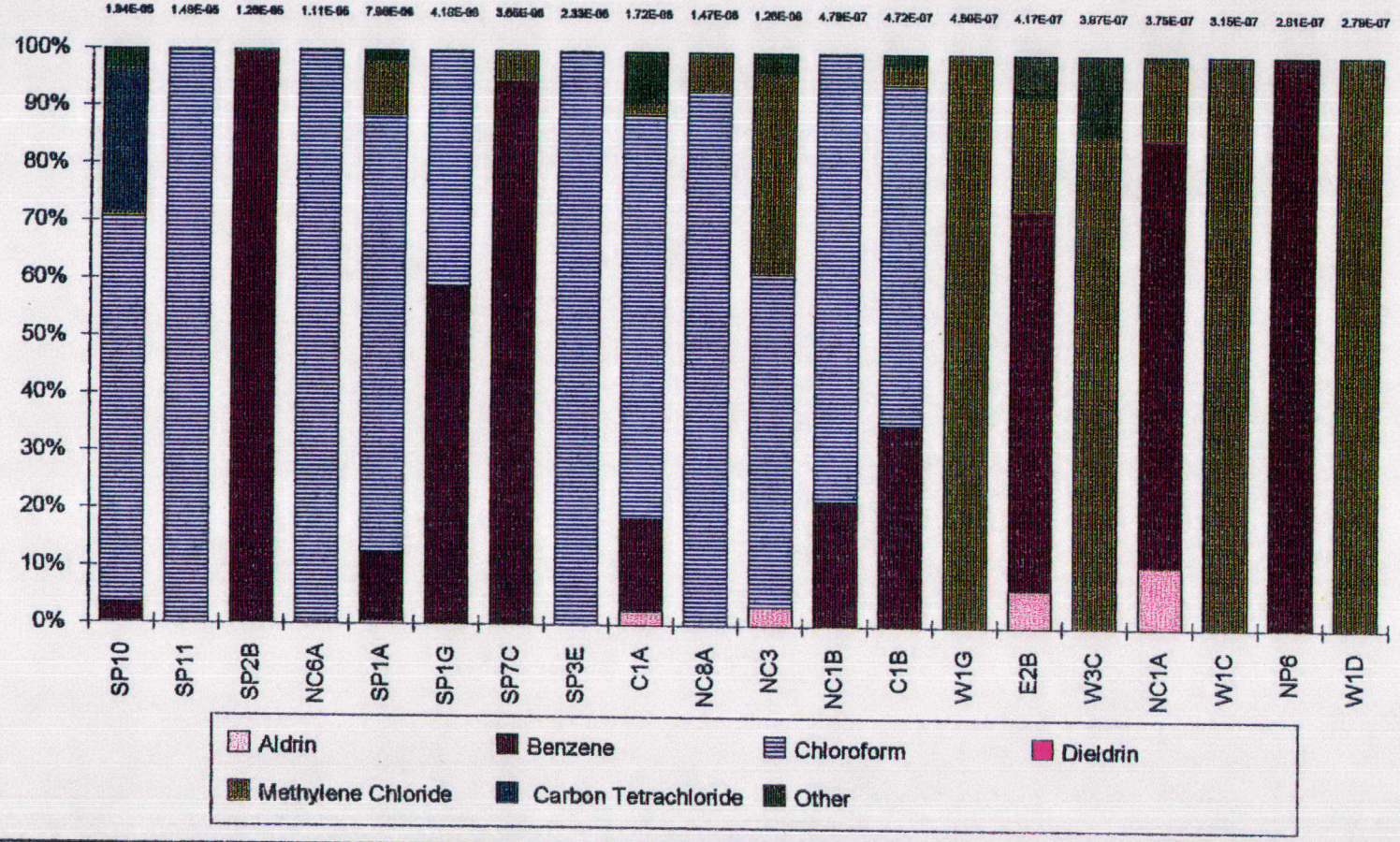


Figure 3.2-13

Chemicals Contributing to Total Indirect Cancer Risks at Selected Sites, Industrial Worker, Horizon 2

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

**Sites listed here are top 20, ranked on total hazard index (see Appendix B.4.4 tables).*
The total site HI is listed above each bar; supporting data are provided in Appendix B, Table B.4.6-4.

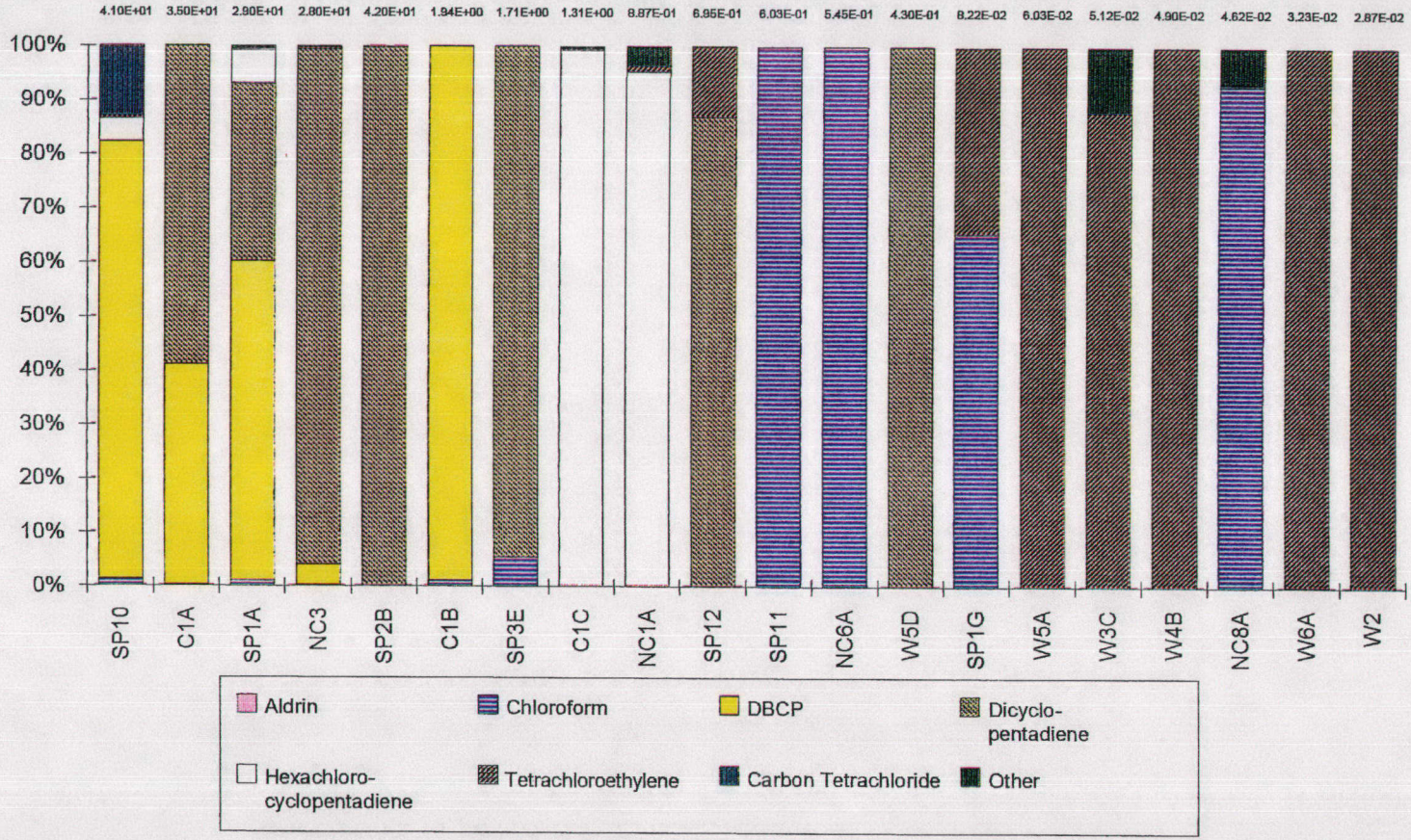
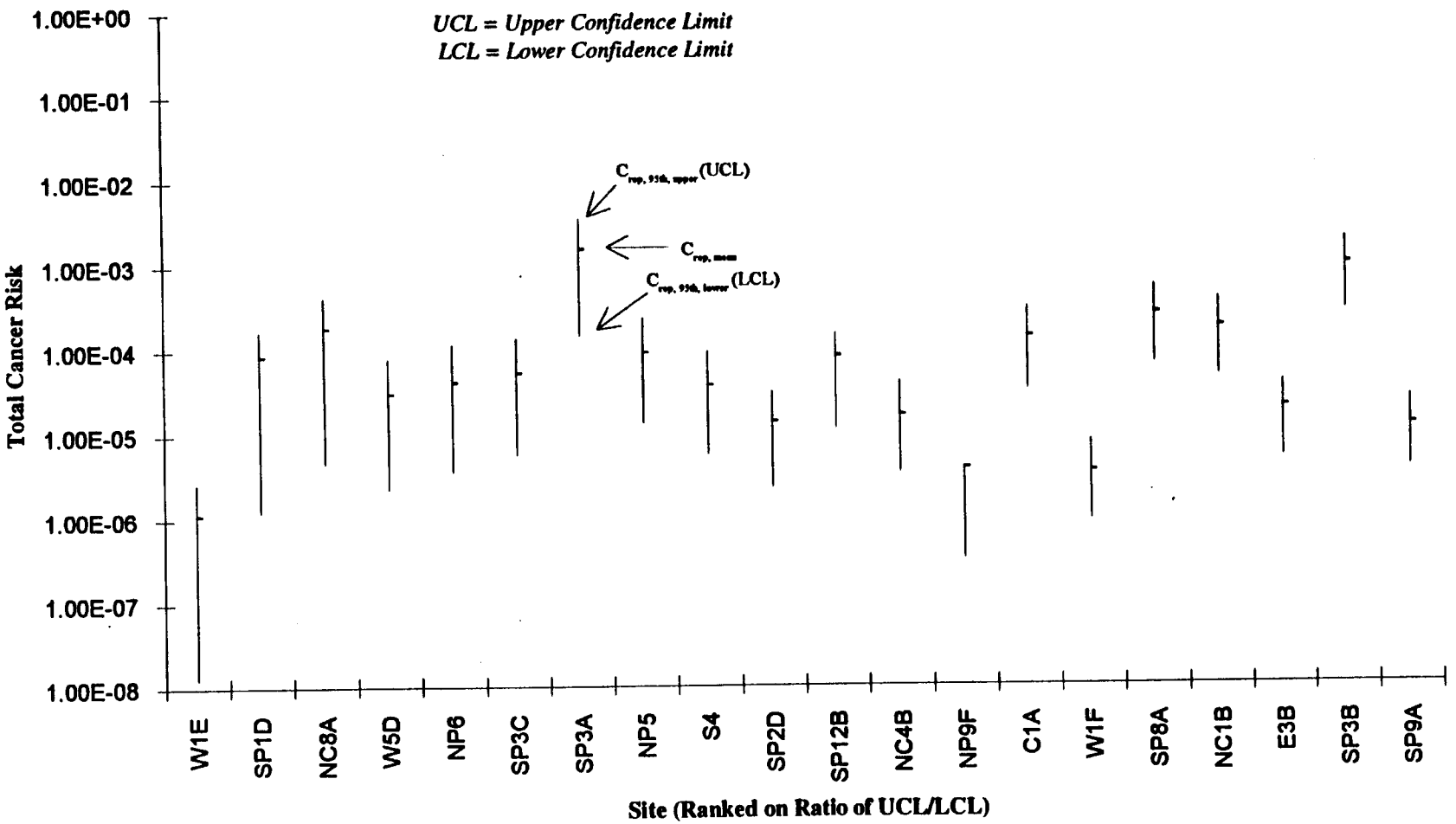


Figure 3.2-14

Chemicals Contributing to Hazard Indices at Selected Sites, Industrial Worker, Horizon 2

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

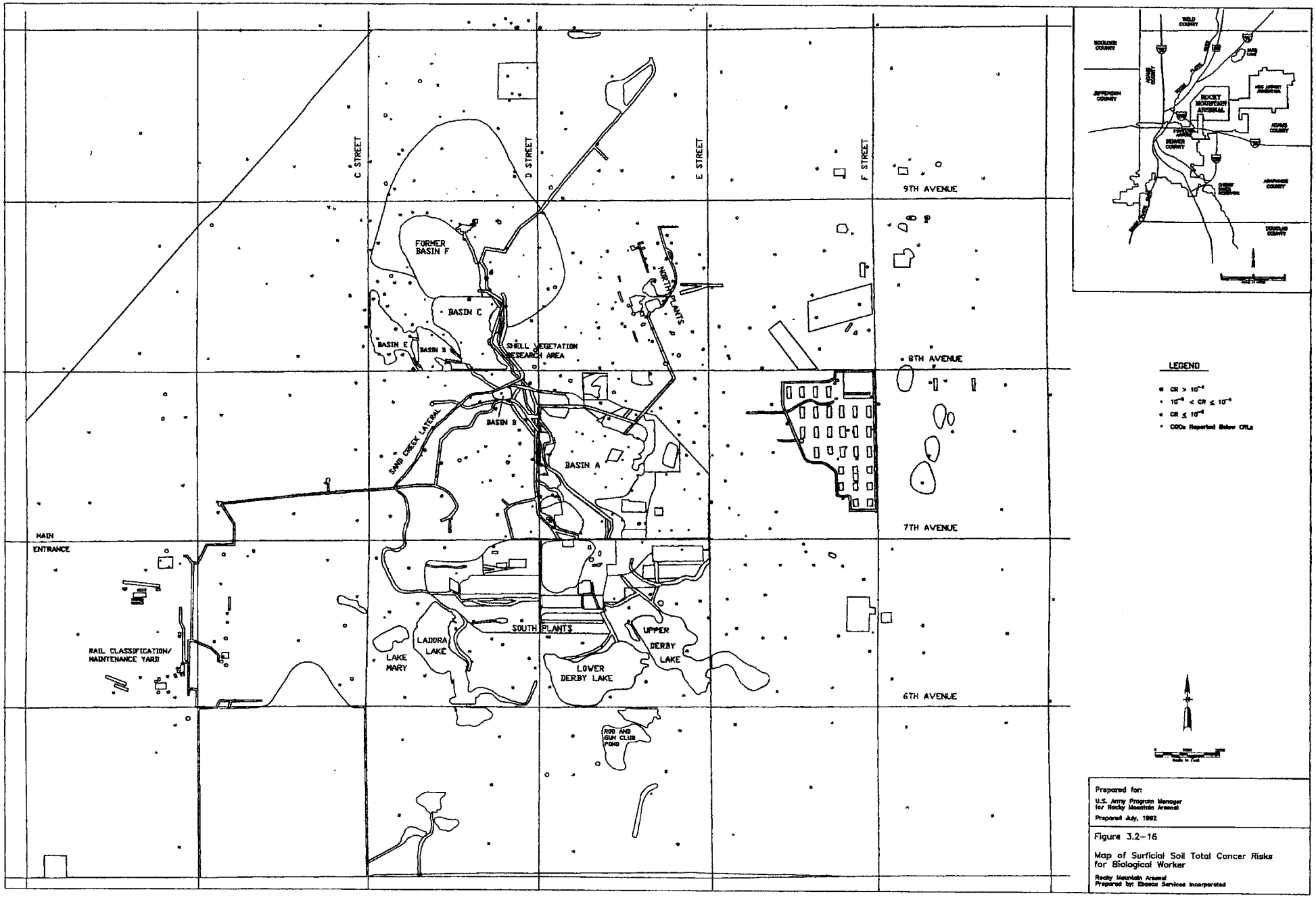


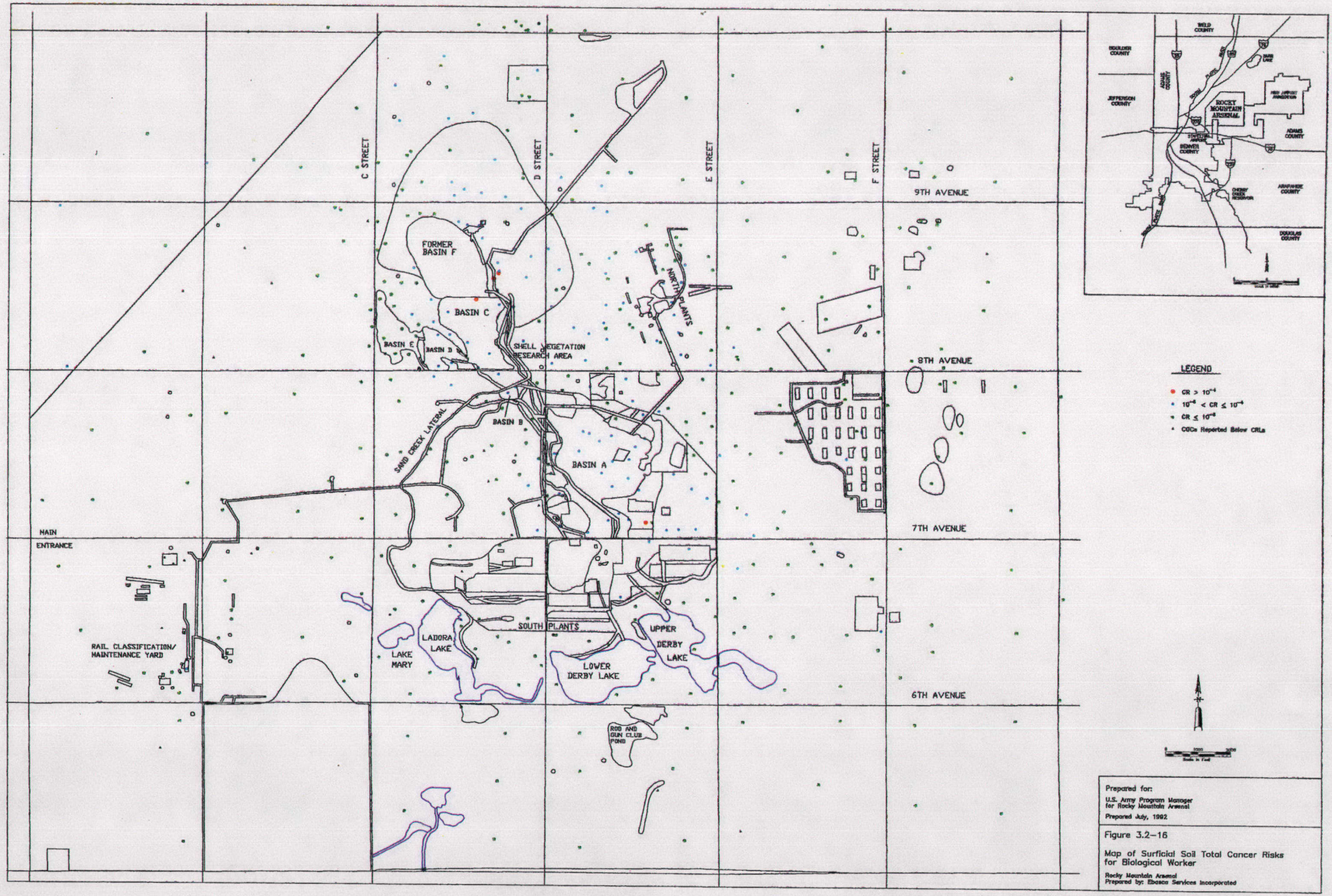
* Sites have $C_{rep\ (mean)}$ risk exceeding 10^{-4}.

Figure 3.2-15

Plot of $C_{rep\ (mean)}$, LCL and UCL Total Cancer Risks: Biological Worker, Horizon 1 (0 - 10 ft)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated


C STREET
D STREET
E STREET
F STREET
9TH AVENUE
8TH AVENUE
7TH AVENUE
6TH AVENUE
FORMER BASIN F
BASIN C
BASIN E
BASIN D
SHELL VEGETATION RESEARCH AREA
NORTH PLANTS
SAND CREEK LATERAL
BASIN B
BASIN A
MAIN ENTRANCE
RAIL CLASSIFICATION/ MAINTENANCE YARD
LADORA LAKE
LAKE MARY
SOUTH PLANTS
UPPER DERBY LAKE
LOWER DERBY LAKE
ROD AND GUN CLUB POND
LEGEND
CR > 10⁻⁴
10⁻⁶ < CR ≤ 10⁻⁴
CR ≤ 10⁻⁶
COCs Reported Below CRLs
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared July, 1992
Figure 3.2-16
Map of Surficial Soil Total Cancer Risks for Biological Worker
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

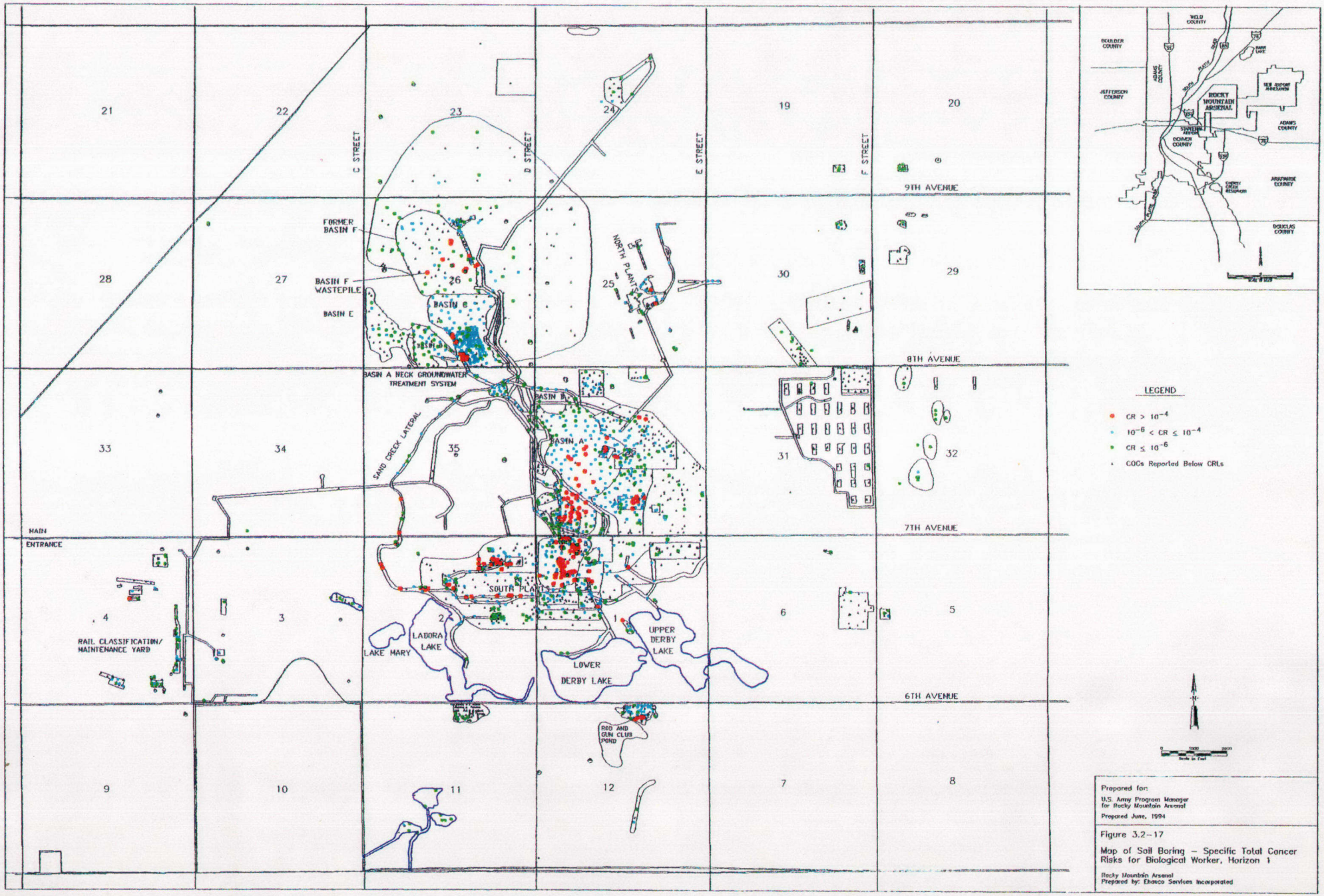


Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared July, 1992

Figure 3.2-16

Map of Surficial Soil Total Cancer Risks for Biological Worker

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

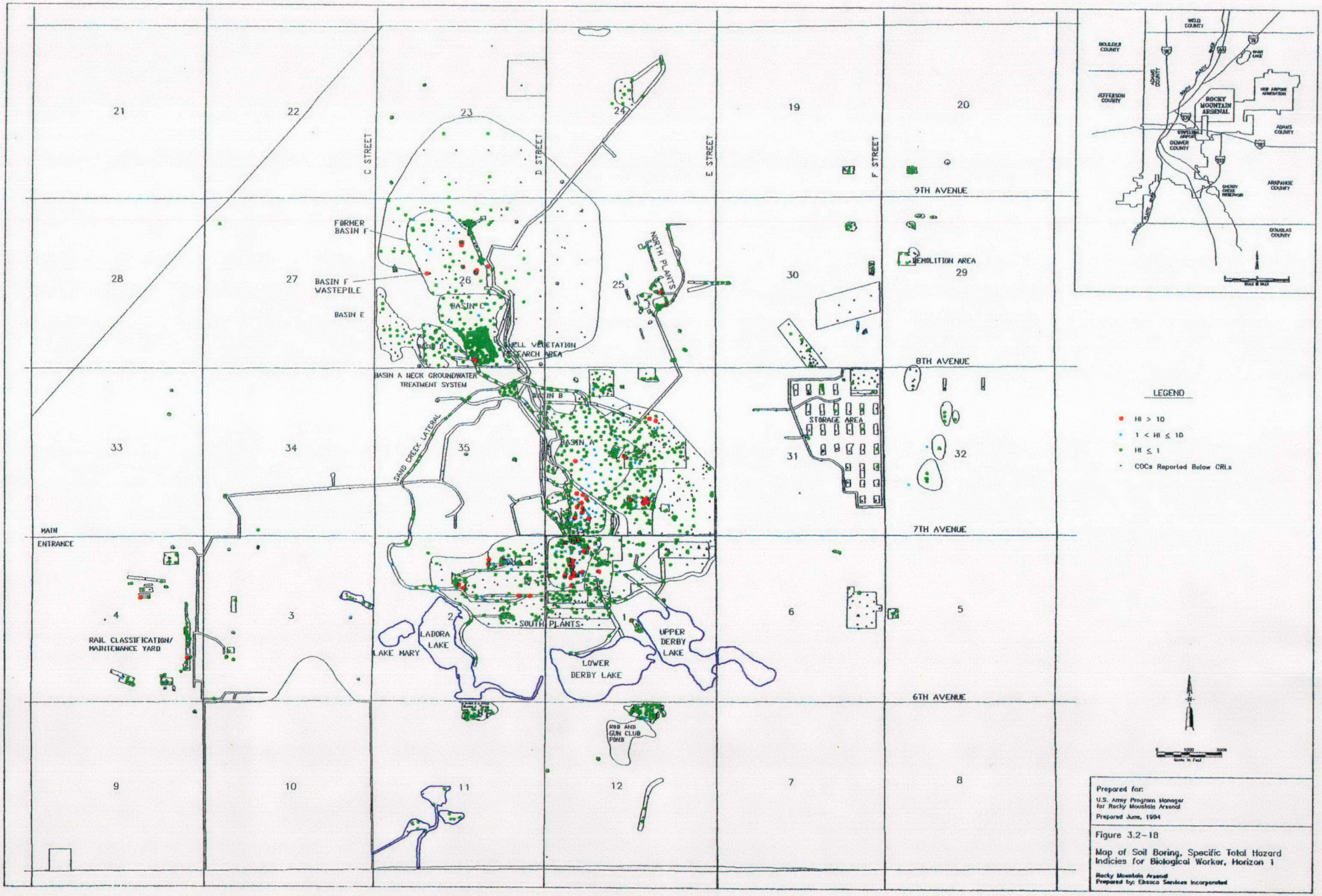


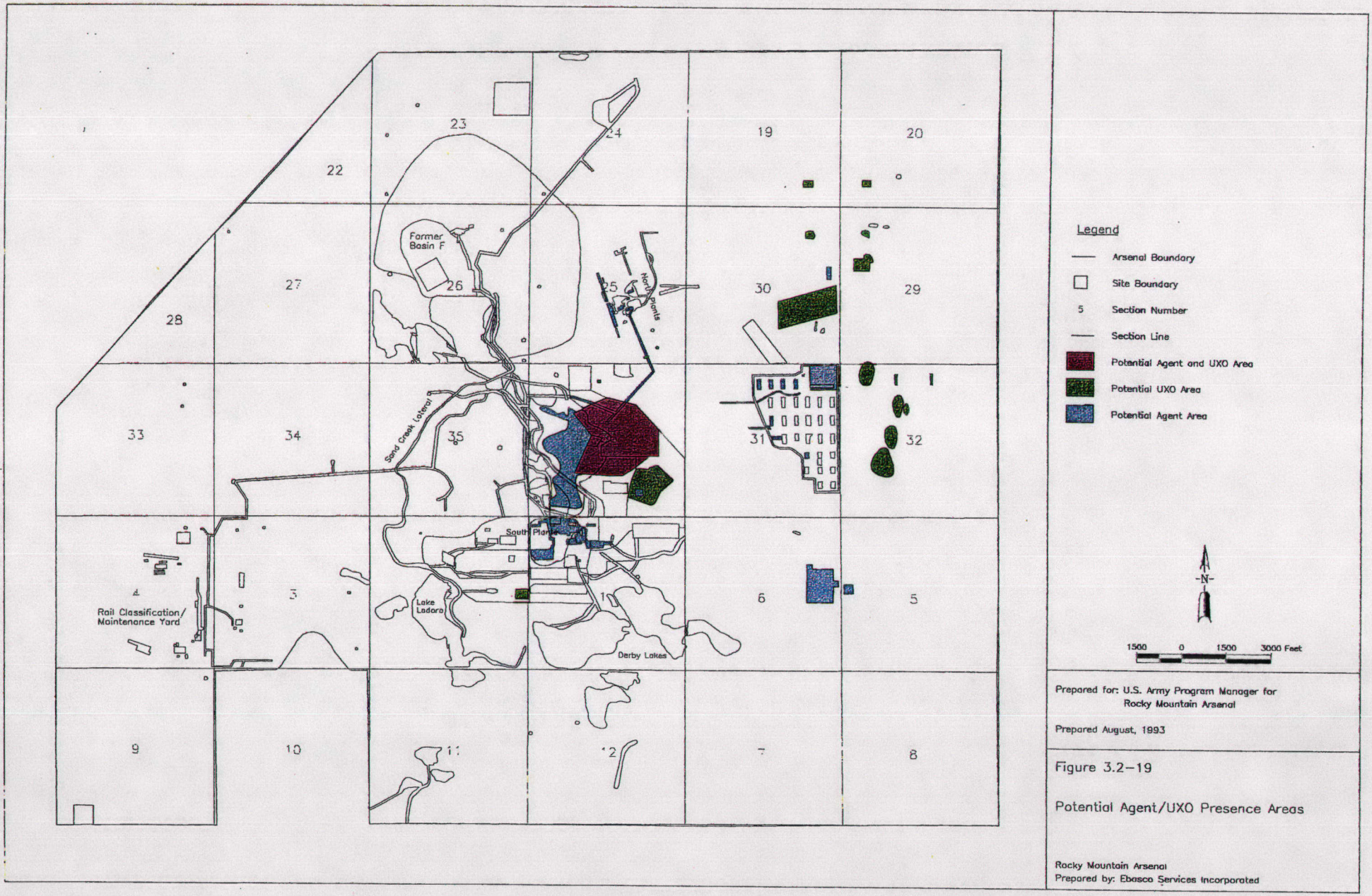
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared June, 1994

Figure 3.2-17

Map of Soil Boring – Specific Total Cancer Risks for Biological Worker, Horizon 1

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated


C STREET
D STREET
E STREET
F STREET
9TH AVENUE
8TH AVENUE
7TH AVENUE
6TH AVENUE
FORMER BASIN F
BASIN F WASTEPILE
BASIN E
BASIN C
BASIN B
BASIN A
SHELL VEGETATION RESEARCH AREA
BASIN A NECK GROUNDWATER TREATMENT SYSTEM
SAND CREEK LATERAL
NORTH PLANTS
SOUTH PLANTS
DEMOLITION AREA
STORAGE AREA
MAIN ENTRANCE
RAIL CLASSIFICATION/ MAINTENANCE YARD
LADORA LAKE
LAKE MARY
LOWER DERBY LAKE
UPPER DERBY LAKE
ROD AND GUN CLUB POND
21
22
23
24
19
20
28
27
26
25
30
29
33
34
35
31
32
4
3
2
1
6
5
9
10
11
12
7
8
LEGEND
HI > 10
1 < HI ≤ 10
HI ≤ 1
COCs Reported Below CRLs
N
0
1000
2000
Scale in Feet
Prepared for:
U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared June, 1994
Figure 3.2-18
Map of Soil Boring, Specific Total Hazard Indicies for Biological Worker, Horizon 1
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated


23
24
19
20
22
Former Basin F
26
25
North Plants
27
30
29
28
33
34
Sand Creek Lateral
35
31
32
South Plants
Lake Ladora
Rail Classification/ Maintenance Yard
3
1
6
5
Derby Lakes
9
10
11
12
7
8
Legend
Arsenal Boundary
Site Boundary
5 Section Number
Section Line
Potential Agent and UXO Area
Potential UXO Area
Potential Agent Area
N
1500 0 1500 3000 Feet
Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal
Prepared August, 1993
Figure 3.2-19
Potential Agent/UXO Presence Areas
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated