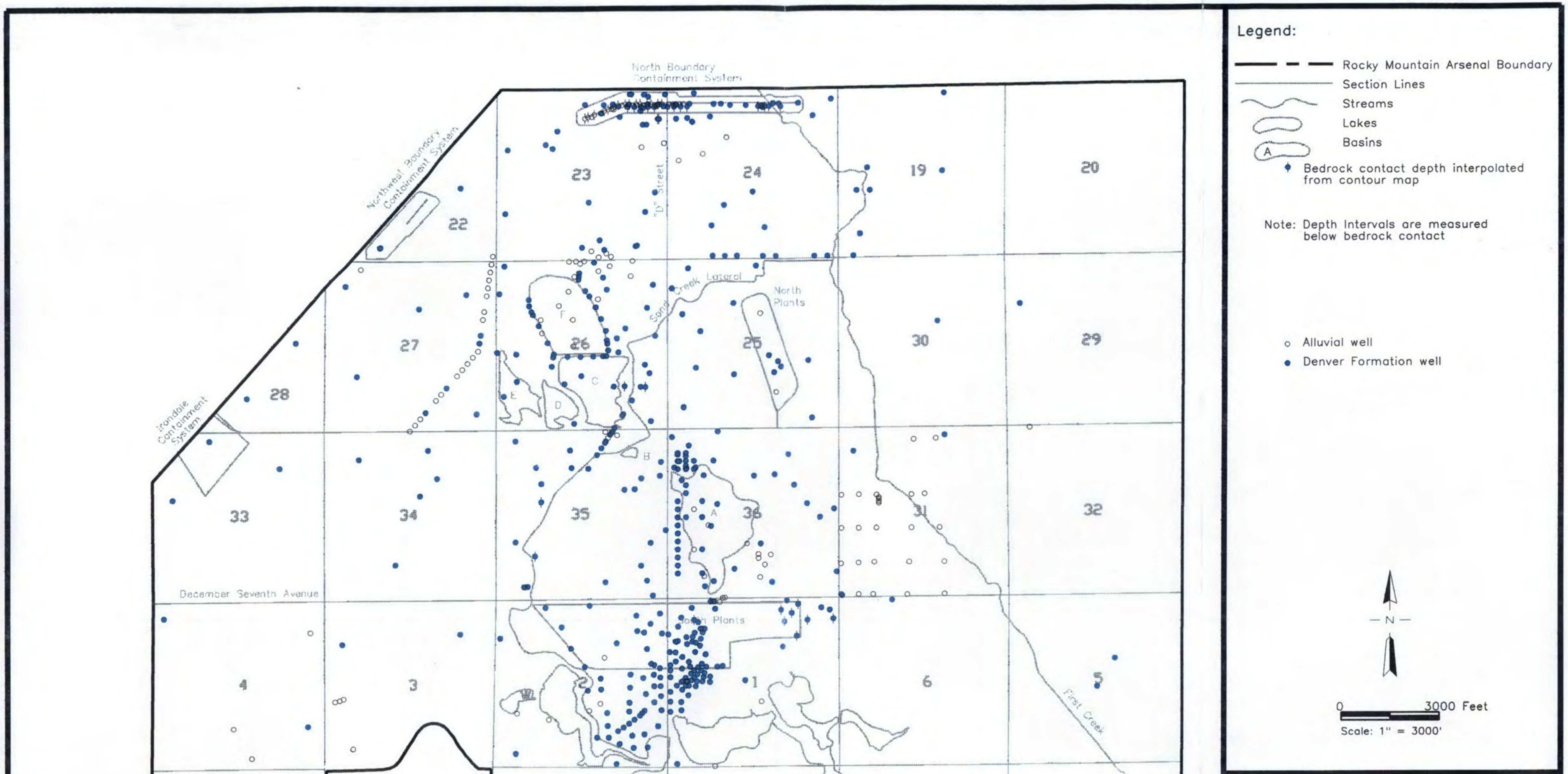
Appendix B

Vertical Extent of Groundwater Contamination in the Denver Aquifer

Figures and Plates

Remedial Investigation Summary Report



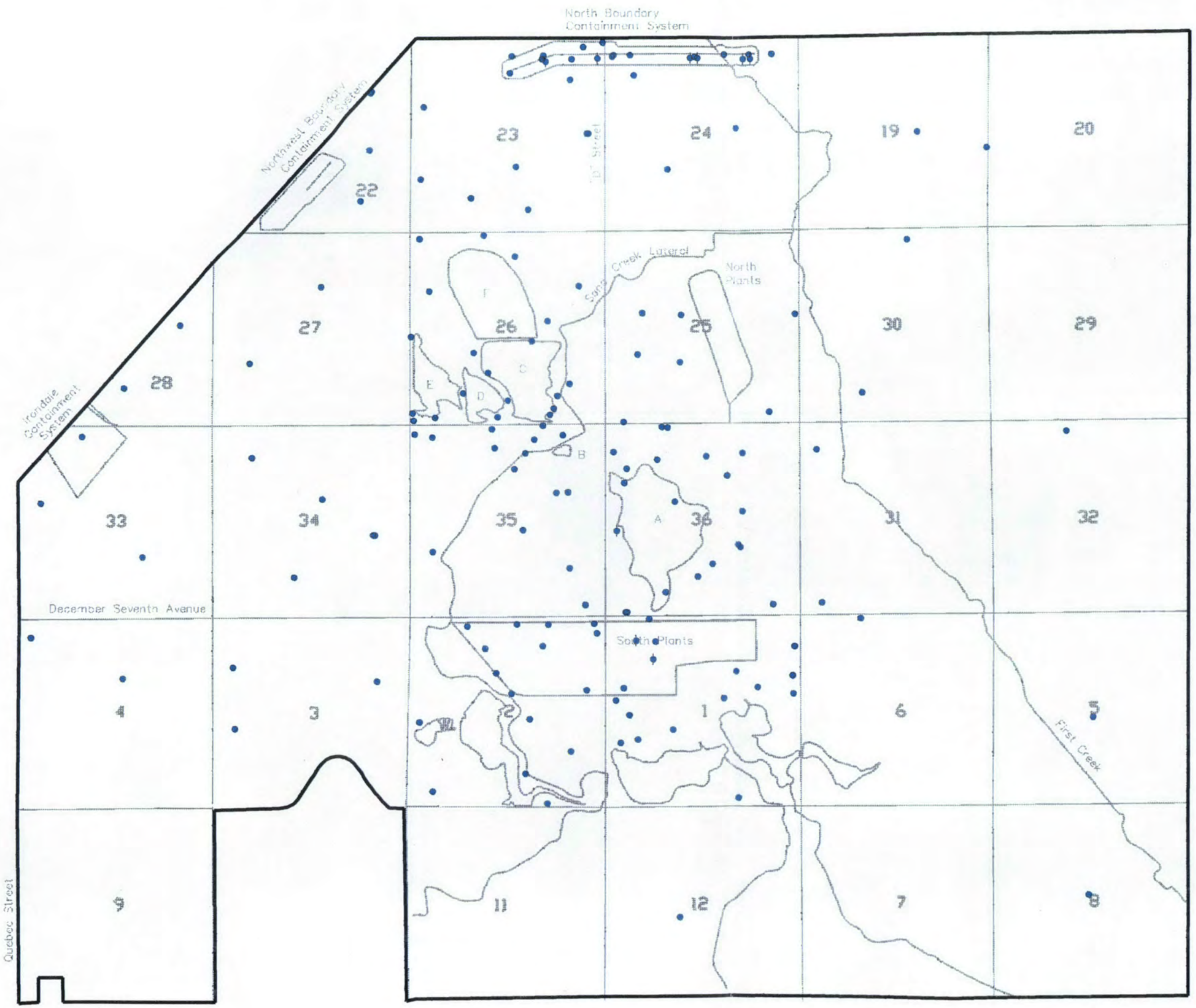
Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared October 1991

FIGURE RISR B.2 – 1
Wells in the 0 to 50 Depth Interval
Considered for the Vertical Extent of
Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins
- ♦ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

- ● Denver Formation well

— N —

0 3000 Feet

Scale: 1" = 3000'

Prepared for:

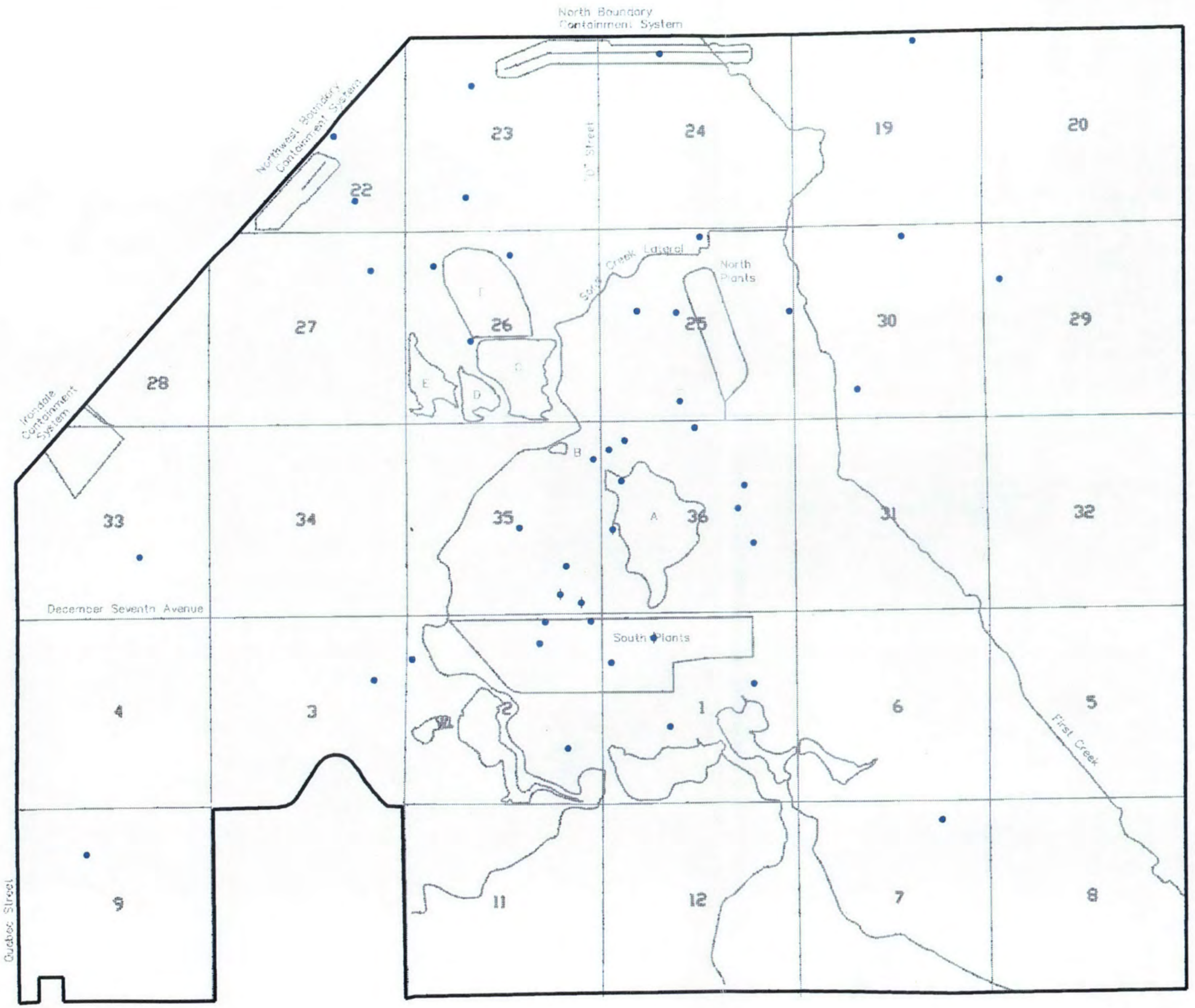
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared October 1991

FIGURE RISR B.2 – 2

Wells in the 50 to 100 Depth Interval Considered for the Vertical Extent of Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

▬ ▬ ▬ Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins
♦ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

● Denver Formation well

N

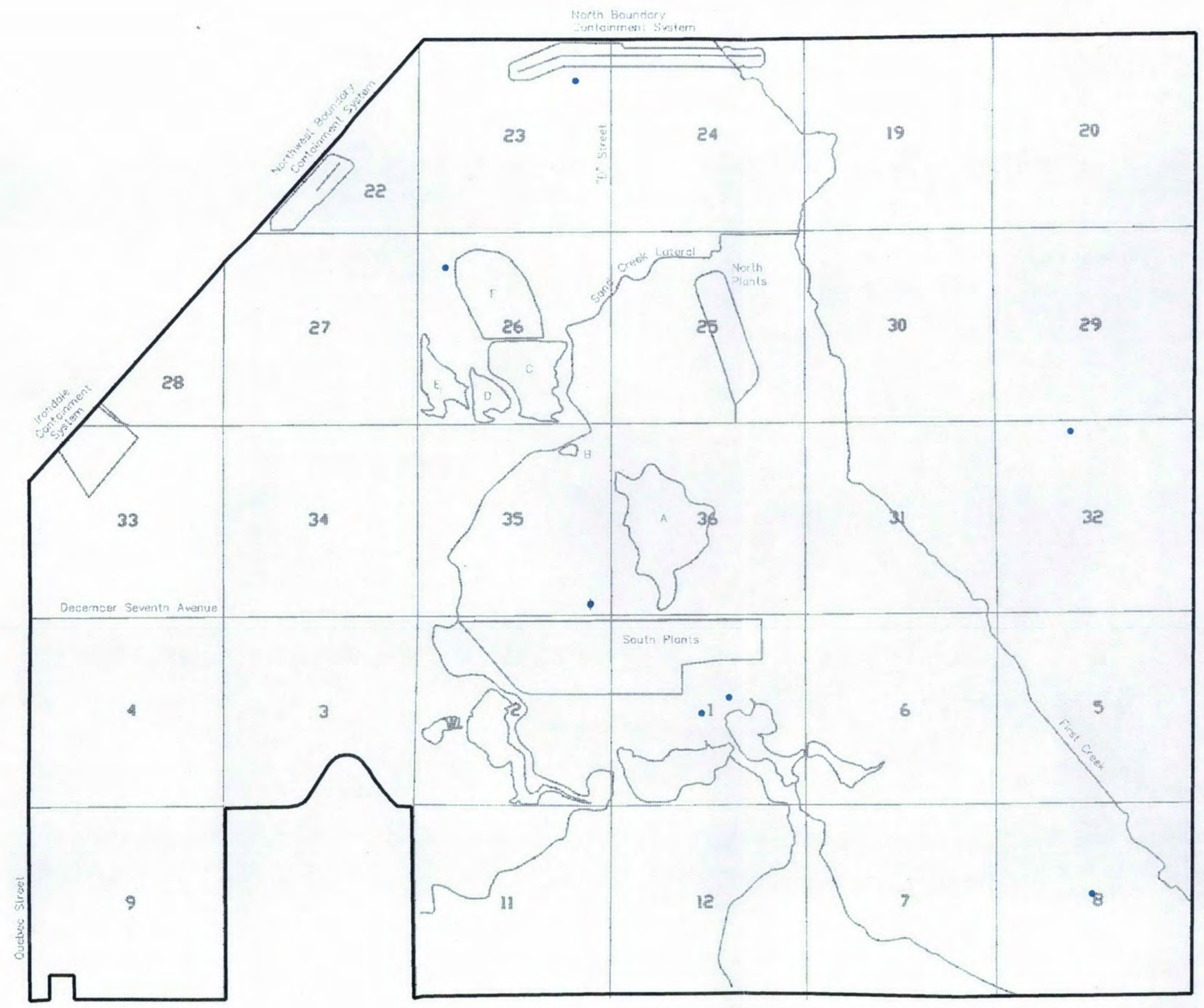
0 3000 Feet
Scale: 1" = 3000'

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

Prepared October 1991

FIGURE RISR B.2 – 3
Wells in the 100 to 150 Depth Interval Considered for the Vertical Extent of Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- ▬ ▬ Rocky Mountain Arsenal Boundary
- ─ Section Lines
- ∿ Streams
- ⬭ Lakes
- Ⓐ Basins
- ♦ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

- ● Denver Formation well

N

0 3000 Feet

Scale: 1" = 3000'

Prepared for:

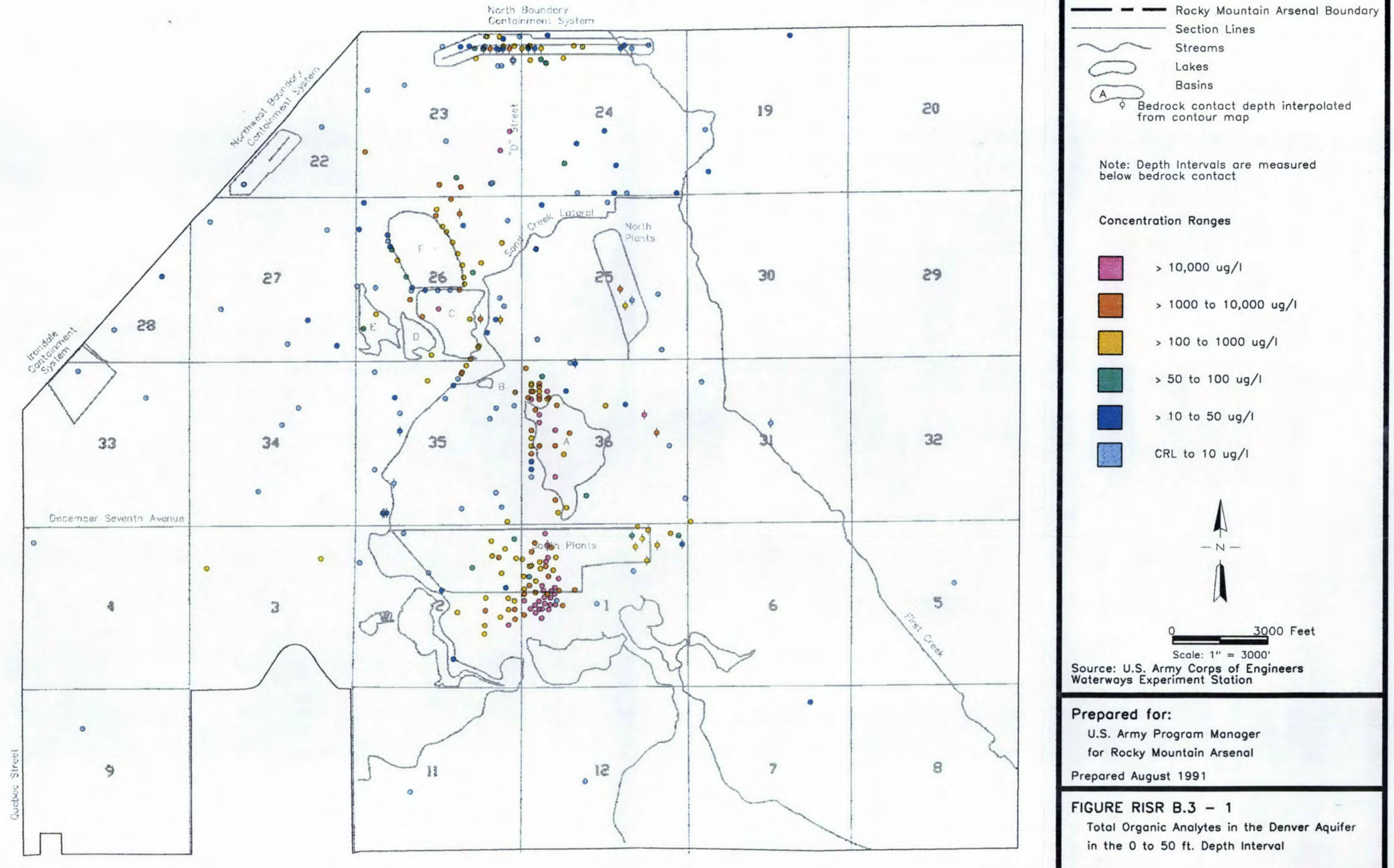
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared October 1991

FIGURE RISR B.2 – 4

Wells in the Greater than 150 Depth Interval Considered for the Vertical Extent of Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

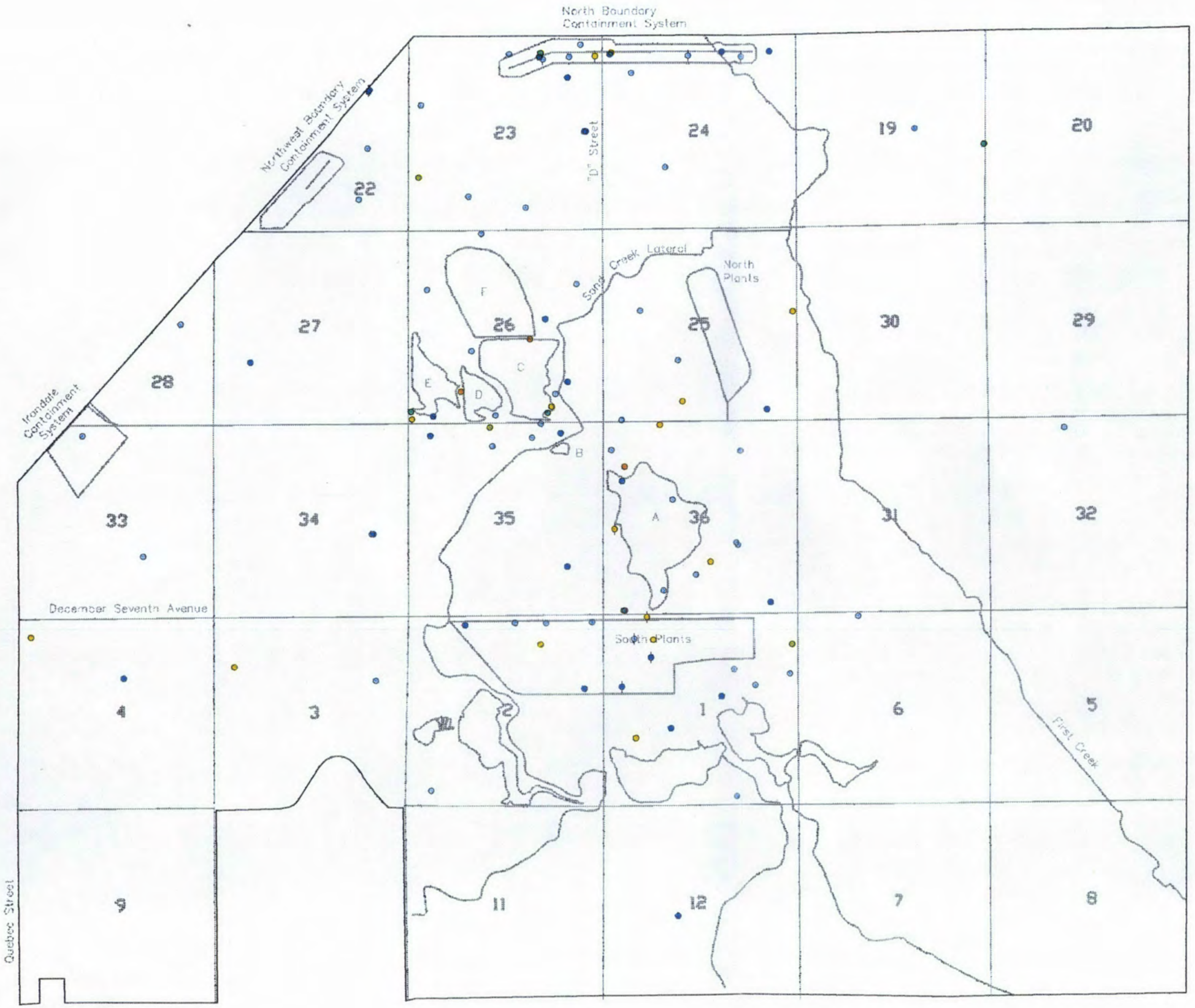
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 1

Total Organic Analytes in the Denver Aquifer in the 0 to 50 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- — — Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins
- Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

🟪	> 10,000 ug/l
🟧	> 1000 to 10,000 ug/l
🟨	> 100 to 1000 ug/l
🟩	> 50 to 100 ug/l
🟦	> 10 to 50 ug/l
▨	CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

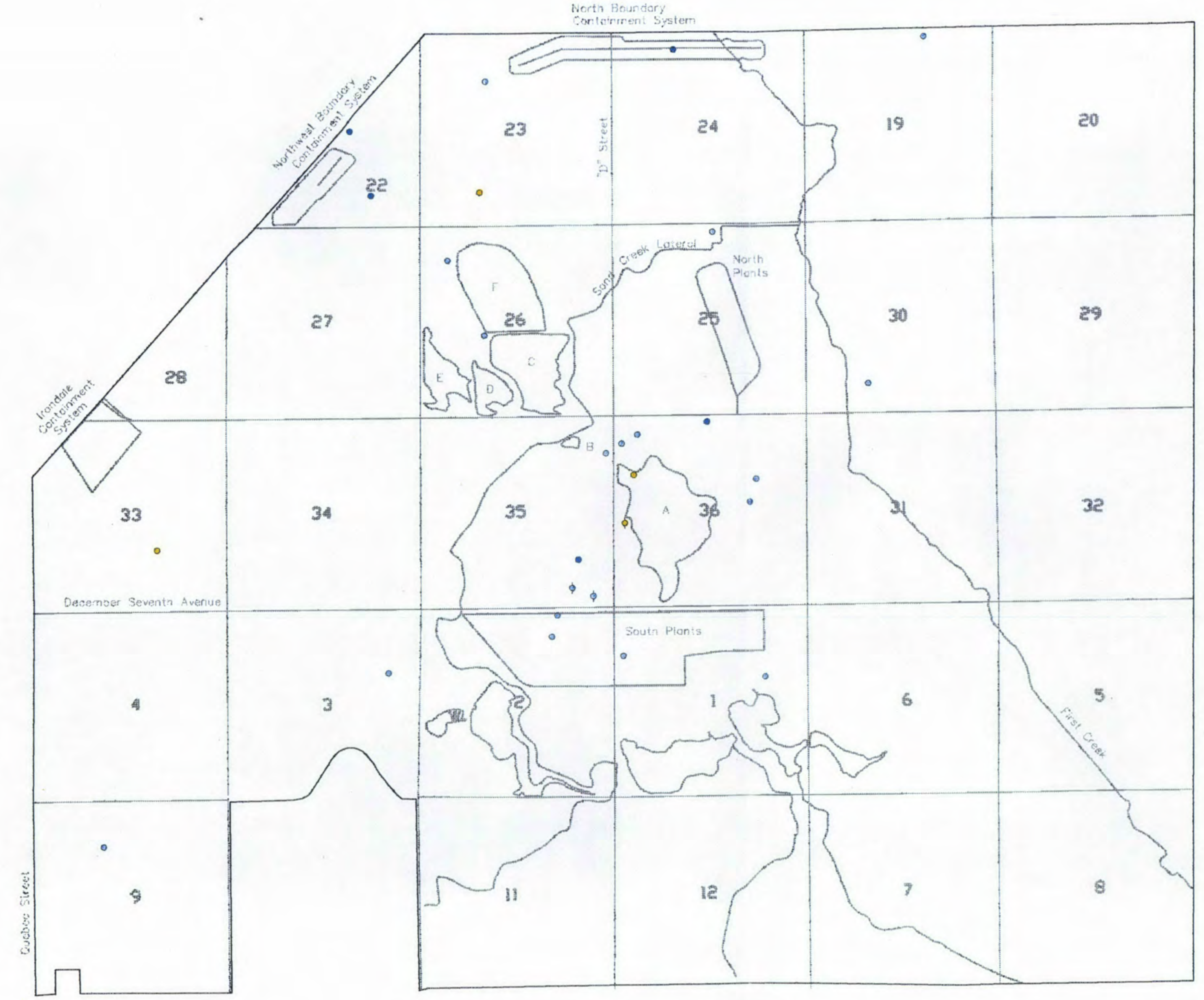
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 2

Total Organic Analytes in the Denver Aquifer in the 50 to 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins
Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

🟪	> 10,000 ug/l
🟧	> 1000 to 10,000 ug/l
🟨	> 100 to 1000 ug/l
🟩	> 50 to 100 ug/l
🟦	> 10 to 50 ug/l
▨	CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

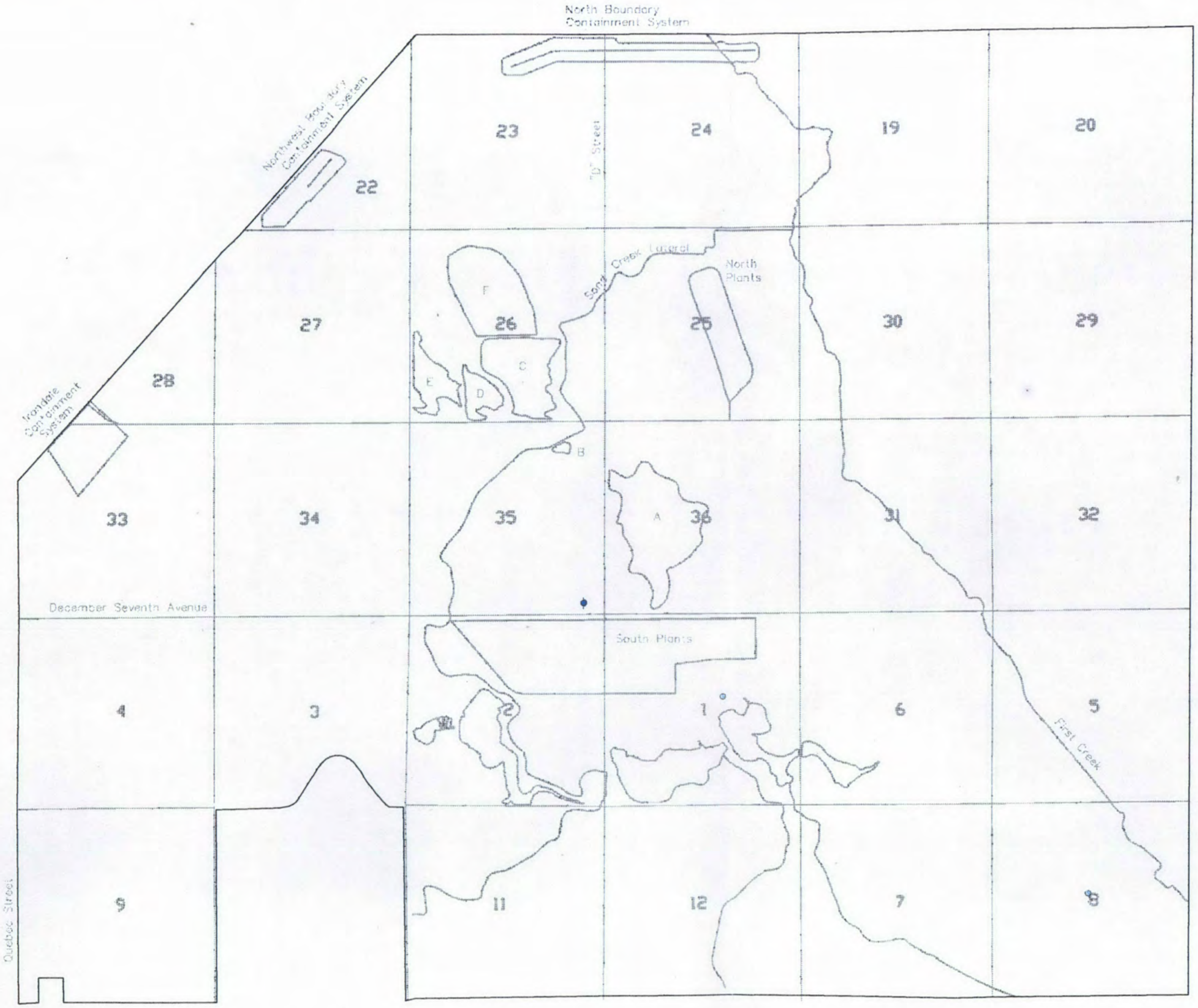
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 3

Total Organic Analytes in the Denver Aquifer in the 100 to 150 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins
Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

🟪	> 10,000 ug/l
🟧	> 1000 to 10,000 ug/l
🟨	> 100 to 1000 ug/l
🟩	> 50 to 100 ug/l
🟦	> 10 to 50 ug/l
🟦	CRL to 10 ug/l

N

0 3000 Feet
Scale: 1" = 3000'

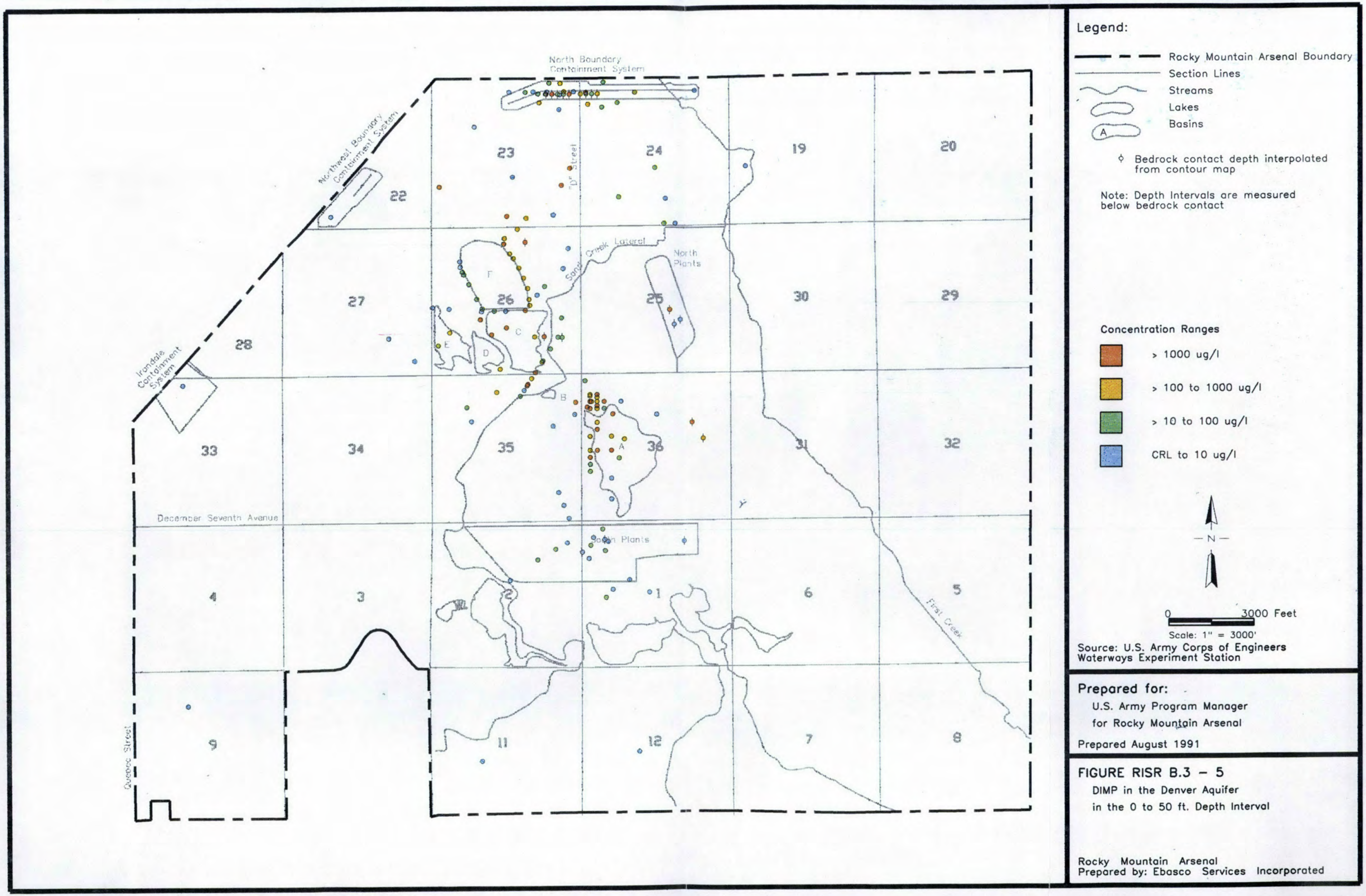
Source: U.S. Army Corps of Engineers Waterways Experiment Station

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

Prepared August 1991

FIGURE RISR B.3 – 4
Total Organic Analytes in the Denver Aquifer in the Greater than 150 ft Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

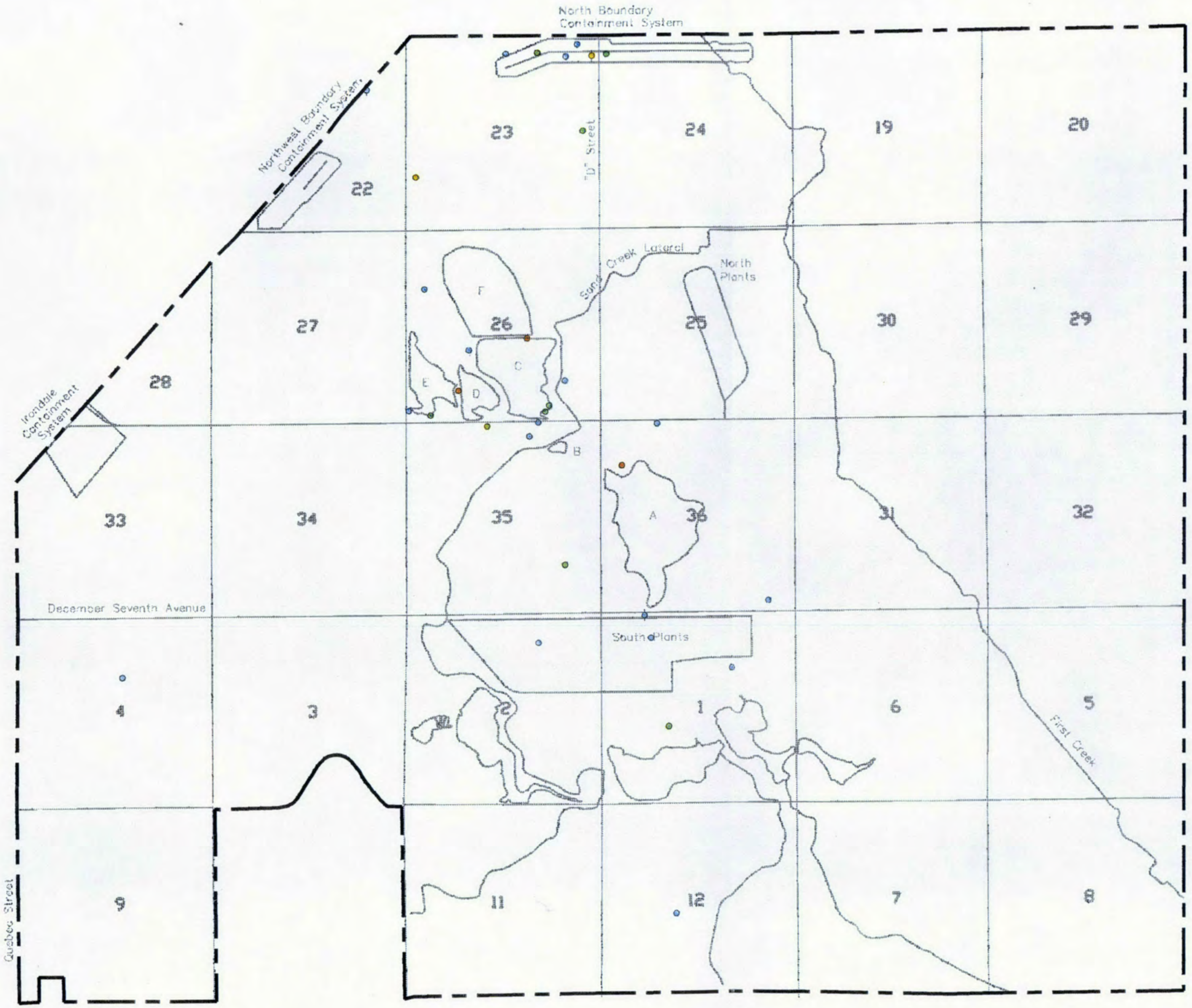
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 5

DIMP in the Denver Aquifer
in the 0 to 50 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins

ϕ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

🟧	> 1000 ug/l
🟨	> 100 to 1000 ug/l
🟩	> 10 to 100 ug/l
🟦	CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

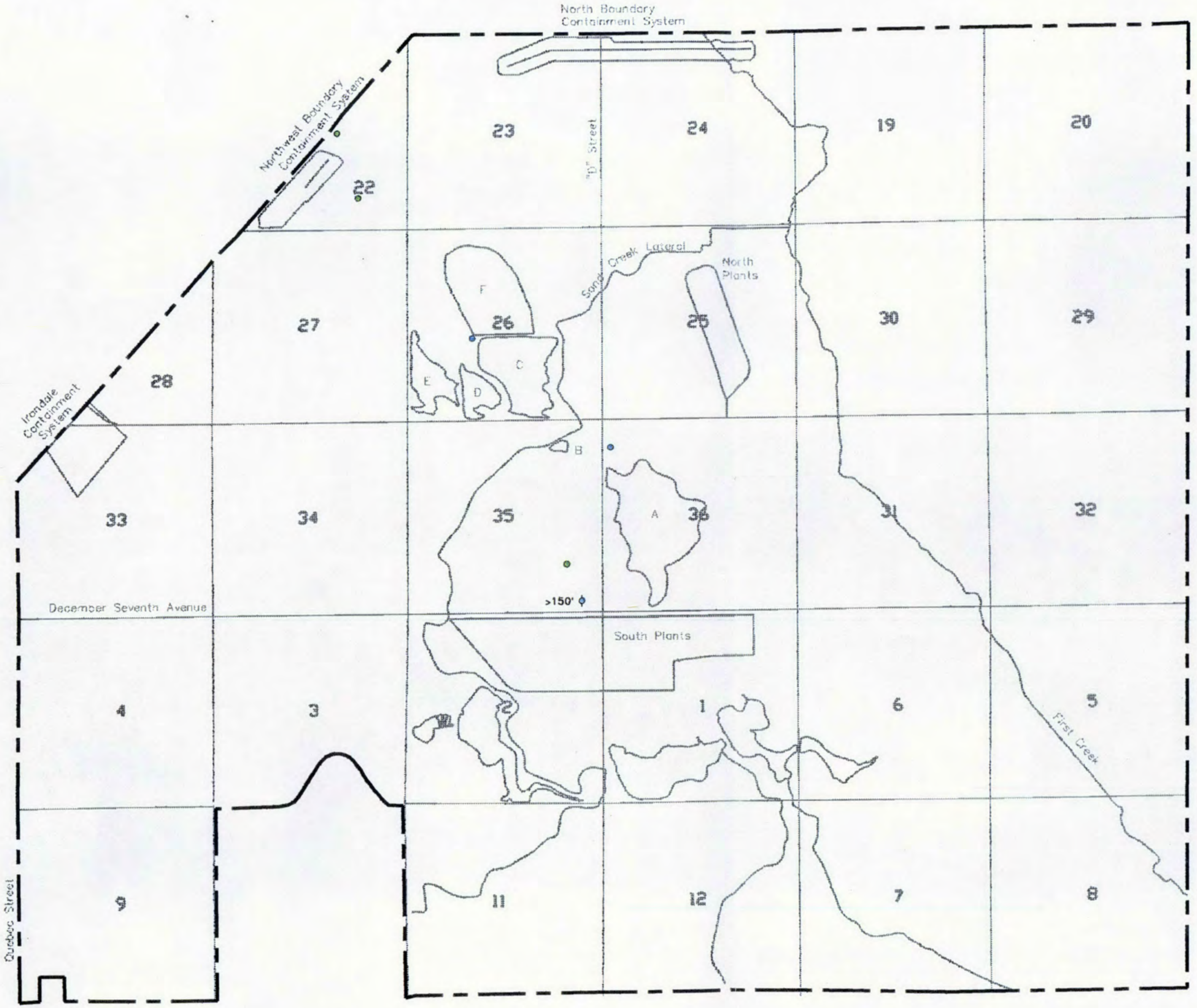
Source: U.S. Army Corps of Engineers
Waterways Experiment Station

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

Prepared August 1991

FIGURE RISR B.3 – 6
DIMP in the Denver Aquifer
in the 50 to 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary

Section Lines

Streams

Lakes

Basins

ϕ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Note: Concentrations were reported in the 100 to 150 ft depth interval unless otherwise noted.

Concentration Ranges

🟧 > 1000 ug/l

🟨 > 100 to 1000 ug/l

🟩 > 10 to 100 ug/l

🟦 CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 7

DIMP in the Denver Aquifer
in the greater that 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

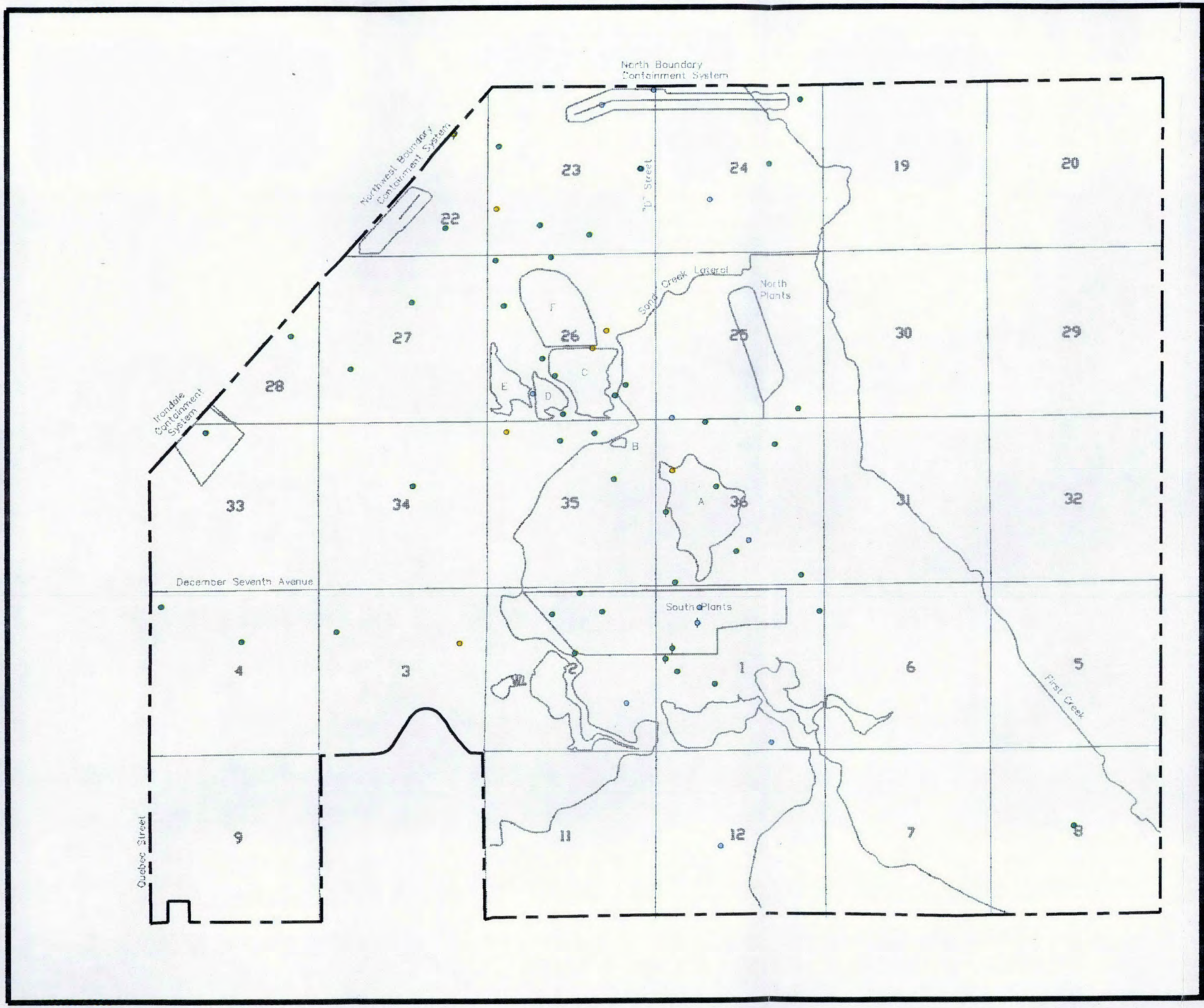
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 8

Arsenic, Mercury, and ICP Metals in the Denver Aquifer in the 0 to 50 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary

Section Lines

Streams

Lakes

Basins

◊ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

🟨 > 100 ug/l

🟩 > 10 to 100 ug/l

🟦 CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

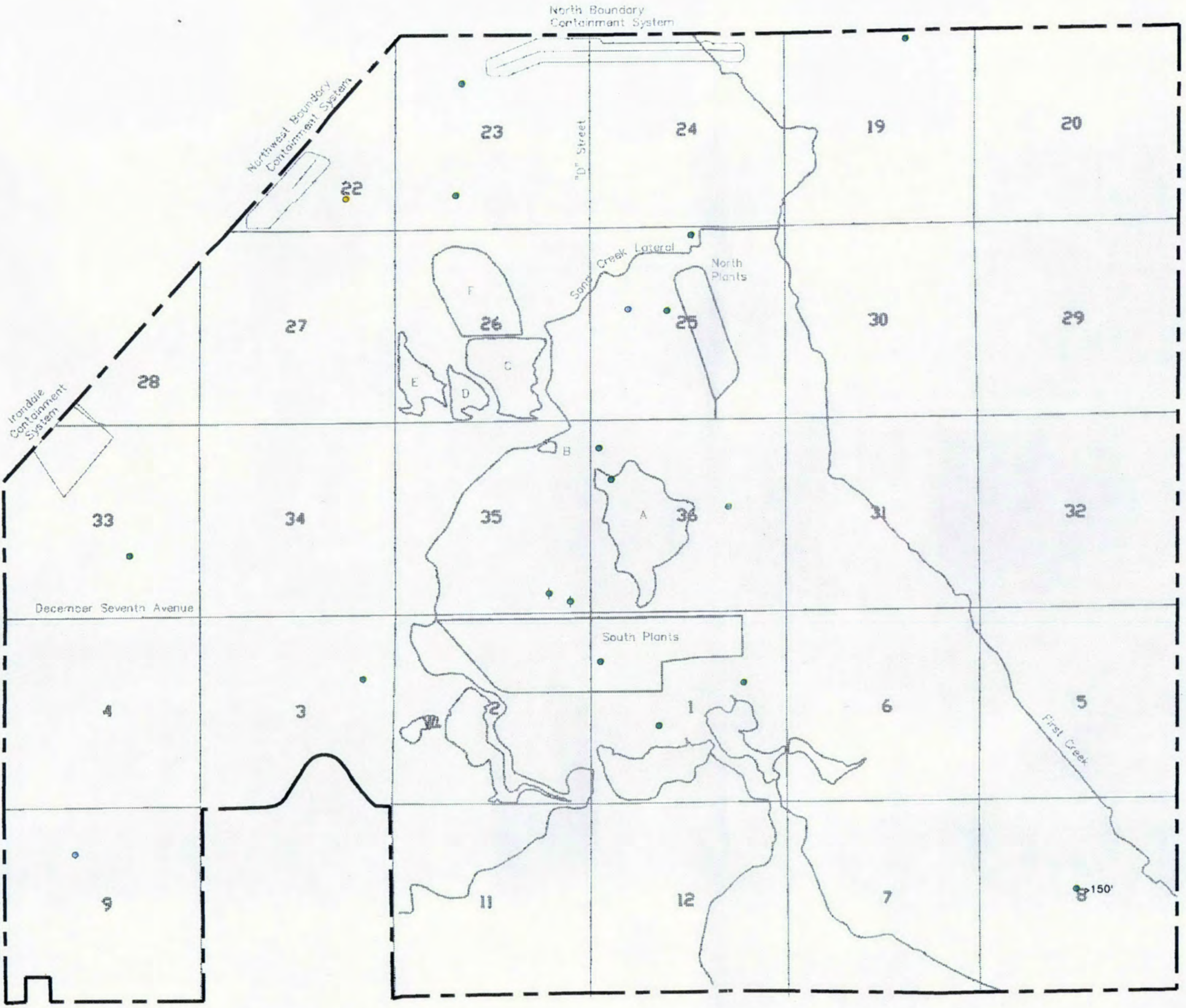
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 9

Arsenic, Mercury, and ICP Metals in the Denver Aquifer in the 50 to 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Note: Concentrations were reported in the 100 to 150 ft depth interval unless otherwise noted.

Concentration Ranges

🟧 > 100 ug/l

🟩 > 10 to 100 ug/l

🟦 CRL to 10 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

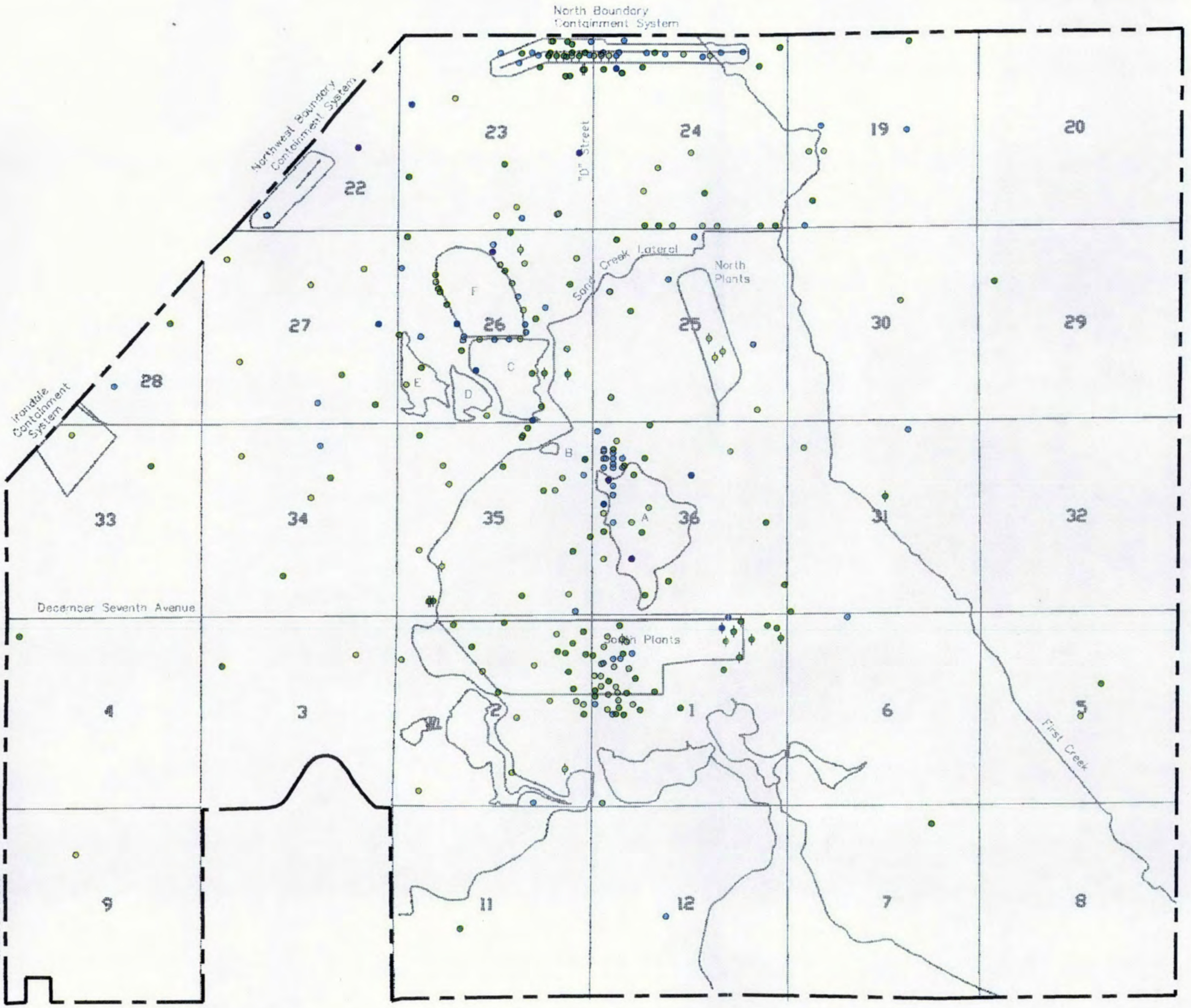
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 10

Arsenic, Mercury, and ICP Metals in the Denver Aquifer Greater than 100 ft

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

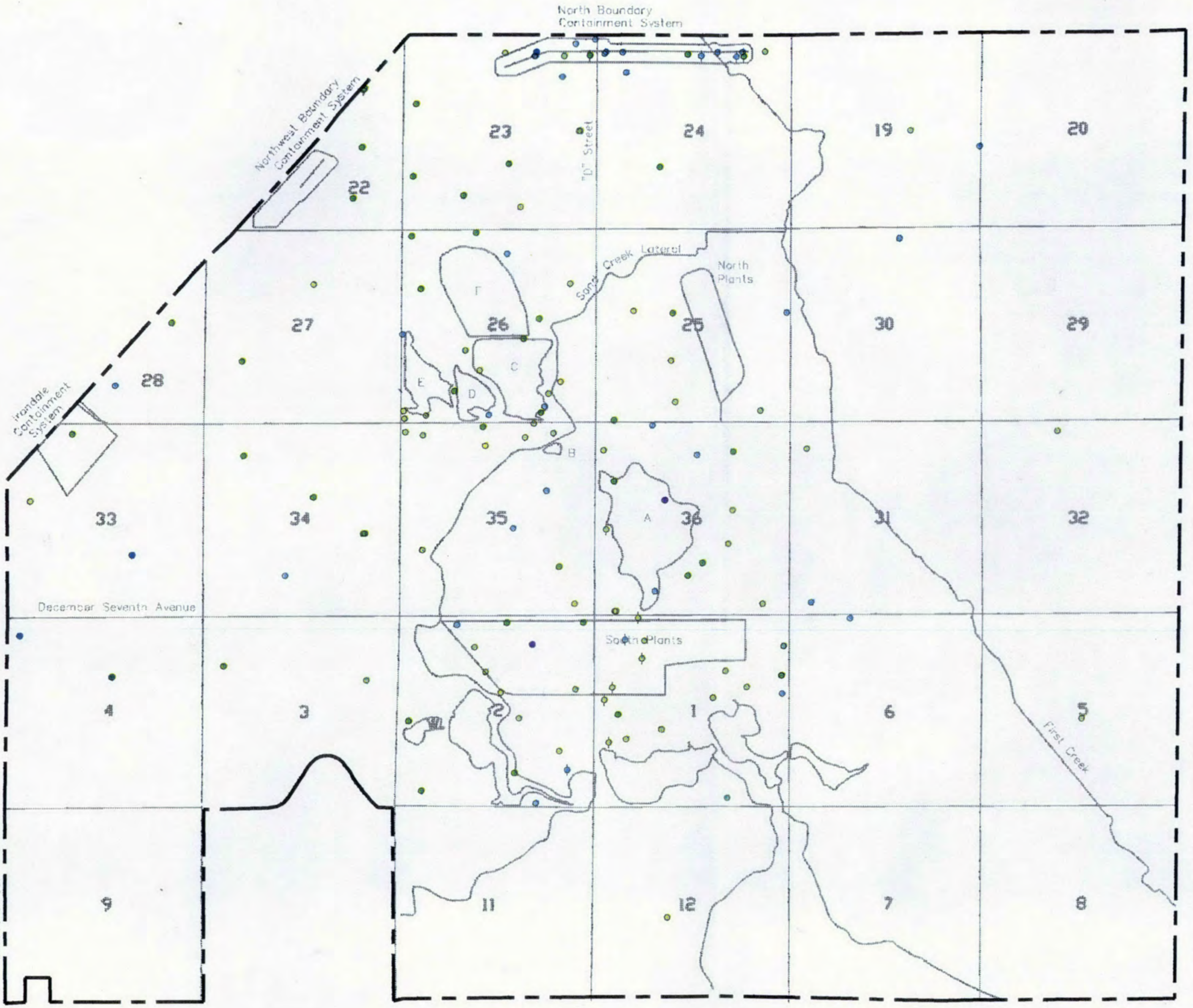
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 11

Fluoride in the Denver Aquifer
in the 0 to 50 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins
- ◊ Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

- 🟪 > 10,000 ug/l
- 🟦 > 5000 to 10,000 ug/l
- 🟩 > 2000 to 5000 ug/l
- 🟩 > 1220 to 2000 ug/l
- 🟦 CRL to 1220 ug/l

N

0 3000 Feet

Scale: 1" = 3000'

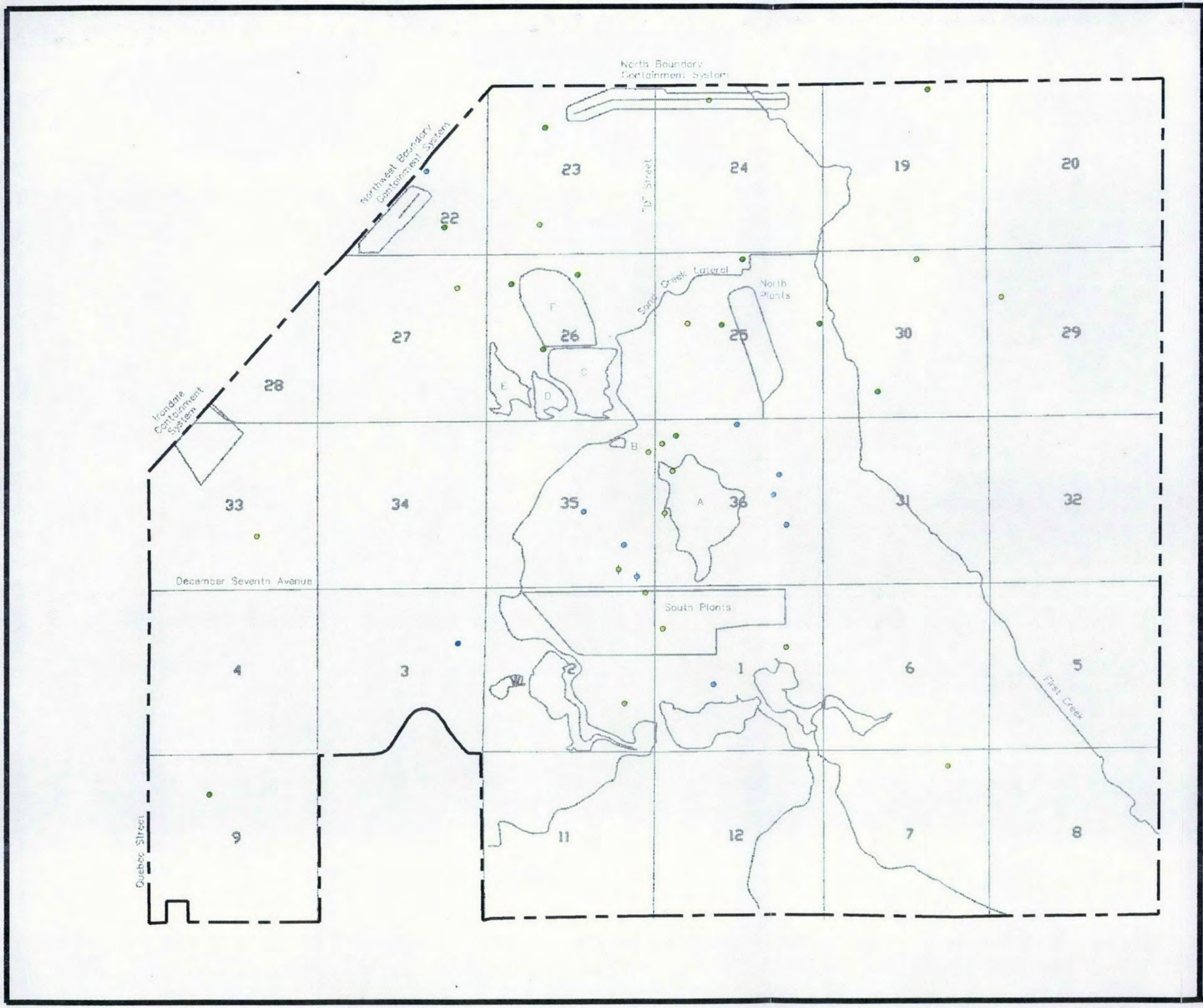
Source: U.S. Army Corps of Engineers
Waterways Experiment Station

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

Prepared August 1991

FIGURE RISR B.3 – 12
Fluoride in the Denver Aquifer
in the 50 to 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



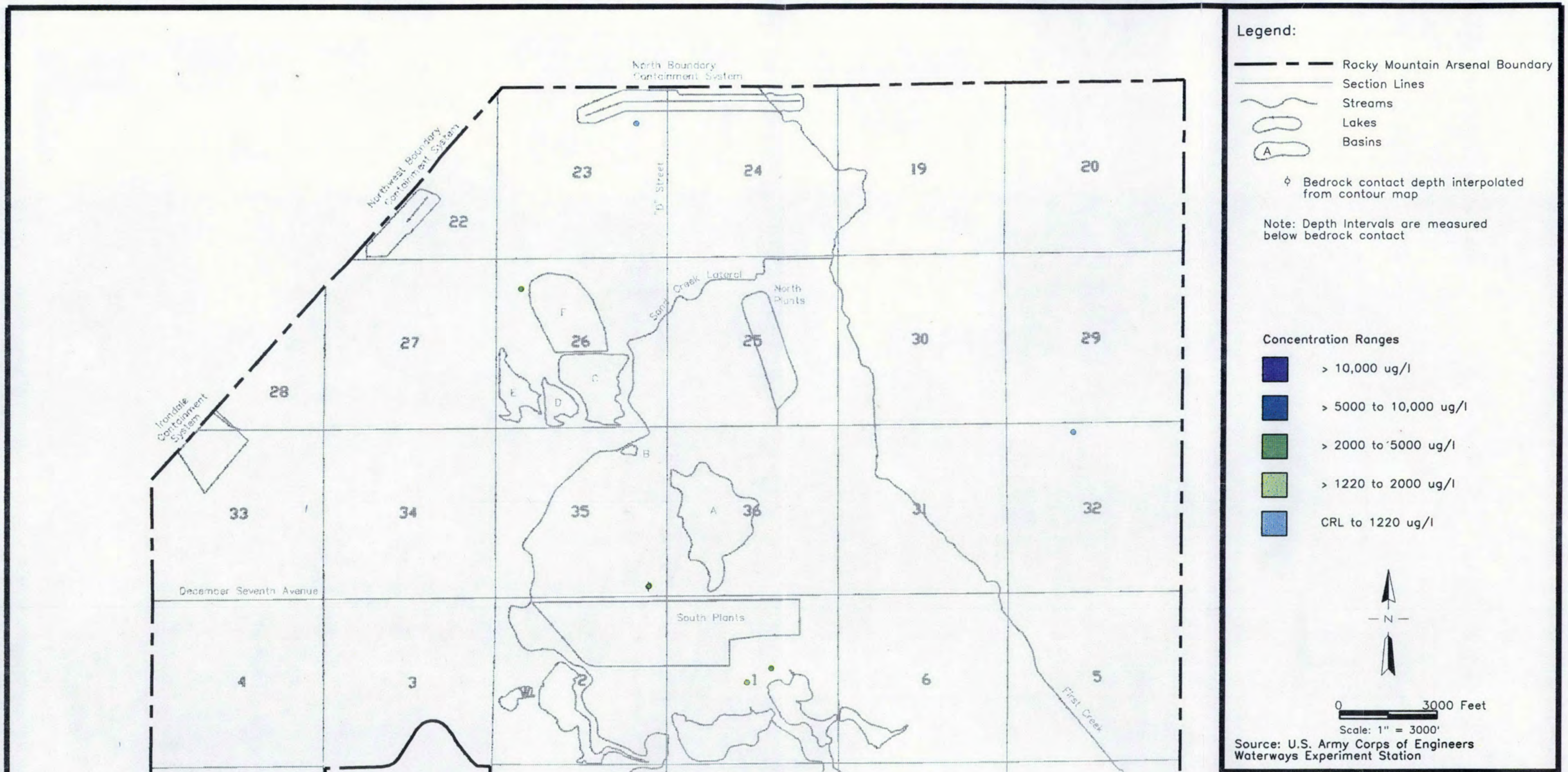
Source: U.S. Army Corps of Engineers Waterways Experiment Station

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

Prepared August 1991

FIGURE RISR B.3 – 13
Fluoride in the Denver Aquifer
in the 100 to 150 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

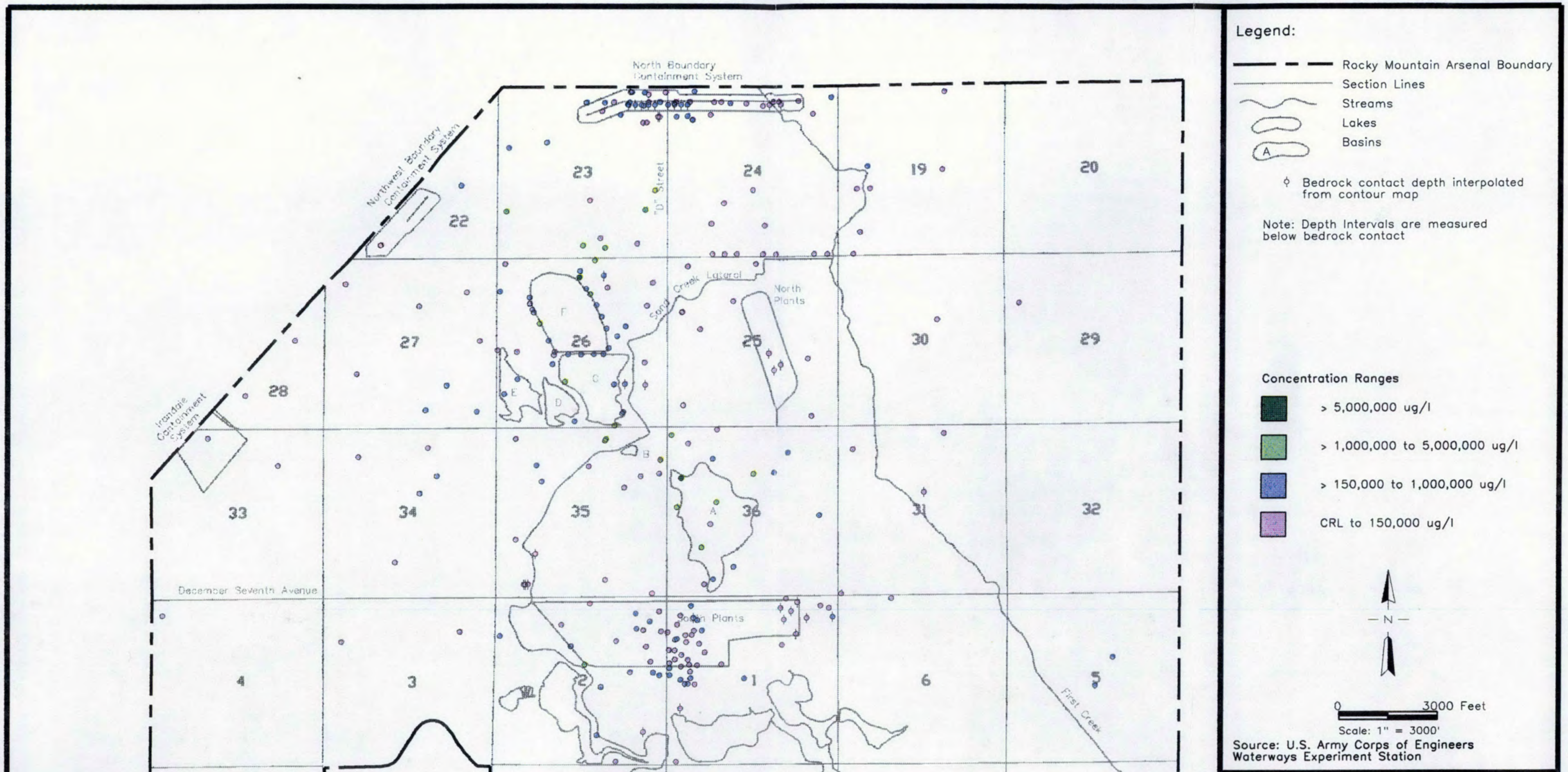
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 14

Fluoride in the Denver Aquifer
Greater than 150 ft

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

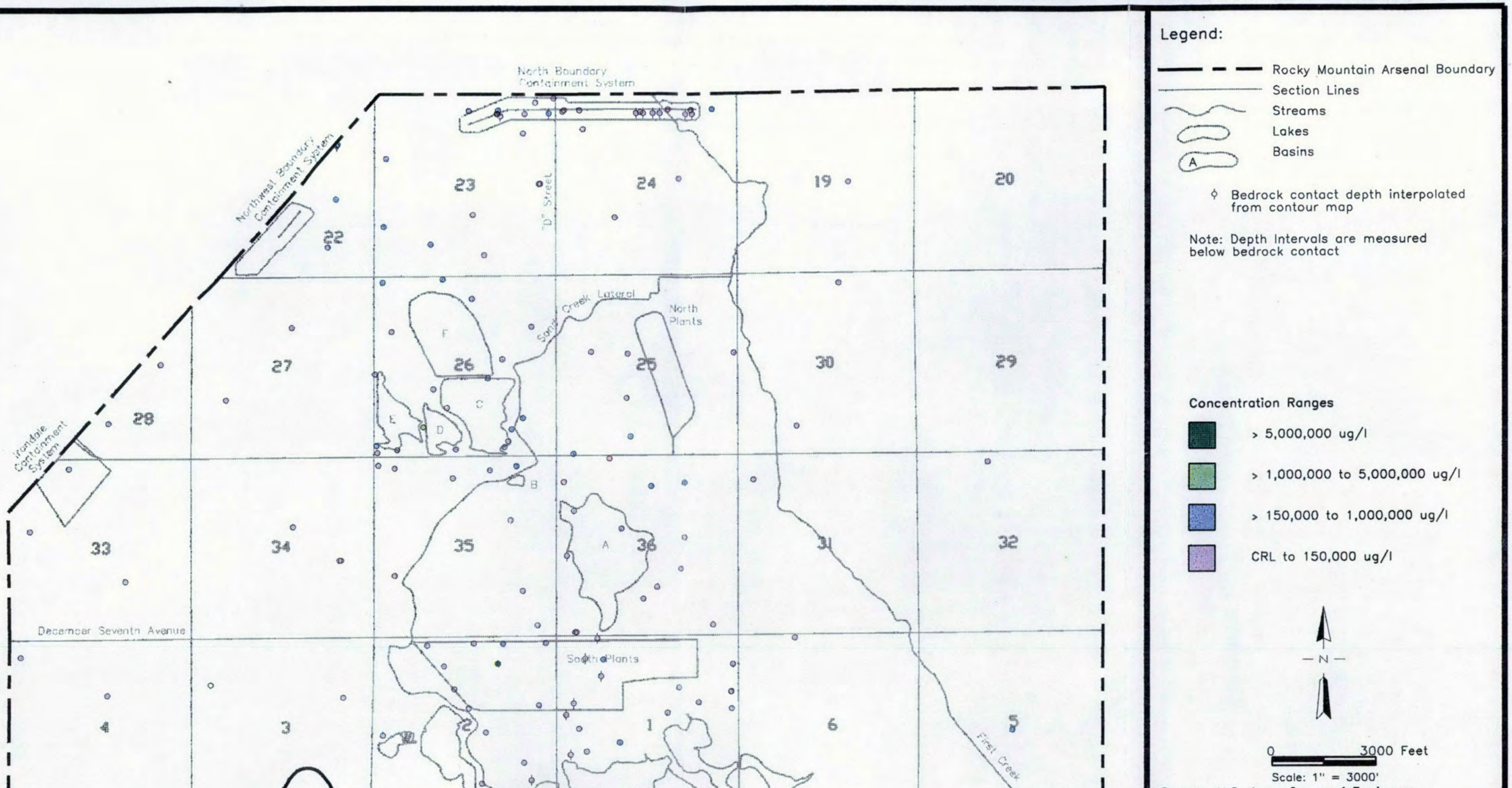
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 15

Chloride in the Denver Aquifer
in the 0 to 50 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



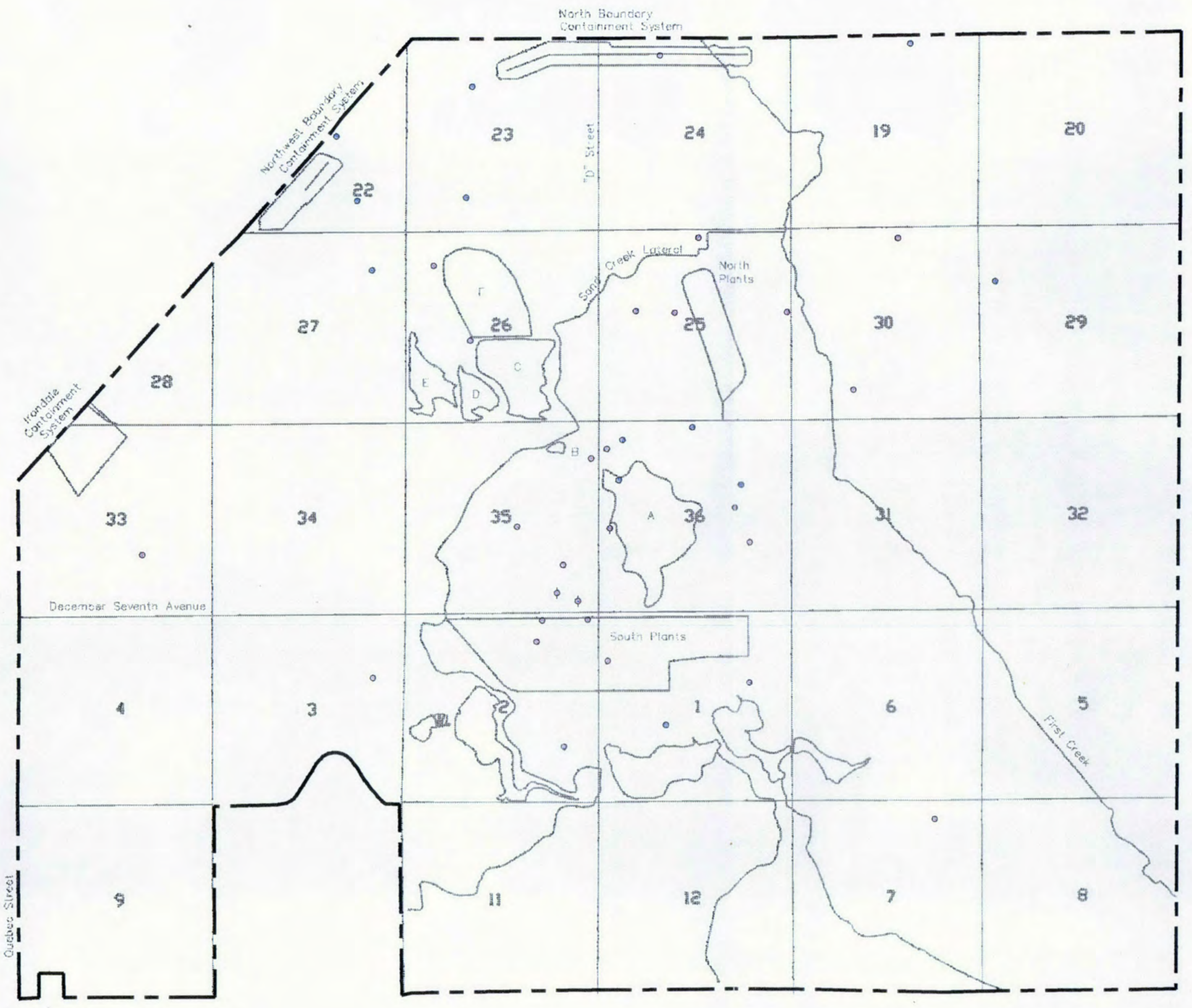
Source: U.S. Army Corps of Engineers Waterways Experiment Station

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

Prepared August 1991

FIGURE RISR B.3 – 16
Chloride in the Denver Aquifer
in the 50 to 100 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

Bedrock contact depth interpolated from contour map

Note: Depth Intervals are measured below bedrock contact

Concentration Ranges

■ > 5,000,000 ug/l
🟩 > 1,000,000 to 5,000,000 ug/l
🟦 > 150,000 to 1,000,000 ug/l
🟪 CRL to 150,000 ug/l

N

0 3000 Feet
Scale: 1" = 3000'

Source: U.S. Army Corps of Engineers Waterways Experiment Station

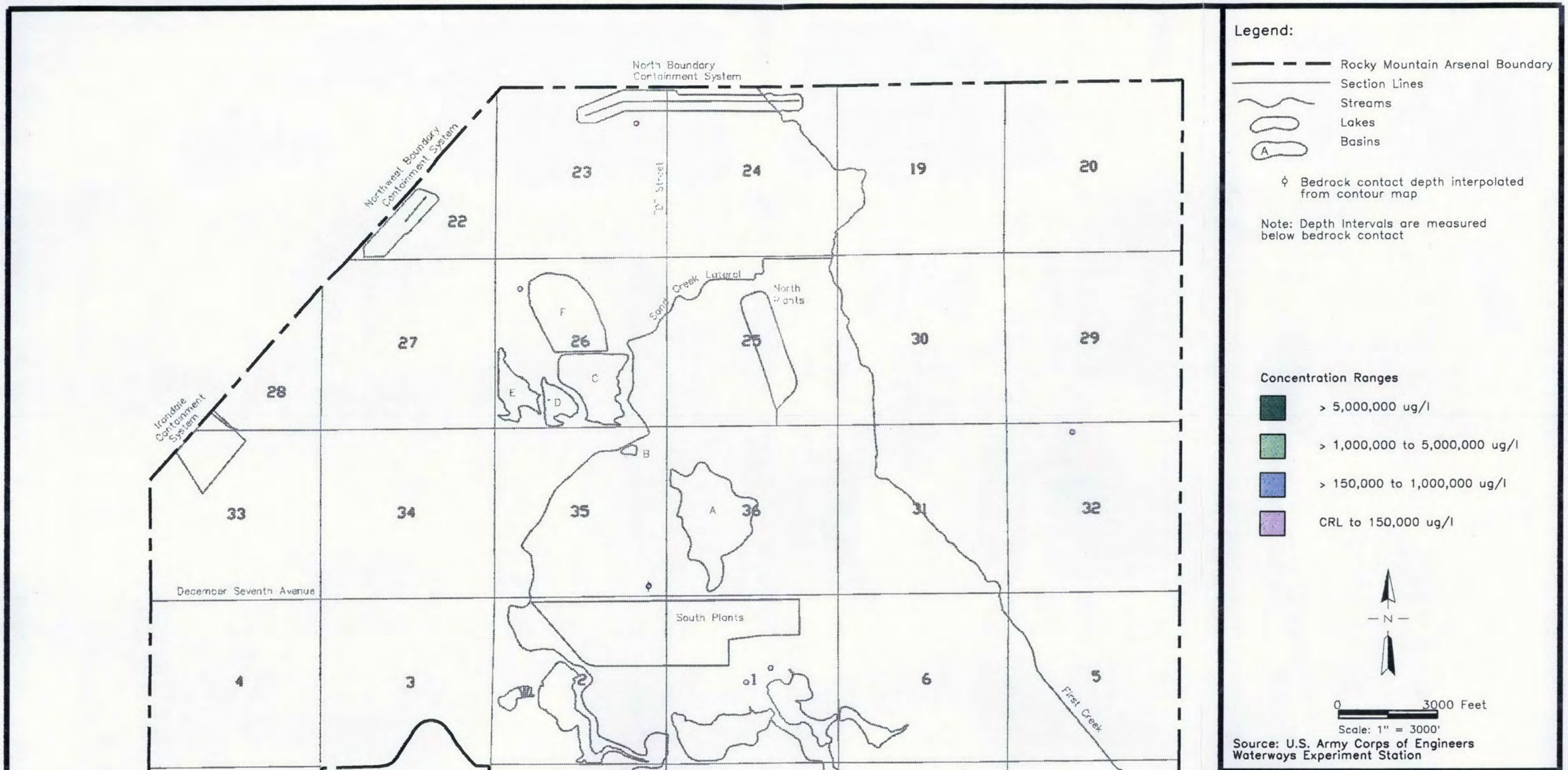
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 17

Chloride in the Denver Aquifer
in the 100 to 150 ft. Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers
Waterways Experiment Station

Prepared for:

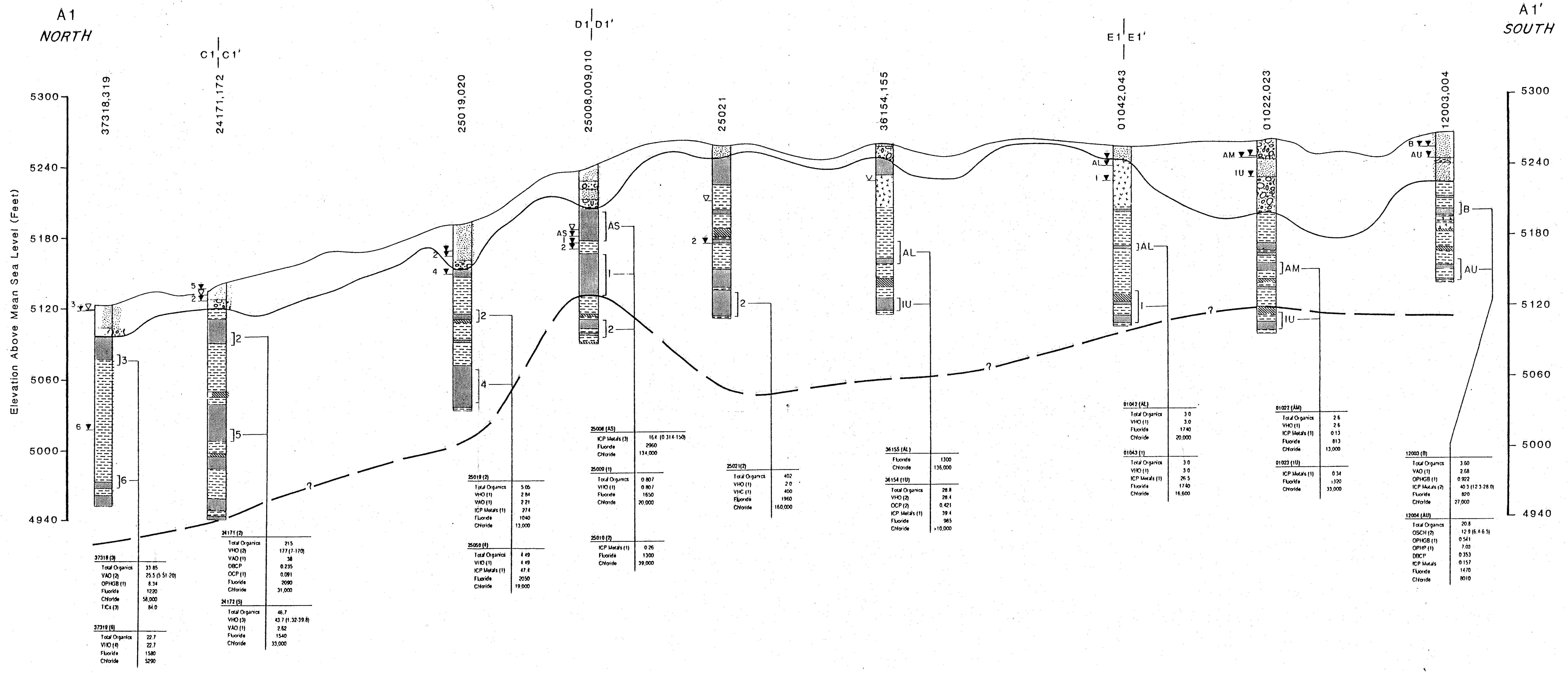
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.3 – 18

Chloride in the Denver Aquifer
Greater than 150 ft

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



37318 (3)	
Total Organics	33.85
VAO (2)	25.5 (5.51-20)
OPHGB (1)	8.34
Fluoride	1220
Chloride	58,000
TICs (3)	84.0

37319 (6)	
Total Organics	22.7
VHO (4)	22.7
Fluoride	1580
Chloride	5290

24171 (2)	
Total Organics	215
VHO (2)	177 (7-170)
VAO (1)	38
DBCP	0.235
OCP (1)	0.091
Fluoride	2090
Chloride	31,000

24172 (5)	
Total Organics	46.7
VHO (3)	43.7 (1.32-39.8)
VAO (1)	2.62
Fluoride	1540
Chloride	33,000

25019 (2)	
Total Organics	5.06
VHO (1)	2.84
VAO (1)	2.21
ICP Metals (1)	274
Fluoride	1040
Chloride	13,000

25050 (4)	
Total Organics	4.49
VHO (1)	4.49
ICP Metals (1)	47.4
Fluoride	2050
Chloride	19,000

25008 (AS)	
ICP Metals (3)	164 (0.314-150)
Fluoride	2960
Chloride	134,000

25009 (1)	
Total Organics	0.807
VHO (1)	0.807
Fluoride	1650
Chloride	20,000

25010 (2)	
ICP Metals (1)	0.26
Fluoride	1300
Chloride	39,000

25021(2)	
Total Organics	402
VHO (1)	2.0
VHC (1)	400
Fluoride	1960
Chloride	160,000

36155 (AL)	
Fluoride	1300
Chloride	136,000

36154 (IU)	
Total Organics	28.8
VHO (2)	28.4
OCP (2)	0.421
ICP Metals (1)	39.4
Fluoride	985
Chloride	>10,000

01042 (AL)	
Total Organics	3.0
VHO (1)	3.0
Fluoride	1740
Chloride	20,000

01043 (1)	
Total Organics	3.0
VHO (1)	3.0
ICP Metals (1)	26.5
Fluoride	1740
Chloride	16,600

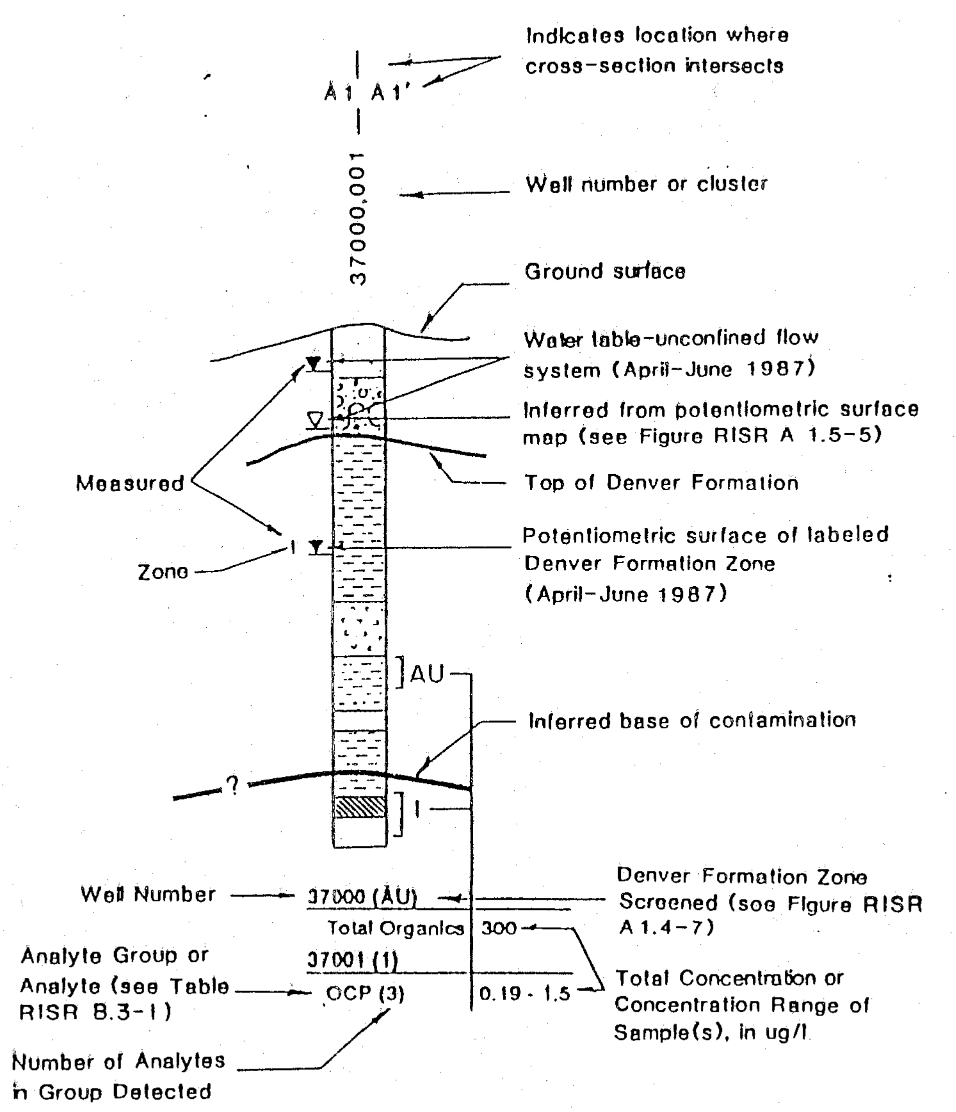
01022 (AM)	
Total Organics	2.6
VHO (1)	2.6
ICP Metals (1)	0.13
Fluoride	813
Chloride	13,000

01023 (IU)	
ICP Metals (1)	0.34
Fluoride	1320
Chloride	33,000

12003 (B)	
Total Organics	3.60
VAO (1)	2.68
OPHGB (1)	0.922
ICP Metals (2)	40.3 (12.3-28.0)
Fluoride	820
Chloride	27,000

12004 (AU)	
Total Organics	20.8
OSCH (2)	12.9 (6.4-6.5)
OPHGB (1)	0.541
OPHP (1)	7.03
DBCP	0.353
ICP Metals	0.157
Fluoride	1470
Chloride	8010

LEGEND



NOTE: Concentrations for Total Organics do not include Tentatively Identified Compounds (TICs)

LITHOLOGY

ALLUVIUM

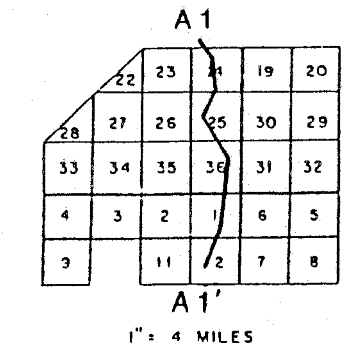
▒	**Fine-Grained Units** Silty clayey sands, poorly graded sand-silt, sandy-clay mixtures.
▒	**Coarse-Grained Units** Poor to well graded gravels, gravel-sand mixtures, clayey gravels, poor to well-graded sands, gravelly sands, little or no fines.

DENVER FORMATION

☐	**Sandstone Units** Fine to coarse-grained, friable to well-cemented. Poorly to moderately-sorted, poorly to well-bedded.
☰	**Claystone Units and Siltstone** Clayey to sandy, grades laterally and vertically into claystone and sandstones, poorly to well-bedded.
▨	**Lignite** Soft to brittle, lignite grades from subbituminous C coal into organic rich claystone, poorly to well-defined bedding and joints.
▒	**Volcaniclastic** Fine to coarse volcanic fragments in a bentonitic clay and silt matrix.

60
VERTICAL
Scale In Feet
0 HORIZONTAL 1500

Vertical Exaggeration – 25X



INDEX MAP

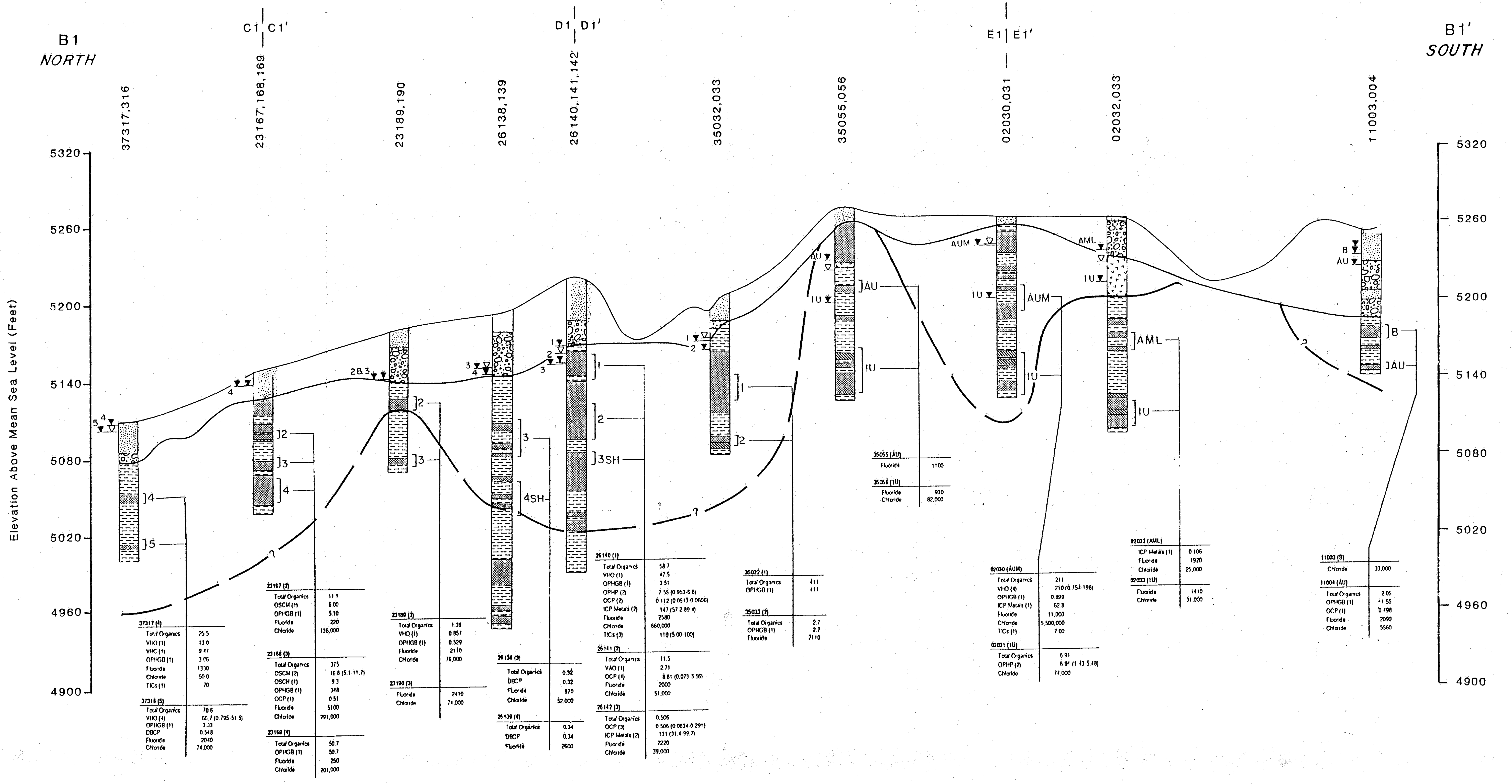
Prepared for:
U.S. Army Program Manager for
the Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.4-1

Vertical Extent of Contamination in the Denver Formation Along Cross-Section A1-A1'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



37317 (4)	
Total Organics	75.5
VHO (1)	13.0
VHC (1)	9.47
OPHGB (1)	3.06
Fluoride	1330
Chloride	50.0
TICs (1)	70

37316 (5)	
Total Organics	70.6
VHO (4)	66.7 (0.795-51.5)
OPHGB (1)	3.33
DBCP	0.548
Fluoride	2040
Chloride	74,000

23167 (2)	
Total Organics	11.1
OSCM (1)	6.00
OPHGB (1)	5.10
Fluoride	220
Chloride	136,000

23168 (3)	
Total Organics	375
OSCM (2)	16.8 (5.1-11.7)
OSCH (1)	9.3
OPHGB (1)	348
OCP (1)	0.51
Fluoride	5100
Chloride	291,000

23169 (4)	
Total Organics	50.7
OPHGB (1)	50.7
Fluoride	250
Chloride	201,000

23189 (2)	
Total Organics	1.39
VHO (1)	0.857
OPHGB (1)	0.529
Fluoride	2110
Chloride	76,000

23190 (3)	
Fluoride	2410
Chloride	74,000

26138 (3)	
Total Organics	0.32
DBCP	0.32
Fluoride	870
Chloride	52,000

26139 (4)	
Total Organics	0.34
DBCP	0.34
Fluoride	2600

26140 (1)	
Total Organics	58.7
VHO (1)	47.5
OPHGB (1)	3.51
OPHP (2)	7.55 (0.953-6.6)
OCP (2)	0.112 (0.0513-0.0606)
ICP Metals (2)	147 (57.2-89.4)
Fluoride	2580
Chloride	660,000
TICs (3)	110 (5.00-100)

26141 (2)	
Total Organics	11.5
VAO (1)	2.71
OCP (4)	8.81 (0.073-5.56)
Fluoride	2000
Chloride	51,000

26142 (3)	
Total Organics	0.506
OCP (3)	0.506 (0.0634-0.291)
ICP Metals (2)	131 (31.4-99.7)
Fluoride	2220
Chloride	39,000

35032 (1)	
Total Organics	411
OPHGB (1)	411

35033 (2)	
Total Organics	2.7
OPHGB (1)	2.7
Fluoride	2110

35055 (AU)	
Fluoride	1100

35056 (1U)	
Fluoride	930
Chloride	82,000

02030 (AUM)	
Total Organics	211
VHO (4)	210 (0.754-198)
OPHGB (1)	0.899
ICP Metals (1)	62.8
Fluoride	11,000
Chloride	5,500,000
TICs (1)	7.00

02031 (1U)	
Total Organics	6.91
OPHP (2)	6.91 (1.43-5.48)
Chloride	74,000

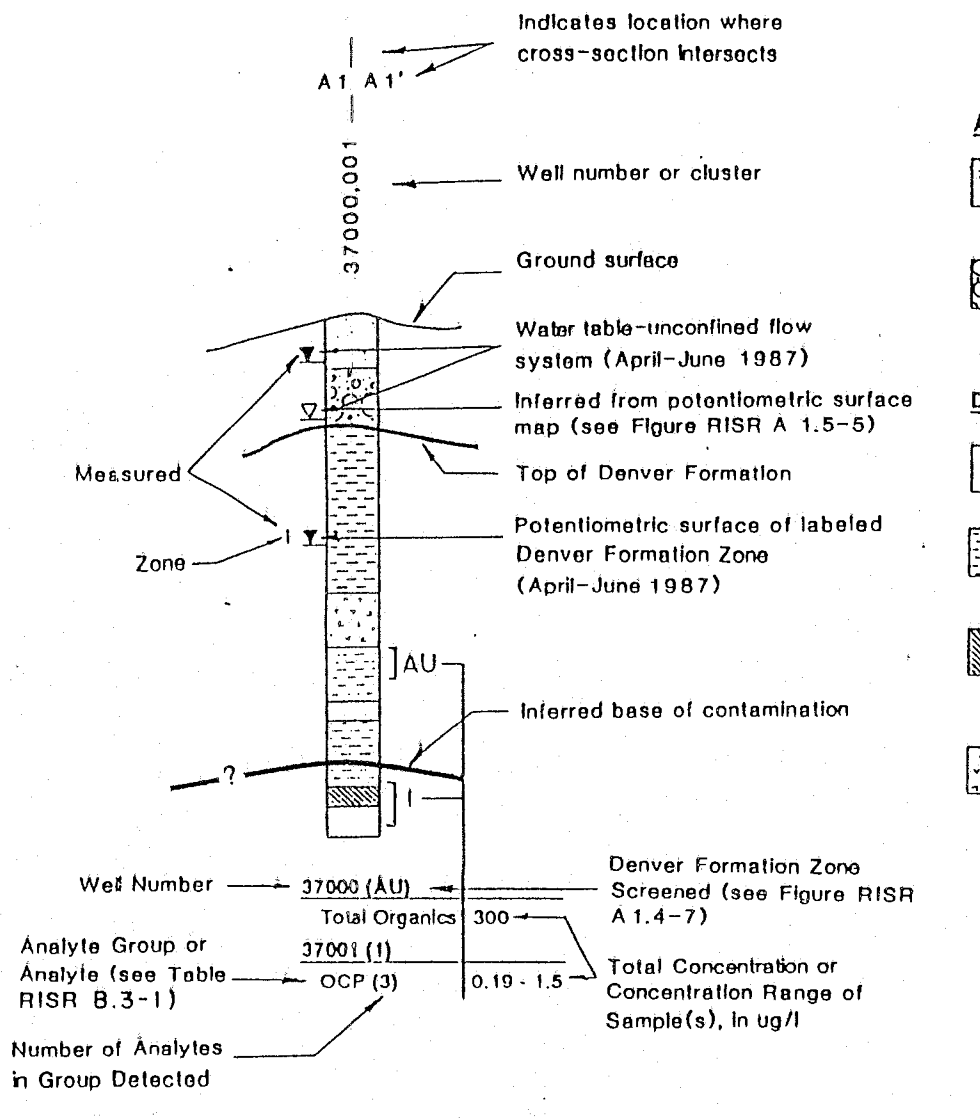
02032 (AML)	
ICP Metals (1)	0.106
Fluoride	1920
Chloride	25,000

02033 (1U)	
Fluoride	1410
Chloride	31,000

11003 (B)	
Chloride	33,000

11004 (AU)	
Total Organics	2.05
OPHGB (1)	•1.55
OCP (1)	0.498
Fluoride	2090
Chloride	5560

LEGEND



37000 (AU)	
Total Organics	300

37001 (1)	
OCP (3)	0.19 - 1.5

NOTE: Concentrations for Total Organics do not include Tentatively Identified Compounds (TICs)

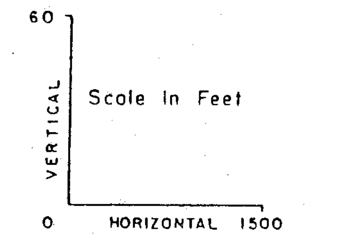
LITHOLOGY

ALLUVIUM

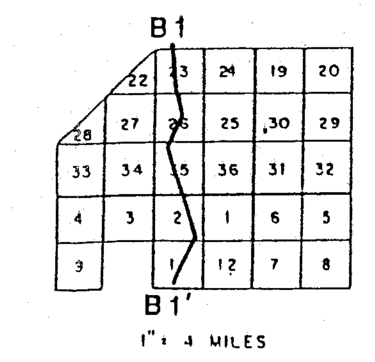
░	**Fine-Grained Units** Silty clayey sands, poorly graded sand-silt, sandy-clay mixtures.
°	**Coarse-Grained Units** Poor to well graded gravels, gravel-sand mixtures, clayey gravels, poor to well-graded sands, gravelly sands, little or no fines.

DENVER FORMATION

☐	**Sandstone Units** Fine to coarse-grained, friable to well-cemented. Poorly to moderately-sorted, poorly to well-bedded.
☰	**Claystone Units and Siltstone** Clayey to sandy, grades laterally and vertically into claystone and sandstones, poorly to well-bedded.
▨	**Lignite** Soft to brittle, lignite grades from subbituminous C coal into organic rich claystone, poorly to well-defined bedding and joints.
⁖	**Volcaniclastic** Fine to coarse volcanic fragments in a bentonitic clay and silt matrix.



Vertical Exageration - 25X



1" = 4 MILES

INDEX MAP

Prepared for:

U.S. Army Program Manager for
the Rocky Mountain Arsenal

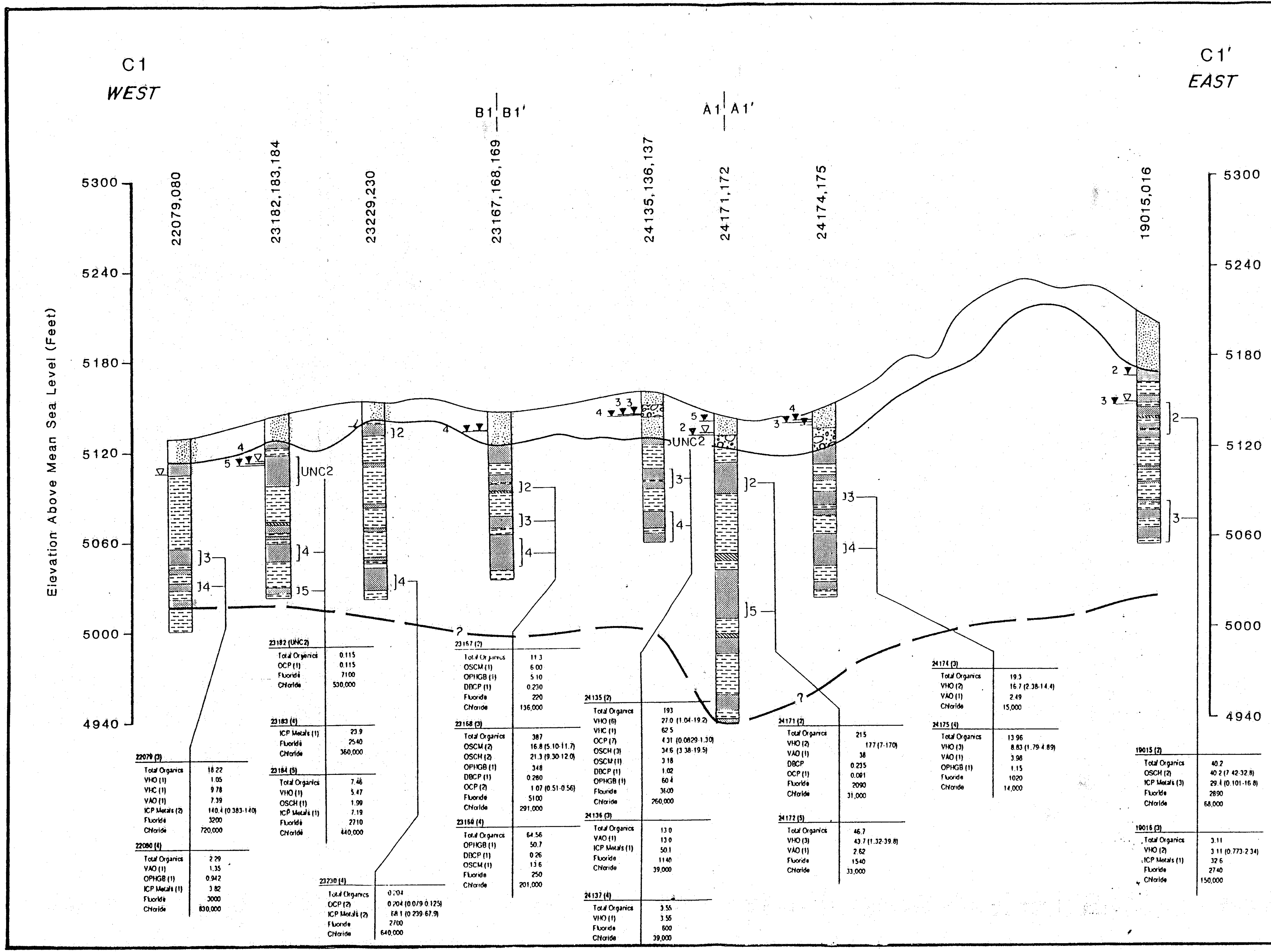
Prepared August 1991

FIGURE RISR B.4-2

Vertical Extent of Contamination in the Denver Formation Along Cross-Section B1-B1'

Rocky Mountain Arsenal

Prepared by: Ebasco Services Incorporated



23182 (UNC2)

Total Organics	0.115
OCP (1)	0.115
Fluoride	7100
Chloride	530,000

23183 (4)

ICP Metals (1)	23.9
Fluoride	2540
Chloride	360,000

23184 (5)

Total Organics	7.46
VHO (1)	5.47
OSCH (1)	1.99
ICP Metals (1)	7.19
Fluoride	2710
Chloride	440,000

22079 (3)

Total Organics	18.22
VHO (1)	1.05
VHC (1)	9.78
VAO (1)	7.39
ICP Metals (2)	140.4 (0.383-140)
Fluoride	3200
Chloride	720,000

22080 (4)

Total Organics	2.29
VAO (1)	1.35
OPHGB (1)	0.942
ICP Metals (1)	3.82
Fluoride	3000
Chloride	830,000

23230 (4)

Total Organics	0.204
OCP (2)	0.204 (0.079-0.125)
ICP Metals (2)	68.1 (0.239-67.9)
Fluoride	2700
Chloride	640,000

23167 (2)

Total Organics	11.3
OSCM (1)	6.00
OPHGB (1)	5.10
DBCP (1)	0.230
Fluoride	220
Chloride	136,000

23168 (3)

Total Organics	387
OSCM (2)	16.8 (5.10-11.7)
OSCH (2)	21.3 (9.30-12.0)
OPHGB (1)	348
DBCP (1)	0.280
OCP (2)	1.07 (0.51-0.56)
Fluoride	5100
Chloride	291,000

23169 (4)

Total Organics	64.56
OPHGB (1)	50.7
DBCP (1)	0.26
OSCM (1)	13.6
Fluoride	250
Chloride	201,000

24135 (2)

Total Organics	193
VHO (6)	27.0 (1.04-19.2)
VHC (1)	62.5
OCP (7)	4.31 (0.0829-1.30)
OSCH (3)	34.6 (3.38-19.5)
OSCM (1)	3.18
DBCP (1)	1.02
OPHGB (1)	60.4
Flouride	3600
Chloride	260,000

24136 (3)

Total Organics	13.0
VAO (1)	13.0
ICP Metals (1)	50.1
Fluoride	1140
Chloride	39,000

24137 (4)

Total Organics	3.55
VHO (1)	3.55
Fluoride	600
Chloride	39,000

24171 (2)

Total Organics	215
VHO (2)	177 (7-170)
VAO (1)	38
DBCP	0.235
OCP (1)	0.091
Fluoride	2090
Chloride	31,000

24172 (5)

Total Organics	46.7
VHO (3)	43.7 (1.32-39.8)
VAO (1)	2.62
Fluoride	1540
Chloride	33,000

24174 (3)

Total Organics	19.3
VHO (2)	16.7 (2.38-14.4)
VAO (1)	2.49
Chloride	15,000

24175 (4)

Total Organics	13.96
VHO (3)	8.83 (1.79-4.89)
VAO (1)	3.98
OPHGB (1)	1.15
Fluoride	1020
Chloride	14,000

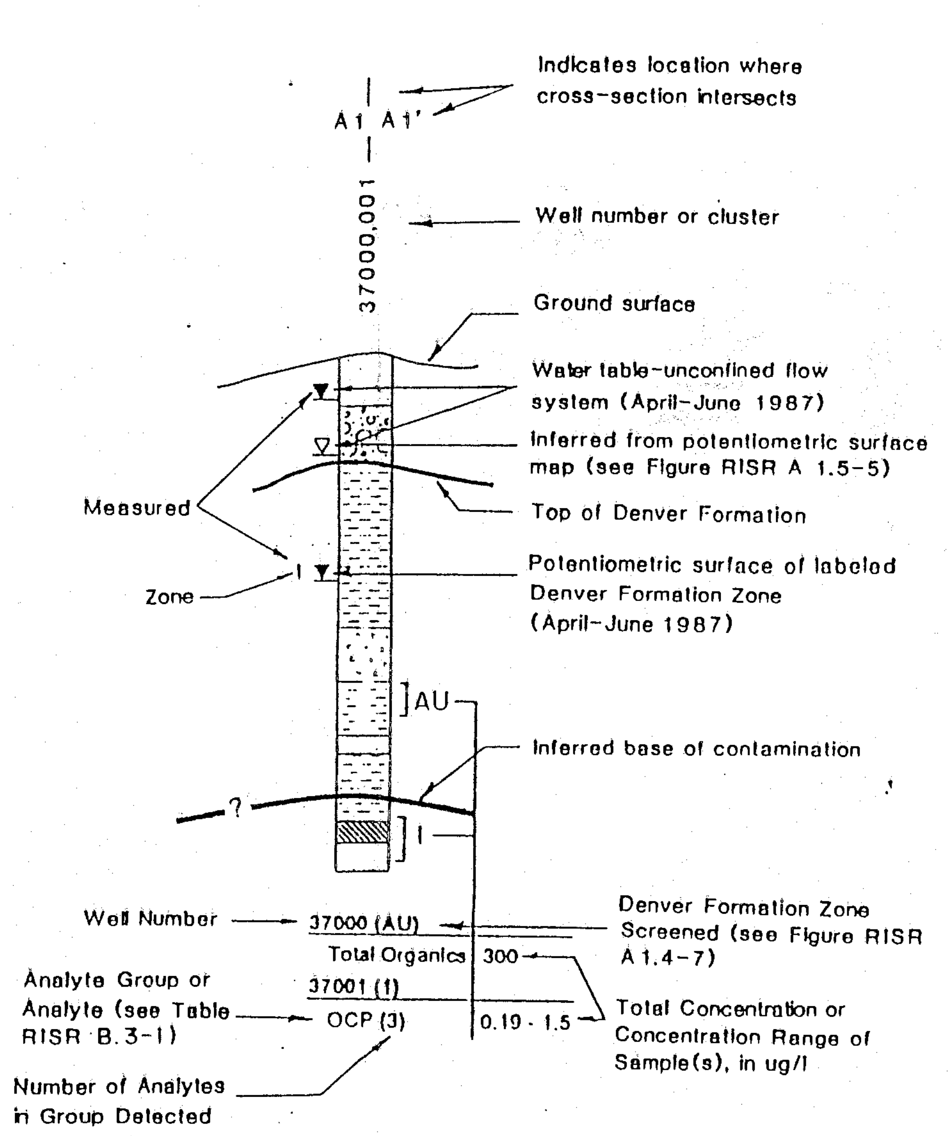
19015 (2)

Total Organics	40.2
OSCH (2)	40.2 (7.42-32.8)
ICP Metals (3)	29.4 (0.101-16.8)
Fluoride	2890
Chloride	68,000

19016 (3)

Total Organics	3.11
VHO (2)	3.11 (0.773-2.34)
ICP Metals (1)	32.6
Fluoride	2740
Chloride	150,000

LEGEND



NOTE: Concentrations for Total Organics do not include Tentatively Identified Compounds (TICs)

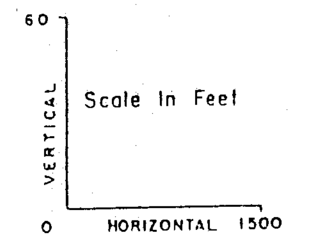
LITHOLOGY

ALLUVIUM

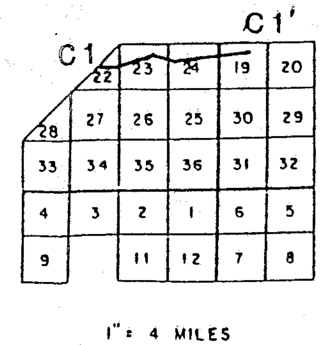
⬚	Fine-Grained Units Silty clayey sands, poorly graded sand-silt, sandy-clay mixtures.
⬚	Coarse-Grained Units Poor to well graded gravels, gravel-sand mixtures, clayey gravels, poor to well-graded sands, gravelly sands, little or no fines.

DENVER FORMATION

▒	Sandstone Units Fine to coarse-grained, friable to well-cemented. Poorly to moderately-sorted, poorly to well-bedded.
☰	Claystone Units and Siltstone Clayey to sandy, grades laterally and vertically into claystone and sandstones, poorly to well-bedded.
▨	Lignite Soft to brittle, lignite grades from subbituminous C coal into organic rich claystone, poorly to well-defined bedding and joints.
⬚	Volcaniclastic Fine to coarse volcanic fragments in a bentonitic clay and silt matrix.



Vertical Exageration - 25X



1" = 4 MILES
INDEX MAP

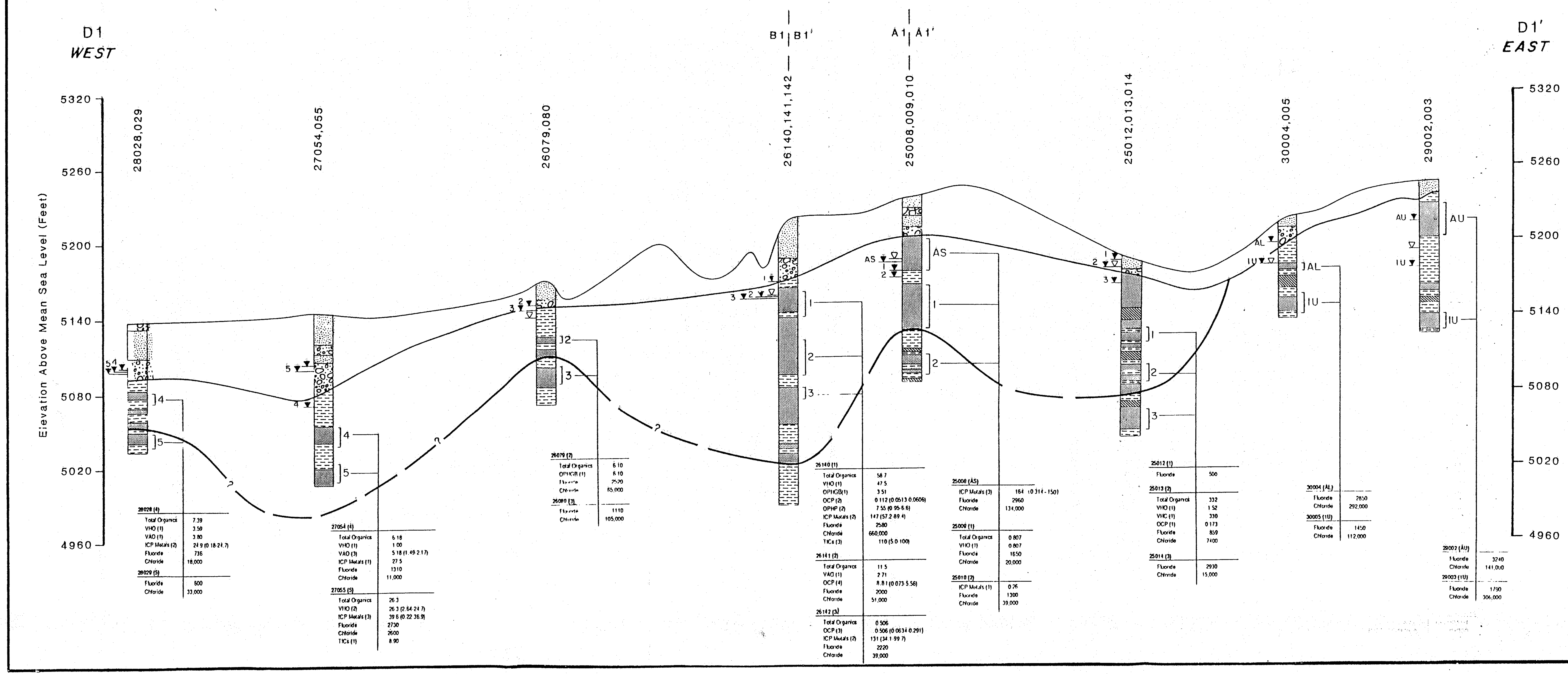
Prepared for:
U.S. Army Program Manager for
the Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.4-3

Vertical Extent of Contamination in the Denver Formation Along Cross-Section C1-C1'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



28028 (4)	
Total Organics	7.39
VHO (1)	3.59
VAO (1)	3.80
ICP Metals (2)	24.9 (0.18-24.7)
Fluoride	736
Chloride	18,000

28029 (5)	
Fluoride	600
Chloride	33,000

27054 (4)	
Total Organics	6.18
VHO (1)	1.00
VAO (3)	5.18 (1.49-2.17)
ICP Metals (1)	27.5
Fluoride	1310
Chloride	11,000

27055 (5)	
Total Organics	26.3
VHO (2)	26.3 (2.64-24.7)
ICP Metals (3)	39.6 (0.22-36.9)
Fluoride	2730
Chloride	2600
TICs (1)	8.90

26079 (2)	
Total Organics	6.10
OPHGB (1)	6.10
Fluoride	2520
Chloride	65,000

26080 (3)	
Fluoride	1110
Chloride	105,000

26140 (1)	
Total Organics	58.7
VHO (1)	47.5
OPHGB(1)	3.51
OCP (2)	0.112 (0.0513-0.0606)
OPHP (2)	7.55 (0.95-6.6)
ICP Metals (2)	147 (57.2-89.4)
Fluoride	2580
Chloride	660,000
TICs (3)	110 (5.0-100)

26141 (2)	
Total Organics	11.5
VAO (1)	2.71
OCP (4)	8.81 (0.073-5.56)
Fluoride	2000
Chloride	51,000

26142 (3)	
Total Organics	0.506
OCP (3)	0.506 (0.0634-0.291)
ICP Metals (2)	131 (34.1-99.7)
Fluoride	2220
Chloride	39,000

25008 (AS)	
ICP Metals (3)	164 (0.314 - 150)
Fluoride	2960
Chloride	134,000

25009 (1)	
Total Organics	0.807
VHO (1)	0.807
Fluoride	1650
Chloride	20,000

25010 (2)	
ICP Metals (1)	0.26
Fluoride	1300
Chloride	39,000

25012 (1)	
Fluoride	500

25013 (2)	
Total Organics	332
VHO (1)	1.52
VHC (1)	330
OCP (1)	0.173
Fluoride	859
Chloride	7400

25014 (3)	
Fluoride	2930
Chloride	15,000

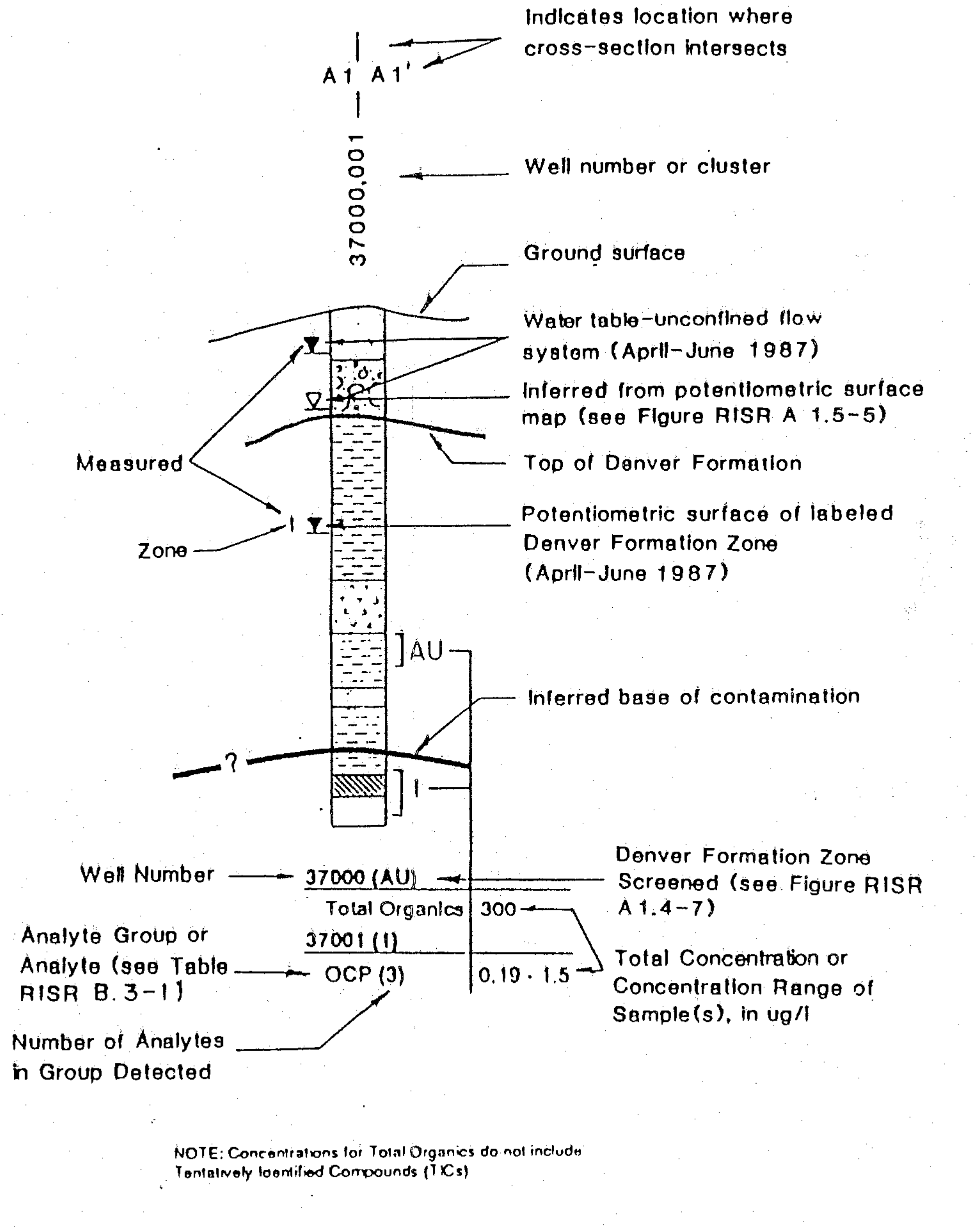
30004 (AL)	
Fluoride	2850
Chloride	292,000

30005 (1U)	
Fluoride	1450
Chloride	112,000

29002 (AU)	
Fluoride	3240
Chloride	141,000

29003 (1U)	
Fluoride	1790
Chloride	306,000

LEGEND



NOTE: Concentrations for Total Organics do not include Tentatively Identified Compounds (TICs)

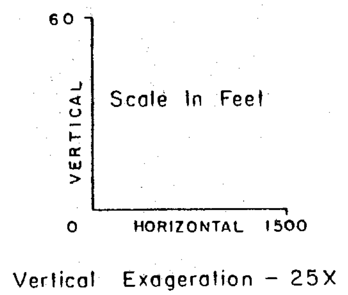
LITHOLOGY

ALLUVIUM

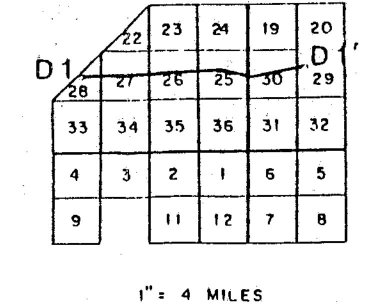
░	**Fine-Grained Units** Silty clayey sands, poorly graded sand-silt, sandy-clay mixtures.
⁘	**Coarse-Grained Units** Poor to well graded gravels, gravel-sand mixtures, clayey gravels, poor to well-graded sands, gravelly sands, little or no fines.

DENVER FORMATION

☐	**Sandstone Units** Fine to coarse-grained, friable to well-cemented. Poorly to moderately-sorted, poorly to well-bedded.
▤	**Claystone Units and Siltstone** Clayey to sandy, grades laterally and vertically into claystone and sandstones, poorly to well-bedded.
▨	**Lignite** Soft to brittle, lignite grades from subbituminous C coal into organic rich claystone, poorly to well-defined bedding and joints.
⁖	**Volcaniclastic** Fine to coarse volcanic fragments in a bentonitic clay and silt matrix.



Vertical Exageration - 25X



1" = 4 MILES
INDEX MAP

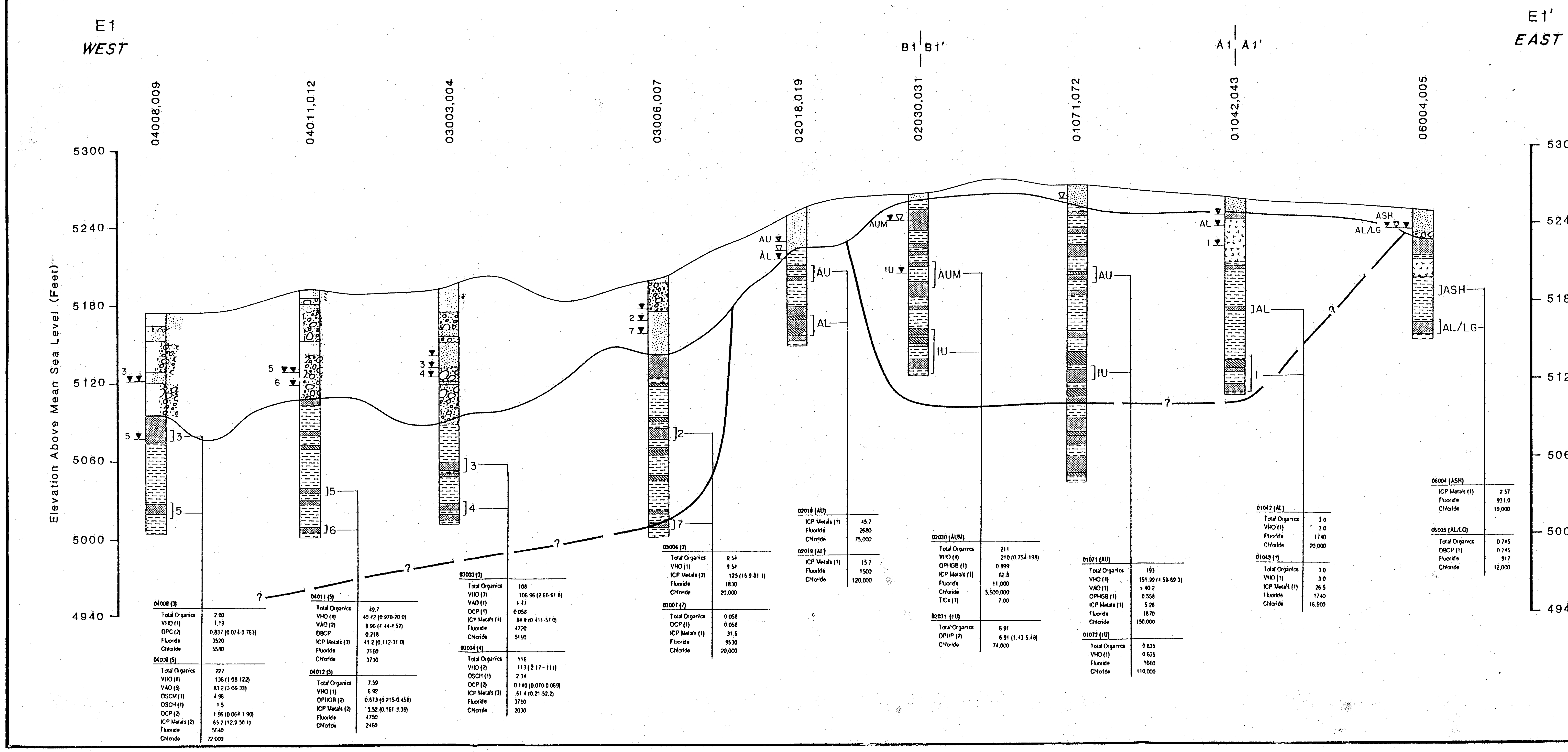
Prepared for:
U.S. Army Program Manager for
the Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.4-4

Vertical Extent of Contamination in the Denver Formation Along Cross-Section D1-D1'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



04008 (3)	
Total Organics	2.00
VHO (1)	1.19
OPC (2)	0.837 (0 074-0.763)
Fluoride	3520
Chloride	5580

04008 (5)	
Total Organics	227
VHO (8)	136 (1 08-122)
VAO (5)	83 2 (3 06-33)
OSCM (1)	4 98
OSCH (1)	1.5
OCP (2)	1 96 (0 064 1 90)
ICP Metals (2)	65 2 (12.9-30 1)
Fluoride	5640
Chloride	22,000

04011 (5)	
Total Organics	49.7
VHO (4)	40.42 (0.978-20 0)
VAO (2)	8.96 (4.44-4.52)
DBCP	0.218
ICP Metals (3)	41.2 (0.112-31.0)
Fluoride	7160
Chloride	3730

04012 (5)	
Total Organics	7.59
VHO (1)	6.92
OPHGB (2)	0.673 (0.215-0.458)
ICP Metals (2)	3.52 (0.161-3.36)
Fluoride	4750
Chloride	2460

03003 (3)	
Total Organics	108
VHO (3)	106 96 (2 66-61 8)
VAO (1)	1.47
OCP (1)	0 058
ICP Metals (4)	84 9 (0 411-57.0)
Fluoride	4720
Chloride	5190

03004 (4)	
Total Organics	116
VHO (2)	113 (2.17 - 111)
OSCH (1)	2 34
OCP (2)	0 140 (0.070-0 069)
ICP Metals (3)	61 4 (0.21-52.2)
Fluoride	3760
Chloride	2030

03006 (2)	
Total Organics	9 54
VHO (1)	9 54
ICP Metals (3)	125 (16 9-81 1)
Fluoride	1830
Chloride	20,000

03007 (7)	
Total Organics	0 058
OCP (1)	0.058
ICP Metals (1)	31.6
Fluoride	9530
Chloride	20,000

02018 (AU)	
ICP Metals (1)	45.7
Fluoride	2680
Chloride	75,000

02019 (AL)	
ICP Metals (1)	15.7
Fluoride	1500
Chloride	120,000

02030 (AUM)	
Total Organics	211
VHO (4)	210 (0.754-198)
OPHGB (1)	0 899
ICP Metals (1)	62.8
Fluoride	11,000
Chloride	5,500,000
TICs (1)	7.00

02031 (1U)	
Total Organics	6 91
OPHP (2)	6 91 (1.43-5.48)
Chloride	74,000

01071 (AU)	
Total Organics	193
VHO (4)	151.99 (4.59-69 3)
VAO (1)	> 40 2
OPHGB (1)	0.558
ICP Metals (1)	5.28
Fluoride	1870
Chloride	150,000

01072 (1U)	
Total Organics	0 635
VHO (1)	0 635
Fluoride	1660
Chloride	110,000

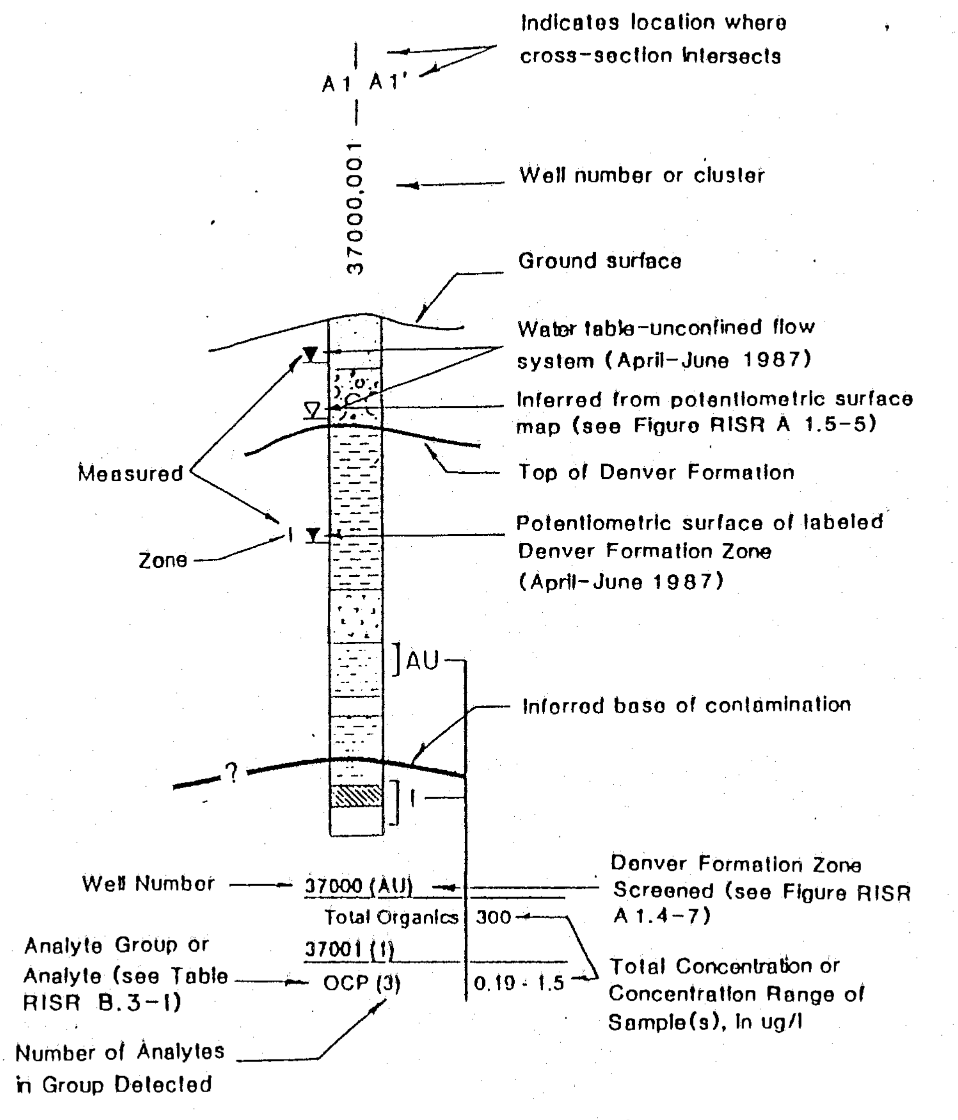
01042 (AL)	
Total Organics	3 0
VHO (1)	3 0
Fluoride	1740
Chloride	20,000

01043 (1)	
Total Organics	3 0
VHO (1)	3 0
ICP Metals (1)	26 5
Fluoride	1740
Chloride	16,600

06004 (ASH)	
ICP Metals (1)	2 57
Fluoride	931.0
Chloride	10,000

06005 (AL/LG)	
Total Organics	0 745
DBCP (1)	0.745
Fluoride	917
Chloride	12,000

LEGEND



NOTE: Concentrations for Total Organics do not include Tentatively Identified Compounds (TICs)

LITHOLOGY

ALLUVIUM

Fine-Grained Units
Silty clayey sands, poorly graded sand-silt, sandy-clay mixtures.

Coarse-Grained Units
Poor to well graded gravels, gravel-sand mixtures, clayey gravels, poor to well-graded sands, gravelly sands, little or no fines.

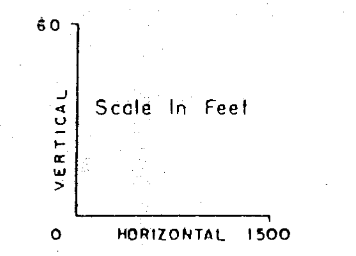
DENVER FORMATION

Sandstone Units
Fine to coarse-grained, friable to well-cemented. Poorly to moderately-sorted, poorly to well-bedded.

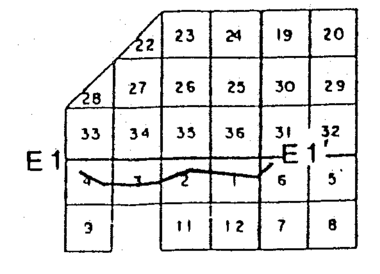
Claystone Units and Siltstone
Clayey to sandy, grades laterally and vertically into claystone and sandstones, poorly to well-bedded.

Lignite
Soft to brittle, lignite grades from subbituminous C coal into organic rich claystone, poorly to well-defined bedding and joints.

Volcaniclastic
Fine to coarse volcanic fragments in a bentonitic clay and silt matrix.



Vertical Exageration - 25X



1" = 4 MILES

INDEX MAP

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

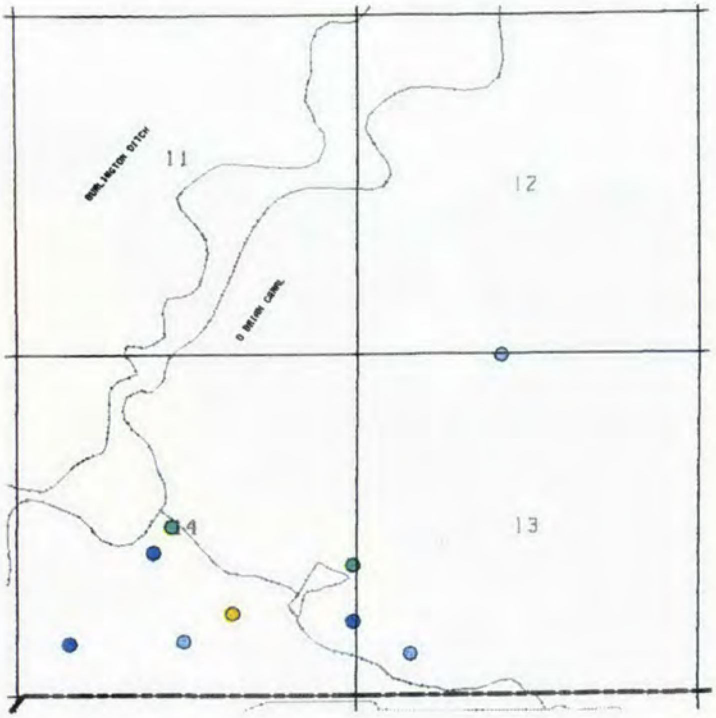
Prepared August 1991

FIGURE RISR B.4-5

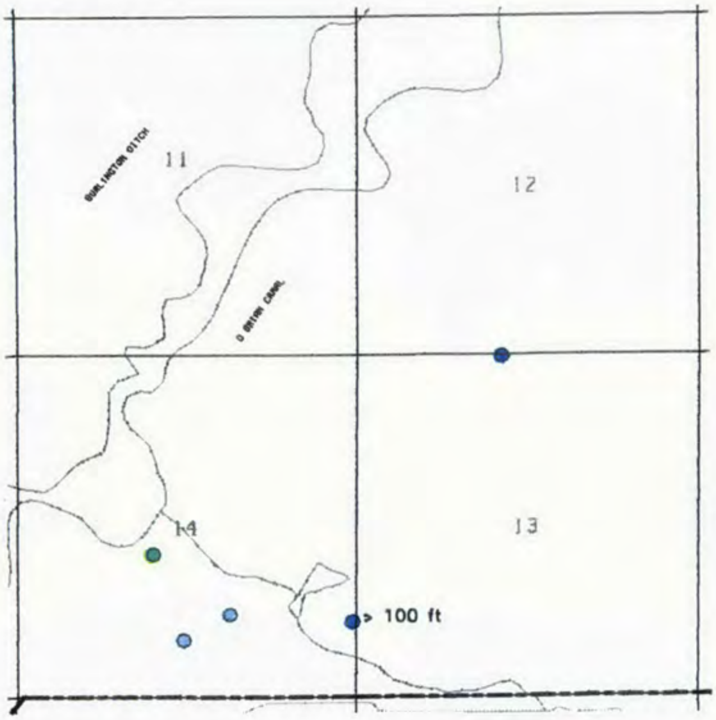
Vertical Extent of Contamination in the Denver Formation Along Cross-Section E1-E1'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Note: Depth intervals are measured
below bedrock contact

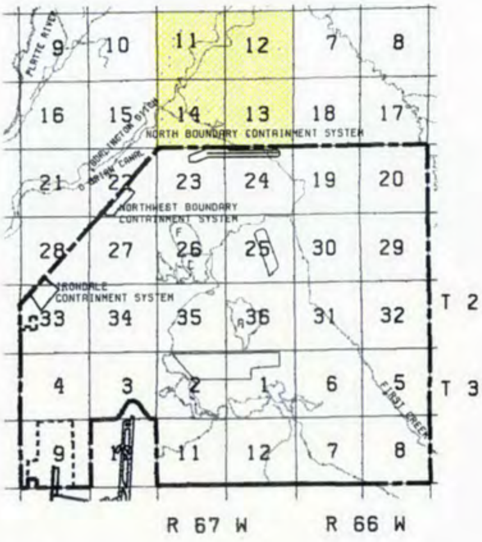


0 – 50 ft. Depth Interval



Greater than 50 ft.
Note: Unless noted, depth
interval is 50 – 100 ft.

INDEX MAP



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

Concentration Ranges

🟪 > 10,000 ug/l

🟧 > 1000 to 10,000 ug/l

🟨 > 100 to 1000 ug/l

🟩 > 50 to 100 ug/l

🟦 > 10 to 50 ug/l

🟦 CRL to 10 ug/l

0 3000 Feet
Scale: 1" = 3000'

N

Source: U.S. Army Corps of Engineers
Waterways Experiment Station

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

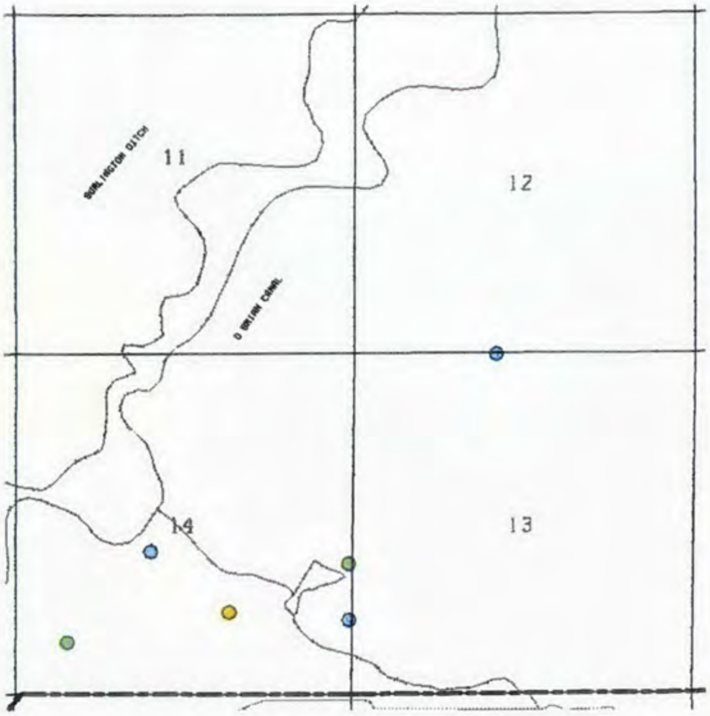
Prepared August 1991

FIGURE RISR B.5 – 1

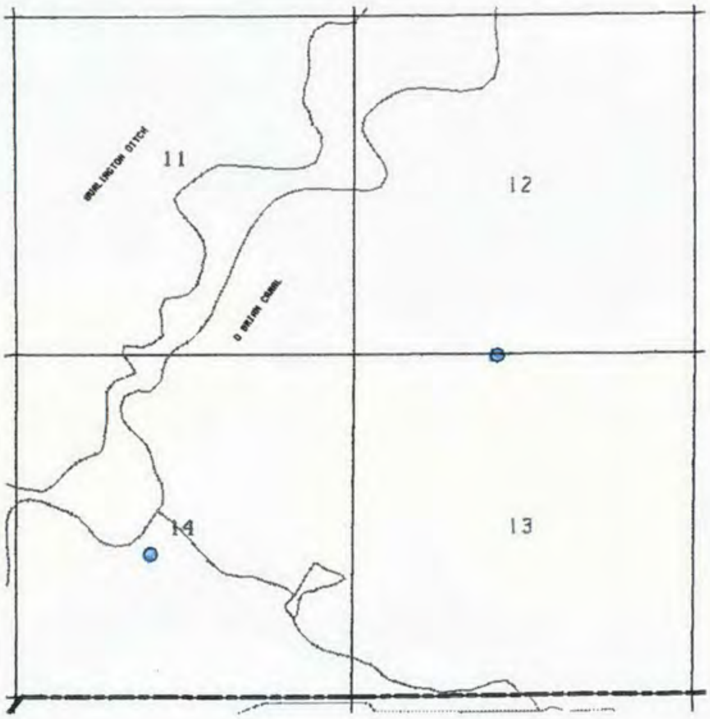
Total Organic Analytes Off Post
in the Denver Aquifer

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Note: Depth intervals are measured
below bedrock contact



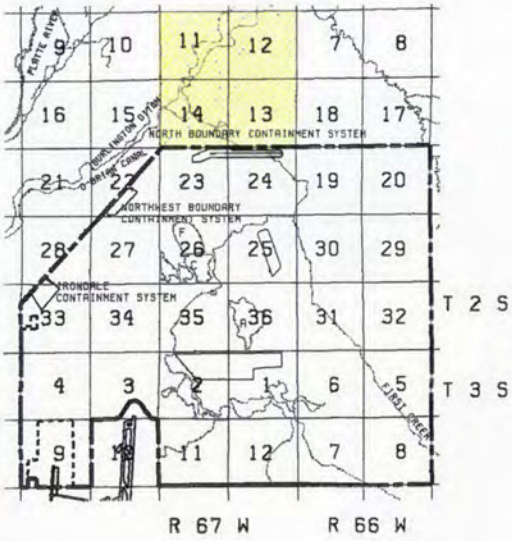
0 – 50 ft. Depth Interval



Greater than 50 ft.

Note: No concentrations reported
below 100 ft.

INDEX MAP



Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins

Concentration Ranges

🟥 > 1000 ug/l

🟨 > 100 to 1000 ug/l

🟩 > 10 to 100 ug/l

🟦 CRL to 10 ug/l

0 3000 Feet

Scale: 1" = 3000'

N

Source: U.S. Army Corps of Engineers
Waterways Experiment Station

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

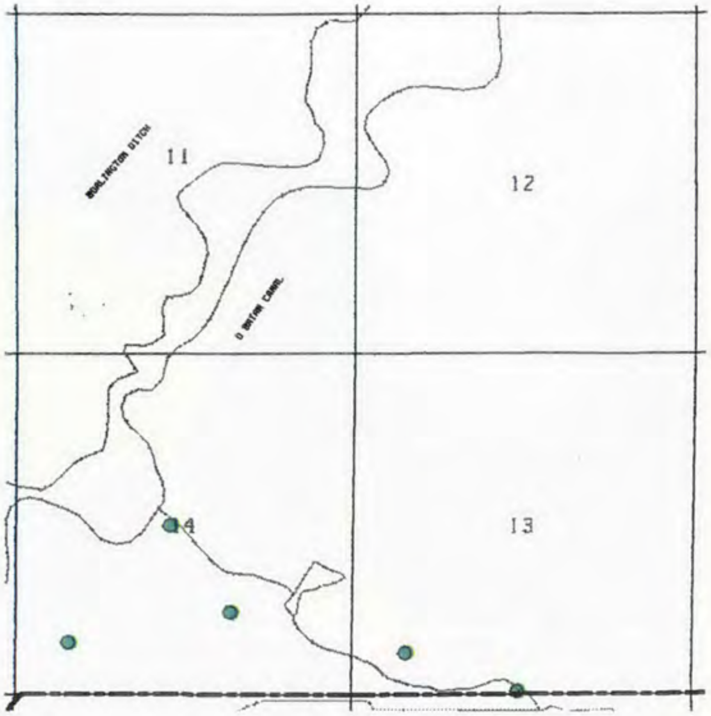
Prepared August 1991

FIGURE RISR B.5 – 2

DIMP Off Post in the Denver Aquifer

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

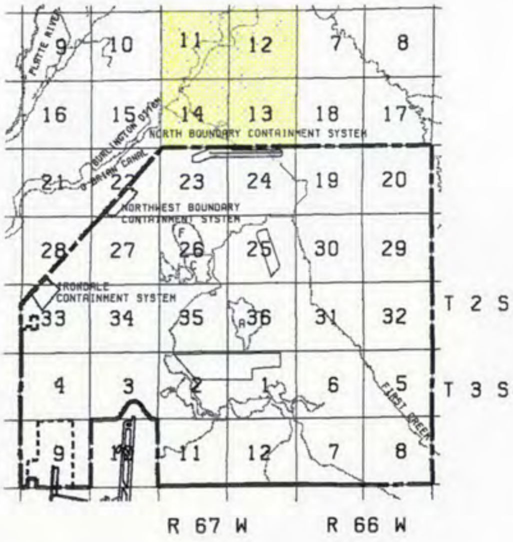
Note: Depth intervals are measured
below bedrock contact



0 – 50 ft. Depth Interval

Note: No concentrations reported
below 50 ft.

INDEX MAP



Legend:

Rocky Mountain Arsenal Boundary

Section Lines

Streams

Lakes

Basins

Concentration Ranges

🟧 > 100 ug/l

🟩 > 10 to 100 ug/l

🟦 CRL to 10 ug/l

0 3000 Feet

Scale: 1" = 3000'

N

Source: U.S. Army Corps of Engineers
Waterways Experiment Station

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

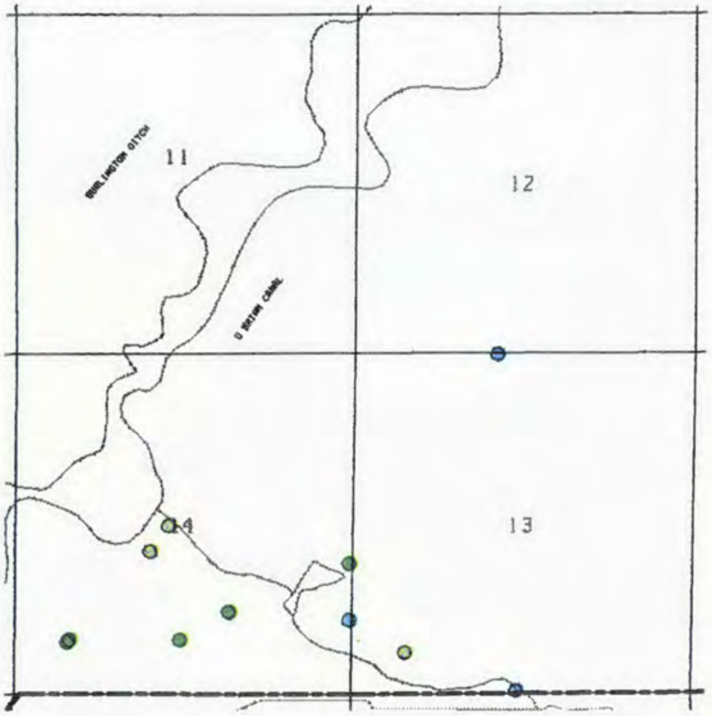
Prepared August 1991

FIGURE RISR B.5 – 3

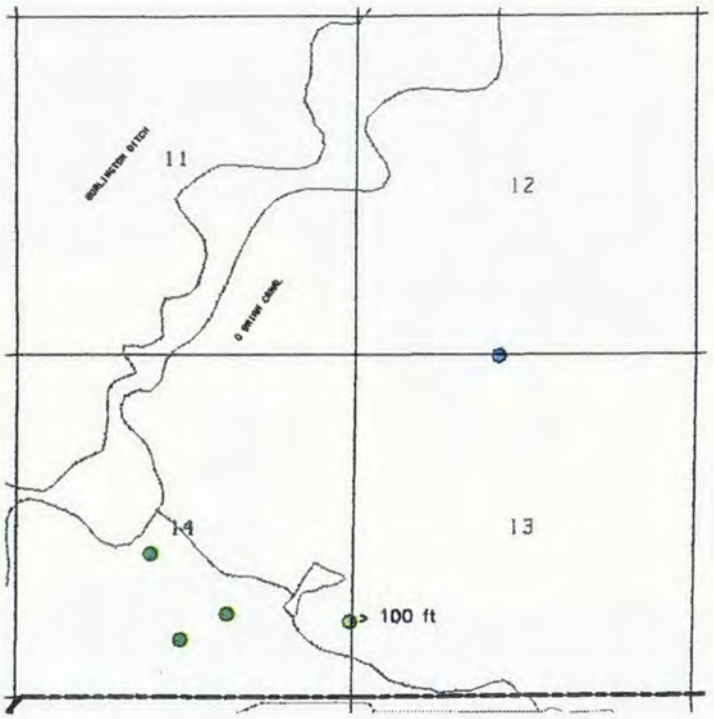
Arsenic, Mercury, and ICP Metals
Off Post in the Denver Aquifer

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Note: Depth intervals are measured
below bedrock contact

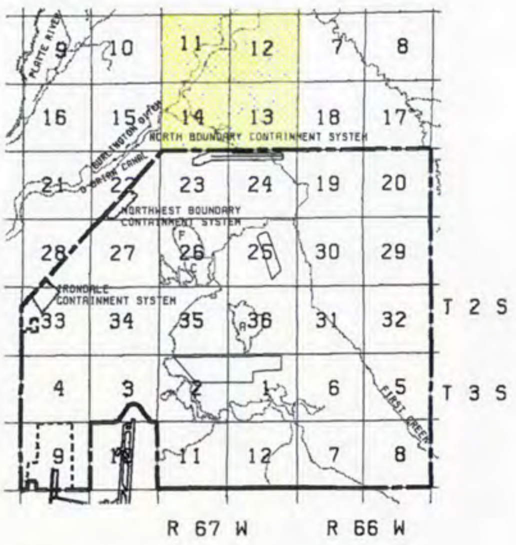


0 – 50 ft. Depth Interval



Greater than 50 ft.
Note: Unless noted, depth
interval is 50 – 100 ft.

INDEX MAP



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

Concentration Ranges

🟪 > 10,000 ug/l
🟦 > 5000 to 10,000 ug/l
🟩 > 2000 to 5000 ug/l
🟩 > 1220 to 2000 ug/l
🟦 CRL to 1220 ug/l

0 3000 Feet
Scale: 1" = 3000'
Source: U.S. Army Corps of Engineers
Waterways Experiment Station

N

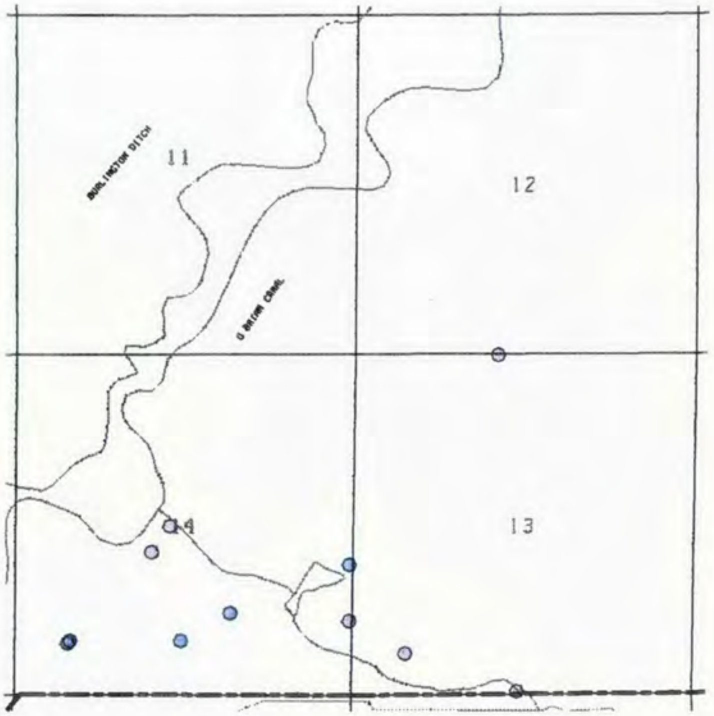
Prepared for:
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

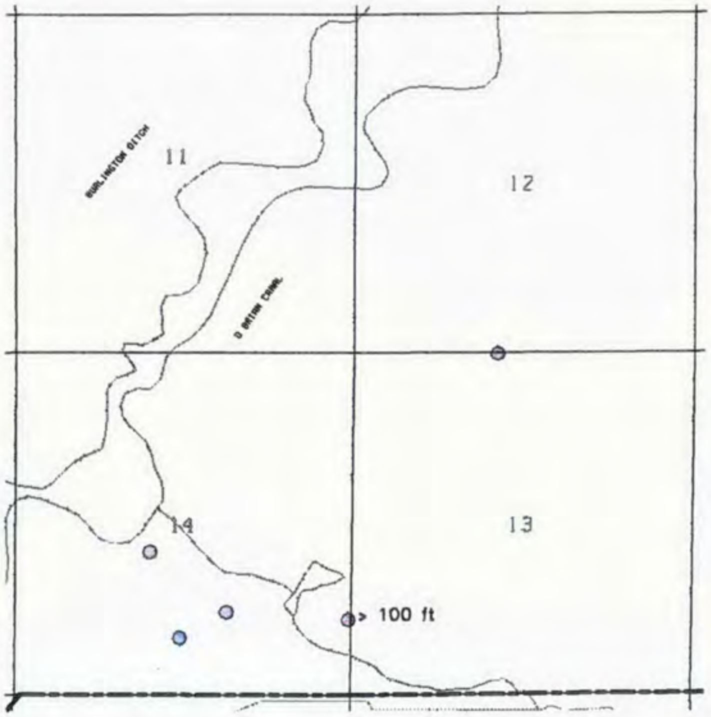
FIGURE RISR B.5 – 4
Fluoride Off Post in the Denver Aquifer

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Note: Depth intervals are measured below bedrock contact



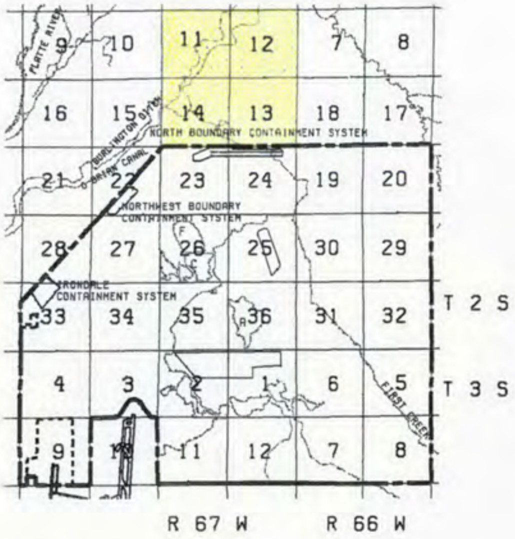
0 – 50 ft. Depth Interval



Greater than 50 ft.

Note: Unless noted, depth interval is 50 – 100 ft.

INDEX MAP



Legend:

Rocky Mountain Arsenal Boundary

Section Lines

Streams

Lakes

Basins

Concentration Ranges

🟩	> 5,000,000 ug/l
🟩	> 1,000,000 to 5,000,000 ug/l
🟦	> 150,000 to 1,000,000 ug/l
🟪	CRL to 150,000 ug/l

0 3000 Feet

Scale: 1" = 3000'

N

Source: U.S. Army Corps of Engineers Waterways Experiment Station

Prepared for:

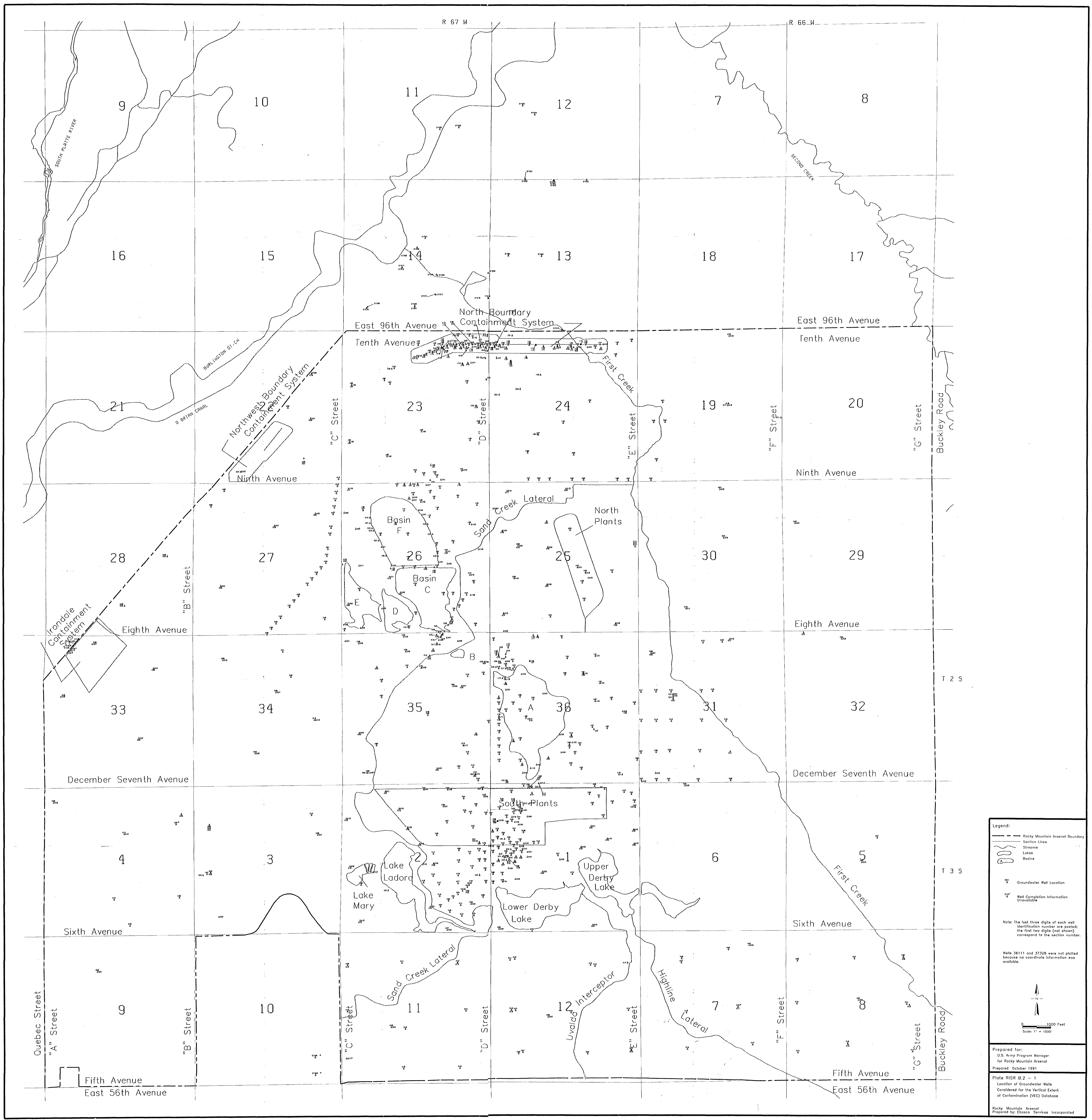
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR B.5 – 5

Chloride Off Post in the Denver Aquifer

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

001 Groundwater Well Location

010* Well Completion Information Unavailable

Note: The last three digits of each well identification number are posted; the first two digits (not shown) correspond to the section number.

Wells 36111 and 37326 were not plotted because no coordinate information was available.

— N —

0 1000 Feet

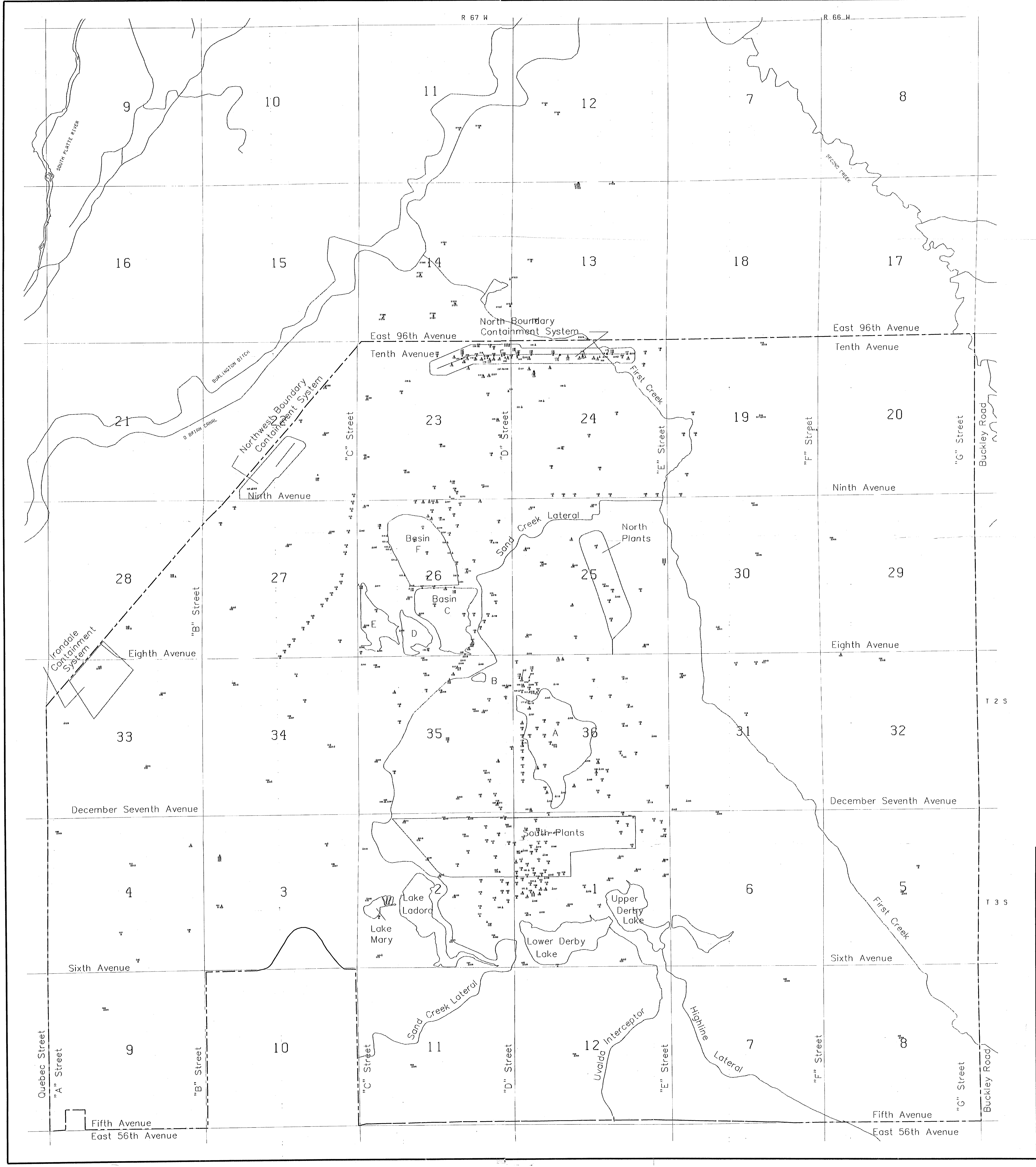
Scale: 1" = 1000'

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

Prepared October 1991

Plate RISR B.2 – 1
Location of Groundwater Wells
Considered for the Vertical Extent
of Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins

Groundwater Well Location

Note: The last three digits of each well identification number are posted; the first two digits (not shown) correspond to the section number.

N

0 1000 Feet

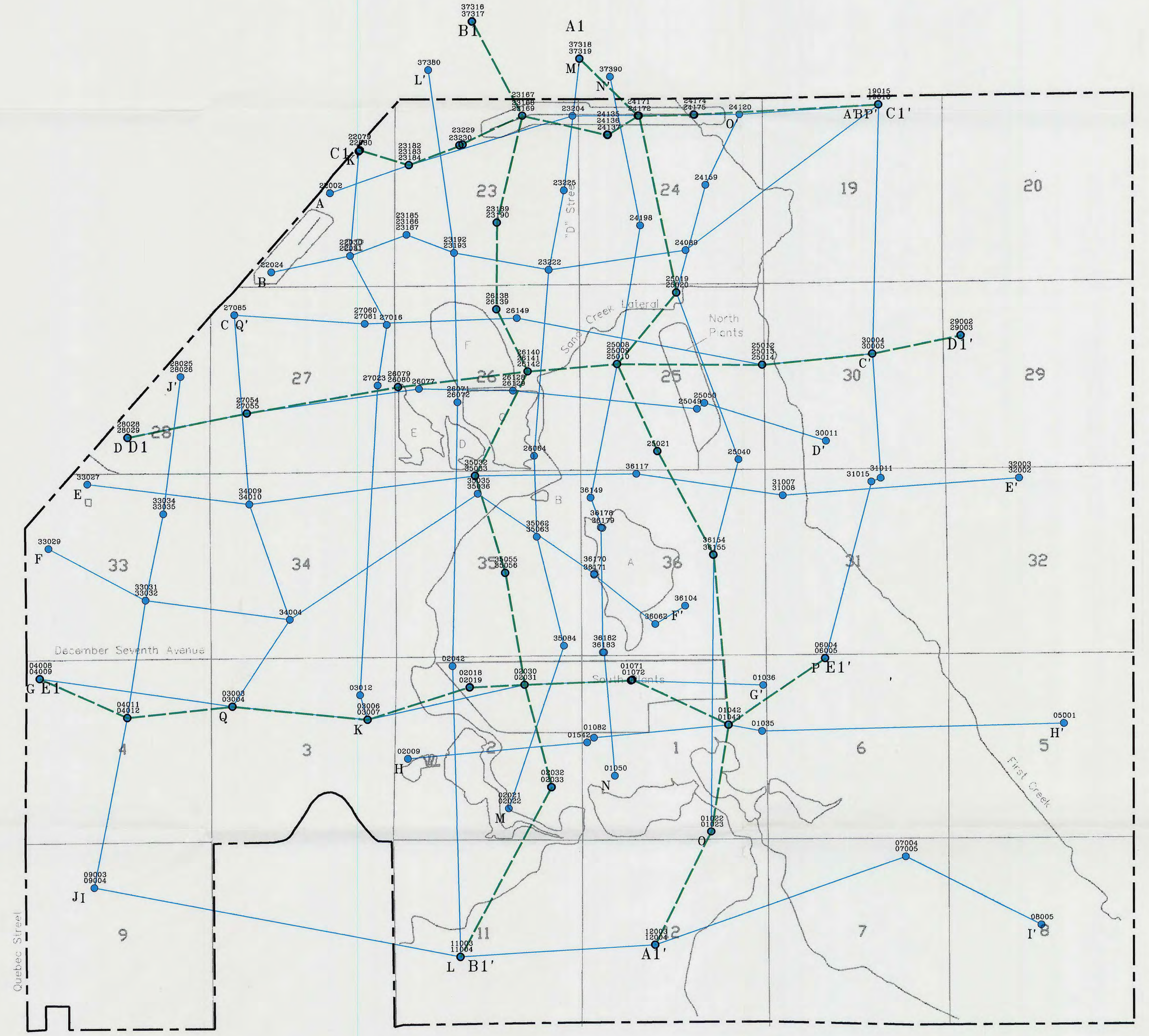
Scale: 1" = 1000'

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

Prepared October 1991

Plate RISR B.2 – 2
Location of Groundwater Wells
Included in the Vertical Extent
of Contamination (VEC) Database

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90

Legend:

Rocky Mountain Arsenal Boundary
Section Lines
Streams
Lakes
Basins

0 2000 Feet
Scale: 1" = 2000'

01050 Well Location and Number

01022
01023 Cluster Well

22002 A — 19015 19016 A' Line of Cross-Section

37318 37319 A1 — 12003 12004 A1' Line of Geologic Cross-Section

Prepared for:

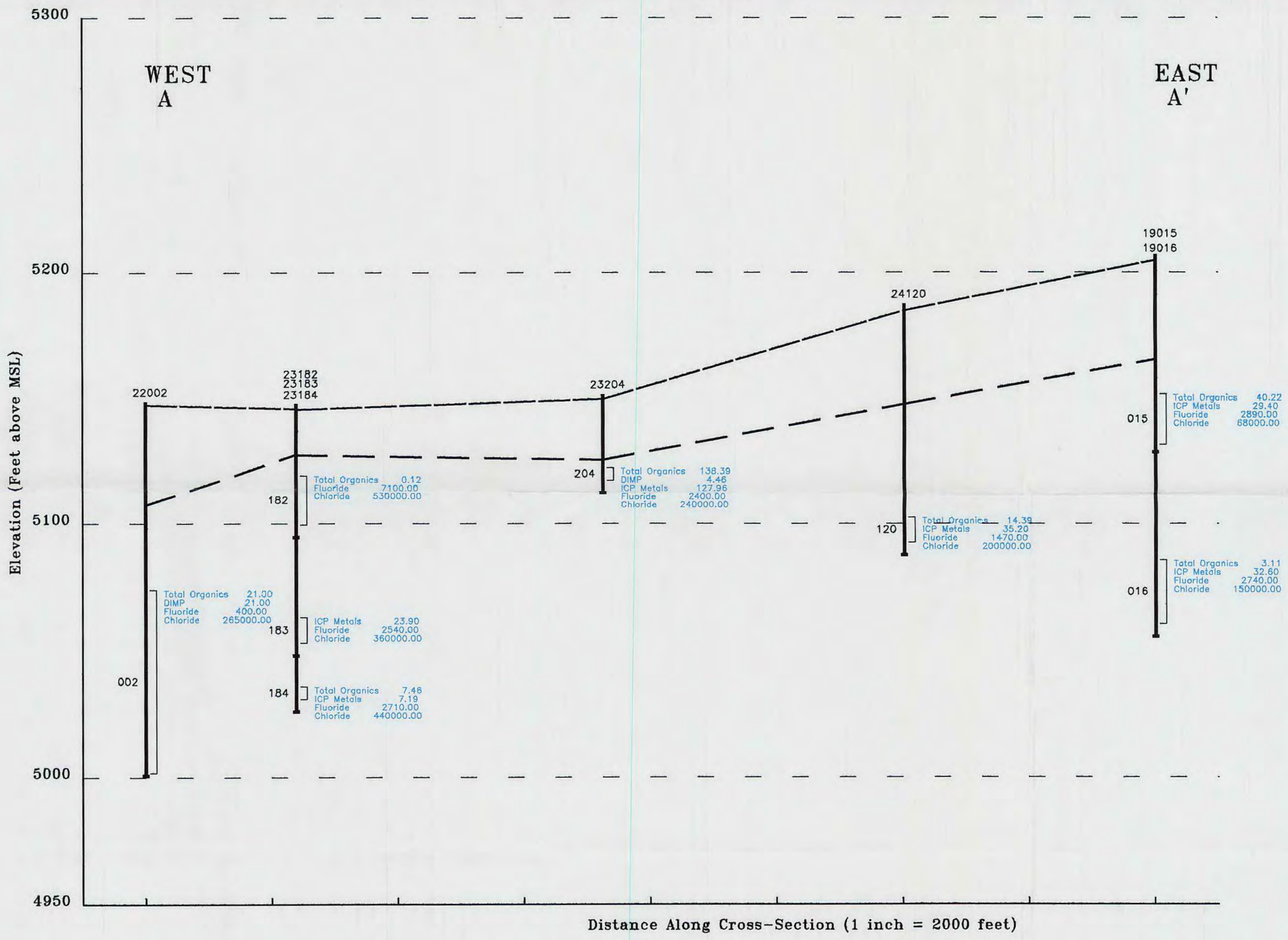
U.S. Army Program Manager
for Rocky Mountain Arsenal

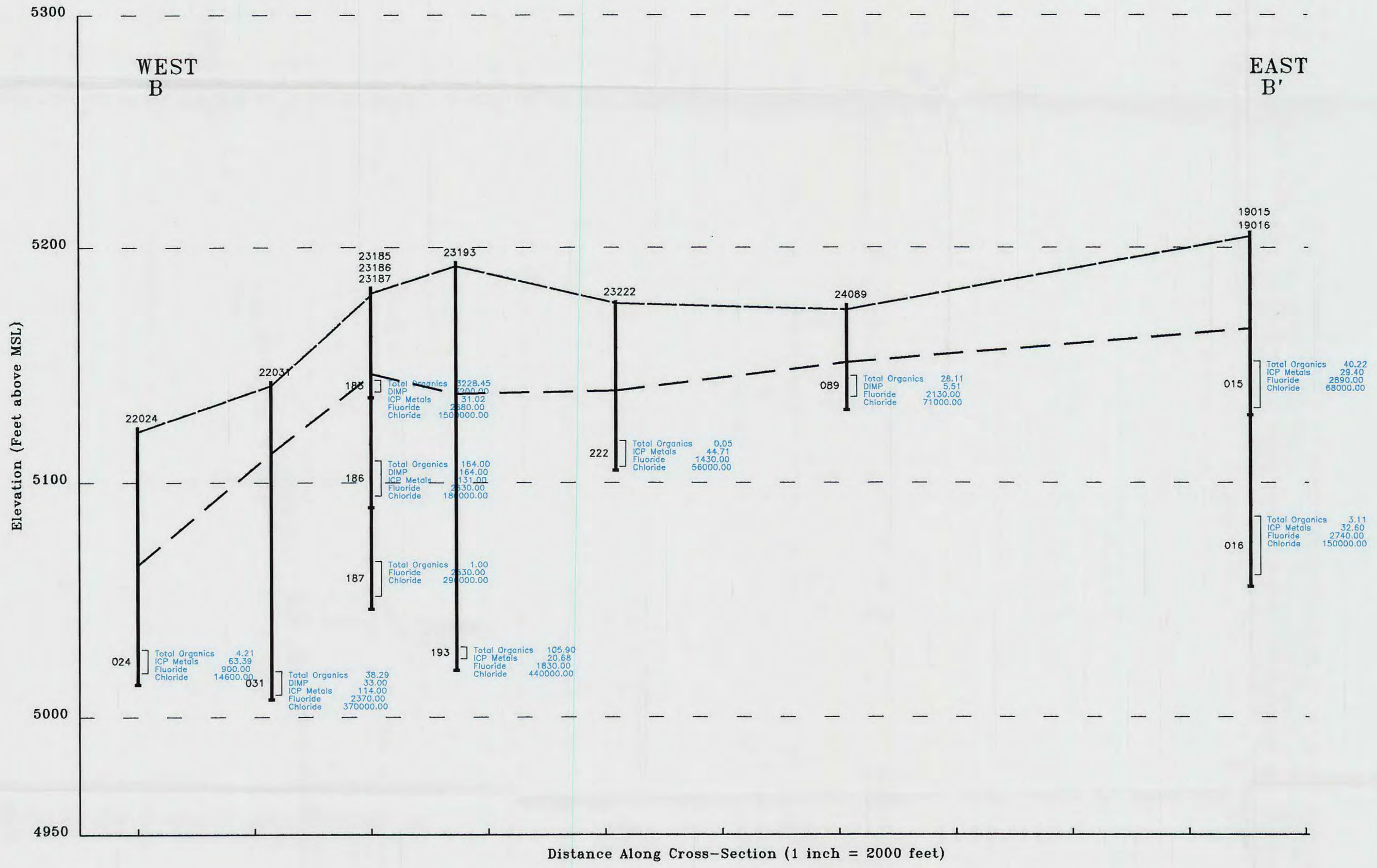
Prepared October 1991

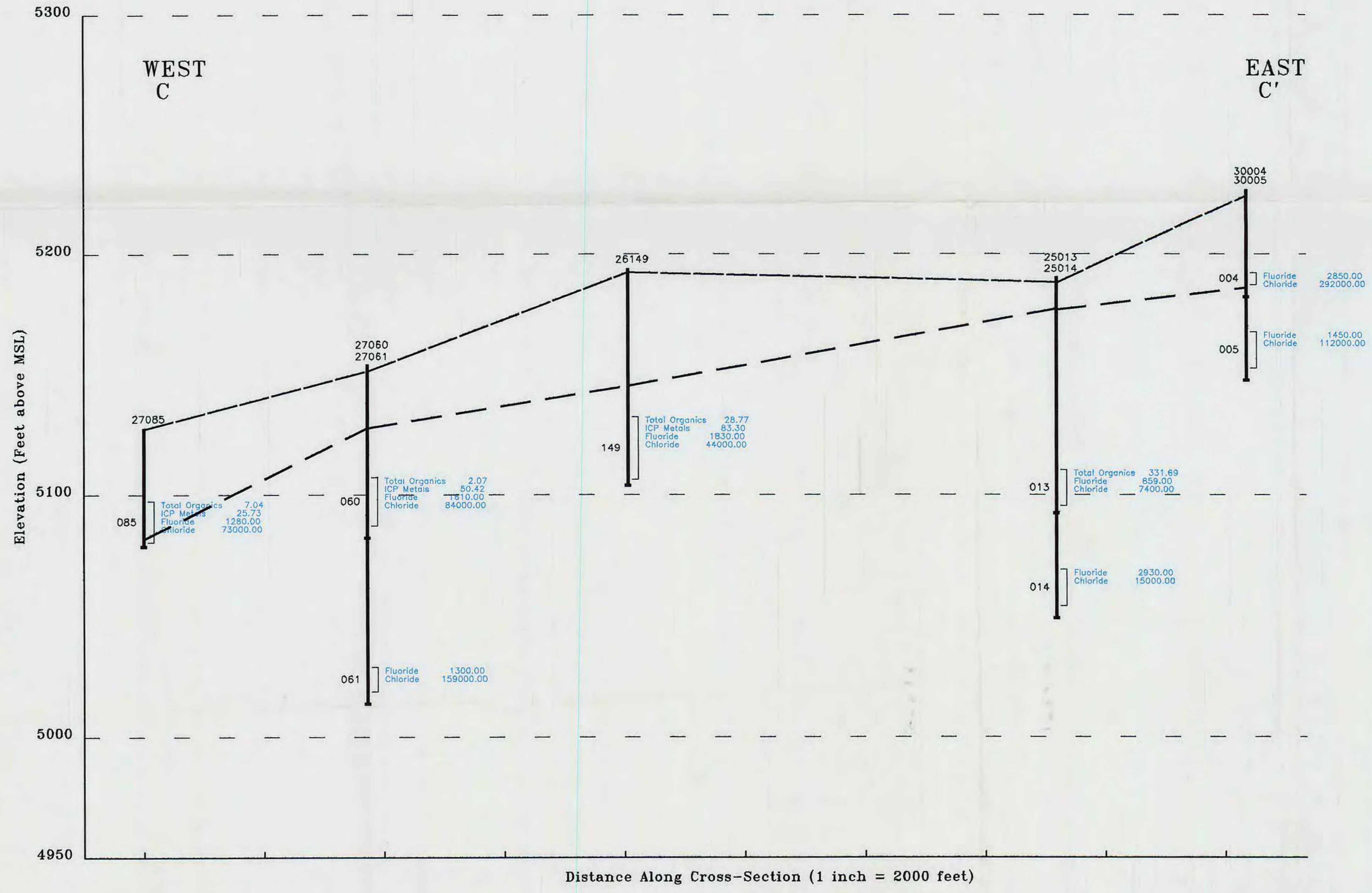
PLATE RISR B.4-1

CROSS-SECTION LOCATION MAP
for A-A' through Q-Q', and
GEOLOGIC CROSS-SECTIONS
A1-A1' through E1-E1'

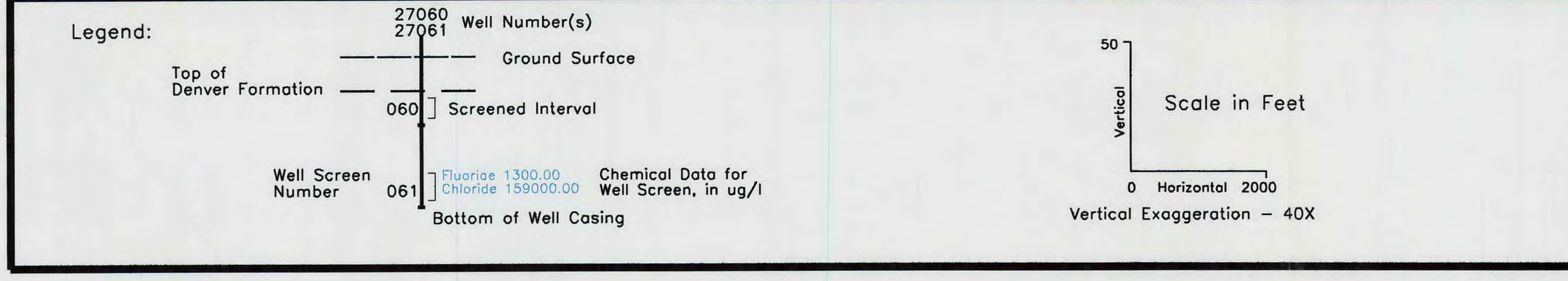
Prepared by: Ebasco Services Incorporated







Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90



Prepared for:

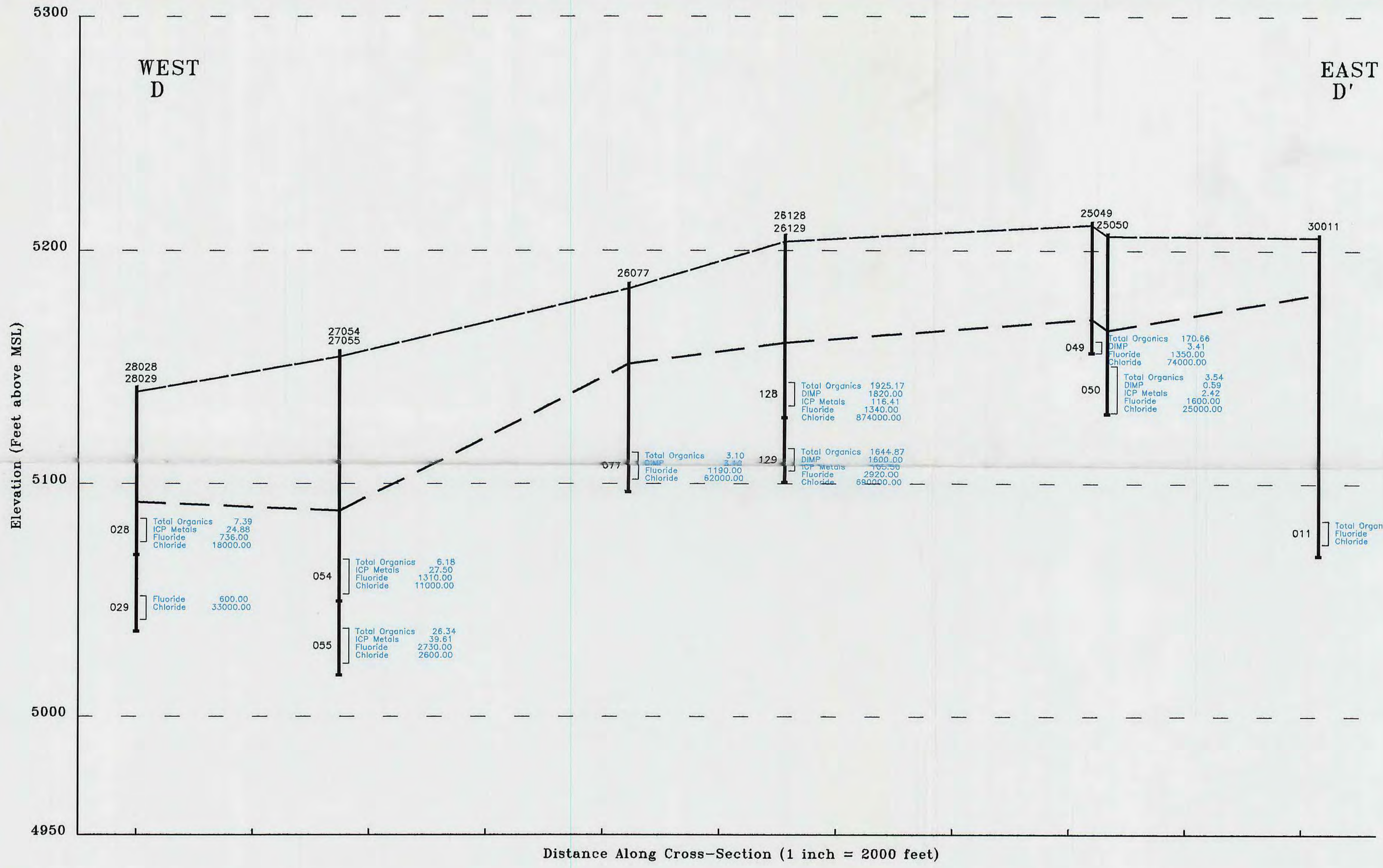
U.S. Army Program Manager
for Rocky Mountain Arsenal

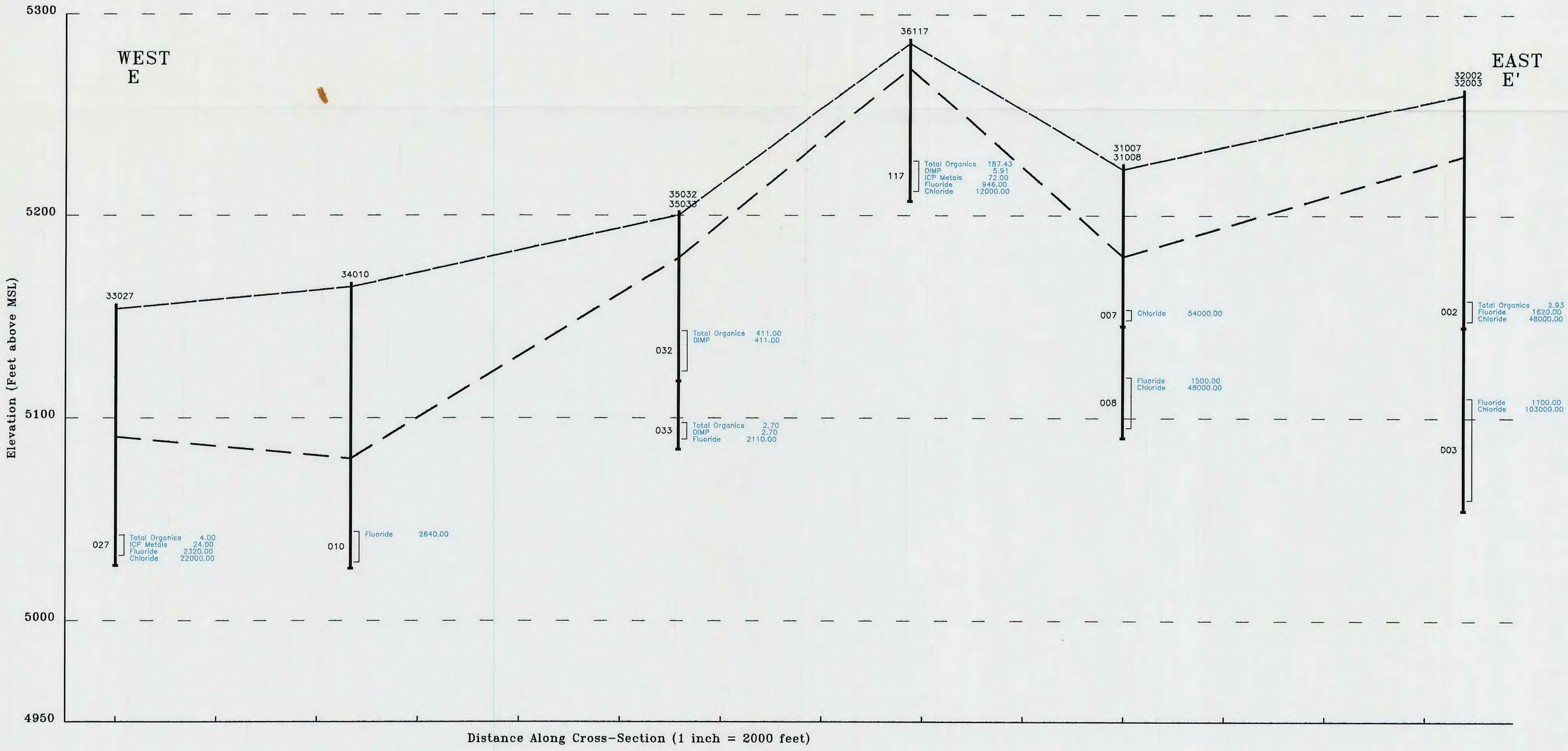
Prepared August 1991

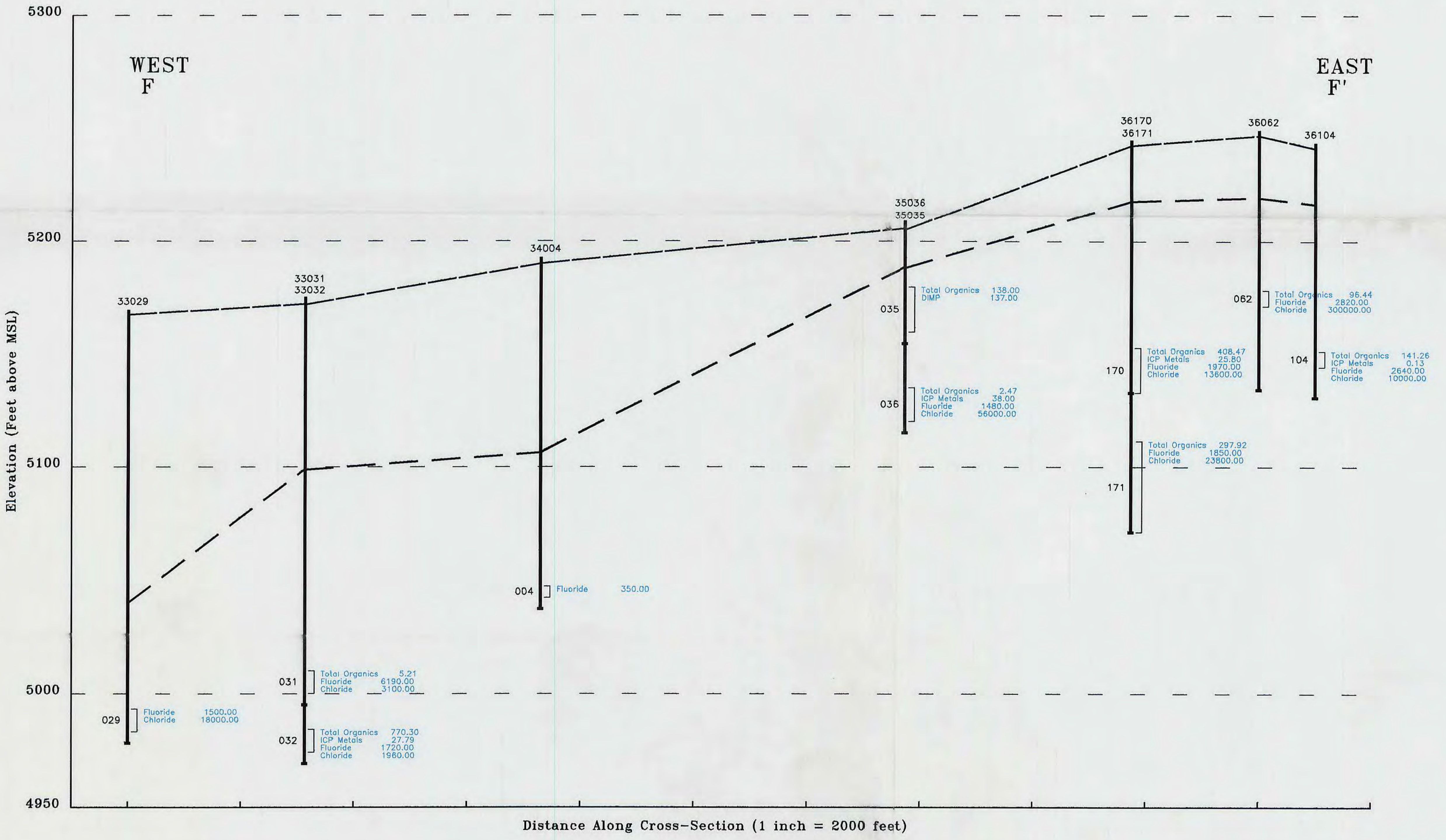
PLATE RISR B.4-2

Cross-Sections A-A', B-B', and C-C'

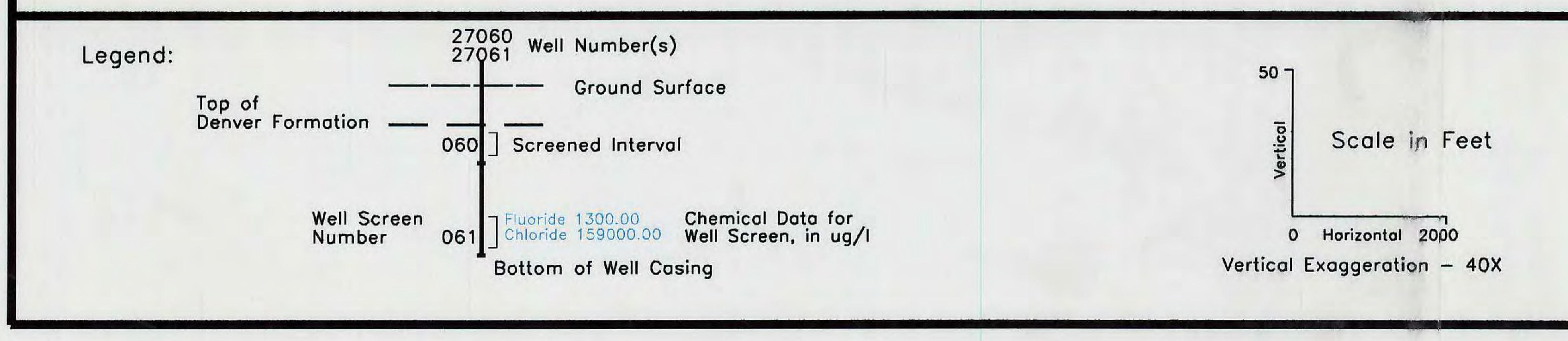
Prepared by: Ebasco Services Incorporated







Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90



Prepared for:

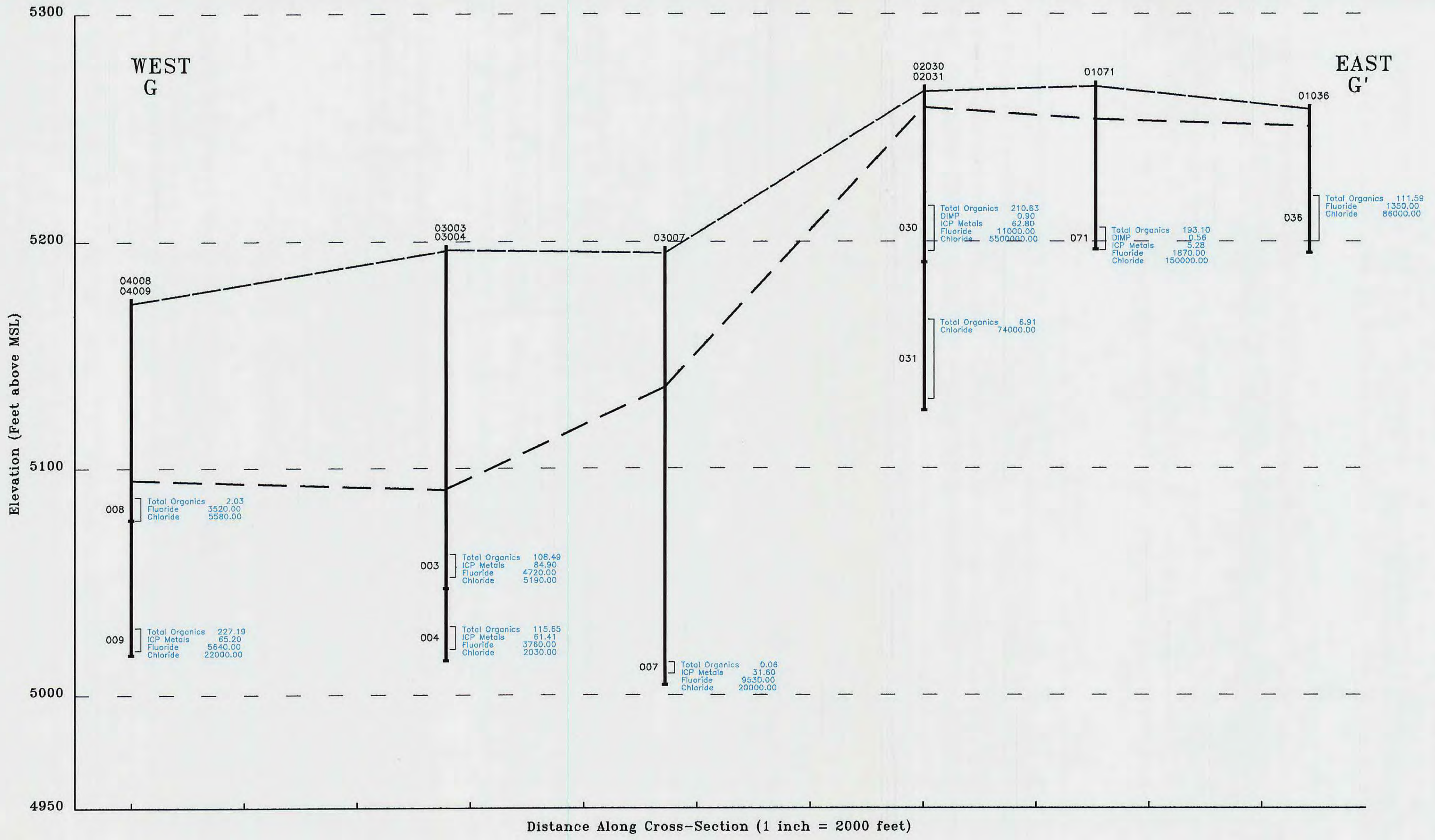
U.S. Army Program Manager
for Rocky Mountain Arsenal

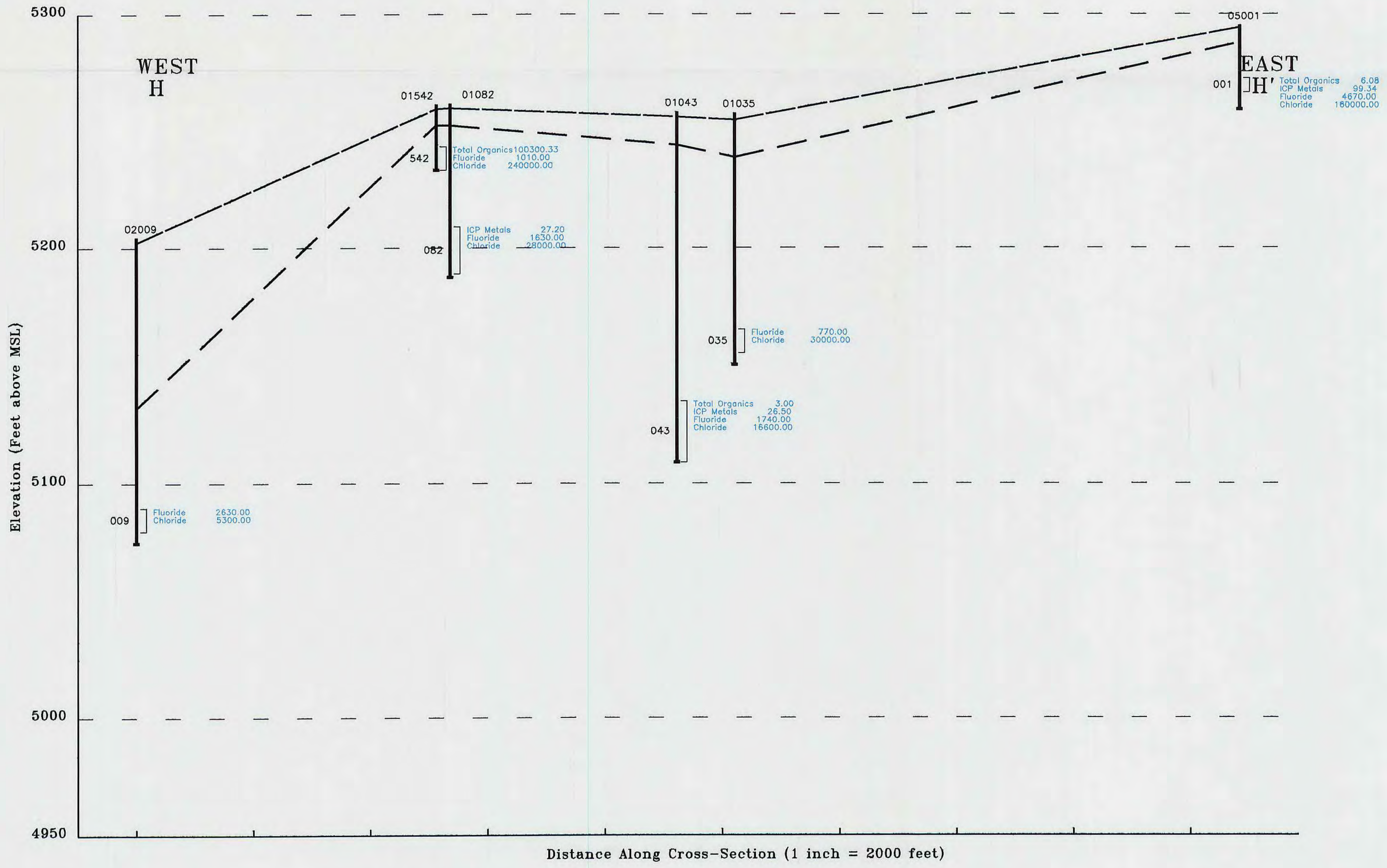
Prepared August 1991

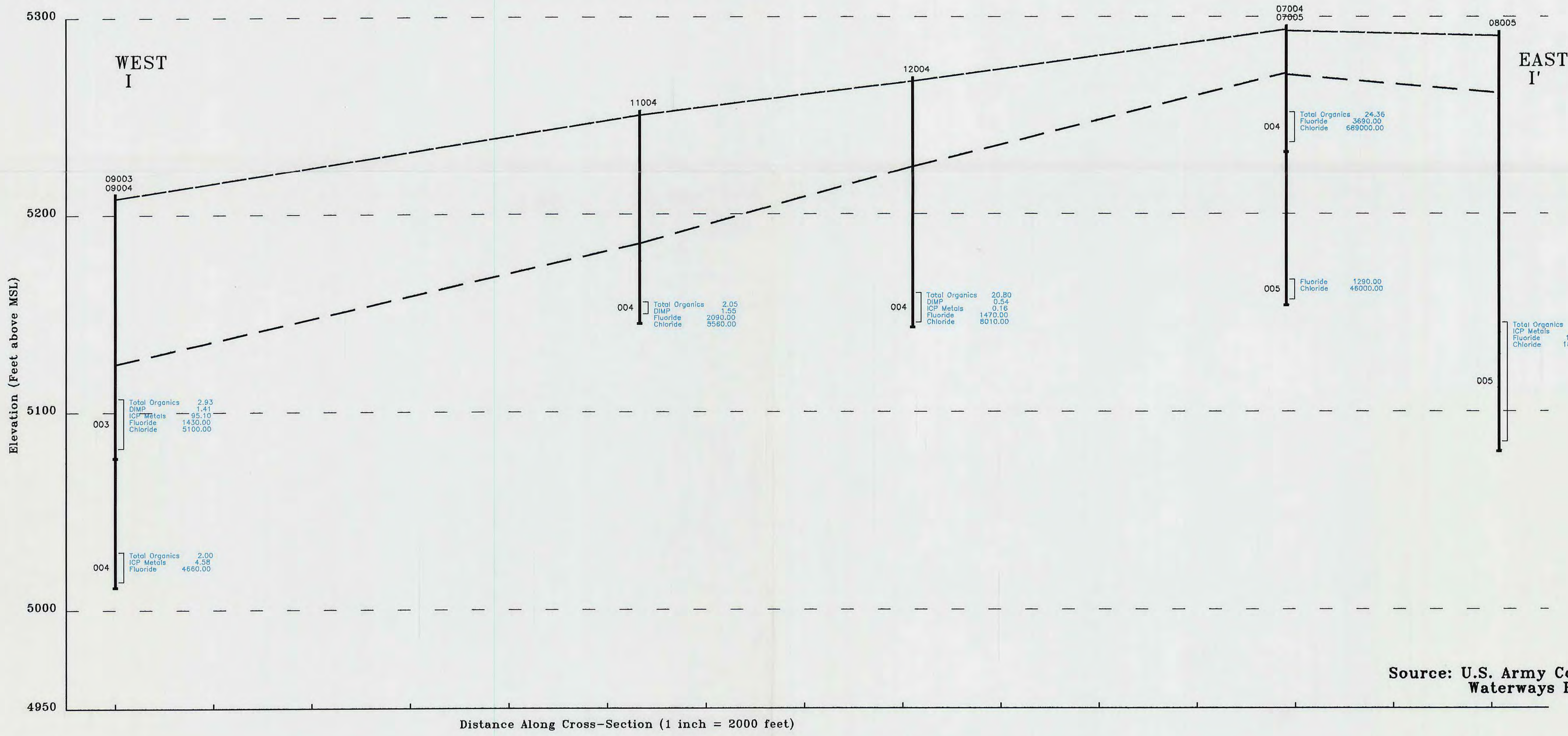
PLATE RISR B.4-3

Cross-Sections D-D', E-E' and F-F'

Prepared by: Ebasco Services Incorporated

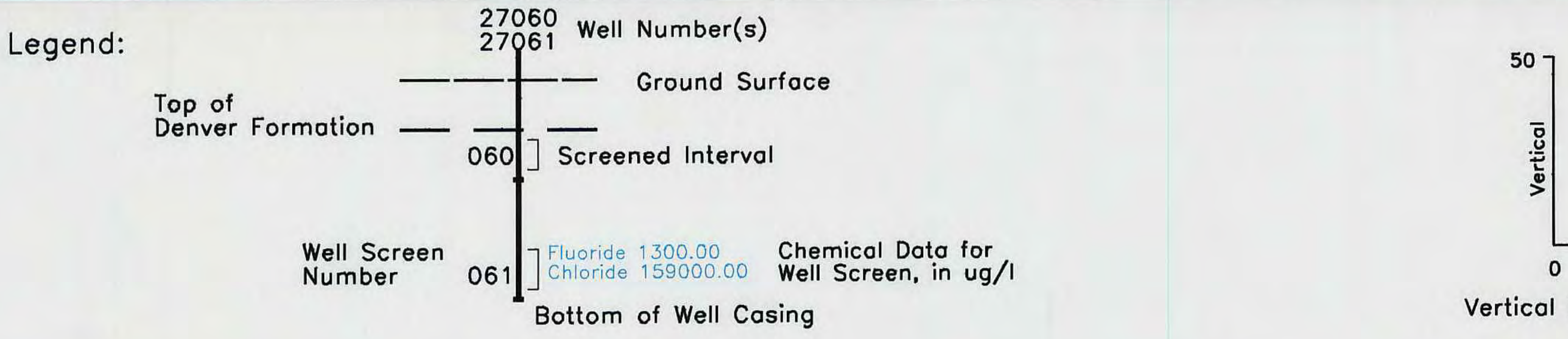


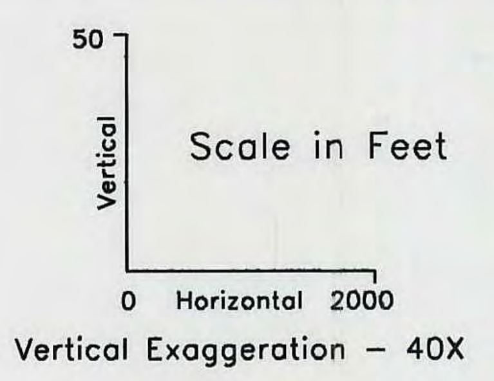




Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90

Legend:





Vertical Exaggeration – 40X

Prepared for:

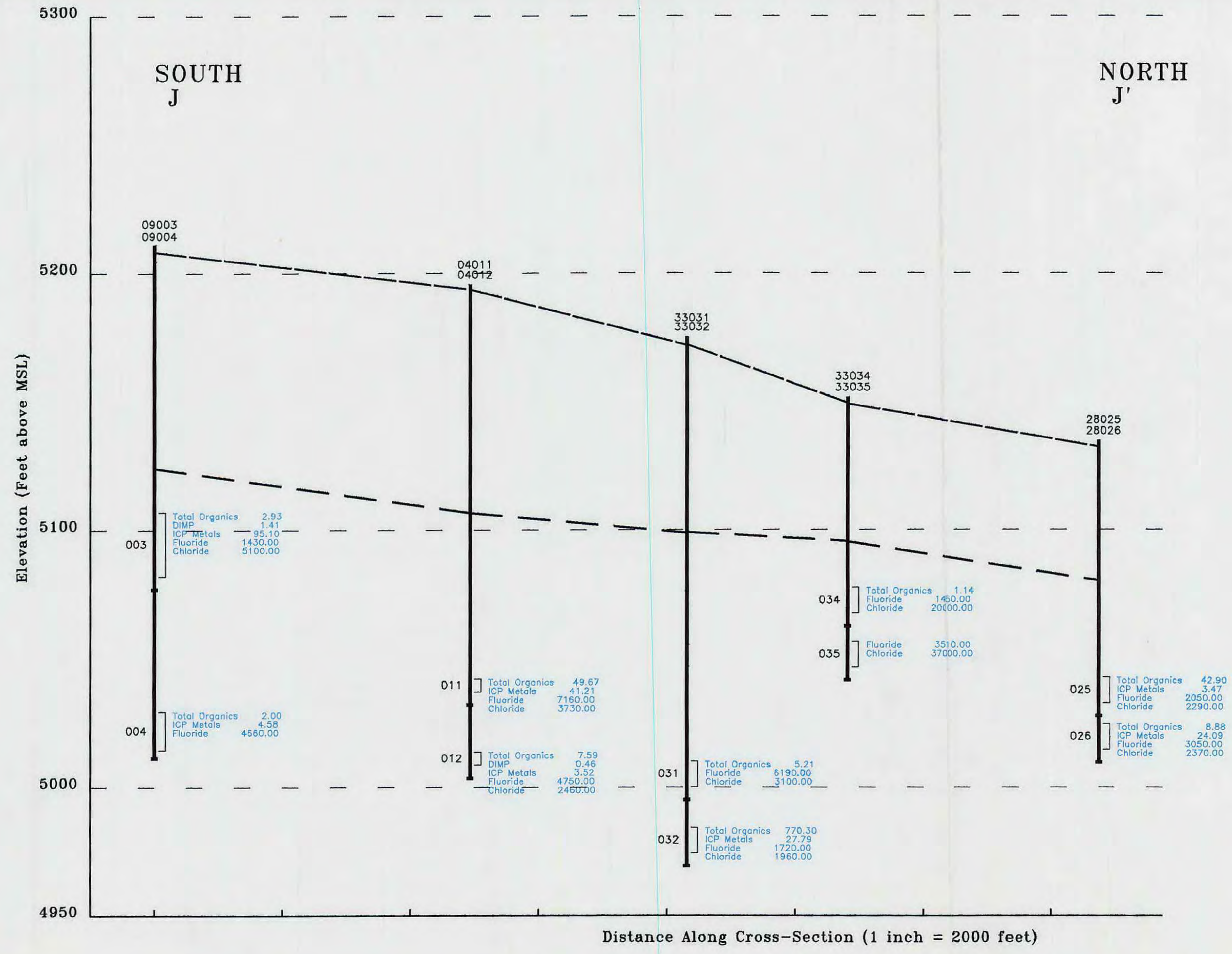
U.S. Army Program Manager
for Rocky Mountain Arsenal

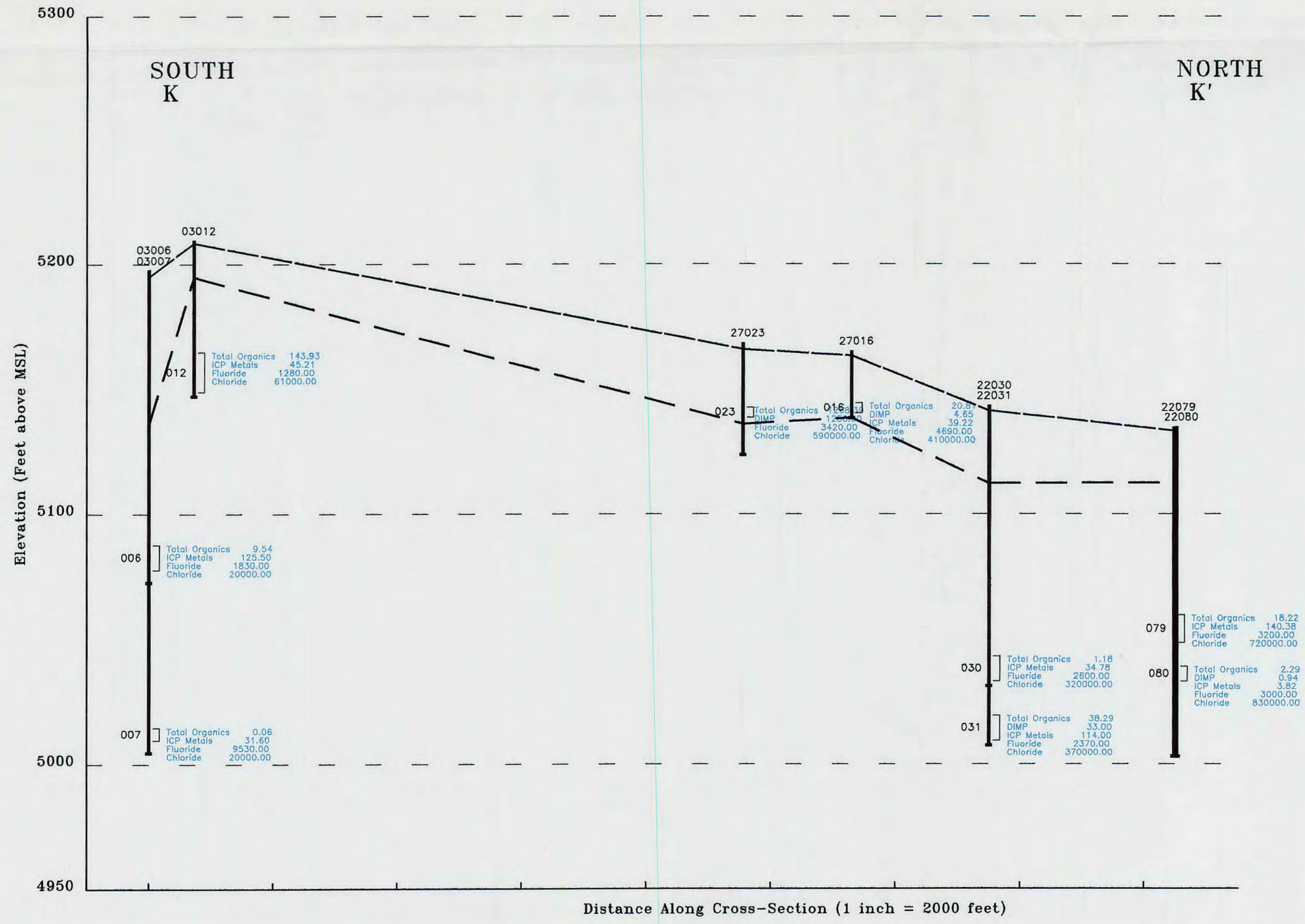
Prepared August 1991

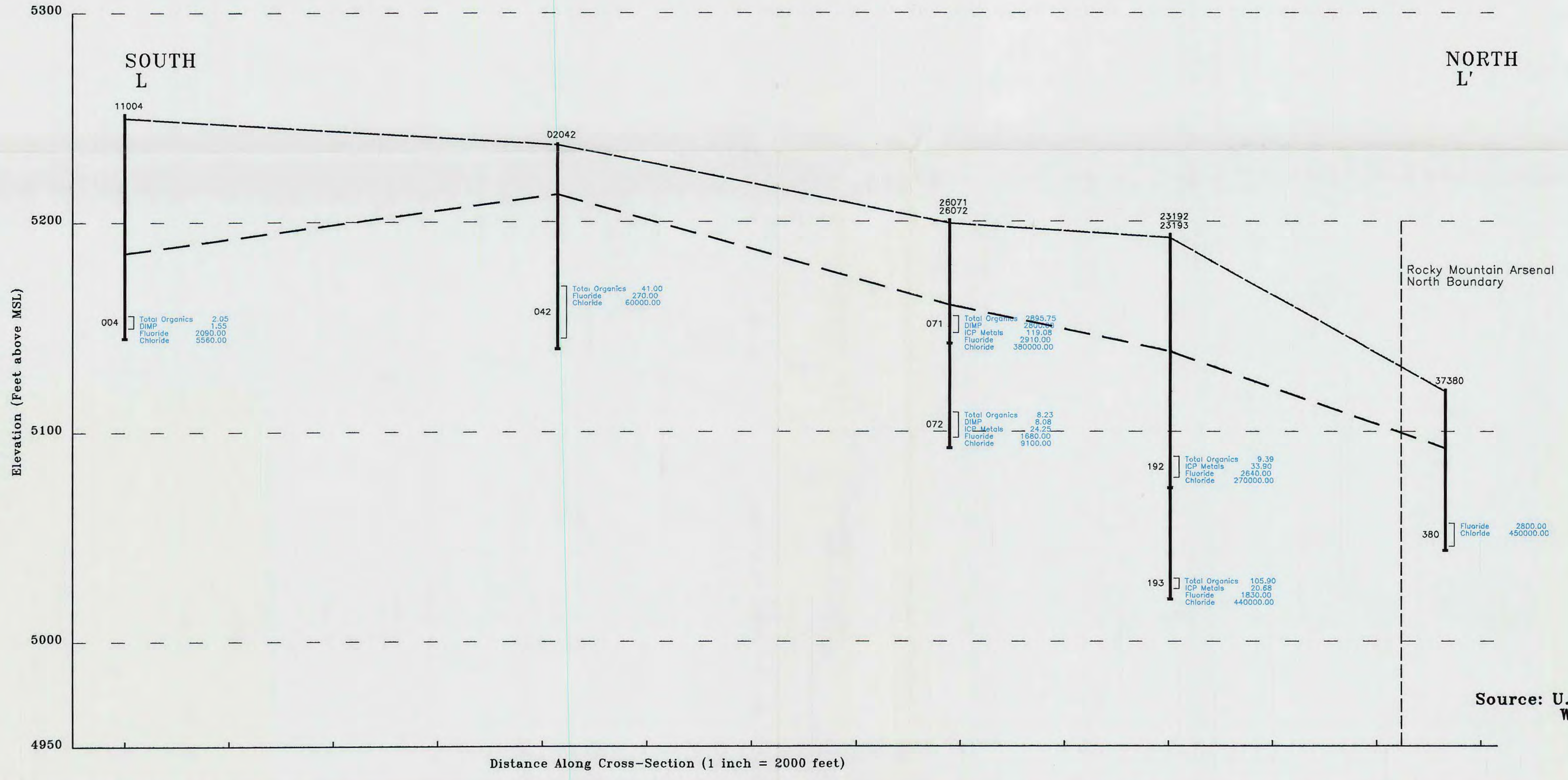
PLATE RISR B.4–4

Cross–Sections G–G', H–H', and I–I'

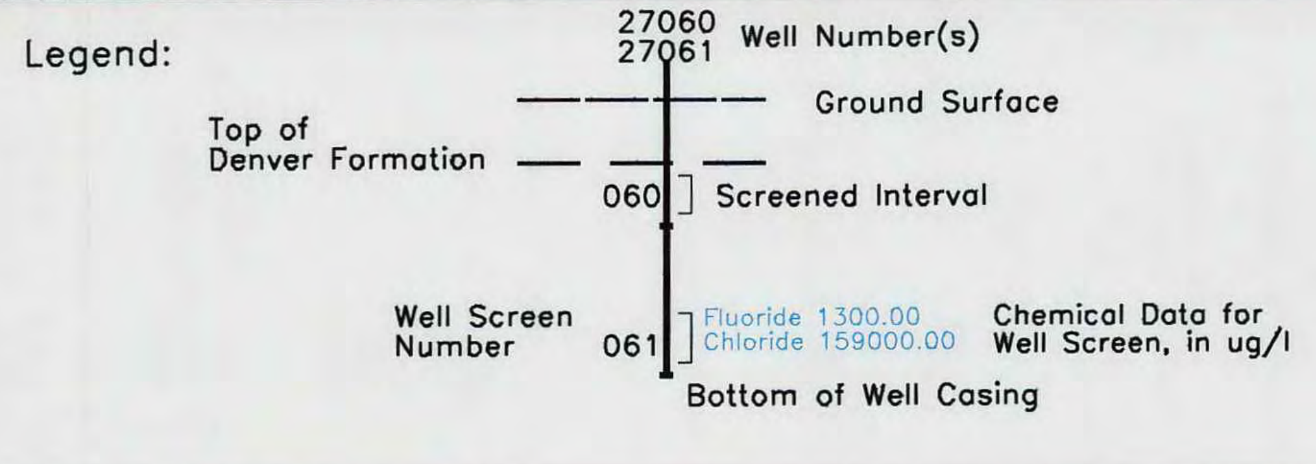
Prepared by: Ebasco Services Incorporated

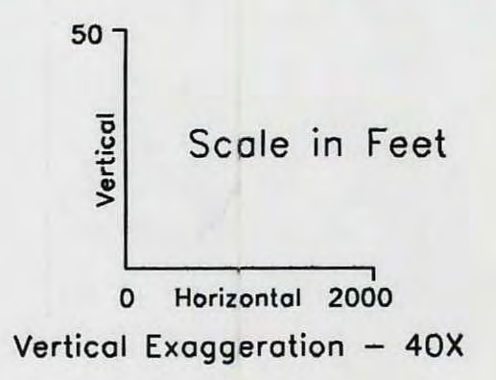






Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90





Prepared for:

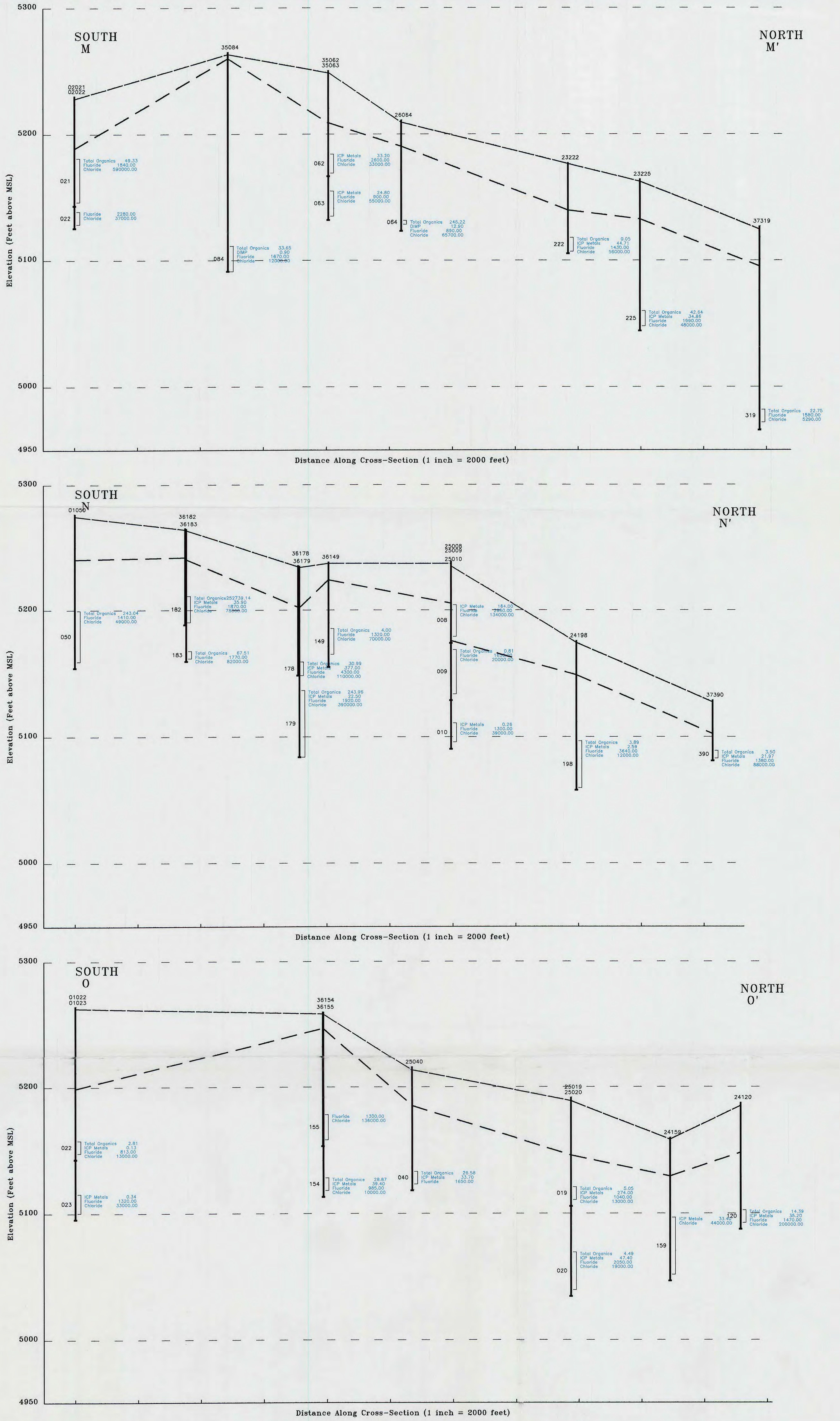
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

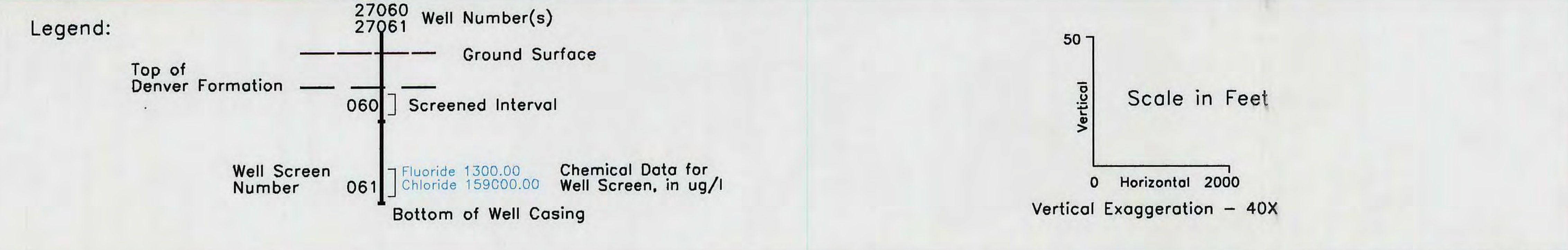
PLATE RISR B.4-5

Cross-Sections J-J', K-K', and L-L'

Prepared by: Ebasco Services Incorporated



**Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90**



Prepared for:

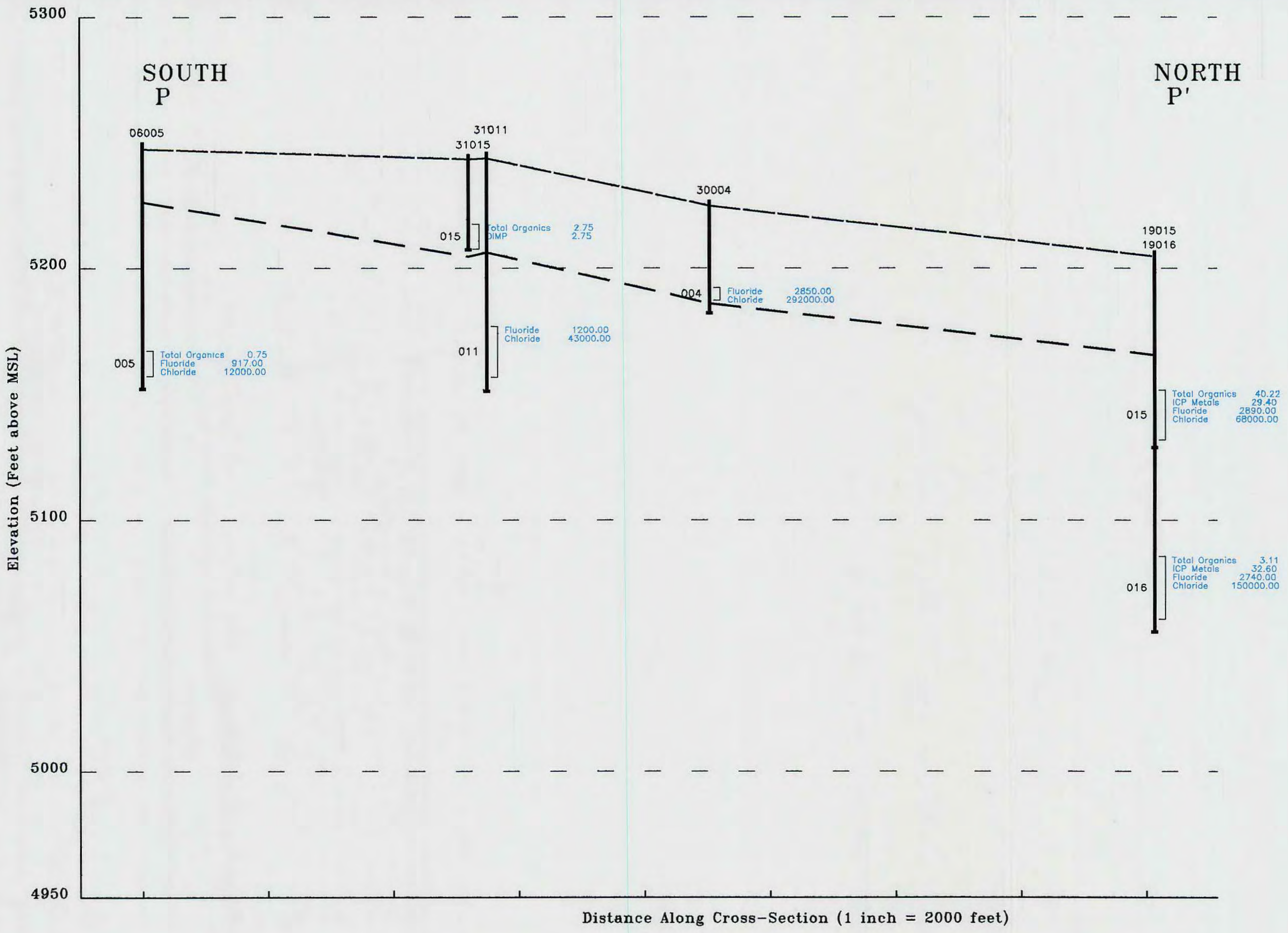
U.S. Army Program Manager
for Rocky Mountain Arsenal

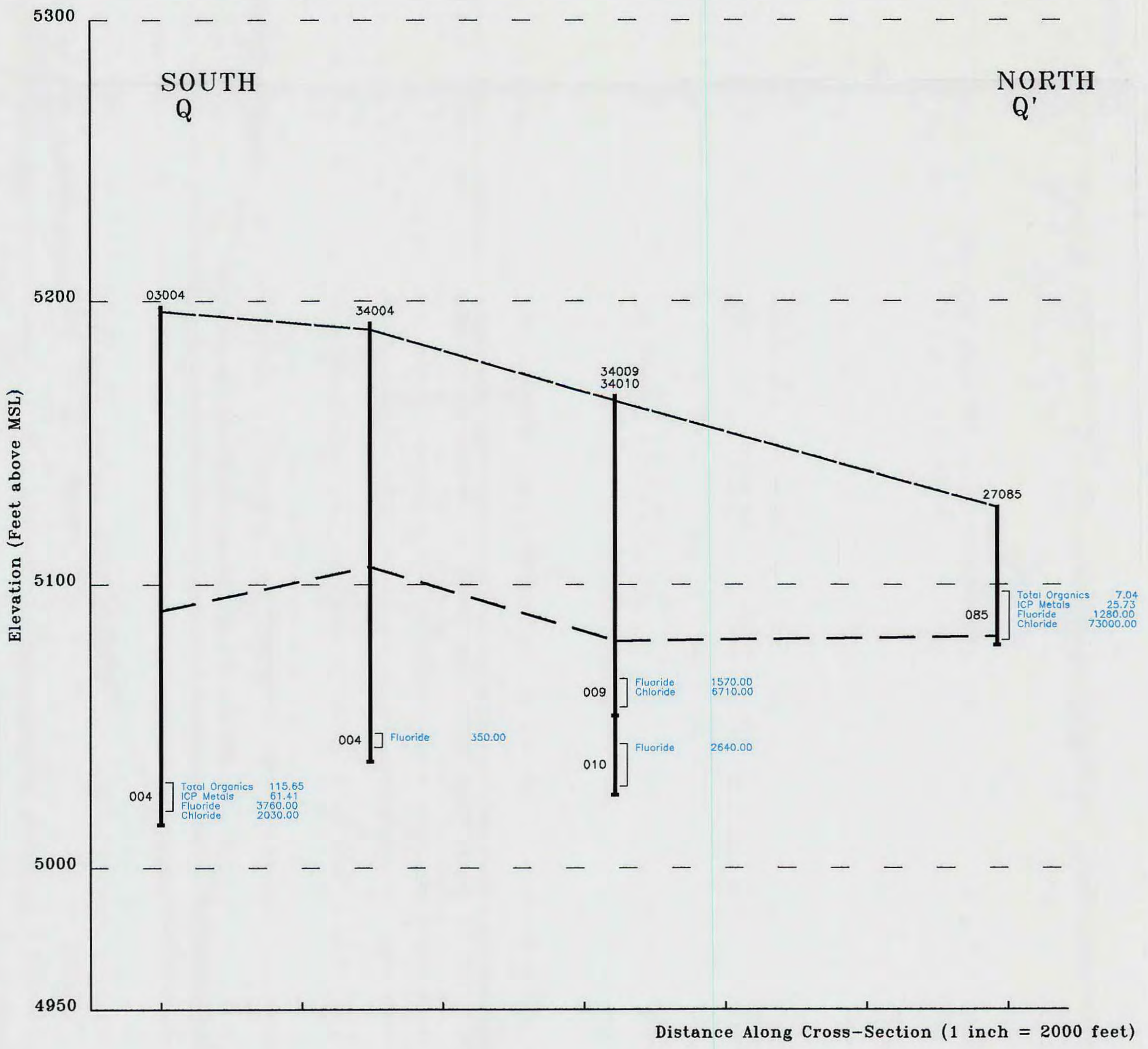
Prepared August 1991

PLATE RISR B.4-6

Cross-Sections M–M', N–N', and O–O'

Prepared by: Ebasco Services Incorporated





Source: U.S. Army Corps of Engineers
Waterways Experiment Station, 8/90

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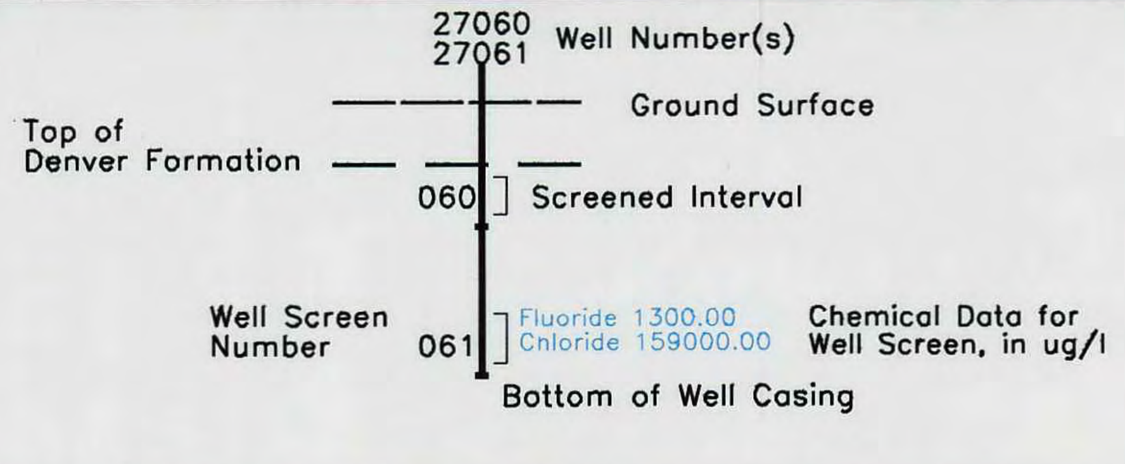

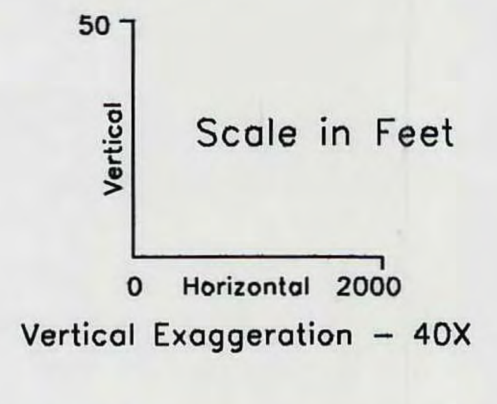

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

PLATE RISR B.4-7

Cross-Sections P-P' and Q-Q'

Prepared by: Ebasco Services Incorporated

TECHNICAL SUPPORT FOR

ROCKY MOUNTAIN ARSENAL

FINAL
REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX C - INTERIM RESPONSE ACTIONS
APPENDIX D - OTHER SPECIAL INVESTIGATIONS
APPENDIX E - CONTAMINANT FATE AND TRANSPORT

VERSION 3.2

January 1992

Contract Number DAAA15-88-D-0024

PREPARED BY:

EBASCO SERVICES INCORPORATED
APPLIED ENVIRONMENTAL, INC.
CH2M HILL DATACHEM, INC.
R.L. STOLLAR AND ASSOCIATES

PREPARED FOR:

U.S. ARMY PROGRAM MANAGER FOR
ROCKY MOUNTAIN ARSENAL

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

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Remedial Investigation Summary Report

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APPENDIX C - TABLE OF CONTENTS
(continued)

APPENDIX C - TABLE OF CONTENTS
(continued)

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Figure

APPENDIX C - LIST OF ABBREVIATIONS

Analyte Groups and Selected Analytes

DBCP	Dibromochloropropane
ICP metals	Metals analyzed for by inductively coupled argon plasma spectroscopy; includes cadmium, chromium, copper, lead, and zinc
OCP	Organochlorine pesticide
ONC	Organonitrogen compound
OPHGB	Organophosphorous compound, GB-agent related
OPHP	Organophosphorous compound, pesticide related
OSCH	Organosulfur compound, herbicide related
OSCM	Organosulfur compound, mustard-agent related
VAO	Volatile aromatic organic
VHC	Volatile hydrocarbon
VHO	Volatile halogenated organic

National Acts and Organizations

Army	U.S. Army
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COE	U.S. Army Corps of Engineers
EPA	U.S. Environmental Protection Agency

Local Terminology

AA/GAC	Activated alumina/granular activated carbon
ACM	Asbestos-containing material
CMP	Comprehensive Monitoring Program
FFA	Federal Facility Agreement
HBSF	Hydrazine blending and storage facility
ICS	Irondale Containment System
IRA	interim response action
ISV	*In situ* vitrification
NBCS	North Boundary Containment System
NWBCS	Northwest Boundary Containment System
PMRMA	U.S. Army Program Manager for Rocky Mountain Arsenal
RI	remedial investigation
RIC	Rocky Mountain Arsenal Information Center
RI/FS	Remedial Investigation/Feasibility Study
RISR	Remedial Investigation Summary Report

APPENDIX C - LIST OF ABBREVIATIONS
(continued)

RMA	Rocky Mountain Arsenal
State	State of Colorado
TIC	Tentatively identified compound

Companies

EBASCO	Ebasco Services Incorporated
ESE	Environmental Sciences and Engineering, Inc.
HLA	Harding Lawson and Associates
MKE	Morrison-Knudsen Engineering
Shell	Shell Oil Company
WCC	Woodward-Clyde Consultants

Measurements and Quantities

ft	Foot, feet
in.	Inch, inches
pH	A measure of acidity or alkalinity
μg/l	Micrograms per liter

Months

Jan	January
Feb	February
Mar	March
Apr	April
May	May
Jun	June
Jul	July
Aug	August
Sep	September
Oct	October
Nov	November
Dec	December

C.1 INTRODUCTION

While not strictly a component of the remedial investigation (RI), many of the interim response actions (IRAs) at the Rocky Mountain Arsenal (RMA) were undertaken in response to information generated in the course of the RI. These actions were implemented in order to expedite the mitigation of contamination prior to the selection of final remedial actions. Thirteen IRAs have been identified by the U.S. Army (Army) in cooperation with the U.S. Environmental Protection Agency (EPA), the State of Colorado (State), and Shell Oil Company (Shell). These IRAs are considered "necessary and appropriate" for implementation prior to the final remediation decisions at RMA (FFA, 1989/RIC 89068R01). Actions requiring removal of material are to be carried out in accordance with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and its regulations and are to be consistent with and contribute to the efficient performance of the final response actions for the on-post and off-post operable units (PMRMA, 1988a/RIC 88131R01). Table RISR C.1-1 lists the 13 IRAs and their specific objectives. Figure RISR C.1-1 identifies IRA locations with the exception of three IRAs: Asbestos Removal, Fugitive Dust Control, and Closure of Abandoned Wells on RMA. Locations of these are not shown because they are being conducted at numerous individual sites across RMA.

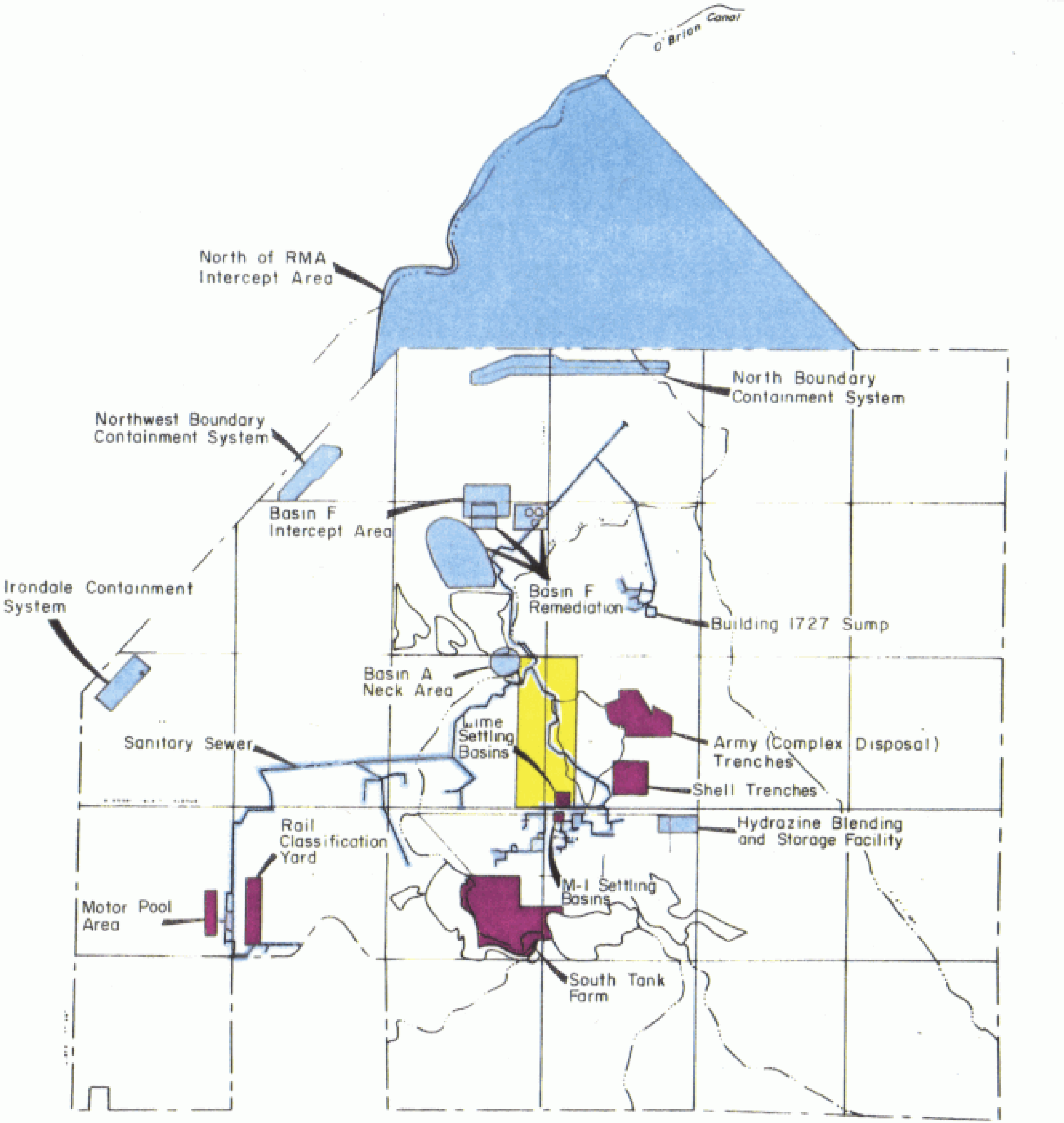
The procedure for IRA implementation is set forth in Section XXII of the Federal Facility Agreement (FFA) (FFA, 1989/RIC 89068R01). Figure RISR C.1-2 outlines the typical IRA process. This process applies to most RMA IRAs. For a variety of technical reasons, a slightly different process was used for the following IRAs: Improvements of the North Boundary Containment System and Evaluation of all Existing Boundary Containment Systems; Closure of Abandoned Wells on RMA; Basin F Liquids, Sludges, and Soils Remediation; and Fugitive Dust Control (PMRMA, 1988a/RIC 88131R01). Several of the IRAs consist of a number of parts that are referred to as components in the text. The actual or estimated schedule deadlines for the various phases and components of the 13 IRAs are listed in Table RISR C.1-2. Implementation of the various IRAs will impact a number of media at RMA. The type and extent of media impact will depend on the type of response

Table RISR C.1-1. Interim Response Actions at the Rocky Mountain Arsenal

IRA	OBJECTIVE
• Groundwater Intercept and Treatment System North of RMA	• Eliminate much of the potential for any future exposure from contaminated alluvial groundwater plumes north of RMA.
• Improvement of the North Boundary Containment System and Evaluation of Existing Boundary Containment Systems	• Evaluate and improve, as necessary, all RMA boundary systems.
• Groundwater Intercept and Treatment System North of Basin F	• Intercept and treat contaminated alluvial groundwater originating from the Basin F area to make boundary systems more efficient.
• Closure of Abandoned Wells on RMA	• Identify, locate, examine, and properly close old or unused wells on RMA to prevent migration of contamination between aquifers.
• Groundwater Intercept and Treatment System in the Basin A Neck Area	• Intercept and treat contaminated groundwater in the alluvial aquifer between Basins A and F, to make boundary systems more efficient.
• Basin F Liquids, Sludges, and Soils Remediation	• Mitigate any potential for infiltration of contaminants to the groundwater, preclude potential for volatile emissions, eliminate any potential impact of Basin F on wildlife, and remediate Basin F liquids.
• Building 1727 Sump Liquid	• Remediate contaminated liquid in the Building 1727 sump to mitigate any remaining threat of release of liquids from this sump.
• Closure of the Hydrazine Facility	• Mitigate any threat of release of wastewater stored at this facility and remediate the aboveground structures.
• Fugitive Dust Control	• Mitigate as expeditiously as possible any threat of the release of wind-blown contaminated dust.
• Sewer Remediation	• Eliminate the RMA sanitary sewer as a potential conduit for contaminant flow.
• Asbestos Removal	• Remove and dispose of friable asbestos at RMA where any potential for human exposure exists.
• Remediation of Other Contamination Sources ("Hot Spots")	• Mitigate the threat of releases from selected "hot spots" contamination sources.

IRA	OBJECTIVE
• Pretreatment of CERCLA Liquid Waste	• Treat wastewater resulting from CERCLA-related activities at RMA.

(PMRMA, 1988a/RIC 88131R01, modified)



Legend

🟦 IRA Location

🟪 Location of Other Contamination Sources ("Hot Spots") IRA Components

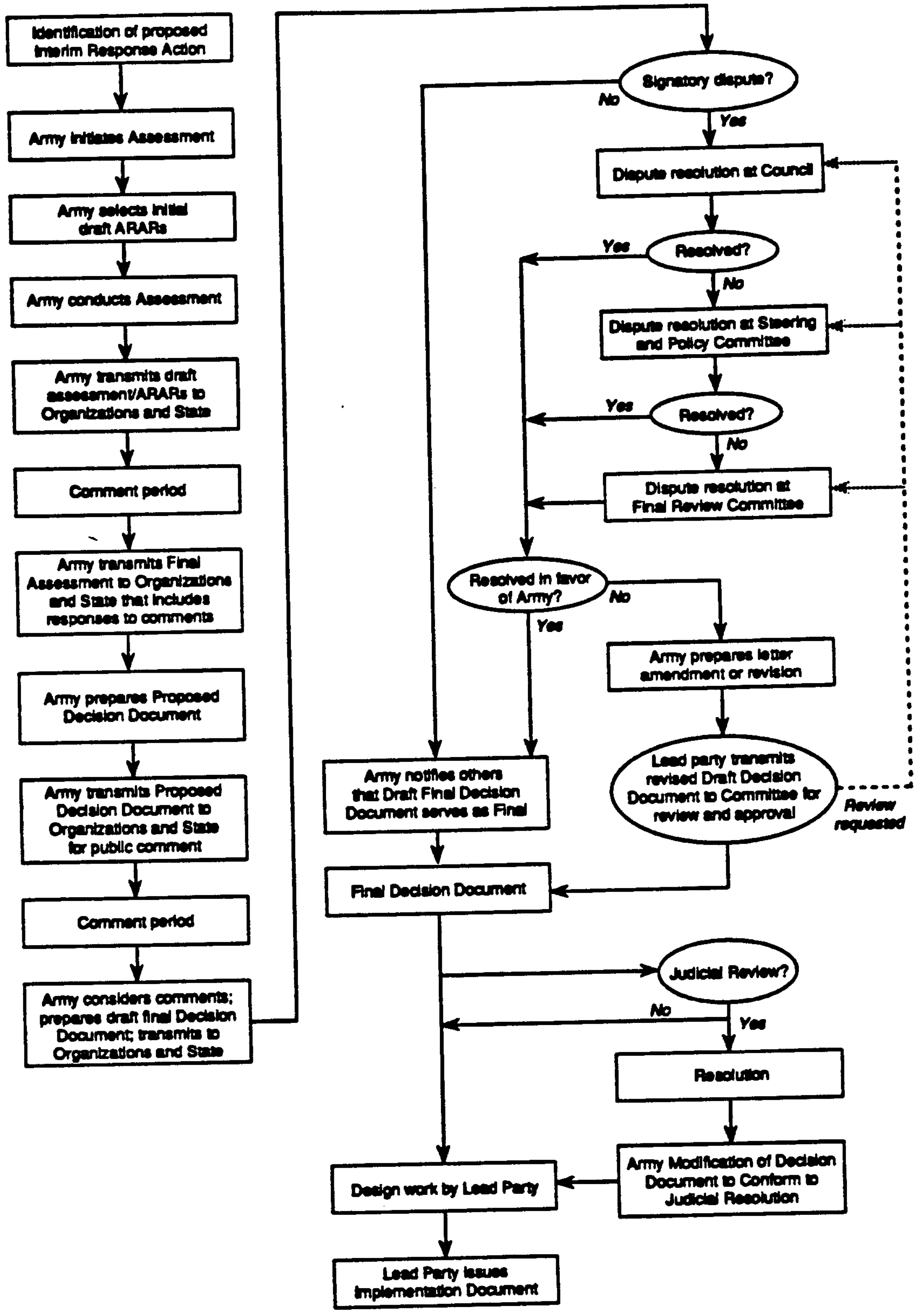
🟨 Area proposed for siting CERCLA Liquid Waste Pretreatment Facility

—— Sanitary Sewer

— — Rocky Mountain Arsenal On-Post Boundary

Note: Asbestos Removal, Fugitive Dust Control, and Abandoned Well Closure IRAs not shown. These IRAs are being conducted at numerous sites throughout RMA.

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal **Prepared August 1991**	FIGURE RISR C.1-1 Location Map for Interim Response Action Areas at the Rocky Mountain Arsenal Rocky Mountain Arsenal Prepared by: Ebasco Services Incorporated



Source: PMRMA, 1988a

Prepared for:

U. S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

Figure RISR C.1-2
Typical Interim Response Action Process

Prepared by: Ebasco Services Incorporated

Table RISR C.1-2. Proposed IRA Schedule Deadlines

IRA	Final Assessment*	Final Decision Document*	Implementation Document*	Start Construction*	Complete IRA*
Groundwater Intercept and Treatment System North of RMA	Dec 88	Jul 89	Oct 90	(Sep 91)	(Dec 92)
Improvement of the North Boundary Containment System and Evaluation of all Existing Boundary Containment Systems					
• North Boundary Containment System Evaluations and Improvements	Jan 89	Apr 89	Jan 90	Feb 90	Dec 90
• Northwest Boundary Containment System Assessment and Improvements (Short-Term Objectives)	---	Jun 90	Jun 90	Jun 90	(Nov 91)
• Northwest Boundary Containment System Assessments and Improvements (Long-Term Objectives)	May 91	(Aug 91)	(Aug 92)	(Dec 92)	(Sep 93)
• North Boundary Containment System Groundwater Recharge Trenches	---	Jul 88	Jul 88	Sep 88	Dec 88

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*Estimated dates shown in parentheses

**Construction phase completed; IRA operation/treatment continuing

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Table RISR C.1-2. Proposed IRA Schedule Deadlines

IRA	Final Assessment*	Final Decision Document*	Implementation Document*	Start Construction*	Complete IRA*
Groundwater Intercept and Treatment System North of Basin F	Jul 88	Dec 88	Aug 89	Dec 89	Sep 90**
Closure of Abandoned Wells	---	Jun 88	---	Apr 88	Feb 90
Groundwater Intercept and Treatment System in the Basin A Neck Area	Sep 88	Feb 89	Jun 89	Nov 89	Jul 90**
Basin F Liquids, Sludges, and Soils Remediation					
• Basin F Remediation - Liquids, Sludges, and Soils Removal (Phase I)	---	Jan 88	---	Mar 88	May 89
• Basin F Remediation - Liquids Treatment (Phase II)	Dec 89	May 90	Dec 90	Mar 91	July 95

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*Estimated dates shown in parentheses
**Construction phase completed; IRA operation/treatment continuing

Table RISR C.1-2. Proposed IRA Schedule Deadlines

IRA	Final Assessment*	Final Decision Document*	Implementation Document*	Start Construction*	Complete IRA*
Building 1727 Sump Liquid	Aug 88	Dec 88	May 89	Jul 89	Nov 89**
Closure of the Hydrazine Facility	Jun 88	Nov 88	Dec 90	(Aug 91)	(Jul 92)
• Phase I	Jun 88	Nov 88	Jan 91	(Oct 91)	(Jul 92)
• Phase II	Jun 88	(Jun 91)	(Jul 91)	(Aug 91)	(Jul 92)
Fugitive Dust Control	---	---	---	Sep 87	(Jun 91)**
Sewer Remediation	Oct 88	Apr 89	Jan 90	Jan 91	(Mar 92)
Asbestos Removal					
• Phases I and II	Apr 88	---	---	Sep 88	Dec 89
• Phase III	(Sep 92)	---	---	(Oct 92)	(Dec 95)

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*Estimated dates shown in parentheses

**Construction phase completed; IRA operation/treatment continuing

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Table RISR C.1-2. Proposed IRA Schedule Deadlines

IRA	Final Assessment*	Final Decision Document*	Implementation Document*	Start Construction*	Complete IRA*
Remediation of Other Contamination Sources ("Hot Spots")					
• Lime Settling Basins	Nov 89	Mar 90	Nov 90	(Jan 92)	(Jun 93)
• M-1 Settling Basins	Nov 89	Mar 90	Dec 90	(Nov 91)	(Dec 92)
• Motor Pool Area-Trichloroethylene Plume	Nov 89	Mar 90	Nov 90	(Jun 91)	(Mar 92)
• Rail Classification Yard-DBCP Plume	Nov 89	Mar 90	Aug 90	Dec 90	(Jun 91)
• Army Complex Disposal Trenches	Jan 90	May 90	Sep 90	Nov 90	(Jun 93)
• Shell Trenches	Jan 90	May 90	Dec 90	Mar 91	(Nov 91)
• South Tank Farm Plume	Jun 90	(May 91)	(Jul 91)	(Nov 91)	(Mar 94)
Pretreatment of CERCLA Liquid Waste	Dec 89	Jun 90	Jan 91	(Jun 91)	(Jul 92)

*Estimated dates shown in parentheses
**Construction phase completed; IRA operation/treatment continuing

RF51/TBL0004.RF5 11/7/91 2:30 pm sma

action being performed. Potential impacts to the water medium, for example, may be the result of improvements to or construction of groundwater intercept and treatment systems that would reduce the migration of contaminated groundwater. Table RISR C.1-3 lists media potentially impacted by the implementation of each specific IRA. The 13 IRAs identified as of May 1991 are summarized in this report. Reports generated for these IRAs (Technical Plans, Alternatives Assessment Reports, Decision Documents, Implementation Documents, and Operational Reports) are listed in Table RISR C.1-4.

C.2 GROUNDWATER INTERCEPT AND TREATMENT SYSTEM NORTH OF RMA

The Groundwater Intercept and Treatment System North of RMA IRA consists of the assessment, selection, and construction of one or more off-post pump and treat systems (FFA, 1989/RIC 89068R01). The specific objectives of this IRA are to continue off-post groundwater monitoring, provide an alternative drinking water supply for residents, mitigate the off-post migration of contaminated alluvial groundwater, and treat contaminated alluvial groundwater to improve off-post groundwater quality (HLA, 1989a/RIC 89222R01).

C.2.1 DESCRIPTION

The Groundwater Intercept and Treatment System North of RMA is in a 4-square-mile area north of RMA and south of the O'Brian Canal (Figure RISR C.1-1). Volatile halogenated organics (VHOs), volatile aromatic organics (VAOs), volatile hydrocarbons (VHCs), organochlorine pesticides (OCPs), GB agent-related organophosphorous compounds (OPHGBs), herbicide-related organosulfur compounds (OSCHs), mustard agent-related organosulfur compounds (OSCMs), dibromochloropropane (DBCP), arsenic, mercury, and the ICP metals (cadmium, chromium, copper, lead, and zinc) have been detected in two off-post groundwater contaminant plumes, referred to as the First Creek Plume and the Northern Plume (HLA, 1989a/RIC 89222R01).

Table RISR C.1-3. Media Potentially Impacted by IRAs

Page 1 of 1

IRA	Soils	Water	Structures	Air	Biota
Groundwater Intercept and Treatment System North of RMA		X			
Improvement of the North Boundary System and Evaluation of all Existing Boundary Systems		X			
Groundwater Intercept and Treatment System North of Basin F		X		X	
Closure of Abandoned Wells on RMA		X			
Groundwater Intercept and Treatment System in the Basin A Neck Area		X		X	
Basin F Liquids, Sludges, and Soils Remediation	X	X	X	X	X
Building 1727 Sump Liquid	X	X	X		
Closure of the Hydrazine Facility			X	X	
Fugitive Dust Control	X	X	X	X	X
Sewer Remediation	X	X		X	
Asbestos Removal			X	X	
Remediation of Other Contamination Sources ("Hot Spots")	X	X	X	X	X
Pretreatment of CERCLA Liquid Waste		X			

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Interim Response Action - General	Draft Final Technical Program Plan FY88 - FY92 (Remedial Investigation/Feasibility Study/Interim Response Actions)	-	12/87	-	88007R02
	Rocky Mountain Arsenal Draft Final Technical Program Plan FY88 - FY92 Remedial Investigation/Feasibility Study/Interim Response Actions, Volumes I and II	-	2/88	-	88110R01
	Final Technical Program Plan FY88-FY92 (Remedial Investigation/Feasibility Study/Interim Response Actions), Volumes I and II	-	3/88	-	88130R01
Groundwater Intercept and Treatment System North of RMA	Off-post Interim Response Action Alternatives Assessment Draft Final Report (IRA)	2.2	5/88	39	88033R01
	Off-post Interim Response Action Alternatives Assessment Draft Final Report (IRA)	2.3	12/88	-	89062R02
	Proposed Decision Document for the Ground Water Intercept and Treatment System North of Rocky Mountain Arsenal (IRA)	-	12/88	-	89062R01
	Draft Final Decision Document for the Ground Water Intercept and Treatment System North of Rocky Mountain Arsenal Interim Response Action (IRA)	-	4/89	-	89122R02
	Draft Final Work Plan for the Ground Water Intercept and Treatment System North of Rocky Mountain Arsenal Interim Response Action (IRA)	-	6/89	-	89192R03
	Revised Draft Final Decision Document for the Ground Water Intercept and Treatment System North of Rocky Mountain Arsenal Interim Response Action (IRA)	-	6/89	-	89192R02
	Final Decision Document for the Ground Water Intercept and Treatment System North of Rocky Mountain Arsenal Interim Response Action (IRA)	-	7/89	-	89222R01
	Off-post Interim Response Action and Remedial Investigation/Feasibility Study Draft Final Field Operations Procedures Plan RIFS1 (IRA)	-	8/89	-	89268R02
	Off-post Interim Response Action and Remedial Investigation/Feasibility Study Draft Final Health and Safety Plan RIFS1 (IRA)	-	8/89	-	89268R03
	Off-post Operable Unit Draft Final Quality Assurance Plan RIFS1 (IRA)	-	8/89	-	89268R01

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Improvement of the North Boundary System and Evaluation of all Existing Boundary Systems	Rocky Mountain Arsenal North Boundary/Containment Treatment System Operational Assessment Report FY85/FY86, Volumes I - III	-	6/87	-	87320R01
	Rocky Mountain Arsenal Northwest Boundary/Containment Treatment System Baseline Conditions System Startup and Operational Report FY85/FY86, Volumes I - III	-	12/87	-	88054R01
	Summary of WES Analysis of Proposed Recharge Trench System for RMA North Boundary	-	1/88	-	88155R01
	North Boundary System Component Response Action Assessment Final Technical Plan	-	2/88	36	88063R08
	Proposed Interim Ground Water Recharge System North Boundary Area	-	2/88	-	88130R01
	Proposed Decision Document for the IRA for the Improvement of the North Boundary System at Rocky Mountain Arsenal via Construction of Ground Water Recharge Trenches (IRA)	-	4/88	-	88141R02
	Rocky Mountain Arsenal North Boundary Flow Rates July 1986 - September 1987	-	5/88	-	88153R01
	Rocky Mountain Arsenal Northwest Boundary Flow Rates: July 1986 - September 1987	-	5/88	-	88153R02
	Draft Final Decision Document for the Interim Response Action for the Improvement of the North Boundary System at RMA via Construction of Ground Water Recharge Trenches (IRA)	-	6/88	-	88328R03
	Water Elevation Report for the North Boundary System October 1986 - September 1987	-	6/88	-	88159R01
	Water Elevation Report for the Northwest Boundary System October 1986 - September 1987	-	6/88	-	88159R02
	Final Decision Document for the Interim Response Action for the Improvement of the North Boundary System at Rocky Mountain Arsenal via Construction of Ground Water Recharge Trenches (IRA)	-	7/88	-	88329R03

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Improvement of the North Boundary System and Evaluation of all Existing Boundary Systems (continued)	Implementation Document for IRA to Improve the North Boundary System via Construction of Ground Water Recharge Trenches (IRA)	-	9/88	-	89139R01
	Boundary Systems Monitoring Final Trenches Plan - RMA	-	9/88	25	88293R10
	North Boundary System Component Response Action Assessment Draft Final Report, Volumes I - III	2.1	11/88	36	88334R01
	North Boundary System Component Response Action Assessment Draft Final Report, Volumes I - III	2.2	11/88	36	88344R02
	Rocky Mountain Arsenal North Boundary Containment/Treatment System Operational Assessment Report FY87 Final Report	-	11/88	-	89263R01
	Rocky Mountain Arsenal Northwest Boundary Containment/Treatment System Operational Assessment Report FY87 Final Report	-	11/88	-	89263R02
	Boundary Control Systems Assessment Remedial Investigation Draft Final Report, Volumes I - III	2.1	12/88	25	89024R02
	Proposed Decision Document for the North Boundary System Improvements Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	1/89	-	89032R01
	North Boundary System Component Response Action Assessment Final Report, Volumes I and III	3.1	2/89	36	89103R01
	Final Decision Document for the North Boundary System Improvements Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	4/89	-	89100R01
	Start-up Performance of Ground Water Recharge Trenches, Rocky Mountain Arsenal	-	8/89	-	89277R01
	Implementation Document for Recharge Trench Project for the North Boundary System Improvements (IRA)	-	11/89	-	90002R08
	Implementation Document for Recharge Trench Project for the North Boundary System Improvements (IRA)	-	1/90	-	90039R02

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Improvement of the North Boundary System and Evaluation of all Existing Boundary Systems (continued)	Implementation Document for North Boundary System Improvements IRA Treatment System Modifications, Volumes I - III	-	3/90	-	90102R04
	Implementation Document for Northwest Boundary System Short-Term Improvements (IRA) Final	-	5/90	-	90192R02
	Implementation Document for Northwest Boundary System Short-Term Improvements IRA Southwest Extension Addendum to Final	-	4/91	-	91162R01
	Northwest Boundary System Long-Term Improvements IRA B(ii) Final Assessment Document	3.2	6/91	-	91172R01
	Proposed Decision Document Northwest Boundary System RMA Long-Term Improvements IRA	2.0	6/91	-	91172R03
Ground Water Intercept and Treatment System North of Basin F	Final Ground Water Intercept and Treatment Systems North of Basin F Interim Response Action Alternatives Assessment (IRA)	3.1	7/88	-	88231R01
	Proposed Decision Document for the Interim Response Action for the Ground Water Intercept and Treatment System North of Basin F at Rocky Mountain Arsenal (IRA)	-	8/88	-	88329R01
	Final Decision Document for the Interim Response Action for the Ground Water Intercept and Treatment System North of Basin F at Rocky Mountain Arsenal (IRA)	-	12/88	-	88349R01
	Preliminary Engineering Design Package for the Ground Water Intercept and Treatment System North of Basin F Interim Response Action (IRA)	-	4/89	-	89100R03
	Implementation Document for Ground Water Intercept and Treatment System North of Basin F, Volumes I - III (IRA)	-	10/89	-	89312R01
Closure of Abandoned Wells on RMA	Draft Final Technical Plan Abandoned Well Program	-	5/87	37	87277R03
	Final Technical Plan Abandoned Well Program	3.1	2/88	37	88076R07
	Final Technical Plan Abandoned Well Program	3.3	2/88	37	88126R05
	Proposed Decision Document for the Interim Response Action for the Closure of Abandoned Wells at Rocky Mountain Arsenal (IRA)	-	3/88	-	88141R01

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Closure of Abandoned Wells on RMA (continued)	Draft Final Decision Document for the Interim Response Action for the Closure of Abandoned Wells at Rocky Mountain Arsenal (IRA)	-	6/88	-	88328R06
	Final Decision Document for the Interim Response Action for the Closure of Abandoned Wells at Rocky Mountain Arsenal (IRA)	-	6/88	-	88329R05
	Draft Final Report Abandoned Well Program, Volumes I - IV	2.0	9/88	37	88356R01
	Final Task Plan RMA Abandoned Well Closure Program (IRA)	3.0	5/89	-	89192R04
	Draft Final Report Rocky Mountain Arsenal Abandoned Well Closure Interim Response Action (IRA)	2.0	11/89	-	90032R01
	Final Report Rocky Mountain Arsenal Abandoned Well Closure Interim Response Action	3.0	2/90	-	90072R07
Groundwater Intercept and Treatment System in the Basin A Neck Area	Draft Final Basin A Neck Ground Water Intercept and Treatment System Interim Response Action Alternatives Assessment (IRA)	2.2	6/88	-	88328R04
	Final Basin A Neck Ground Water Intercept and Treatment System Interim Response Action Alternatives Assessment (IRA)	3.2	9/88	-	88330R02
	Proposed Decision Document for the Basin A Neck Ground Water Intercept and Treatment System Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	9/88	-	88329R04
	Draft Final Decision Document for the Basin A Neck Ground Water Intercept and Treatment System Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	12/88	-	88352R01
	Final Decision Document for the Basin A Neck Ground Water Intercept and Treatment System Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	2/89	-	89032R02
	Implementation Document for Interim Response Action for the Ground Water Intercept System for Basin A Neck at the Rocky Mountain Arsenal (IRA)	-	6/89	-	89192R01
	Implementation Document for Ground Water Intercept and Treatment System for Basin A Neck (IRA) Volumes I - III	-	8/89	-	89262R05

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Basin F Liquids, Sludges, and Soils Remediation	Preliminary Design Specification for Interim Action, Rocky Mountain Arsenal Basin F	-	4/87	-	89010R01
	95% Submittal Design Analysis Notebook for Interim Action, Rocky Mountain Arsenal Basin F	-	4/87	-	89011R01
	Hazardous Waste Cleanup Interim Action of Basin F	-	5/87	-	87176M03
	Draft Bench-scale Laboratory Incineration of Basin F Wastes, Rocky Mountain Arsenal	-	5/87	17	87126R01
	Site Specific Safety Plan for Interim Action, Rocky Mountain Arsenal Basin F	-	5/87	-	87176R02
	Interim Action of Basin F Hazardous Waste Cleanup Specifications for Service Contract	-	5/87	-	87176R01
	Absorption Testing and Monitoring of Ammonia and Volatile Organics, Basin F, Rocky Mountain Arsenal, Commerce City, CO	-	6/87	-	87236R02
	Literature Research and Review of Ground Water Quality and Treatment Systems for Basin F, Rocky Mountain Arsenal Final Engineering Report	-	6/87	-	87198R01
	Design Analysis Notebook for Interim Action, Rocky Mountain Arsenal Basin F	-	7/87	-	87271R03
	60% Design Cost Estimate Interim Action, Rocky Mountain Arsenal Basin F	-	8/87	-	87289R01
	Laboratory Investigation of Organic Contaminant Immobilization by Proprietary Processing of Basin F Liquid, Rocky Mountain Arsenal, Denver, CO	-	8/87	-	87271R04
	Draft Final Technical Plan for Basin F Interim Response Action Support	2.2	9/87	31	87307R01
	Draft Final Baseline Contamination Assessment Basin F Tank Site, Army Sites North	-	10/87	21	87314R01
	Feasibility Analysis Basin F Interim Well System Rocky Mountain Arsenal and Results from Shallow Seismic Reflection Surveys near Reservoir F	-	12/87	-	88162R03
	Final Technical Plan Basin F Interim Response Action Support	3.1	12/87	31	87336R09

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Basin F Liquids, Sludges, and Soils Remediation (continued)	Final Decision Document for the Interim Action of Basin F Hazardous Waste Cleanup, Rocky Mountain Arsenal (IRA)	-	88	-	88141R03
	Draft Final Baseline Contamination Assessment Basin F Tank Site, Army Sites North	-	1/88	21	88103R03
	Data Report for the Health and Safety and Air Monitoring Program for the SIP Engineering Basin F Tankage Project at the Rocky Mountain Arsenal	-	3/88	-	89116R01
	Draft Bench Scale Laboratory Incineration of Section 36 Wastes (Expansion Program) Rocky Mountain Arsenal	-	3/88	17	88097R04
	Evaluation of Three Leading Innovative Technologies for Potential Application to Basin F Materials at Rocky Mountain Arsenal	-	4/88	-	88364R01
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action RMA, Commerce City, CO, Safety Health and Emergency Response Plan (IRA)	-	6/88	-	88189R05
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action RMA, Commerce City, CO, Analytical Work Plan for Ground Water (IRA)	-	6/88	-	88189R02
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action RMA, Commerce City, CO, Foundation Soil Investigation Work Plan (IRA)	-	6/88	-	88189R04
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action RMA, Commerce City, CO, Field Investigation Work Plan (IRA)	-	6/88	-	88189R03
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action RMA, Commerce City, CO, General Work Plan (IRA)	-	6/88	-	88189R01
	Final Volume 1 Summary Report for Incineration of Basin F Wastes at Rocky Mountain Arsenal	-	9/88	17	88286R01
	Final Volume 2 Selection of Incineration Technology of Basin F Wastes at Rocky Mountain Arsenal	-	9/88	17	88286R02

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Basin F Liquids, Sludges, and Soils Remediation (continued)	Final Volume 3 Analysis of Pilot Plant Alternatives for the Incineration of Basin F Wastes at Rocky Mountain Arsenal	-	9/88	17	88286R03
	Final Volume 4 Bench-scale Laboratory Incineration of Basin F Wastes at Rocky Mountain Arsenal	-	9/88	17	88286R04
	Final Volume 5 Bench-scale Laboratory Incineration of Section 36 Wastes (Expansion Program) at Rocky Mountain Arsenal	-	9/88	17	88286R05
	Final Volume 6 Full Scale Incineration System Conceptual Design for Basin F Wastes, Rocky Mountain Arsenal	-	9/88	17	88286R06
	Rocky Mountain Arsenal Basin F Liquid Treatment Interim Response Action Technology Inventory and Screening (IRA)	-	10/88	-	89192R05
	Evaluation of Three Leading Innovative Technologies for Potential Application to Basin F Materials at Rocky Mountain Arsenal	-	11/88	-	89004R01
	Examination of Odors Associated with Rocky Mountain Arsenal Basin F	-	11/88	-	89061R02
	Technical Support for Basin F Liquids Remediation Rocky Mountain Arsenal, Commerce City, CO, Draft Task Plan, Volume I (IRA)	2.1	12/88	-	89101R01
	Phase I Site Investigation and Analysis Basin F Ground Water Treatment Interim Response Action Preliminary Geotechnical and Ground Water Report	-	1/89	-	89012R01
	Final Task Plan Task IRA-2 Basin F Liquids Treatment Design, Volumes I - III (IRA)	3.0	3/89	IRA-2	89192R06
	1 Million Btu/Hour Pilot Study for Morrison - Knudsen Engineers on RMA Basin F Liquid	-	4/89	-	89291R01
	Draft Final Treatment Assessment Report Task IRA2 Basin F Liquids Treatment Design, Volumes I and II (IRA)	-	10/89	IRA-2	89282R03
	Proposed Decision Document for the Interim Response Action Basin F Liquid Disposal, Rocky Mountain Arsenal (IRA)	2.0	12/89	-	90032R02

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Basin F Liquids, Sludges, and Soils Remediation (continued)	Final Treatment Assessment Report Task IRA-2 Basin F Liquid Treatment Design, Volumes I - III (IRA)	3.0	12/89	IRA-2	90032R03
	Draft Public Health Risk Assessment Report Submerged Quench Incinerator Task IRA-2 Basin F Liquids Treatment Design (IRA)	2.1	1/90	IRA-2	90039R01
	Draft Final Decision Document for the Interim Response Action Basin F Liquid Treatment Rocky Mountain Arsenal (IRA), Volumes I and II	3.1	4/90	-	90102R05
	Final Decision Document for the interim Response Action Basin F Liquid Treatment Rocky Mountain Aresenal (IRA), Volumes I and II	3.2	5/90	-	90142R03
	Basin F Interim Action Close-out Safety Report Final Draft, Volumes I and II	-	9/89	-	91219R01
	Basin F Interim Response Action Operation/Maintenance Manual and Inspection Procedures	-	1/90	-	90079R01
Building 1727 Sump Liquid	Building 1727 Sump Interim Response Action Assessment Draft Final Treatability Study	-	7/87	30	88244R01
	Interim Response Action Alternatives Assessment Draft Final Report 1727 (IRA)	2.3	5/88	30	88134R01
	Sump 1727 Interim Response Action Alternatives Assessment Final Report (IRA)	3.2	7/88	30	88243R01
	Proposed Decision Document for the Interim Response Action for Building 1727 Sump at Rocky Mountain Arsenal (IRA)	-	8/88	-	88329R06
	Draft Final Decision Document for the Interim Action for Building 1727 Sump at Rocky Mountain Arsenal (IRA)	-	11/88	-	89005R01
	Final Decision Document for the Interim Response Action for Building 1727 Sump at Rocky Mountain Arsenal (IRA)	-	12/88	-	89019R01
	Draft Implementation Document for the Interim Response Action for Building 1727 Sump at Rocky Mountain Arsenal (IRA)	-	2/89	-	89062R04
	Final Implementation Document for the Interim Response Action for Building 1727 Sump at Rocky Mountain Arsenal (IRA)	-	5/89	-	89139R02

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Closure of the Hydrazine Facility	Definition of Regulatory Requirements, Site Assessment, and Disposal Analysis for Decommissioning the Hydrazine Blending and Storage Facility, Rocky Mountain Arsenal, CO, Final Report	-	8/87	-	89109R01
	Draft Final Report Hydrazine Blending and Storage Facility Wastewater Treatment and Decommissioning Assessment	2.2	4/88	34	88127R03
	Final Report Hydrazine Blending and Storage Facility Waste Water Treatment and Decommissioning Assessment	3.1	6/88	34	88196R07
	Proposed Decision Document for the Interim Response Action at the Rocky Mountain Arsenal Hydrazine Blending and Storage Facility (IRA)	-	7/88	-	88328R02
	Draft Final Decision Document for the Interim Response Action at the Rocky Mountain Arsenal Hydrazine Blending and Storage Facility (IRA)	-	9/88	-	89262R04
	Final Decision Document for the Interim Response Action at the Rocky Mountain Arsenal Hydrazine Blending and Storage Facility (IRA)	-	10/88	-	88329R02
	Draft Final Task Plan Hydrazine Blending and Storage Facility Interim Response Action Implementation (IRA) Volumes I - IV	-	6/89	-	89272R03
	Final Task Plan Hydrazine Blending and Storage Facility Interim Response Action Implementation, Volumes I - IV(IRA)	-	8/89	-	89262R03
Fugitive Dust Control	Draft Implementation Document for the Application of Dust Suppressant at Basin A, Section 36 of the Rocky Mountain Arsenal (IRA)	-	12/89	-	90009R01
Sewer Remediation	Final Technical Plan Sewers and Process Water Systems Investigations	3.1	11/87	10	87336R03
	Draft Final Sanitary Sewer Remediation Interim Response Action Alternatives Assessment (IRA)	2.1	8/88	-	88328R01
	Final Sanitary Sewer Remediation Interim Response Action Alternatives Assessment (IRA)	3.2	9/88	-	88330R01

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Sewer Remediation (continued)	Proposed Decision Document for the Sanitary Sewer System Interim Response Action at Rocky Mountain Arsenal (IRA)	-	1/89	-	89032R04
	Final Decision Document for the Sanitary Sewer System Interim Response Action at Rocky Mountain Arsenal (IRA)	-	3/89	-	89100R02
	Rocky Mountain Arsenal Sanitary Sewer Interim Response Action Draft Implementation Plan, Volumes I and II (IRA)	-	1/90	-	90032R05
Asbestos Removal	Asbestos Sampling Report for the Rocky Mountain Arsenal in Commerce City, CO (IRA)	-	1/89	-	89062R03
	Draft Interim Response Action Technical Plan Asbestos Removal - Phase II Removal (IRA)	2.0	4/89	-	89122R01
	Final Interim Response Action Technical Plan Asbestos Removal - Phase II Removal (IRA)	3.0	7/89	-	89222R02
	Interim Response Action Final Report Asbestos Removal - Phase II Removal (IRA)	3.0	12/89	-	90009R04
Remediation of Other Contamination Sources ("Hot Spots")	Remediation of Other Contamination Sources Draft Task Plan, Text and Appendices A - F (IRA)	2.0	4/89	-	89122R03
	Final Task Plan Remediation of Other Contamination Sources, Text and Appendices A, B, C, F (IRA)	3.0	6/89	-	89222R05
	Results of Field and Laboratory Investigations Conducted for the Remediation of Other Contamination Sources Interim Response Action, Volumes I and II (IRA)	2.0	11/89	-	90002R06
Lime Settling Basins	Alternative Assessment of Interim Response Actions for Other Contamination Sources Lime Settling Basins (IRA)	1.0	8/89	-	89262R01
	Proposed Decision Document for the Interim Response Action at the Lime Settling Basins, Rocky Mountain Arsenal (IRA)	2.0	11/89	-	90002R01
	Final Alternative Assessment of Interim Response Actions for Other Contamination Sources Lime Settling Basins (IRA)	3.0	11/89	-	90032R04

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Remediation of Other Contamination Sources ("Hot Spots") (continued) M - 1 Settling Basins	Treatability Test Report for Application of *in situ* Vitrification Technology to Pesticide, Arsenic, and Mercury Contaminated Soils from the M - 1 Ponds Site of Rocky Mountain Arsenal, CO	-	8/89	-	90043R01
	Final Decision Document for the Interim Response Action at the Lime Settling Basins Rocky Mountain Arsenal (IRA)	4.0	3/90	-	90072R02
	Alternative Assessment of Interim Response Actions for Other Contamination Sources M1 Settling Basins (IRA)	2.0	9/89	-	89262R06
	Proposed Decision Document for the Interim Response Actions at the M - 1 Settling Basins Rocky Mountain Arsenal (IRA)	2.0	11/89	-	90002R02
	Final Alternatives Assessment of Interim Response Action for Other Contamination Sources M - 1 Settling Basins, Rocky Mountain Arsenal (IRA)	3.1	11/89	-	90002R05
	Final Decision Document for the Interim Response Action at the M-1 Settling Basins, Rocky Mountain Arsenal (IRA)	4.0	3/90	-	90072R03
Motor Pool Area-Trichloroethylene Plume	Draft Summary Report Western Tier TCE Soil Gas Investigation, Rocky Mountain Arsenal	2.1	8/87	38	87277R04
	Final Western Tier Trichloroethylene Investigation Technical Plan	-	10/87	38	87336R08
	Final Summary Report Western Tier TCE Soil Gas Investigation, Rocky Mountain Arsenal	3.2	1/88	38	88046R01
	Alternative Assessment of Interim Response Actions for Other Contamination Sources Motor Pool Area (IRA)	2.0	9/89	-	89262R07
	Proposed Decision Document for the Interim Response Action at the Motor Pool Area, Rocky Mountain Arsenal (IRA)	2.0	11/89	-	90002R03
	Final Alternatives Assessment of Interim Response Actions for Other Contamination Sources, Motor Pool Area (IRA)	3.1	11/89	-	90002R04
	Preliminary Engineering Design Package for Rail Classification Yard/Motor Pool Area Interim Response Action (IRA)	4.0	2/90	-	90072R04

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
Remediation of Other Contamination Sources ("Hot Spots") (continued)	Final Decision Document for the Interim Response Action at the Motor Pool Area, Rocky Mountain Arsenal (IRA)	--	6/90	-	90192R03
Rail Classification Yard - DBCP Plume	Irondale DBCP Control System Rocky Mountain Arsenal, Review of 1986 Operations	-	7/87	-	87271R01
	Evaluation of Shell Chemical Company's Ground Water DBCP Control System at Rocky Mountain Arsenal FY85/FY86, Volumes I and II	-	6/88	-	88195R01
	Draft Final Alternatives Assessment for Other Contamination Sources Interim Response Action Rail Classification Yard, RMA (IRA)	-	11/89	-	89262R02
	Proposed Decision Document for Other Contamination Sources Interim Response Action Rail Classification Yard RMA (IRA)	-	6/90	-	90192R03
	Preliminary Engineering Design Package for Rail Classification Yard/Motor Pool Area Interim Response Action (IRA)	-	11/89	-	90002R07
	Final Decision Document for Other Contamination Sources Interim Response Action Rail Classification Yard RMA (IRA)	-	3/90	-	90072R05
Army (Complex Disposal) Trenches	Draft Final Alternative Assessment of Interim Response Actions for Other Contamination Sources Complex Disposal Trenches (IRA)	2.0	9/89	-	89282R01
	Final Alternatives Assessment of Interim Response Actions for Other Contamination Sources Complex Disposal Trenches Rocky Mountain Arsenal (IRA)	3.1	1/90	-	90039R04
	Final Decision Document for the Interim Response Action at the Complex Disposal Trenches Rocky Mountain Arsenal (IRA)	4.0	4/90	-	90102R02
Shell Trenches	Draft Final Alternatives Assessment for Other Contamination Sources of Interim Response Action Shell Section 36 Trenches, RMA (IRA)	-	9/89	-	89282R02
	Final Alternatives Assessment Other Contamination Sources Interim Response Action Shell Section 36 Trenches, RMA (IRA)	-	1/90	-	90039R03
	Final Decision Document for Other Contamination Sources Interim Response Action Shell Section 36 Trenches, RMA (IRA)	-	4/90	-	90102R03

Table C.1-4 List of Interim Response Action Reports for Rocky Mountain Arsenal

IRA	Report Title	Version	Date	Task	RIC Number
South Tank Farm Plume	Report of Hydrogeologic and Water Quality Investigations in the South Tank Farm Plume, Section 2, RMA	-	7/89	-	89216R01
	Draft Final Alternatives Assessment Other Contamination Sources Interim Response Action South Tank Farm Plume (IRA)	-	3/90	-	90102R01
	Final Decision Document for other Contamination Sources Interim Response Action South Tank Farm Plume	-	5/91	-	91122R02
Pretreatment of CERCLA Liquid Waste	Draft Final Work Plan CERCLA Wastewater Treatment System Interim Response Action (IRA)	-	10/88	-	88328R07
	Final Work Plan CERCLA Wastewater Treatment System Interim Response Action (IRA)	-	1/89	-	89032R03
Pretreatment of CERCLA Liquid Waste (continued)	CERCLA Wastewater Treatment System Needs Assessment and Processes Treatability Study Draft Final Report (IRA)	-	6/89	-	89222R04
	CERCLA Wastewater Treatment System Revised Draft Assessment, Volumes I and II (IRA)	-	10/89	-	89312R02
	Proposed Decision Document for the CERCLA Wastewater Treatment System Interim		12/89		90009R02
	CERCLA Wastewater Treatment System Final Assessment, Volumes I and II (IRA)	-	12/89	-	90009R03
	Draft Final Decision Document for the CERCLA Wastewater Treatment System Interim Response Action at the Rocky Mountain Arsenal (IRA)	-	4/90	-	90142R02

The final alternative selected for the IRA will incorporate groundwater extraction and recharge systems to remove contaminants from the groundwater. Physical barriers or permanent structures will not be used because they would affect groundwater flow directions and velocities and might interfere with the final remediation of alluvial groundwater. Groundwater extraction will therefore be accomplished with extraction wells or subsurface drains. Organic contaminants will be removed from the water with a carbon adsorption treatment system. The treated water will be returned to the alluvium by using recharge wells (HLA, 1989a/RIC 89222R01).

C.2.2 IMPACT

Implementation of this IRA will affect groundwater north of RMA. Extraction and treatment of contaminated groundwater will intercept and arrest the migration of contaminants.

C.2.3 STATUS

The Alternatives Assessment and Decision Documents are finalized; pilot testing has been completed. The Implementation Document was released in October 1990. Construction is scheduled to start September 1991, with a proposed completion date of December 1992.

C.3 IMPROVEMENT OF THE NORTH BOUNDARY CONTAINMENT SYSTEM AND EVALUATION OF ALL EXISTING BOUNDARY CONTAINMENT SYSTEMS

This IRA consists of three components: (i) implementation of groundwater recharge trenches to increase the reinjection rate of treated groundwater for the North Boundary Containment System (NBCS); (ii) assessment, selection, and implementation of any appropriate improvements to the Irondale Containment System (ICS) and Northwest Boundary Containment System (NWBCS) as necessary; and (iii) assessment of the need for and implementation of any necessary improvements (such as expansion) to the NBCS (FFA, 1989/RIC 89068R01).

C.3.1 DESCRIPTION

The existing NBCS (Figure RISR C.1-1) uses wells for extraction of contaminated groundwater. It treats the organic contaminants with carbon adsorbers, and reinjects the treated groundwater by means of recharge wells and trenches. Component (i) of this IRA, which was completed in 1988, consisted of the construction of recharge trenches along the western half of the existing NBCS. These recharge trenches so increase the system's ability to reinject treated water that a positive hydraulic head is established on the downgradient side of the system's slurry wall (PMRMA, 1988c/RIC 88329R03).

The existing NWBCS (Figure RISR C.1-1) operates in the same manner as the NBCS. Under component (ii) of this IRA, a schedule is currently being formulated for the NWBCS that allows the assessment and implementation of modifications to the system through the short- and long-term phases of the IRA. Shell or its contractor will be responsible for the short-term phase, which may include additional wells and recharge trenches, improved system operation, and improved reliability. The organic contaminants will be treated to the same degree as in the existing NWBCS. The Army is responsible for the long-term assessment of this system.

For component (iii) of this IRA, Shell or its contractor will be responsible for constructing more recharge trenches along the eastern half of the existing NBCS. Modifications to the existing treatment plant will include improved system operation and reliability, including reduced carbon usage and reduced carbon fine recirculation throughout the system (PMRMA, 1989b/RIC 89100R01). The organic contaminants will be treated to the same level as in the existing NBCS.

C.3.2 IMPACT

Implementation of this IRA will impact groundwater at RMA because the NBCS and NWBCS will minimize the amount of contaminated groundwater that migrates off post.

C.3.3 STATUS

For component (i), construction and implementation of improvements to the NBCS are currently underway. This IRA was completed in December 1990.

Component (ii) of this IRA is divided into short- and long-term improvements. For the short-term improvements, the Decision Document was finalized and the Draft Implementation Document was issued in June 1990. Construction on the system extension began in June 1990 and is scheduled to be completed in November 1991. The assessment for long-term improvements is currently underway. The Final Assessment is scheduled for May 1991.

Component (iii) of this IRA, construction and implementation of NBCS recharge trenches, was completed in December 1988.

C.4 GROUNDWATER INTERCEPT AND TREATMENT SYSTEM NORTH OF BASIN F

The Groundwater Intercept and Treatment System North of Basin F IRA (Figure RISR C.1-1) consists of the assessment, selection, and implementation of a system to intercept and treat contaminated alluvial groundwater north of Basin F (FFA, 1989/ RIC 89068R01). The specific objectives_of this IRA include increasing the efficiency of the boundary containment systems, and collecting operational data that will be useful for the design of the final response for contaminated alluvial groundwater originating from the Basin F area (PMRMA, 1988f/ RIC 88349R01).

C.4.1 DESCRIPTION

A pretreatment system using one extraction well was located just north of Basin F, and an air stripping operation was constructed next to the Basin A Neck treatment system. Contaminated groundwater will be extracted and pretreated through a packed column air stripper. This groundwater will be combined with Basin A Neck groundwater and treated by carbon adsorption. After the volatile and semivolatile organic compounds are reduced to appropriate levels, the treated groundwater will be reinjected via the Basin A Neck recharge trenches (MKE,1989a/RIC 89100R03).

C.4.2 IMPACT

The implementation of this IRA will impact the water and air at RMA. Extraction and treatment of contaminated groundwater close to its source will reduce the concentrations of contaminants downgradient at the NBCS and will reduce the potential for volatilization of contaminants from groundwater.

C.4.3 STATUS

The construction phase of this IRA began in December 1989 and was completed in September 1990. The operation and treatment phase of this IRA is ongoing.

C.5 CLOSURE OF ABANDONED WELLS ON RMA

The Closure of Abandoned Wells on RMA IRA consists of plugging and closing wells that are not currently part of, or are not suitable for, future use in an RMA monitoring program (FFA, 1989/RIC 89068R01). Concern over possible downward contaminant migration from potentially contaminated aquifers to underlying uncontaminated aquifers via unused or poorly constructed wells at RMA is the basis for this IRA. This IRA does not follow the typical IRA implementation procedures outlined in Figure RISR C.1-2, but was originally implemented (in part) under Tasks 4, 44, and 37. This IRA was completed in February 1990. One additional well was found by paving contractors in May 1990, and was closed during June 1990.

C.5.1 DESCRIPTION

A preliminary evaluation and summary of RMA wells was conducted under the groundwater screening and monitoring programs of Remedial Investigation/Feasibility Study (RI/FS) Tasks 4 and 44 (ESE, 1986/RIC 86317R01). Task 37 was established as the first step in addressing the objective of closing unused and abandoned wells on RMA. The study area for

Task 37 was limited to those areas of RMA that were within or downgradient of potential contamination source areas. Each well considered in the Task 37 program was screened for inclusion in a first-level field search, based on characteristics such as proximity to known contamination plumes, depth, or penetration of two or more aquifers. If the well could not be found in the first-level field search using visual observation and conventional geophysics, it was screened for inclusion into a more elaborate second-level search that used specialized geophysical techniques. A total of 39 wells were closed under this task in 1988 (EBASCO, 1988d/RIC 88356R01).

The objectives of this IRA included identifying abandoned wells not previously addressed under Task 37, conducting field searches for all abandoned wells, measuring well parameters, noting condition of wells, and closing all abandoned wells located through the field search. A total of 312 wells were closed under this IRA (R.F. Weston, 1990b/RIC 90072R07).

C.5.2 IMPACT

Potential groundwater contamination has been minimized by reducing the probability of downward contaminant migration between aquifers via unused or poorly constructed wells.

C.5.3 STATUS

The closure of abandoned wells began in April 1988 and was completed in February 1990.

C.6 GROUNDWATER INTERCEPT AND TREATMENT SYSTEM IN THE BASIN A NECK AREA

The Groundwater Intercept and Treatment System in the Basin A Neck Area IRA (Figure RISR C.1-1) consists of the design and construction of a system to intercept and treat alluvial groundwater in the Basin A Neck area (FFA, 1989/RIC 89068R01). The specific objectives of the IRA include minimizing the migration of contaminants from Basin A through the Basin A Neck alluvial aquifer; improving the efficiency of the boundary treatment system; collecting operational data on the interception, treatment, and recharge of contaminated groundwater to be used in the selection and design of the final response action; and accelerating groundwater remediation within RMA.

C.6.1 DESCRIPTION

The Basin A Neck is an alluvium-filled paleochannel in the bedrock surface between Rattlesnake Hill and North Plants Hill. Groundwater from the Basin A area flows northwest through this paleochannel (EBASCO, 1988c/RIC 88330R02). The groundwater intercept and treatment system is located in Sections 26 and 35, in the "narrow" portion of the Basin A Neck, in order to intercept contaminated groundwater originating from the neck area and from Basin A (PMRMA, 1989a/RIC 89032R02).

The extraction system consists of seven alluvial extraction wells emplaced near the center of the paleochannel. Alluvial piezometers were constructed in the vicinity of the extraction wells to provide connections between permeable zones and to assist in groundwater extraction. An activated carbon adsorption treatment system is used to remove organic contaminants from groundwater. The recharge system consists of gravel-filled trenches constructed across the deeper, more permeable parts of the alluvial paleochannel. A soil-bentonite slurry wall was constructed across the alluvial neck between the recharge trench and extraction wells to limit the amount of recirculation between the two systems.

C.6.2 IMPACT

The implementation of this IRA impacts the water and air at RMA. Extraction and treatment of contaminated groundwater will reduce the concentrations of contaminants downgradient at the NBCS and will reduce the potential for volatilization of contaminants from groundwater.

C.6.3 STATUS

The construction phase of this IRA began in November 1989 and was completed in July 1990. The operational and treatment phase of this IRA is ongoing.

C.7 BASIN F LIQUIDS, SLUDGES, AND SOILS REMEDIATION

The Basin F Liquids, Sludges, and Soils Remediation IRA (Figure RISR C.1-1) consists of the remediation of contaminated liquids, sludges, and soils from within and underneath Basin F (FFA, 1989/RIC 89068R01). Specific objectives are to prevent potential infiltration of contaminated liquids to groundwater, eliminate potential adverse impacts to wildlife that come in contact with contaminated basin materials, and eliminate emissions of volatiles from Basin F (PMRMA,1988b/RIC 88141R03).

C.7.1 DESCRIPTION

This IRA consists of two components: (i) Basin F-Liquids, Sludges, and Soil Removal, and (ii) Basin F Remediation-Liquids Treatment.

Construction of the Liquids, Sludges, and Soil Removal component began in March 1988. This component included transfer of the remaining basin liquids into temporary storage tanks constructed by Shell under the September 26, 1986, Memorandum of Understanding; construction of a lined waste storage pile, a double-lined leachate surface impoundment, and a double-lined evaporation pond (Pond A); excavation of Basin F soils from 6 in. below the original asphalt liner to specified depths, as directed by the U.S. Army Corps of Engineers (COE), to expose visually clean soil; stabilization of excavated soils by absorption before they were placed in the waste pile; and final grading, capping, and revegetation of the excavated area (PMRMA, 1988b/RIC 88141R03). A total of about 8.5 million gallons of liquid were actually transferred from Basin F. Four million gallons were transferred to storage tanks and 4.5 million gallons were transferred to Pond A (WCC, 1989d/RIC 90032R03).

A 16-acre double-lined waste storage pile was constructed to house an estimated 500,000 cubic yards of excavated soil. The waste pile has a multimedia cover and a leachate detection/collection system to reduce the chance of infiltration, leachate formation, and subsequent leakage. A synthetic liner and a 1-ft clay cap were placed on top of the waste pile, and a 1-ft clay cap was placed over the area within the original fenced Basin F boundary. Monitoring activities and cap maintenance will be performed until final remediation (PMRMA, 1988b/RIC 88141R03). Photographs in Figure RISR C.7-1 show the Basin F area on March 8, 1988, prior to the implementation of the Liquids, Sludges, and Soils Removal IRA component (top), and the basin area on May 8, 1989, as this component was nearing completion (bottom).

Steps involved in the Basin F Remediation-Liquids Treatment IRA component include selecting the final treatment process for Basin F liquids temporarily stored in tanks and in Pond A, conducting pilot-scale testing to support engineering design of the selected treatment process, and developing an engineering design package for the selected treatment process (WCC, 1989a/RIC 89192R06; WCC, 1990a/RIC 90102R05). The Assessment Document (WCC, 1989d/ RIC 90032R03) identified five treatment technologies that could treat the Basin F Liquid. The Final Decision Document specifies submerged quench incineration as the treatment technology that will be used to treat the Basin F Liquids (WCC, 1989d/RIC90032R03). Construction of this IRA began in March 1991.

C.7.2 IMPACT

The removal and storage of basin liquids, sludges, and soils and the installation of a cap on the basin area and waste pile have potentially impacted the soils, water, structures, air, and biota. Basin soils and sludges have been stabilized and contained until a final remedial decision is implemented; the potential for infiltration or migration of contaminants to groundwater has been minimized; vapor emission from basin liquids has been reduced or eliminated; additional structures, storage tanks, and surface impoundments have been constructed; and biota are no longer directly exposed to basin materials.

C.7.3 STATUS

The construction phase for the Liquids, Sludges, and Soils Removal component was initiated March 1988 and completed May 1989. The Final Decision Document for the Liquids Treatment Component was released in May 1990. The Implementation Document was

Basin F – March 8, 1988 prior to implementation of IRA

Basin F – May 8, 1989 nearing completion of the Liquids, Sludges, and Soils Removal IRA component

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Prepared August 1991	FIGURE RISR C.7-1 Basin F Remediation – Liquids, Sludges, and Soils Removal Photographs Rocky Mountain Arsenal Prepared by: Ebasco Services Inc.

released in December 1990, with construction beginning in March 1991. This IRA is scheduled for completion in July 1995.

C.8 BUILDING 1727 SUMP LIQUID

The Building 1727 Sump Liquid IRA (Figure RISR C.1-1) consists of the remediation of contaminated sump liquid to mitigate any remaining threat of the release of liquids from this sump (FFA, 1989/RIC 89068R01).

C.8.1 DESCRIPTION

Between 1953 and 1982 the Building 1727 chemical sump reportedly overflowed several times, causing release of liquids to the surrounding area and into a nearby drainage ditch that emptied into First Creek (EBASCO, 1989a/RIC 89166R05). In 1987 an emergency response was implemented to pump over 50,000 gallons of sump liquid to tanks and tanker trailers, and an activated alumina/granular activated carbon (AA/GAC) treatment system was installed to treat the stored sump liquid (PMRMA, 1988e/RIC 89019R01).

The emergency response AA/GAC treatment system was determined to be the preferred alternative for this IRA. The system was installed in October and November 1987 in Building 1713, and consists of a wastewater holding tank, a pH adjustment system, and two parallel AA/GAC treatment lines. The manual treatment system operates on an as-needed basis and has a capacity of 5 gpm when both AA/GAC treatment lines are used. The treatment system has achieved the proposed effluent limits for the following contaminants of concern: arsenic (50 ug/l), cadmium (10 ug/l), lead (50 ug/l), and fluorine (4,000 ug/l). These effluent limits are equivalent to the maximum contaminant levels specified in 40 CFR 141.11. The system has also achieved the health-based standard for isopropylmethylphosphonic acid (16.8 ppm), which is used by the Army in the absence of a promulgated standard (PMRMA, 1989d/RIC 89139R02). Effluent meeting these standards is discharged to the RMA sanitary sewage treatment system; effluent not meeting these standards is retreated (PMRMA, 1988e/RIC 89019R01).

C.8.2 IMPACT

Implementation of this IRA has impacted soil, water, and structures. With the continued operation of this treatment system, there is no longer a threat of sump overflow, which eliminates the potential for further structure, surface water, or soil contamination in the immediate area.

C.8.3 STATUS

The construction phase of this IRA was completed in November 1989. Currently, the system operates on an as-needed basis and maintenance operations are ongoing.

C.9 CLOSURE OF THE HYDRAZINE FACILITY

The Closure of the Hydrazine Facility IRA consists of two components: (i) treatment and disposal of pretreated liquids in tanks used for storage of hydrazine blending waste products; and (ii) dismantling and disposal of all remaining aboveground structures (FFA, 1989/ RIC 89068R01).

C.9.1 DESCRIPTION

The hydrazine blending and storage facility (HBSF) was used as a depot to receive, blend, store, and distribute hydrazine fuels (Figure RISR C.1-1) (PMRMA, 1988d/RIC 88329R02). The 10-acre facility was owned by the U.S. Air Force and operated by the Army between 1959 and 1982 (HLA, 1989b/RIC 89262R03). Anhydrous hydrazine and unsymmetrical dimethylhydrazine were shipped to RMA and blended to produce Aerozine 50 on an as-needed basis by the Air Force. Additional operations included loading and unloading of railcars and tank trucks; destruction of off-spec Aerozine 50; and storage of Aerozine 50, anhydrous hydrazine, monomethyl hydrazine, monopropellent hydrazine, hydrazine 70, unsymmetrical dimethylhydrazine, and hydrazine (PMRMA, 1988d/RIC 88329R02). Approximately 300,000 gallons of hydrazine wastewater are currently stored at the HBSF.

An ultraviolet/hydrogen peroxide unit was chosen as the best available technology for treatment of wastewater stored at the HBSF. Wastewater will be pumped into an on-site treatment facility, treated, sampled for effluent concentration of the contaminants of concern, and disposed in the RMA sewer treatment plant before off-post release. If the effluent concentration of contaminants is too high, the water will be treated again. After all the wastewater is treated and disposed, all remaining aboveground structures will be dismantled, decontaminated, and disposed (PMRMA, 1990). Construction of this IRA is scheduled to begin in October 1991.

C.9.2. IMPACT

Implementation of this IRA will impact the structures and air at RMA.

C.9.3 STATUS

The Implementation Document for this IRA was released in December 1990. Construction of the treatment facility is complete, and start-up testing is underway. Estimated completion of this IRA is scheduled for July 1992.

C.10 FUGITIVE DUST CONTROL

The Fugitive Dust Control IRA consists of the selection and implementation of a dust suppressant program (FFA, 1989/RIC 89068R01). The purpose of this IRA is to prevent airborne transport of potentially contaminated dust, primarily from the unvegetated areas of Basins A and F (PMRMA, 1989e/RIC 90009R01). This IRA has not followed the typical process outlined in Figure RISR C.1-2, as it was implemented prior to the FFA, and is ongoing.

C.10.1 DESCRIPTION

Basin A was constructed for the evaporation of aqueous industrial wastes generated during manufacturing operations at RMA. Liquids contained in Basin A were transferred to Basin F between December 1956 and September 1957 (EBASCO, 1989c/RIC 89166R07). Since that time fugitive dust has been observed emanating from the dry, unvegetated portions of Basin A during high-wind events. OCPs and metals have been detected in fugitive dust samples collected downwind of Basin A (EBASCO, 1989b/RIC 89166R06).

Potential fugitive dust emission areas will be periodically inspected until the cleanup at RMA is completed, with areas of potential hazard being treated with a dust suppressant. Inspection of known areas and identification of new areas of potential dust emissions is part of this IRA's implementation strategy (PMRMA, 1990).

C.10.2 IMPACT

Minimization of airborne contaminated dust from unvegetated areas to downwind areas will impact the air and soil at RMA.

C.10.3 STATUS

The Draft Implementation Document for this IRA was released in December 1989 (PMRMA, 1989e/RIC 90009R01). Application of a dust suppressant (Dusdown 70) was conducted in the spring and summer of 1988 in the Basin A area. Dust supressant is being reapplied to the area in May 1991. Assessment of future applications will be on a case-by-case basis until the final Record of Decision.

C.11 SEWER REMEDIATION

The Sewer Remediation IRA consists of the remediation of certain priority portions of the sanitary sewer system to minimize the potential for contaminant migration, with first priority given those sewer segments located below groundwater (FFA, 1989/RIC 89068R01).

C.11.1 DESCRIPTION

Sewer investigations in the South Plants area have revealed line sags, offset and leaking joints, broken joints and pipe sections, and crushed pipe. Parts of the sewer line may be below the water table or may have been below it in the past. Groundwater entering the sewer line through broken joints and pipe sections may flow downline to the sewage treatment plant (Section 24), or may exfiltrate to surrounding soil at points along the way (PMRMA, 1989c/RIC 89100R02). Infiltration of groundwater into sewer lines is not a concern in the North Plants area as the groundwater table is located approximately 10 to 20 ft below the sewer lines, but there is a possibility of surface water runoff entering several exposed sewer connections in this area. Figure C.1-1 indicates the location of the sanitary sewer on RMA.

The Sewer Remediation IRA will address three areas of concern along the RMA sewer system. In the South Plants area, inactive sewer lines will be abandoned in place and plugged by placing concrete into selected manholes. Cut-off walls constructed from sheet pile will be installed at every plugged manhole. Wastewater from the South Plants liquid treatment facility will be transported through existing sewer lines to manhole 97, where a temporary aboveground pressurized line will transport flow to manhole 93 near the RMA Fire Station. A new pressurized sewer line (force main) will be installed from the fire station to the administration area sewer line. In the North Plants area, seven exposed sewer connections will be capped or plugged. The third area of concern, the interceptor line between manholes 98 and 46, will be abandoned in place and plugged with cement at 12 manholes.

C.11.2 IMPACT

The implementation of this IRA will impact the soils and groundwater at RMA. As a result of plugging and grouting sewer lines, installing cut-off walls, and redirecting waste flow through new pipelines, the possibility of infiltration, transport, or exfiltration of potentially contaminated water through sewer lines to downline areas, soils, or groundwater will be minimized. Air may be temporarily impacted during the pipe installation operations if soils contaminated by volatile compounds are exposed during excavations.

C.11.3 STATUS

The Draft Implementation Document (R.F. Weston, 1990a/RIC 90032R05) was released in January 1990 with construction beginning in January 1991. Completion of this IRA is estimated for March 1992.

C.12 ASBESTOS REMOVAL

The Asbestos Removal IRA consists of the prompt removal and disposal of friable and flaking asbestos-containing material (ACM) where a potential for human exposure exists (FFA, 1989/RIC 89068R01). This IRA is exempt from Decision and Implementation Document requirements (PMRMA, 1990).

C.12.1 DESCRIPTION

This IRA will be conducted in three phases. Phases I and II, which are completed, consisted of the assessment of 38 occupied buildings and the removal of friable ACM from ten buildings. Phase III, which is proposed, consists of the removal of all ACM on RMA (PMRMA, 1990).

The proposed strategy for this IRA includes the inspection of buildings, tanks, foundations, substations, and pipe runs (units), by a certified asbestos inspector, to determine the probable presence of ACM. Suspected ACM will be sampled, as required, to determine the type and amount. Air sampling will be conducted in and around each unit. If necessary, removal and disposal will be conducted as required by regulations and in the most cost-effective manner (PMRMA, 1990).

C.12.2 IMPACT

The implementation of this IRA will impact both structures and air and will minimize any immediate hazard posed by ACM.

C.12.3 STATUS

Phases I and II of this IRA were completed by December 1989. Anticipated release of the Assessment Document for the proposed Phase III component is September 1992. Implementation of the IRA is scheduled for October 1992; completion is scheduled for December 1995.

C.13 REMEDIATION OF OTHER CONTAMINATION SOURCES ("HOT SPOTS")

The Remediation of Other Contamination Sources IRA consists of the assessment and, as necessary, the selection and implementation of IRAs for specific source areas ("hot spots") that require immediate attention (FFA, 1989/RIC 89068R01). The following areas have been included in this IRA:

- Lime Settling Basins
- M-1 Settling Basins
- Motor Pool Area - Trichloroethylene Plume
- Rail Classification Yard - DBCP Plume
- Army (Complex Disposal) Trenches
- Shell Trenches
- South Tank Farm Plume

Proposed source areas may be added to this IRA upon review, evaluation, and approval of technical data by the Army, Organizations and State (FFA, 1989/RIC 89068R01). Figure C.1-1 shows the approximate locations of the seven "hot spot" IRAs.

C.13.1 DESCRIPTION

The **Lime Settling Basins** consist of three unlined evaporation basins, each covering approximately 1 acre. Wastewater from the production of Army agents was routinely treated with lime to precipitate metals and reduce the arsenic concentration and then discharged into the basins. Subsequent discharges of wastewater from the production of pesticides resulted in the addition of pesticides to the basins' sludge. The sludge and nearby soils contain elevated concentrations of OCPs, OSCHs, OSCMs, arsenic, mercury, and ICP metals and are a source of contamination to the groundwater (EBASCO, 1989c/ RIC 89166R07). The preferred IRA alternative consists of a slurry wall and vegetative cap and a limited groundwater extraction system that will be installed to maintain groundwater levels within the enclosed basin (PMRMA, 1990).

The **M-1 Settling Basins** were used to treat wastewater from the lewisite disposal facility and, to a lesser degree, to treat wastes from alleged spills in other buildings that may have been routed through floor drains and the connecting piping to the basins (EBASCO, 1988b/RIC 88286R10). The M-1 settling basins were backfilled in 1947 and are now covered with soil. A few structures were constructed in these areas. Waste materials in the basins and nearby soils contain elevated concentrations of arsenic, mercury, agent, OCPs and other organics, and are a source of arsenic contamination to the groundwater. The preferred IRA alternative is *in situ* vitrification (ISV), installation of a subsurface barrier wall around the basins, and removal of several tanks and associated structures (PMRMA, 1990).

The **Motor Pool Area - Trichloroethylene Plume** is located in the western portion of RMA. The motor pool appears to be a source of the trichloroethylene groundwater plume in the unconfined flow system in this area. The motor pool consists of buildings and tanks used for cleaning and servicing equipment, vehicles, and railroad cars and for storing fuel, road oil, and flammable liquids (WCC, 1989c/RIC 90002R04). Cleaning solvent and maintenance operation waste liquids may have been discharged from some buildings through floor drains and pipes that emptied into unlined drainages (WCC, 1989b/RIC 89222R05). Groundwater in this area will be extracted and piped to the Irondale Containment System for treatment. In addition, bench-scale soil vapor extraction will be utilized.

The **Rail Classification Yard - DBCP Plume** is located in the western part of RMA. Between 1967 and 1974, DBCP, a pesticide manufactured by Shell, was temporarily stored in box cars in the railyard prior to shipment. DBCP was detected in off-post alluvial groundwater in 1980, and subsequent groundwater sampling indicated that the rail classification yard was a probable source (EBASCO, 1988a/RIC 88076R04). The preferred IRA alternative consists of a groundwater extraction and treatment system. The system will be designed and implemented in conjunction with the motor pool area groundwater extraction/treatment system. Both of these systems will be designed to intercept contamination near the source. The ICS prevents these plumes from migrating off post (PMRMA, 1990).

The **Army (Complex Disposal) Trenches** were used for the disposal of solid chemical waste and potentially contaminated tools, equipment, containers, rejected incendiaries, and empty munition casings that were decontaminated with caustic and then incinerated in pits or trenches. Soil samples collected from representative trenches showed elevated concentrations of ICP metals and relatively low concentrations of arsenic, mercury, and many organic contaminants, including members of all the analyte groups except pesticide-related organophosphorous compounds (OPHPs) and organonitrogen compounds (ONCs). A large variety of tentatively identified compounds (TICs) were also detected in intratrench soils. The preferred IRA alternative consists of continued groundwater monitoring in this area, due to the relatively small contribution to groundwater contamination from upgradient sources. Additional wells will be installed and a reevaluation program established to periodically update the trench contribution to groundwater contamination. If reevaluations determine significant changes, a more active response action may be proposed (PMRMA, 1990).

The **Shell Trenches** were used between 1952 and 1965 for the disposal of liquid and solid wastes generated from pesticide manufacturing (MKE, 1989b/RIC 89282R02). Elevated concentrations of VHOs, VHCs, VAOs, OPHGBs, DBCP, arsenic, and mercury were detected downgradient of the trenches, indicating that the Shell trenches are a source of contamination to groundwater in this area. A dense, nonaqueous phase liquid has also been detected in the Shell trenches. The preferred IRA alternative consists of the installation of both, a subsurface barrier wall around the trench area and a cap with a soil and vegetative cover (PMRMA, 1990).

The **South Tank Farm Plume**, located between South Plants and the lakes area, consists of two separate groundwater plumes extending toward the lakes, one of which consists of light, nonaqueous phase liquids. The south tank farm consists of 11 tanks used for storage of alcohol, bicycloheptadiene buttons, dicyclopentadiene, D-D soil fumigant, and sulfuric acid. Records indicate benzene was also used or stored in this area, because there are references to an alleged 100,000-gallon spill. VAOs, primarily benzene, were detected at elevated concentrations in the groundwater beneath the south tank farm and are part of a plume emanating from the south tank farm. The Implementation Document is scheduled to be released in July 1991, and start of construction estimated to begin in November 1991.

C.13.2 IMPACT

Implementation of the various "hot spot" IRAs will impact, to varying degrees, the soils, water, air, biota, and structures at RMA.

C.13.3 STATUS

Table C.1-2 lists the actual or proposed estimated IRA schedule deadlines for the seven "hot spot" IRAs. Final or Draft Final Assessment and Decision Documents have been released for the individual "hot spot" IRAs. In general, Implementation Documents are anticipated to be released by December 1990; construction or implementation will begin in the spring and summer of 1991. Completion of these seven "hot spot" IRAs is scheduled between June 1992 and November 1993.

C.14 PRETREATMENT OF CERCLA LIQUID WASTE

The Pretreatment of CERCLA Liquid Waste IRA consists of the development and implementation of a program to treat wastewater and decontamination water generated from various activities at RMA before the water is discharged to the sanitary sewer (FFA, 1989/RIC 89068R01).

C.14.1 DESCRIPTION

A number of RMA activities, (including RI/FS, Comprehensive Monitoring Program (CMP), IRA, decontamination pad, and RMA laboratory activities), generate wastewaters requiring pretreatment before disposal. The preferred alternative for this IRA is to construct a new wastewater treatment facility that will handle batches of wastewater from various areas at RMA. Each batch will be analyzed to determine the proper treatment process, and, after treatment, to verify contaminant removal (PMRMA, 1990). The wastewater treatment system will consist of modules such as granular activated carbon, ultraviolet/chemical oxidation, activated alumina, prefiltering, and precipitation. Once treated to levels set forth in the Decision Document, the wastewaters will be discharged to the RMA sewer system (PMRMA, 1990). The proposed location of the CERCLA Wastewater Treatment System is indicated in Figure C.1-1.

C.14.2 IMPACT

Implementation of this IRA will impact wastewater on RMA.

C.14.3 STATUS

The Draft Implementation Document was released in January 1991. The start of construction activities is scheduled for 1991 with an estimated completion date of July 1992.

C.15 REFERENCES CITED

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EBASCO. 1988d, September. Draft Final Report Abandoned Well Program. Version 2.0. Volumes I through IV. Task No. 37

RIC 89166R05
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EBASCO. 1989b, July. Final Remedial Investigation Report Volume X, Central Study Area. Version 3.3, Volumes I through VIII.

RIC 89166R07
EBASCO. 1989c, July. Final Remedial Investigation Report Volume XI, North Central Study Area. Version 3.3, Volumes I through XIV.

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RIC 89100R03
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RIC 88131R01
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RIC 88141R03
PMRMA. 1988b. Draft Final Decision Document for the Interim Action of Basin F Hazardous Waste Cleanup Rocky Mountain Arsenal IRA.

RIC 88329R03
PMRMA. 1988c, July. Final Decision Document for the Interim Response Action for the Improvement of the North Boundary System at Rocky Mountain Arsenal via Construction of Groundwater Recharge Trenches.

RIC 88329R02
PMRMA. 1988d, October. Final Decision Document for the Interim Response Action at the Rocky Mountain Arsenal Hydrazine Blending and Storage Facility.

RIC 89019R01
PMRMA. 1988e, December. Final Decision Document for the Interim Response Action for Building 1727 Sump at RMA.

RIC 88349R01
PMRMA. 1988f, December. Final Decision Document for the Interim Response Action for the Groundwater Intercept and Treatment System North of Basin F Rocky Mountain Arsenal.

RIC 89032R02
PMRMA. 1989a, February. Final Decision Document for the Basin A Neck Groundwater Intercept and Treatment System Interim Response Action at the Rocky Mountain Arsenal.

RIC 89100R01
PMRMA. 1989b, April. Final Decision Document for the North Boundary System Improvements Interim Response Action at the Rocky Mountain Arsenal.

RIC 89100R02
PMRMA. 1989c, April. Final Decision Document for the Sanitary Sewer System Interim Response Action at Rocky Mountain Arsenal.

RIC 89139R02
PMRMA. 1989d, May. Final Implementation Document for the Interim Response Action for Building 1727 Sump at RMA.

RIC 90009R01
PMRMA. 1989e, December. Draft Implementation Document for the Application of Dust Suppressant at Basin A, Section 36 of Rocky Mountain Arsenal (IRA).

PMRMA. 1990, July. One-Page Fact Sheets on Interim Response Actions.

RIC 90032R05
R.F. Weston, Inc. 1990a, January. Rocky Mountain Arsenal Sanitary Sewer Interim Response Action Draft Implementation Plan. Volumes 1 and 2.

RIC 90072R07
R.F. Weston, Inc. 1990b, February. Final Report Rocky Mountain Arsenal (RMA) Abandoned Well Closure Interim Response Action (IRA). Version 3.0. Volumes I through IV.

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WCC (Woodward-Clyde Consultants). 1989a, March. Final Task Plan Task IRA-2 Basin F Liquids Treatment Design. Version 3.0. Volumes I through III.

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WCC. 1989b, June. Final Task Plan Remediation of Other Contamination Sources.

RIC 90002R04
WCC. 1989c, November. Final Alternatives Assessment of Interim Response Actions for Other Contamination Sources, Motor Pool Area. Version 3.1.

RIC 90032R03
WCC. 1989d, December. Final Treatment Assessment Report Task IRA-2, Basin F Liquid. Volumes I through III. Version 3.0.

RIC 90102R05
WCC. 1990a, April. Draft Final Decision Document for the Interim Response Action Basin F Liquid Treatment, Rocky Mountain Arsenal.

Appendix D1

Surficial Soils Investigation
Text and Figures

Remedial Investigation Summary Report

APPENDIX D1 - TABLE OF CONTENTS

APPENDIX D1 - LIST OF TABLES

APPENDIX D1 - LIST OF FIGURES

APPENDIX D1 - LIST OF ABBREVIATIONS

Acronyms

AA	Atomic absorption spectroscopy
BCRL	Below certified reporting limit
CDH	Colorado Department of Health
CMP	Comprehensive Monitoring Program
CRL	Certified reporting limit
DCPD	Dicyclopentadiene
DIMP	Diisopropylmethyl phosphonate
EPA	U.S. Environmental Protection Agency
ESE	Environmental Science and Engineering
GC/ECD	Gas chromatography/electron capture detector
GC/MS	Gas chromatography/mass spectroscopy
ICP	Inductively - coupled argon plasma spectroscopy
IR	Indicator range
IRA	Interim response action
MKE	Morrison-Knudsen Engineering
NA	Not analyzed
OCP	Organochlorine pesticide
PMRMA	Program Manager for Rocky Mountain Arsenal
RI	Remedial investigation
RIC	Resource Information Center
RISR	Remedial Investigation Summary Report
RMA	Rocky Mountain Arsenal
Shell	Shell Chemical Company
SVOC	Semivolatile organic compound
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency

Chemical Symbols

As	Arsenic
Hg	Mercury

Measurements

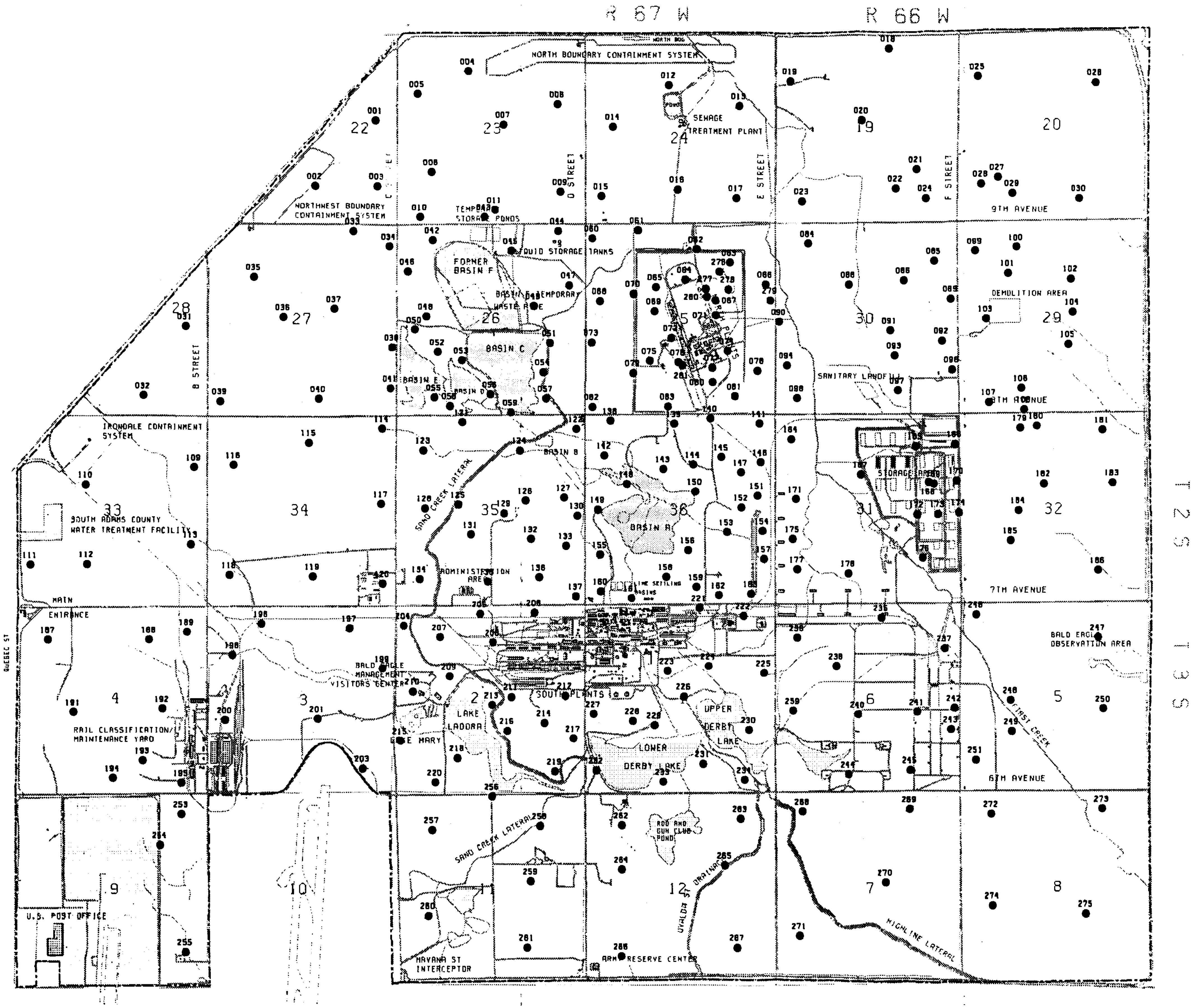
mph	Miles per hour
μg/g	Micrograms per gram

D1 SURFICIAL SOILS INVESTIGATION

D1.1 INTRODUCTION AND OBJECTIVES

The surficial soils investigation is the first component of a two-task program undertaken by the U.S. Army (Army) in cooperation with the organizations and state in order to better characterize the nonsource areas of the Rocky Mountain Arsenal (RMA). The ground disturbance investigation, discussed in Appendix D2, is the second component of the program. The surficial soil investigation was designed to investigate potential contaminant distribution specifically associated with eolian transport from contaminated source areas, to improve the remedial investigation (RI) database for nonsource areas, and to provide information for the endangerment assessment to aid in assessing human exposure to surface contaminants via ingestion, dermal exposure, and inhalation.

While the soils/sewers RI sampling program in nonsource areas composited samples from the 0- to 1-ft and 4- to 5-ft depth intervals, the surficial soil investigation used a sampling interval of 0 to 2 inches to investigate contamination at the surface only. The samples were analyzed for arsenic, mercury, semivolatile organic compounds (SVOCs), and organochlorine pesticides (OCPs): analytes that exhibit low mobility and high affinity for soils, and although they resist transport by solution or volatilization, may migrate by eolian transport. The Colorado Department of Health (CDH) originally proposed 272 surficial soil sampling locations distributed primarily in the nonsource areas of RMA (CDH, 1988). The Army, in conjunction with Shell Chemical Company (Shell), investigated 172 of the locations; Shell investigated the remaining 100 locations. At the request of EPA, the total number of sites to be sampled by Shell later increased to 106. However, one sampling location was inadvertently sampled by both Shell and the Army, and another was not sampled by Shell. In addition, one sample was lost at the lab when the sample bottle was accidentally broken. In all, 276 locations were sampled and analyzed. Sample locations for the surficial soil program are shown in Figure RISR D1.1-1. A data summary report presenting the complete analytical results of the surficial soil investigation was released in April 1991 (EBASCO, 1991/RIC 91121R01).



LEGEND

	Major Drainage		Road
	Minor Drainage	3	Section Number
	Railroad Tracks	▨	Structure
	Basin		Former Structure
	Former Basin		Arsenal Boundary
	Lakes and Ponds		
	RMA Property/Leased		

013
● Surficial Soil Sample Location

N

0 3000 Feet
Scale: 1" = 3000'

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

Prepared August 1991

FIGURE RISR D1.1-1

Surficial Soil Investigation
Sample Location Map

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

D1.2 BACKGROUND

Recognition of the potential for contaminant transport by wind at RMA predates the RI. The air monitoring and sampling programs conducted as part of the RI, and subsequently continued as part of the comprehensive monitoring program (CMP), were based on this recognition. Observations of airborne contaminants have been documented by various agencies and personnel at RMA since the 1960s. Data from pre-RI investigations indicated that dust and vapor emissions from known fugitive sources within RMA contained contaminants specific to the source (ESE, 1988b/RIC 88263R01). Basins A and F were recognized as sources of vapor emissions and airborne dusts. Volatile hydrocarbons, volatile aromatic organics, organosulfur compounds, organophosphorous compounds, OCPs, and heavy metals were reported in air samples collected near the basins during pre-RI investigations and in the course of the RI.

Between 1961 and 1966, the Army intermittently operated a spray raft to enhance evaporation of aqueous wastes in Basin F. Although operations were restricted to times when the wind and humidity conditions were within prescribed limits, it is believed that some droplets and possibly salt particles resulting from their evaporation were transported into adjacent areas (EBASCO, 1989/RIC 89166R07). In addition, a spray evaporation system was operated east of Basin F between 1975 and 1978 in order to evaporate contaminated water drained from the North Bog. In 1974 and 1975 OCPs, dicyclopentadiene (DCPD) and diisopropylmethylphosphonate (DIMP) were detected in the North Bog water (EBASCO, 1989/RIC 89166R07).

The possibility of windborne contamination emanating from both Basins A and F has been virtually eliminated in recent years by interim response actions (IRAs) undertaken at these sites. The IRAs are discussed in greater detail in Appendix C of this report. Dust suppressants were applied to a 75-acre area of Basin A in 1982 and 1988 (PMRMA, 1989/RIC 90009R01). Downwind areas are being monitored, and dust suppressants will be reapplied on an as-needed basis. Additional information for the Basin A IRA can be obtained at the JARDF located at RMA. Basin F has been eliminated as a source of windborne contaminants by the Basin F IRA, completed in 1989. Contaminated fluids were transferred from Basin F to storage tanks, contaminated solid material was excavated and placed in a waste pile, the area was regraded, and both Basin F and the waste pile were covered with a low permeability clay cap (PMRMA, 1988/RIC 88141R03).

D1.3 METHODS

Surficial soil samples were collected during the first two weeks of October 1989. Field personnel kept notes of distinctive geographic or cultural features observed in the vicinity of sampling sites during sampling operations to adequately document each site being sampled. Samples were composited from six 2-inch-deep subsamples evenly spaced around the perimeter of a 30-ft diameter circle, centered at the surveyed stake marking each location. Subsamples were collected by inserting a hand operated sampling device containing a 2-inch-diameter polybutyrate tube into the soil to a depth of 2 inches. The tube, including the subsample, was then withdrawn and moved to the next subsampling location where another subsample was collected in the same manner. This process was repeated at each subsampling location until six subsamples were stacked within the sampling tube. The tube was then removed from the sampling device and emptied into a clean metal pan. Vegetative material and pebbles were removed from the sample material and the material was homogenized by hand mixing before being placed in a jar for transport to the laboratory. Clean surgical gloves were worn during this procedure.

All 172 of the Army's sampling locations were sampled including one location that was also sampled by Shell. However, one sample was accidentally destroyed before an analysis could be performed. One hundred seventy-one Army samples were analyzed for OCPs. Of these, 113 were also analyzed for SVOCs. Of the 106 Shell sampling locations, 100 samples including the location also sampled by the Army were analyzed for OCPs, and of these, 47 were also analyzed for SVOCs, 47 for arsenic, and 44 for mercury. Samples from the six additional sites in Section 25, all requested by the EPA, were analyzed for arsenic only. In all, 277 locations were sampled and samples from 276 locations were analyzed; 270 were analyzed for OCPs, 159 for SVOCs, 53 for arsenic, and 44 for mercury.

The Army's and Shell's contracting laboratories used analytical methods certified by the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and/or the Program Manager for RMA. Samples were analyzed semiquantitatively for SVOCs, including OCPs, by a gas chromatography/mass spectrometry (GC/MS) method based on EPA Methods 3540 and 8270 (DataChem, 1986; EPA, 1982a, b). Samples were analyzed quantitatively for OCPs by a gas chromatography/ electron capture detector (GC/ECD) method based on modified EPA Method 608 (DataChem, 1987; EPA, 1982a, b). Atomic absorption spectroscopy (AA) was used by the Morrison-Knudsen Engineering (MKE) lab to quantitatively identify arsenic and mercury. Specific protocols for all analytical methods used by all contracting laboratories may be obtained from PMRMA. Table RISR D1.3-1 lists analytical methods and target analytes for the surficial soil program.

Each analytical method is certified by USATHAMA over a specific concentration range. The certified reporting limit (CRL) is the lowest concentration of a particular analyte that a specific laboratory using a specific method is certified to detect. During routine sample analysis, analytical results must either fall within or be diluted to fall within the certified range in order to be considered valid. In addition, the laboratory quality assurance plan for RMA requires that all analyses on a sample be completed within a specified holding time to be considered valid (EBASCO, 1985/RIC 86241R02). The laboratory analysis and data validation QA/QC programs governing the collection and handling of data developed by the Surficial Soil Investigation are specified in the Procedures Manual to the Technical Plan Volume II (EBASCO, 1985/RIC 86241R02) and the Chemical Quality Assurance Plan (PMRMA, 1989/RIC 89244R01).

Table RISR D1.3-1 Analytical Methods and Target Analytes for Surficial Soils Investigation at RMA

ANALYTES	SYNONYMS	ABBREVIATIONS
Semivolatile Organic Compounds (GC/MS)*		**SVOCs**
1,4-Oxathiane		OXAT
2,2-bis(Para-chlorophenyl)-1,1-dichloroethane	Dichlorodiphenylethane	PPDDE
2,2-bis(Para-chlorophenyl)-1,1,1-trichloroethane	Dichlorodiphenyltrichloroethane	PPDDT
Aldrin		ALDRN
Atrazine		ATZ
Chlordane		CLDAN
Chlorophenylmethyl sulfide	p-Chlorophenylmethyl sulfide	CPMS
Chlorophenylmethyl sulfone	p-Chlorophenylmethyl sulfone	CPMSO2
Chlorophenylmethyl sulfoxide	p-Chlorophenylmethyl sulfoxide	CPMSO
Dibromochloropropane		DBCP
Dicylopentadiene		DCPD
Dieldrin		DLDRN
Diisopropylmethyl phosphonate		DIMP
Dithiane		DITH
Endrin		ENDRN
Hexachlorocyclopentadiene		CL6CP
Isodrin		ISODR
Malathion		MLTHN
Parathion		PRTHN
Supona	2-Chloro-1 (2,4-dichlorophenyl) vinyldiethyl phosphates	SUPONA
Vapona		DDVP
Organochlorine Pesticides (GC/ECD)*		**OCPs**
2,2-bis(Para-chlorophenyl)-1,1-dichloroethylene	Dichlorodiphenylethane	PPDDE
2,2-bis(Para-chlorophenyl)-1,1,1-trichloroethane	Dichlorodiphenyltrichloroethane	PPDDT
Aldrin		ALDRN

Table RISR D1.3-1 Analytical Methods and Target Analytes for Surficial Soils Investigation at RMA

Page 2 of 2

ANALYTES	SYNONYMS	ABBREVIATIONS
Chlordane		CLDAN
Dieldrin		DLDRN
Organochlorine Pesticides (GC/ECD)* (continued)		OCPs
Endrin		ENDRN
Hexachlorocyclopentadiene		CL6CP
Isodrin		ISODR
Arsenic (AA)*		AS
Mercury (AA)*		HG

* Key to Analytical Methods

GC/MS - Gas Chromatography/Mass Spectrometry
GC/ECD - Gas Chromatography/Electron Capture Detector
AA - Atomic Absorption Spectroscopy

D1.4 RESULTS

Analytical results (to two significant figures) for the Army and Shell surficial soil data are summarized in Tables RISR D1.4-1a and D1.4-2a, respectively. These tables include CRLs and indicator ranges (IRs). The IR is the analyte concentration that is expected to occur naturally in soils. Tables RISR D1.4-1b and D1.4-2b tabulate the analytical results by sample location. Due to their length, all four tables are presented following Section D1.6.

D1.4.1 Organic Analytes

Figure RISR D1.4-1 shows the distribution of total organics in surficial soils (0 to 2 inches). Observed analyte concentrations are contoured to show their variation and to highlight regions with elevated concentrations. Contour lines were drawn by linearly interpolating summed concentrations of organic analytes between sample locations. OCPs were detected in 256 of the 270 samples analyzed. Most of the 14 samples lacking OCP detections were located near the outer boundaries of RMA. Dieldrin was the most frequently detected organic analyte, followed by aldrin and chlordane. The possible ranges of half-lives for dieldrin and aldrin in soil are quite large and depend on several factors including soil type, soil moisture content, availability of sunlight, and bioactivity of the soil. The highest summed concentrations of organic analytes were 930 µg/g in sample SS26049, collected along a road east of Basin F in Section 26, and 120 µg/g in sample SS36159, collected south of the insecticide pits in Section 36. In general, the high concentrations of organic analytes occur eastward and somewhat southeastward of Basins A, C, and F. Concentrations decrease abruptly to the west and more slowly to the east, north, and south. Also, there are isolated high detections in Section 31 (in the new toxic storage yards area) and Section 6 (near the old toxic storage yards areas).

Of the 159 unique samples analyzed for SVOCs, nine were rejected by quality control. SVOCs were detected in 35 of the remaining 150 samples. Thirty-four of these were OCP detections, and one was a Supona detection. Supona is an organophosphorus pesticide and was detected in sample SS36159, collected south of the insecticide pits in Section 36.

Legend:

- Rocky Mountain Arsenal Boundary
- Section Lines
- Streams
- Lakes
- Basins
- 10 Contour, dashed where inferred

Concentration Ranges

- 🟥 > 100.0 ug/g
- 🟪 > 10.0 to 100.0 ug/g
- 🟨 > 1.0 to 10.0 ug/g
- 🟩 > 0.1 to 1.0 ug/g
- 🟦 CRL to 0.1 ug/g
- ○ BCRL

N

0 3000 Feet

Scale: 1" = 3000'

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared: August 1991

FIGURE RISR D1.4–1

Distribution of Total Organics
in Surficial Soils (0–2 in.)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

D1.4.2 Inorganic Analytes

Surficial soils were analyzed for two inorganic compounds, arsenic and mercury. Figure RISR D1.4-2 shows the locations of all surficial soil samples that were analyzed for inorganics and highlights those samples that had detections of inorganics above the IR. Arsenic was detected in all 53 samples that were analyzed for arsenic. Mercury was detected in 19 of the 44 samples that were analyzed for mercury. As a general rule, arsenic concentrations were an order of magnitude larger than mercury concentrations.

Outside of Section 36, there is very little variation in the magnitude of arsenic detections. Only three arsenic detections exceed the IR for arsenic (CRL - 10 µg/g). All three are in Section 36, in the vicinity of Basin A. Of the 19 mercury detections in surficial soils, five are above the IR (CRL - 0.10 µg/g). All five were collected in Section 36 near the margin of Basin A.

D1.5 INTERPRETATIONS AND CONCLUSIONS

Contaminants may migrate from source areas to surficial soils in nonsource areas by two principal mechanisms, eolian (windblown) transport and surface water transport. In addition, some contaminants, especially pesticides, may be detected in nonsource areas due to their direct application there for weed or insect control. While surface water is an important mechanism along creeks and ditches, and may be a factor during relatively rare overland runoff flow, the pattern of surficial soil contaminant detections shown in Figures RISR D1.4-1 and RISR D1.4-2 does not suggest surface water transport as a principal distribution mechanism. Direct application of pesticides at RMA has generally been restricted to specific areas and does not account for the pattern of contamination shown in the figures. The contamination distribution pattern is consistent with a windblown distribution mechanism. Hence, it is believed that eolian transport is the predominant contaminant migration pathway for surficial soils in nonsource areas. Figure RISR D1.5-1 presents a windrose for the annual wind conditions in the RMA vicinity. Winds at RMA most commonly blow from the south or south-southwest at windspeeds of less than 11.5 miles per hour (mph). Winds less

Prepared for:

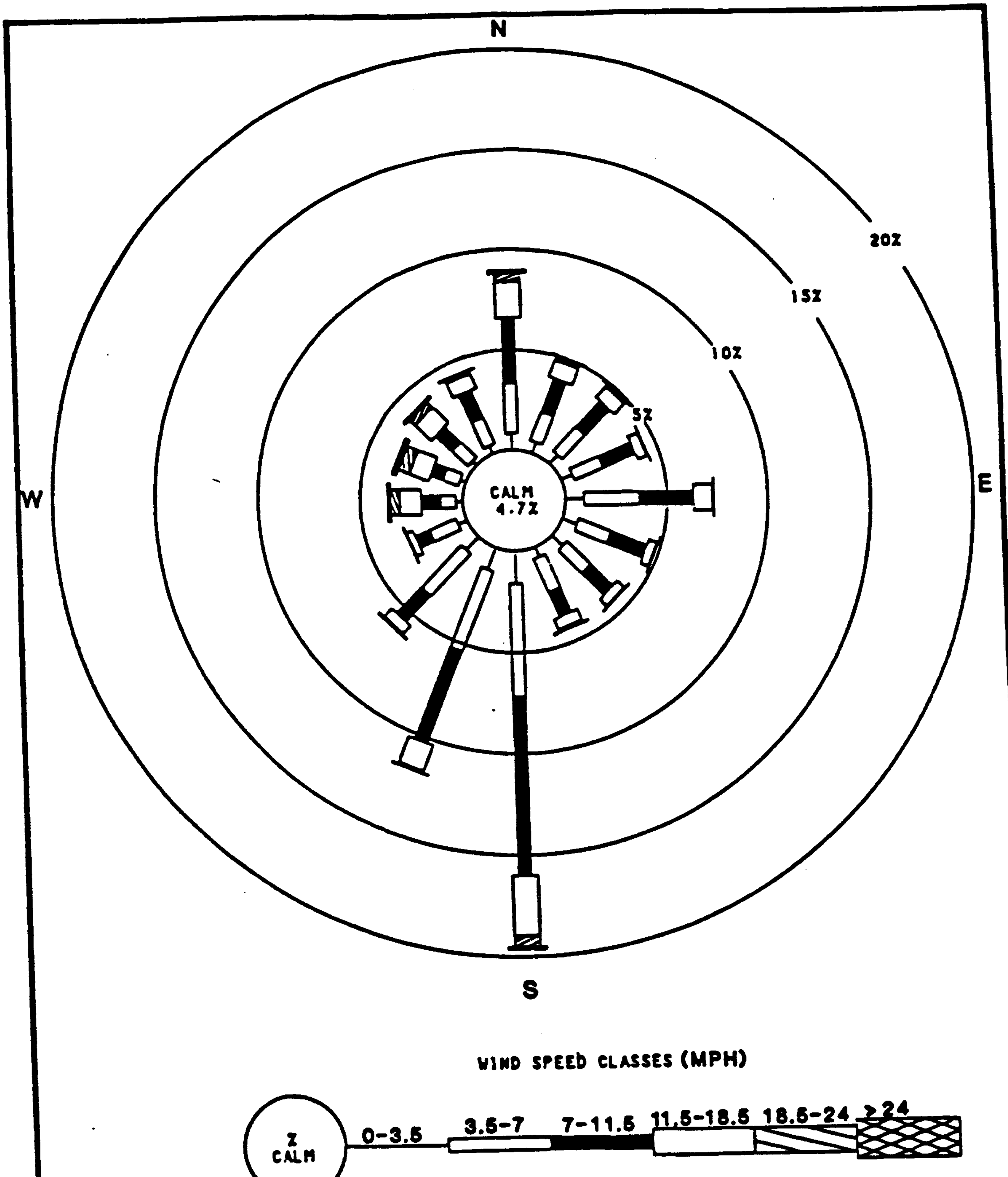
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR D1.4-2

Distribution of Arsenic and Mercury in Surficial Soils (0-2 in.) Greater than the Indicator Range

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Source: ESE, 1988

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

Prepared August 1991

FIGURE RISR DI.5-1
Annual Wind Rose for RMA Vicinity
(Stapleton International Airport 1975-1979)
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

T80-AR-[illegible]

commonly originate from the west and northwest, but nearly 50 percent of those that do exceed 11.5 mph. These "chinook" winds normally occur in midwinter when conditions tend to be dry and, therefore, favorable for eolian transport of materials. Winds blow only occasionally from the eastern quadrants and 80 percent of the time they are slower than 11.5 mph. Studies of wind as a transport agent indicate that a minimum windspeed of approximately 7 mph is required to entrain silt-sized particles. This "threshold value" increases for larger particles. The average annual windspeed at RMA, 9 mph, is sufficient only to entrain silt and some fine-sand-sized particles. Studies further indicate that sand is transported by wind at a rate roughly proportional to the cube of the windspeed above the threshold value (Chorley et al., 1984). Therefore strong winds, such as the chinook winds that blow from the west-northwest at RMA, and the strong winds from the south and southwest, though not common, could account for most eolian transport of contaminated sediments.

The surficial soil program results indicate that Basins A and F were once significant source areas of windborne contamination. It should be emphasized that the potential to emit windborne contaminants from Basins A and F has been greatly reduced due to the IRAs previously discussed in Section D1.2. The surficial soil program data, however, appear to show a relict pattern of windborne contamination resulting from primary source areas in the basins, primarily Basins A and F. Although few surficial soil samples were taken within the basins themselves, they have been well documented as contaminated aqueous waste disposal sites and were characterized as contaminated areas as a part of the soils/sewers RI.

Elevated concentrations of organic analytes, especially dieldrin, were detected in surficial soil samples collected in areas immediately to the east and southeast of the basins. As a general rule, concentrations diminish rapidly to the west of the basins, and more slowly to the east and north. Isolated detections in the toxic storage yard (Section 31) might be attributed to eolian transport from an upwind source area, such as Basin A, or from the application of pesticides (EBASCO, 1988a/RIC 88196R03). OCPs are not known to have been stored or spilled in the toxic storage yard. The general distribution of contaminants in surficial soils is consistent with the observed wind conditions at RMA, with the strongest winds originating in the west-northwest and the most frequent winds originating in the south.

D1.6 REFERENCES CITED

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Appendix D1

Surficial Soils Investigation
Tables

Remedial Investigation Summary Report

Table RISR D1.4-1a. Summary of Army Analytical Results for the Surficial Soils Investigation at RMA.

Constituent Detected	Number of Samples*	Concentration (µg/g) Range	Median**	Mean**	Standard Deviation**	DataChem Certified Reporting Limit	Indicator Level	PPLV
<u>Semivolatile Organics (N=113)</u>								
Aldrin	1	0.6	-	-	-	0.3	CRL	0.12
Dieldrin	15	0.4 - 10	0.6	1	2	0.3	CRL	0.12
Endrin	0	-	-	-	-	0.5	CRL	590
Isodrin	0	-	-	-	-	0.3	CRL	140
Dichlorodiphenyltrichloroethane	0	-	-	-	-	0.5	CRL	5.7
Dichlorodiphenylethane	0	-	-	-	-	0.6	CRL	5.7
Chlordane	2	2 - 8	-	-	-	0.2	CRL	1.5
Hexachlorocyclopentadiene	0	-	-	-	-	0.6	CRL	2600
Supona	0	-	-	-	-	0.6	CRL	300
<u>Organochlorine Pesticides (N=171)</u>								
Aldrin	111	0.0024-7.8	0.010	0.099	0.74	0.0021	CRL	0.12
Dieldrin	151	0.0025-920	0.052	6.4	75	0.0018	CRL	0.12
Endrin	79	0.0057-1.2	0.020	0.066	0.17	0.0047	CRL	590
Isodrin	31	0.0024-0.39	0.0057	0.023	0.068	0.0019	CRL	140
Dichlorodiphenyltrichloroethane	74	0.0031-0.32	0.011	0.022	0.040	0.0028	CRL	5.7
Dichlorodiphenylethane	16	0.0049-0.061	0.0088	0.017	0.017	0.0047	CRL	5.7
Chlordane	12	0.027-0.26	0.062	0.090	0.068	0.023	CRL	1.5
Hexachlorocyclopentadiene	11	0.0018-0.0060	0.0028	0.0031	0.0012	0.0014	CRL	2600

CRL - The indicator level is the Certified Reporting Limit for DataChem laboratories, as appropriate.

µg/g-micrograms per gram

N - Number of samples analyzed

PPLV - Preliminary Pollutant Limit Value for Industrial Worker

** - Number of samples in which constituent was detected; only these results were used in statistical analyses; GT values were not used in statistical analyses.*

*** - Median, mean, and standard deviation not calculated when constituent detected in fewer than 5 samples.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS01221	SS01223	SS01225	SS01226	SS01228	SS01229	SS01230	SS01231	SS01232	SS02204	SS02205	SS02207
Geologic Material	fine sand w/clay, silt	fine sand w/silt	clayey fine sand	clayey fine sand	silty med. sand	clayey sand w/silt	silty fine sand	clayey fine sand w/ silt	clayey fine sand w/ silt	silty fine sand w/ clay	fine to coarse sand	silty fine to med sand
% Fines (Visually determined)	15	5	45	40	15	30	10	20	20	15	20	15
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL
Dieldrin	0.8	1	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.029	0.088	0.0066	0.010	0.0071	0.0075	0.0034	BCRL	0.011	0.0057	0.0079	0.0072
Dieldrin	0.97	0.94	0.078	0.16	0.049	0.099	0.043	0.094	0.071	0.044	0.041	0.027
Endrin	0.090	0.016	0.020	0.016	BCRL	0.014	0.0070	0.0086	BCRL	BCRL	BCRL	BCRL
Isodrin	0.0066	0.0025	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.045	0.017	0.015	0.017	0.0062	0.0097	0.0044	0.013	0.015	BCRL	0.0083	BCRL
Dichlorodiphenylethane	0.015	0.0075	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0061	BCRL
Chlordane	0.092	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	0.0029	BCRL	0.0028	0.0027	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.
BCRL - Below certified reporting limit
NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA. Page 2 of 15.

	SITE IDENTIFICATION											
	SS02208	SS02210	SS02211	SS02212	SS02213	SS02216	SS02217	SS02219	SS02220	SS03196	SS03198	SS03199
Geologic Material	fine to med. sand w/ clay	clayey sand w/silt	fine to med. sand w/ silt	fine sand w/ silt	sandy clay w/ silt	fine to med. silty sand	fine to med. silty sand	clayey sand w/ silt	silty sand w/ clay	fine to med. silty sand	fine to med. silty sand	fine to med. sand w/ silt
% Fines (Visually determined)	10	15	5	5	60	15	15	15	20	10	15	5
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
Dieldrin	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
Chlordane	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	0.0041	0.029	0.0072	0.0049	0.0065	0.0032	0.0029	BCRL	BCRL	0.0029
Dieldrin	BCRL	BCRL	0.045	0.27	0.052	0.24	0.15	0.038	0.029	BCRL	0.017	0.008
Endrin	BCRL	BCRL	BCRL	0.017	BCRL	BCRL	0.0081	BCRL	BCRL	BCRL	BCRL	BCRL
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	0.0082	0.0032	0.0092	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	0.010	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA-Not analyzed

	SITE IDENTIFICATION											
	SS03200	SS03203	SS04188	SS04189	SS04192	SS04194	SS04195	SS05248	SS05249	SS05250	SS06235	SS06237
Geologic Material	fine to med. silty sand	sandy clay w/ silt	fine to med. silty sand	clayey sand w/ silt	fine to med. silty sand	silty, fine sand	fine sand w/ silt	fine to med. sand	fine to med. sandy clay	fine to med. sand,clay	fine sandy clay	fine clayey sand
% Fines (Visually determined)	15	55	10	15	10	20	25	20	55	5	55	30
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA
Dieldrin	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA
Chlordane	BCRL	NA	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	BCRL	0.0028	BCRL	BCRL	BCRL	BCRL	0.0044	0.022	BCRL	BCRL	0.0072	0.0024
Dieldrin	0.010	0.0066	0.0054	BCRL	BCRL	0.010	0.010	0.0052	0.041	0.0092	0.095	0.013
Endrin	0.0069	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0057	BCRL	0.013	BCRL
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0029	BCRL
Dichlorodiphenyltrichloroethane	0.034	BCRL	BCRL	BCRL	BCRL	BCRL	0.014	BCRL	0.0053	BCRL	0.0080	0.0034
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA. Page 4 of 15.

	SITE IDENTIFICATION											
	SS06239	SS06240	SS06241	SS06242	SS06243	SS06245	SS07268	SS07270	SS08272	SS08274	SS09254	SS11256
Geologic Material	slightly sandy clay	silty sand w/ clay	medium silty sand	fine silty sand w/ clay	fine to med. clayey sand	fine to med. sand w/ clay	fine to coarse sand	fine sand w/ silt	v. fine sand w/ clay	fine sand w/ clay	silty fine sand w/ clay	clayey fine sand w/ silt
% Fines (Visually determined)	80	30	5	35	40	10	30	10	65	20	25	20
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NA	NA	BCRL	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
Dieldrin	NA	NA	BCRL	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
Chlordane	NA	NA	BCRL	8	BCRL	NA	BCRL	NA	NA	NA	NA	NA
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.0074	0.0050	0.0079	0.037	0.0097	BCRL	0.010	BCRL	0.0075	BCRL	BCRL	0.0063
Dieldrin	0.20	0.057	0.069	0.082	0.070	0.015	0.020	0.011	0.045	0.0051	BCRL	0.041
Endrin	0.020	0.0080	0.011	0.036	0.0095	BCRL	BCRL	BCRL	0.0082	BCRL	BCRL	BCRL
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0085
Dichlorodiphenylethane	BCRL	BCRL	BCRL	0.061	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	GT 4.0*	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

* *- The GC/ECD Chlordane analysis result for sample number SS06242 incorporates a dilution factor of 10.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS11259	SS11260	SS12262	SS12263	SS12265	SS12266	SS19019	SS19020	SS19021	SS19022	SS20025	SS20027
Geologic Material	silty fine to coarse sand	silty fine to med. sand	clayey fine sand	fine sand w/ silt	silty fine sand	clayey fine sand	silty sand	fine clayey sand w/ silt	clayey sand w/ silt	clayey fine sand	fine sand w/ clay, gravel	clayey fine sand w/ silt
% Fines (Visually determined)	15	10	25	5	15	20	20	30	30	30	20	30
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	NA	NA	BCRL	NA	NA	NA	NA	BCRL	BCRL	BCRL	NA	BCRL
Dieldrin	NA	NA	BCRL	NA	NA	NA	NA	BCRL	BCRL	BCRL	NA	BCRL
Chlordane	NA	NA	BCRL	NA	NA	NA	NA	BCRL	BCRL	BCRL	NA	BCRL
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0087	BCRL	BCRL	BCRL	BCRL
Dieldrin	0.0091	0.012	0.026	0.011	0.014	0.012	0.011	0.015	GT0.10	GT0.10	0.0025	0.0056
Endrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0037
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	0.0031	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.
BCRL - Below certified reporting limit
NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS20028	SS22002	SS22003	SS23006	SS23008	SS23009	SS23010	SS23043	SS24014	SS24017	SS25061	SS25062
Geologic Material	clayey fine sand w/ silt	fine sandy clay	clayey sand w/ silt	fine to med. clayey sand	fine sandy clay	fine sandy clay	fine clayey sand	fine sand w/ clay	sand and clay	fine sandy clay	clayey sand w/ silt	clayey sand w/ silt
% Fines (Visually determined)	30	55	25	40	60	60	35	25	70	75	25	25
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	BCRL	NA	NA	NA	NA	BCRL	BCRL	BCRL	BCRL	NA	NA	NA
Dieldrin	BCRL	NA	NA	NA	NA	BCRL	BCRL	0.5	BCRL	NA	NA	NA
Chlordane	BCRL	NA	NA	NA	NA	BCRL	BCRL	BCRL	BCRL	NA	NA	NA
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	BCRL	0.011	0.0070	0.010	0.016	0.083	0.0062	BCRL	0.16	0.011
Dieldrin	0.0062	0.0063	0.022	0.074	0.069	0.17	0.086	0.60	0.066	0.016	0.65	0.071
Endrin	BCRL	BCRL	BCRL	0.0081	BCRL	0.021	0.011	0.11	0.0063	BCRL	0.15	0.013
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0079	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.0038	BCRL	BCRL	BCRL	0.0041	0.0058	BCRL	0.024	0.0048	BCRL	0.095	0.010
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS25063	SS25065	SS25067	SS25068	SS25069	SS25070	SS25073	SS25074	SS25076	SS25078	SS25079	SS25080
Geologic Material	clayey sand w/ silt	poorly-graded sand	med. sand w/ silt	clayey fine sand	poorly-graded sand	poorly-graded sand w/ clay	sand w/ clay and silt	sand w/ clay and silt	poorly-sorted sand w/ clay	clayey silty fine sand	silty clayey fine sand	silty fine sand w/ clay
% Fines (Visually determined)	20	30	30	25	20	30	10	30	20	35	35	25
SOIL CHEMISTRY												
Semivolatile Organics (ug/g)												
Aldrin	NA	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Dieldrin	NA	BCRL	BCRL	NA	BCRL	BCRL	1	BCRL	BCRL	NA	0.4	BCRL
Chlordane	NA	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Organochlorine Pesticides (ug/g)												
Aldrin	0.0058	0.049	0.024	LT0.21*	0.044	0.0068	0.53	0.041	0.073	0.030	0.087	0.015
Dieldrin	0.041	0.62	0.17	1.2	0.29	0.045	2.8	0.41	0.25	LT0.018**	1.3	0.022
Endrin	0.015	0.073	0.031	LT0.47*	0.038	0.0073	BCRL	BCRL	0.067	0.022	0.062	0.013
Isodrin	BCRL	0.0040	BCRL	0.013	BCRL	BCRL	0.026	0.0047	0.0032	BCRL	0.0071	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	0.017	0.017	BCRL	BCRL	0.029	0.013	0.023	0.0072	0.010	0.0041
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0050	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0022	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

** - The GC/ECD Aldrin and Endrin analyses results for sample number SS25068 incorporate a dilution factor of 100.*

*** - The GC/ECD Dieldrin analysis result for sample number SS25078 incorporates a dilution factor of 10.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA. Page 8 of 15.

	SITE IDENTIFICATION											
	SS25081	SS25082	SS25083	SS26042	SS26044	SS26047	SS26048	SS26049	SS26050	SS26053	SS26054	SS26055
Geologic Material	clayey fine sand w/ silt	med. sand w/ silt	silty sand w/ clay	clayey sand	slightly clayey sand	well-graded sandy clay	fine sandy clay	poorly-graded sand	poorly-graded sand	poorly-graded sand w/ clay	fine sand w/ clay	poorly-graded sand, clay
% Fines (Visually determined)	35	10	15	25	10	50	85	3	7	65	85	20
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NA	NA	NA	BCRL	BCRL	BCRL	REJ	REJ	REJ	REJ	REJ	REJ
Dieldrin	NA	NA	NA	BCRL	0.5	0.6	REJ	REJ	REJ	REJ	REJ	REJ
Chlordane	NA	NA	NA	BCRL	BCRL	BCRL	REJ	REJ	REJ	REJ	REJ	REJ
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.045	0.015	0.033	0.013	0.076	0.11	0.011	7.8	0.0050	0.076	0.31	0.017
Dieldrin	0.41	0.70	0.30	0.16	0.49	0.61	0.13	920	0.064	0.96	4.1	0.11
Endrin	0.054	0.014	0.031	0.023	0.065	0.10	0.024	0.97	0.042	0.077	0.36	0.018
Isodrin	0.0051	BCRL	BCRL	BCRL	0.0057	0.015	BCRL	0.39	BCRL	0.048	0.023	BCRL
Dichlorodiphenyltrichloroethane	0.015	0.0047	BCRL	0.017	0.032	0.052	0.0055	0.32	0.0048	0.017	0.040	0.0038
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	0.0069	BCRL	BCRL	BCRL	BCRL	0.017	BCRL
Chlordane	0.16	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.26	BCRL	BCRL	0.045	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0035	BCRL	BCRL	0.0060	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

REJ - These sample lots were rejected by Quality Control.

	SITE IDENTIFICATION											
	SS26056	SS26058	SS26059	SS27034	SS27035	SS27036	SS27037	SS27039	SS27041	SS28031	SS29099	SS29100
Geologic Material	poorly-graded sand	poorly-graded sand	poorly-graded sand	clayey sand w/ silt	clayey sand w/ silt	silty sand	clayey sand w/ silt	silty sand w/ clay	silty fine sand	silty sand w/ clay	clayey sand w/ silt	sand w/ silt, clay
% Fines (Visually determined)	2	65	3	25	25	15	25	15	15	15	20	20
SOIL CHEMISTRY												
Semivolatile Organics (ug/g)												
Aldrin	REJ	REJ	REJ	NA	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL
Dieldrin	REJ	REJ	REJ	NA	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL
Chlordane	REJ	REJ	REJ	NA	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL
Organochlorine Pesticides (ug/g)												
Aldrin	LT0.021*	0.052	0.33	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dieldrin	0.12	0.32	6.4	BCRL	BCRL	BCRL	0.015	BCRL	0.046	BCRL	0.011	0.0088
Endrin	0.10	0.049	1.2	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Isodrin	0.0073	0.0036	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.048	0.017	GT0.10	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	0.010	BCRL	0.052	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	0.0039	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

REJ - These sample lots were rejected by Quality Control.

** - The GC/ECD Aldrin analysis result for sample number SS26056 incorporates a dilution factor of 10.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS29101	SS29102	SS29105	SS29106	SS29107	SS29108	SS30084	SS30085	SS30086	SS30088	SS30089	SS30090
Geologic Material	silty sand w/ clay	sandy clay w/ silt	clayey sand w/ silt	silty sand w/ clay	silty fine sand w/ clay	silty fine sand w/ clay	silty fine sand	fine clayey sand	fine sand w/ clay	clayey sand w/ silt	clayey sand w/silt	fine sandy clay
% Fines (Visually determined)	20	70	25	20	20	25	25	45	90	30	40	60
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL	NA	BCRL	NA
Dieldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL	NA	BCRL	NA
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL	NA	BCRL	NA
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0059	0.0050	0.0083	0.0061	0.0070	0.0067
Dieldrin	0.0081	BCRL	0.0092	0.0082	0.0098	0.020	0.020	0.010	0.020	0.032	0.025	0.070
Endrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0096
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0045
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.
BCRL - Below certified reporting limit
NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.   Page 11 of 15.

	SITE IDENTIFICATION											
	SS30092	SS30093	SS30094	SS30095	SS30096	SS31164	SS31165	SS31166	SS31168	SS31170	SS31173	SS31175
Geologic Material	fine clayey sand	fine clayey sand	fine sandy clay	fine sand w/ silt	clayey sand w/ silt	fine sandy clay	very fine sand, clay	very fine sandy clay	very fine to med. sand	fine sandy clay	med. to very fine sand	fine sandy clay
% Fines (Visually determined)	40	40	60	10	25	65	85	60	35	60	65	77
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	BCRL	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dieldrin	BCRL	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Organochlorine Pesticides (µg/g)												
Aldrin	0.0054	0.0048	0.026	NA*	0.0090	0.015	BCRL	0.0095	0.0029	BCRL	0.0044	0.0072
Dieldrin	0.040	0.027	0.20	NA*	0.046	0.11	0.0091	0.069	0.012	0.040	0.035	0.16
Endrin	0.0063	BCRL	0.034	NA*	0.0062	0.0095	BCRL	0.011	BCRL	0.0058	BCRL	0.029
Isodrin	BCRL	BCRL	BCRL	NA*	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0026
Dichlorodiphenyltrichloroethane	BCRL	BCRL	0.0066	NA*	BCRL	0.0062	BCRL	BCRL	BCRL	BCRL	BCRL	0.012
Dichlorodiphenylethane	BCRL	BCRL	BCRL	NA*	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	NA*	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.057
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	NA*	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

NA - Lab sample was accidentally destroyed before analysis could be performed.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS31177	SS31178	SS32179	SS32180	SS32181	SS32182	SS32184	SS32185	SS33109	SS33111	SS33112	SS34114
Geologic Material	very fine sand, clay	fine sandy clay	very fine sand, clay	fine sandy clay	slightly sandy clay	slightly sandy clay	sandy clay	poorly-graded clayey sand	silty sand w/ clay	silty fine sand w/ clay	silty sand w/ clay	silty sand w/ clay
% Fines (Visually determined)	80	75	72	80	85	90	70	35	15	20	25	25
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NA	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
Dieldrin	NA	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
Chlordane	NA	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.023	0.0040	0.0058	0.0028	0.0036	BCRL	0.0056	BCRL	BCRL	BCRL	BCRL	0.0050
Dieldrin	0.30	0.067	0.021	0.023	0.024	0.014	0.061	0.017	0.0034	BCRL	0.0034	0.071
Endrin	0.050	0.010	BCRL	BCRL	BCRL	BCRL	0.0096	BCRL	BCRL	BCRL	BCRL	BCRL
Isodrin	0.0057	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.016	0.0056	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0098
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	0.085	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.
BCRL - Below certified reporting limit
NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA. Page 13 of 15.

	SITE IDENTIFICATION											
	SS34116	SS34117	SS34118	SS34120	SS35122	SS35123	SS35125	SS35126	SS35130	SS35132	SS35134	SS35135
Geologic Material	silty fine sand w/ clay	clayey fine sand w/ clay	silty fine sand w/ clay	clayey fine sand	clayey fine sand w/ silt	clayey sand w/ silt	silty fine sand	sandy clay w/ silt	silty sand w/ clay	silty sand w/ clay	clayey sand w/ silt	silty fine sand w/ clay
% Fines (Visually determined)	20	30	15	25	25	35	10	65	20	15	20	20
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	NA	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA
Dieldrin	NA	NA	NA	NA	BCRL	NA	NA	BCRL	0.6	BCRL	NA	NA
Chlordane	NA	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	0.0030	BCRL	0.0029	0.013	0.013	0.040	0.020	0.012	0.011	BCRL	0.020
Dieldrin	0.0030	0.029	0.0092	0.025	0.21	0.084	0.20	0.097	0.26	BCRL	BCRL	BCRL
Endrin	BCRL	BCRL	BCRL	BCRL	0.032	0.016	0.048	0.012	0.042	BCRL	BCRL	0.011
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0027	0.0024	0.0025	BCRL	BCRL	0.0026
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	0.074	0.0049	0.0072	0.021	0.012	BCRL	0.0054	0.0062	0.047
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	0.0049	BCRL	0.0064	BCRL	0.0054	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0018	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION											
	SS35136	SS35137	SS36138	SS36140	SS36141	SS36142	SS36143	SS36144	SS36145	SS36146	SS36147	SS36149
Geologic Material	fine sand w/ silt	poorly-sorted sand w/ clay	silty fine sand	clayey sand w/ silt	sand w/ clay, silt	silty fine sand	fine sand w/ silt	silty fine sand	silty fine sand	clayey fine sand w/ silt	silty sand w/ clay	silty sand w/ clay
% Fines (Visually determined)	15	10	10	30	60	15	10	20	25	25	25	25
SOIL CHEMISTRY												
<u>Semivolatile Organics (ug/g)</u>												
Aldrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Dieldrin	BCRL	0.5	0.4	BCRL	BCRL	BCRL	BCRL	0.5	BCRL	NA	BCRL	1
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	BCRL
<u>Organochlorine Pesticides (ug/g)</u>												
Aldrin	0.0069	0.015	0.013	0.027	0.014	0.015	0.016	0.013	0.0077	0.019	0.0081	BCRL
Dieldrin	0.069	0.31	0.14	0.22	0.11	0.19	0.19	0.34	0.18	LT0.018*	0.097	0.0040
Endrin	BCRL	0.043	0.020	0.057	0.015	0.017	0.019	0.037	0.013	0.11	0.013	BCRL
Isodrin	BCRL	0.0030	BCRL	BCRL	BCRL	0.0030	BCRL	BCRL	BCRL	0.0079	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	0.032	BCRL	0.012	0.0047	BCRL	0.037	0.0060	BCRL	0.015	0.0066	BCRL
Dichlorodiphenylethane	BCRL	0.0052	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	0.031	BCRL	BCRL	0.045	0.047	BCRL	0.17	BCRL	BCRL
Hexachlorocyclopentadiene	BCRL	0.0021	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

** - The GC/ECD Dieldrin analysis result for sample number SS36146 incorporates a dilution factor of 10.*

Table RISR D1.4-1b. Army Analytical Results for the Surficial Soils Investigation at RMA.

	SITE IDENTIFICATION			
	SS36152	SS36153	SS36157	SS36162
Geologic Material	fine sand w/ silt, clay	silty fine sand w/ clay	clayey fine sand w/ silt	fine sand w/ silt
% Fines (Visually determined)	15	15	25	5
SOIL CHEMISTRY				
Semivolatile Organics (µg/g)				
Aldrin	BCRL	BCRL	BCRL	0.6
Dieldrin	BCRL	0.7	0.5	10
Chlordane	BCRL	2	BCRL	BCRL
Organochlorine Pesticides (µg/g)				
Aldrin	0.0053	0.017	0.013	LT2.1**
Dieldrin	0.18	0.42	0.26	14
Endrin	0.036	LT0.19 *	0.067	0.30
Isodrin	0.0029	0.031	0.0062	0.058
Dichlorodiphenyltrichloroethane	0.019	LT0.11*	0.030	0.094
Dichlorodiphenylethane	BCRL	0.015	BCRL	0.027
Chlordane	BCRL	0.066	BCRL	0.027
Hexachlorocyclopentadiene	BCRL	BCRL	0.0020	0.0046

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

** - The GC/ECD Endrin and Dichlorodiphenyltrichloroethane analyses results for sample number SS36153 incorporate a dilution factor of 40.*

*** - The GC/ECD Aldrin analysis result for sample number SS36162 incorporates a dilution factor of 1000.*

Table RISR D1.4-2a. Summary of Shell Analytical Results for the Surficial Soil Sampling Program at RMA.

Constituent Detected	Number of Samples*	Concentration (µg/g) Range	Median**	Mean**	Standard Deviation**	ESE Certified Reporting Limit	Indicator Level	PPLV
<u>Semivolatile Organics (N=47)</u>								
Aldrin	3	1 - 6	-	-	-	0.7	CRL	0.12
Dieldrin	8	2 - 40	7	10	10	0.6	CRL	0.12
Endrin	0	-	-	-	-/	0.3	CRL	590
Isodrin	0	-	-	-	-	0.3	CRL	140
Dichlorodiphenyltrichloroethane	0	-	-	-	-	0.6	CRL	5.7
Dichlorodiphenylethane	0	-	-	-	-	0.5	CRL	5.7
Chlordane	5	2 - 20	9	10	8	0.7	CRL	1.5
Hexachlorocyclopentadiene	0	-	-	-	-	0.7	CRL	2600
Supona	1	0.5	-	-	-	0.2	CRL	300
<u>Organochlorine Pesticides (N=100)</u>								
Aldrin	67	0.0035-22	0.016	0.48	2.7	0.0026	CRL	0.12
Dieldrin	99	0.0023-87	0.038	1.8	9.3	0.0019	CRL	0.12
Endrin	64	0.0023-13	0.014	0.43	1.8	0.002	CRL	590
Isodrin	26	0.0022-0.28	0.0042	0.038	0.072	0.0017	CRL	140
Dichlorodiphenyltrichloroethane	22	0.0025-0.21	0.0053	0.015	0.043	0.0023	CRL	5.7
Dichlorodiphenylethane	14	0.0026-0.16	0.0054	0.032	0.052	0.0022	CRL	5.7
Chlordane	28	0.021-33	0.057	2.3	6.9	0.014	CRL	1.5
Hexachlorocyclopentadiene	0	-	-	-	-	0.0037	CRL	2600
<u>Arsenic (N=53)</u>	53	1.3-45	3.2	4.8	7.6	0.91	CRL-10	0.74
<u>Mercury (N=44)</u>	19	0.028-2.1	0.054	0.29	0.58	0.027	CRL-0.10	910

CRL - The indicator level is the Certified Reporting Limit for ESE laboratories, as appropriate.

N - Number of samples analyzed

PPLV - Preliminary Pollutant Limit Value for Industrial Worker

** - Number of samples in which constituent was detected; only these results were used in statistical analyses; GT values were not used in statistical analyses.*

*** - Median, mean, and standard deviation not calculated when constituent detected in fewer than 5 samples.*

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 1 of 9.

	SITE IDENTIFICATION											
	SS01222	SS01224	SS01227	SS01228	SS01233	SS01234	SS02206	SS02209	SS02214	SS02215	SS02218	SS03197
Soil Texture	clay loam	fine sandy loam	sandy loam	not described	loamy sand	sandy loam	sandy loam	sandy loam	sandy loam	sandy loam	sandy loam	loamy sand
% Fines (Visually determined)	70	38	38		18	38	38	38	38	38	38	18
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA	NA
Dieldrin	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA	NA
Chlordane	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA	NA
Supona	BCRL	BCRL	BCRL	BCRL	NA	NA	BCRL	BCRL	BCRL	NA	NA	NA
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.066	0.022	0.012	0.0086	0.0050	BCRL	0.032	0.038	0.0067	BCRL	0.0075	0.0035
Dieldrin	1.0	0.15	0.11	0.068	0.035	0.0088	0.16	0.17	0.055	0.0099	0.022	0.011
Endrin	0.12	0.020	0.015	0.011	0.0048	BCRL	0.014	0.0056	0.0050	BCRL	0.0031	BCRL
Isodrin	0.010	0.0034	BCRL	BCRL	BCRL	BCRL	0.0036	0.0032	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	0.0086	0.0070	BCRL	BCRL	BCRL	0.0074	0.0055	0.0025	0.0031	BCRL
Dichlorodiphenylethane	0.0098	0.0036	0.0040	0.0026	BCRL	BCRL	0.0042	0.0059	BCRL	BCRL	BCRL	BCRL
Chlordane	0.28	0.057	0.057	0.033	0.028	BCRL	0.041	BCRL	BCRL	BCRL	BCRL	BCRL
<u>Arsenic (µg/g)</u>	2.0	1.5	1.4	1.6	NA	NA	1.3	1.3	1.3	NA	NA	NA
<u>Mercury (µg/g)</u>	0.055	0.040	BCRL	NA	NA	NA	BCRL	0.062	BCRL	NA	NA	NA

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 2 of 9.

	SITE IDENTIFICATION											
	SS03201	SS04187	SS04191	SS04193	SS05246	SS05247	SS05251	SS06236	SS06238	SS06244	SS07269	SS07271
Soil Texture	sandy loam	sandy loam	fine sandy loam	sandy loam	sandy loam	sandy loam	loamy sand	sandy loam	sandy loam	loamy sand	fine sandy loam	sandy loam
% Fines (Visually determined)	38	38	38	38	38	38	18	38	38	18	38	38
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	NA	NA	NA	NA
Dieldrin	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	NA	NA	NA	NA
Chlordane	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	NA	NA	NA	NA
Supona	NA	NA	NA	BCRL	NA	NA	BCRL	BCRL	NA	NA	NA	NA
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	BCRL	BCRL	0.0087	0.0036	0.0067	0.016	0.011	BCRL	0.0067	BCRL
Dieldrin	0.0052	0.0032	0.0035	0.0062	0.012	0.015	0.013	0.23	0.12	0.026	0.023	BCRL
Endrin	BCRL	BCRL	BCRL	BCRL	BCRL	0.0025	0.0047	0.049	0.019	0.0043	0.010	BCRL
Isodrin	BCRL	0.0022	BCRL	BCRL	BCRL	BCRL	0.0031	BCRL	0.0037	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.0027	0.0050	BCRL	0.0032	BCRL	BCRL	BCRL	0.015	0.0089	0.0065	0.0047	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.058	BCRL	0.022	BCRL
Arsenic (µg/g)	NA	NA	NA	1.5	NA	NA	1.6	2.1	NA	NA	NA	NA
Mercury (µg/g)	NA	NA	NA	BCRL	NA	NA	BCRL	0.054	NA	NA	NA	NA

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 3 of 9.

	SITE IDENTIFICATION											
	SS08273	SS08275	SS09253	SS09255	SS11257	SS11258	SS11261	SS12264	SS12267	SS19018	SS19023	SS19024
Soil Texture	sandy loam	sandy loam	sandy loam	loam	loamy sand	clay	sandy loam	clay loam	sandy loam	loamy sand	sandy loam	clay loam
% Fines (Visually determined)	38	38	38	60	18	80	38	70	38	18	38	70
SOIL CHEMISTRY												
Semivolatile Organics (μg/g)												
Aldrin	NA	NA	BCRL	NA	NA	BCRL	NA	NA	NA	NA	NA	BCRL
Dieldrin	NA	NA	BCRL	NA	NA	BCRL	NA	NA	NA	NA	NA	BCRL
Chlordane	NA	NA	BCRL	NA	NA	BCRL	NA	NA	NA	NA	NA	BCRL
Supona	NA	NA	BCRL	NA	NA	BCRL	NA	NA	NA	NA	NA	BCRL
Organochlorine Pesticides (μg/g)												
Aldrin	BCRL	BCRL	BCRL	BCRL	0.0052	0.0067	BCRL	0.0039	BCRL	BCRL	BCRL	BCRL
Dieldrin	0.013	0.0030	0.0049	0.0038	0.016	0.0099	0.011	0.022	0.0088	0.0070	0.019	0.012
Endrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0040	0.0040	BCRL	BCRL	0.0030	0.0041
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	0.0035	BCRL	BCRL	BCRL	BCRL	0.0028	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Arsenic (μg/g)	NA	NA	NA	NA	NA	2.6	NA	NA	NA	NA	NA	3.6
Mercury (μg/g)	NA	NA	NA	NA	NA	BCRL	NA	NA	NA	NA	NA	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 4 of 9.

	SITE IDENTIFICATION											
	SS20026	SS20029	SS20030	SS22001	SS23004	SS23005	SS23007	SS23011	SS24012	SS24013	SS24015	SS24016
Soil Texture	fine sandy loam	loam	loam	fine sandy loam	sandy loam	clay loam	sandy loam	clay loam	fine sandy loam	loam	clay loam	clay loam
% Fines (Visually determined)	38	60	60	38	38	70	38	70	38	60	70	70
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	NA	BCRL	NA	NA	NA	BCRL	NA	BCRL	NA	NA	BCRL	BCRL
Dieldrin	NA	BCRL	NA	NA	NA	BCRL	NA	BCRL	NA	NA	BCRL	BCRL
Chlordane	NA	BCRL	NA	NA	NA	BCRL	NA	BCRL	NA	NA	BCRL	BCRL
Supona	NA	BCRL	NA	NA	NA	BCRL	NA	BCRL	NA	NA	BCRL	BCRL
Organochlorine Pesticides (µg/g)												
Aldrin	BCRL	BCRL	BCRL	0.0054	0.012	BCRL	0.020	0.051	0.0083	BCRL	0.027	0.0071
Dieldrin	0.0025	0.0057	0.0039	0.024	0.11	0.024	0.11	0.31	0.015	0.014	0.11	0.038
Endrin	BCRL	BCRL	BCRL	0.0052	0.017	BCRL	0.023	0.089	BCRL	BCRL	BCRL	0.0059
Isodrin	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0044	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Arsenic (µg/g)	NA	3.5	NA	NA	NA	4.3	4.9	3.9	NA	NA	3.8	4.2
Mercury (µg/g)	NA	BCRL	NA	NA	NA	BCRL	NA	0.034	NA	NA	BCRL	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 5 of 9.

	SITE IDENTIFICATION											
	SS25060	SS25064	SS25066	SS25071	SS25072	SS25075	SS25077	SS25276	SS25277	SS25278	SS25279	SS25280
Soil Texture	loam	clay loam	loam	clay loam	fine sandy loam	fine sandy loam	clay loam	not described	not described	not described	not described	not described
% Fines (Visually determined)	60	70	60	70	38	38	40					
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NA	BCRL	NA	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
Dieldrin	NA	BCRL	NA	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
Chlordane	NA	BCRL	NA	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
Supona	NA	BCRL	NA	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA	NA
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	0.080	0.025	0.010	0.050	0.12	0.12	0.062	NA	NA	NA	NA	NA
Dieldrin	0.23	0.19	0.033	0.16	0.33	0.39	0.19	NA	NA	NA	NA	NA
Endrin	0.037	0.014	0.0062	0.029	0.046	0.058	0.035	NA	NA	NA	NA	NA
Isodrin	0.0039	BCRL	BCRL	0.0029	0.0058	0.0065	0.0033	NA	NA	NA	NA	NA
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	NA	NA	NA
Dichlorodiphenylethane	BCRL	0.091	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	NA	NA	NA
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	NA	NA	NA	NA	NA
<u>Arsenic (µg/g)</u>	NA	4.8	3.0	7.2	4.5	NA	3.1	3.8	4.8	2.7	2.3	4.2
<u>Mercury (µg/g)</u>	NA	0.042	NA	0.030	0.039	NA	BCRL	NA	NA	NA	NA	NA

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 6 of 9.

	SITE IDENTIFICATION											
	SS25281	SS26045	SS26046	SS26051	SS26052	SS26057	SS27033	SS27038	SS27040	SS28032	SS29103	SS29104
Soil Texture	not described	sandy loam	loam	sandy clay loam	sandy loam	clay loam	sandy clay loam	sandy loam	sandy loam	sandy loam	loam	loam
% Fines (Visually determined)		38	60	43	38	70	43	38	38	38	60	60
SOIL CHEMISTRY												
Semivolatile Organics (µg/g)												
Aldrin	NA	1	BCRL	5	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA
Dieldrin	NA	8	BCRL	8	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA
Chlordane	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA
Supona	NA	BCRL	BCRL	BCRL	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA
Organochlorine Pesticides (µg/g)												
Aldrin	NA	0.86	0.0064	5.1	0.066	0.095	BCRL	0.0044	BCRL	BCRL	BCRL	BCRL
Dieldrin	NA	5.4	0.072	20	0.25	0.47	0.012	0.038	0.0084	0.0039	0.015	0.0053
Endrin	NA	0.85	0.013	3.7	0.048	0.14	0.0023	0.0050	BCRL	BCRL	BCRL	0.0029
Isodrin	NA	0.046	BCRL	0.19	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	NA	BCRL	0.0033	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.0034	BCRL	BCRL
Dichlorodiphenylethane	NA	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	NA	BCRL	0.040	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.042	BCRL	BCRL
Arsenic (µg/g)	3.2	NA	3.0	4.6	2.5	4.0	NA	1.7	NA	NA	NA	NA
Mercury (µg/g)	NA	NA	0.032	0.043	BCRL	BCRL	NA	BCRL	NA	NA	NA	NA

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 7 of 9.

	SITE IDENTIFICATION											
	SS30087	SS30091	SS30097	SS30098	SS31167	SS31169	SS31171	SS31172	SS31174	SS31176	SS32183	SS32186
Soil Texture	not described	not described	loamy sand	fine sandy loam	loam	sandy loam	sandy loam	sandy clay loam	clay loam	fine sandy loam	clay loam	clay loam
% Fines (Visually determined)			18	38	60	38	38	43	70	38	70	70
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NS	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL	NA	NA	NA
Dieldrin	NS	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL	NA	NA	NA
Chlordane	NS	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL	NA	NA	NA
Supona	NS	NA	BCRL	NA	NA	BCRL	NA	BCRL	BCRL	NA	NA	NA
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	NS	0.0074	0.015	0.025	0.012	0.011	0.016	0.0094	0.0064	0.0084	BCRL	BCRL
Dieldrin	NS	0.030	0.063	0.14	0.035	1.5	0.085	0.18	0.036	0.069	0.014	0.022
Endrin	NS	0.0050	0.0075	0.020	BCRL	0.0089	0.014	0.0060	0.0051	0.0063	0.0036	0.0048
Isodrin	NS	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenyltrichloroethane	NS	BCRL	BCRL	BCRL	BCRL	BCRL	0.0078	BCRL	BCRL	0.0026	BCRL	BCRL
Dichlorodiphenylethane	NS	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chlordane	NS	BCRL	BCRL	BCRL	BCRL	0.024	0.11	0.028	BCRL	BCRL	BCRL	BCRL
<u>Arsenic (µg/g)</u>	NS	NA	NA	NA	NA	3.2	NA	2.8	2.2	NA	NA	3.3
<u>Mercury (µg/g)</u>	NS	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	NA	NA	BCRL

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA.

	SITE IDENTIFICATION											
	SS33110	SS33113	SS34115	SS34119	SS35121	SS35124	SS35127	SS35128	SS35129	SS35131	SS35133	SS36139
Soil Texture	sandy loam	sandy loam	sandy loam	fine sandy loam	loam	sandy loam	sandy loam	loam	sandy loam	sandy loam	loam	v. fine sandy loam
% Fines (Visually determined)	38	38	38	38	60	38	38	60	38	38	60	38
SOIL CHEMISTRY												
<u>Semivolatile Organics (µg/g)</u>												
Aldrin	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Dieldrin	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Chlordane	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	BCRL	NA	BCRL	BCRL
Supona	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	BCRL	NA	BCRL	BCRL
<u>Organochlorine Pesticides (µg/g)</u>												
Aldrin	BCRL	BCRL	BCRL	0.0074	0.055	0.071	0.015	0.013	0.051	0.031	0.040	0.039
Dieldrin	0.0023	0.0036	0.013	0.014	0.28	0.21	0.11	0.061	0.17	0.12	0.20	0.42
Endrin	BCRL	BCRL	BCRL	BCRL	0.040	BCRL	0.016	0.0072	0.019	0.018	0.025	0.031
Isodrin	BCRL	0.0022	BCRL	BCRL	0.0033	BCRL	BCRL	BCRL	BCRL	BCRL	0.0033	0.0053
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.018	0.0056	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	0.0042	BCRL	BCRL	BCRL	BCRL	BCRL	0.012	0.0048	BCRL
Chlordane	BCRL	BCRL	BCRL	BCRL	BCRL	0.024	0.036	BCRL	0.023	0.021	0.056	0.11
<u>Arsenic (µg/g)</u>	NA	NA	NA	NA	2.4	NA	1.6	2.2	1.6	NA	4.7	4.1
<u>Mercury (µg/g)</u>	NA	NA	NA	NA	BCRL	NA	BCRL	BCRL	BCRL	NA	BCRL	0.028

NOTE: All samples were taken from a depth of 0 to 2 inches.

BCRL - Below certified reporting limit

NA - Not analyzed

Table RISR D1.4-2b. Shell Analytical Results for the Surficial Soil Sampling Program at RMA. Page 9 of 9.

	SITE IDENTIFICATION										
	SS36148	SS36150	SS36151	SS36154	SS36155	SS36156	SS36158	SS36159	SS36160	SS36161	SS36163
Soil Texture	fine sandy loam	loamy sand	loam	sandy clay loam	sandy loam	fine sandy loam	sandy loam	sandy clay loam	sandy loam	sandy loam	fine sandy loam
% Fines (Visually determined)	38	18	60	70	38	38	38	43	38	38	38
SOIL CHEMISTRY											
<u>Semivolatile Organics (µg/g)</u>											
Aldrin	LT3*	BCRL	NA	BCRL	BCRL	BCRL	BCRL	6	BCRL	BCRL	NA
Dieldrin	9	3	NA	BCRL	BCRL	5	5	40	BCRL	2	NA
Chlordane	9	20	NA	BCRL	BCRL	20	2	BCRL	BCRL	2	NA
Supona	BCRL	BCRL	NA	BCRL	BCRL	BCRL	BCRL	0.5	BCRL	BCRL	NA
<u>Organochlorine Pesticides (µg/g)</u>											
Aldrin	BCRL	0.19	0.012	0.0064	0.016	0.31	0.31	22	1.2	0.36	0.077
Dieldrin	27	3.0	0.091	0.036	0.54	6.6	10	87	4.4	3.2	0.81
Endrin	BCRL	1.1	0.015	0.0078	BCRL	3.3	3.3	13	BCRL	0.87	0.068
Isodrin	BCRL	BCRL	0.0023	BCRL	0.0062	BCRL	0.093	0.28	0.19	0.11	0.0080
Dichlorodiphenyltrichloroethane	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	0.21	BCRL	BCRL	BCRL	BCRL
Dichlorodiphenylethane	BCRL	BCRL	BCRL	BCRL	0.010	BCRL	0.13	BCRL	BCRL	0.16	0.0038
Chlordane	BCRL	33	0.13	0.11	0.44	18	6.0	BCRL	0.19	3.8	0.18
<u>Arsenic (µg/g)</u>	45	39	NA	2.7	3.3	11	5.1	3.0	3.7	5.8	NA
<u>Mercury (µg/g)</u>	1.8	2.1	NA	BCRL	0.057	0.44	0.25	0.043	0.10	0.17	NA

NOTE: All samples were taken from a depth of 0 to 2 inches.
BCRL - Below certified reporting limit

NA - Not analyzed

Appendix D2

Ground Disturbance Investigation

Text, Tables, and Figures

Remedial Investigation Summary Report

APPENDIX D2 - TABLE OF CONTENTS

APPENDIX D2 - LIST OF TABLES

APPENDIX D2 - LIST OF FIGURES

APPENDIX D2 - LIST OF ABBREVIATIONS

Analyte Groups and Selected Analytes

ICP metals	Metals analyzed for by inductively coupled argon plasma spectrometry; includes cadmium, chromium, copper, lead, and zinc
SVOC	Semivolatile organic compound
VOC	Volatile organic compound

National Acts and Organizations

EMSL	Environmental Monitoring and Support Laboratory (EPA)
EPA	U.S. Environmental Protection Agency
OSWER	Office of Solid Waste Emergency Response
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency

Local Terminology

BCRL	Below certified reporting limit
BKD	Background
CAR	Contamination Assessment Report
CDH	Colorado Department of Health
CRL	Certified reporting limit
GD	Ground disturbance
IR	Indicator range
NE	Northeast
NW	Northwest
OS	Open storage yard
PMRMA	U.S. Army Program Manager for Rocky Mountain Arsenal
QA/QC	Quality assurance/quality control
REJ	Analytical results rejected by QA/QC
RIC	Resource Information Center
RISR	Remedial Investigation Summary Report
RMA	Rocky Mountain Arsenal
S	Number of samples analyzed
SAR	Study Area Report
SE	Southeast
SW	Southwest
T	Trench

Companies

EBASCO	Ebasco Services Incorporated
ESE	Environmental Sciences and Engineering, Inc.

APPENDIX D2 - LIST OF ABBREVIATIONS
(continued)

Analytical Methods

CVAA	Cold vapor atomic absorption spectroscopy
GC/MS	Gas chromatography/mass spectrometry
GFAA	Graphite furnace atomic absorption spectroscopy
ICP	Inductively coupled argon plasma spectroscopy

Chemical Symbols

Cd	Cadmium
Cr	Chromium
Cu	Copper
Pb	Lead
Zn	Zinc

Measurements and Quantities

°C	Degrees Centigrade
ft	Foot, feet
µg/g	Micrograms/gram

D2 GROUND DISTURBANCE INVESTIGATION

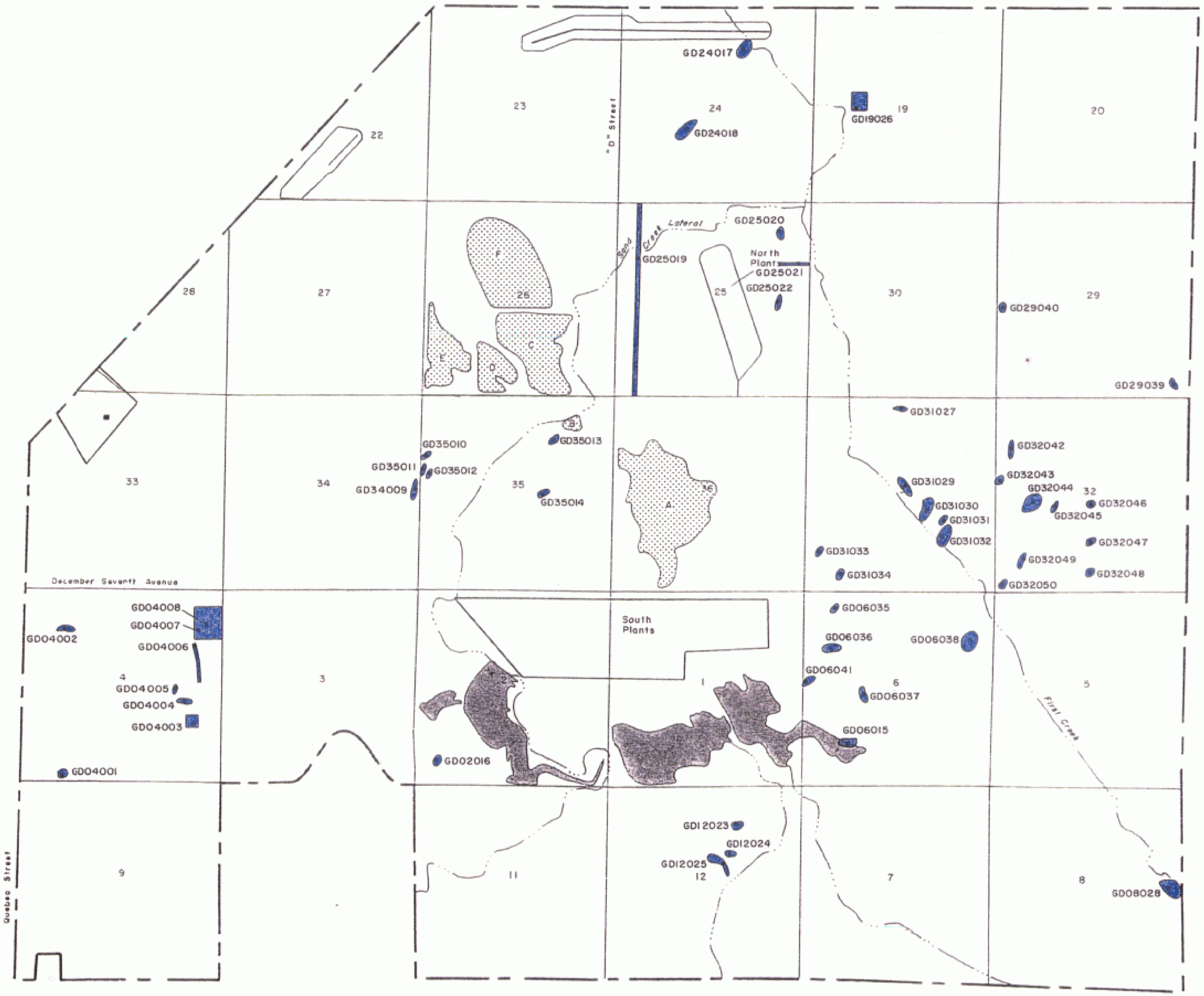
D2.1 INTRODUCTION AND OBJECTIVES

The Ground Disturbance Investigation is one component of the two-task program undertaken to further characterize the nonsource areas of the Rocky Mountain Arsenal (RMA). The surficial soil investigation is the other component of the program.

The Ground Disturbance Investigation was designed to evaluate areas of disturbed ground that, because of their location in designated nonsource areas, were not as extensively characterized as potential source areas. The ground disturbances were located by analyzing aerial photographs dating back to 1943. EBASCO reviewed 100 ground disturbances proposed by Colorado Department of Health (CDH, 1988) and excluded 63 of them from further consideration in the ground disturbance program because they had either been previously investigated; were no longer discernible in the field; were located in an area that corresponded to a site as shown on the June 1989 preliminary map "Area of Known or Inferred Occurrence of Analytes Above Background Levels at the Rocky Mountain Arsenal;" were related to containment system construction, were natural drainage depressions or were found to be the result of non-RMA activities such as farming. A total of 44 boring locations were sited at the 37 ground disturbances that required additional investigation. During its review of the CDH list, the Army identified two additional ground disturbance areas that merited investigation but were not identified on the original list. Six additional borings were located at these two sites. All 50 sampling locations are shown in Figure RISR D2.1-1 and described in Table RISR D2.1-1. The Final Ground Disturbance Investigation Data Summary Report was released in August, 1990 (EBASCO, 1990/RIC 90247R01).

D2.2 FIELD METHODS

Soil samples were collected during the last week of October and the first week of November 1989. A small trailer-mounted drill rig was used to collect samples from the 0- to 1-ft and 4 to 5-ft depth intervals at each of the 50 ground disturbance sampling locations. A core barrel containing a 2-inch-diameter polybutrate sampling tube was advanced into the ground to



Legend

▬ ▬ Rocky Mountain Arsenal Boundary
Road or Section Lines
Stream or Drainage Ditch
Lakes
Ⓐ Waste Basins
Ground Disturbance Investigation Sites
Boring Location
GD32047
Site Number
Section Number

NOTE: Size of disturbances has been exaggerated for display purposes.

N

0 3000 Feet
Scale: 1"=3000'

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

Prepared August 1991

FIGURE RISR D2.1-1

Ground Disturbance Investigation
Sample Location Map

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

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Table RISR D2.1-1 Description of Ground Disturbance Investigation Sampling Locations.

Sample Number	Date of Photos That Show Ground Disturbance	Description of Disturbed Area From Aerial Photographs and Field Investigation
GD02016*	1980-1988	Scarred area in the SW corner of the section.
GD04001	1948-1980	Two ground scars in SW corner of Section 4. Some revegetation has occurred; however, the scars are still discernible in the field. Sample was taken from eastern scar.
GD04002	1948-1988	Two trenches (T3) in NW corner of Section 4. Sample was taken from east-west oriented trench.
GD04003	1948-1988	Scarred area corresponding to open storage yard 2 (OS2) near the motor pool.
GD04004	1948-1980	Two trenches (T2) located north of the motor pool. Sample was taken from southern trench. Both trenches are evident in the field.
GD04005	1948-1965	Ground stain north of trench 1 (T1). Trench 1 is north of T2 and north of the motor pool. Stressed vegetation and remnants of the trench were found during field reconnaissance.
GD04006	1948-1988	Two parallel ditches adjacent to the railroad tracks south of open storage yard 1 (OS1). A dark liquid is apparent in the western ditch in the 1948 photo. Sample was collected from this ditch.
GD04007 GD04008	1948-1988	Scarred area corresponding to open storage yard 1 (OS1) in the NE corner of the section.
GD06015	1948-1988	Ground disturbance just north of the eastern part of Upper Derby Lake.
GD06035	1948-1980	Ground scar north of ditch D10 and SE of building 785. A row of buildings was present in the 1948 photo, but not in later photographs. Upon a recent field visit it was concluded that this scar is a relict of the building foundations from 1948 that never revegetated.
GD06036	1948-1980	Ground disturbance located along south side of ditch D19. Field investigation revealed that disturbance is a local, apparently unnatural depression with stressed vegetation.
GD06037	1948-1970	A NW-SE oriented light toned area in west half of Section 6. Disturbed area is located in southern-most row of storage sheds or bunkers two structures from the west end.

*Note: First two digits are Section number; last three digits are consecutive boring number.

RIFS5-Table RISR D.1-1-bp 8/15/91

Table RISR D2.1-1 Description of Ground Disturbance Investigation Sampling Locations.

Sample Number	Date of Photos That Show Ground Disturbance	Description of Disturbed Area From Aerial Photographs and Field Investigation
GD06038	1952-1988	A number of light toned areas where ditch D21 crosses the rail line in the NE corner of Section 6.
GD06041	1937-1988	A light toned area near the east central boundary of Section 6. Ground disturbance extends from the intersection of D19 and D20 south toward Upper Derby Lake, and is a low area with stressed vegetation.
GD08028	1958-1988	Dark patch located south of the channel at G Street in the east central part of Section 8.
GD12023	1955-1988	A light toned area in the NE quadrant of Section 12. Disturbed ground is on the eastern end of the mounded area.
GD12024 GD12025	1971-1988	Two low areas containing standing water SE of the Rod and Gun Club Pond and NW of the Uvalda Street Drainage.
GD19026	1974-1988	Small bermed area SW of firing range in west central part of Section 19.
GD24017	1986-1988	Small pond located south of the overflow ditch just south of the North Boundary Containment System.
GD24018	1948-1988	Large scar located west of the sanitary line in the central part of Section 24.
GD 25019	1962-1988	Linear ground scar parallel to D street in the western part of Section 25, west of North Plants.
GD25020	1975-1988	Possible trenches and ground scar along the NE corner of the GB plant fence. The topsoil has recently been removed during groundworking activities and the scar is no longer apparent in the 1988 photos.
GD25021	1964-1988	Linear scar in the NE quadrant of Section 25 between the GB plant fence and E Street.
GD25022	1975-1988	Ground scar north of the original ditch leading from the GB plant. Some grading was done after 1986 and the scar was partially removed.
GD29039	1964-1986	Small area of bare ground in the SE corner of Section 29. Disturbed area was still present during a recent field investigation.

Table RISR D2.1-1 Description of Ground Disturbance Investigation Sampling Locations.

Sample Number	Date of Photos That Show Ground Disturbance	Description of Disturbed Area From Aerial Photographs and Field Investigation
GD29040	1964-1986	Small circular ground scar near the western boundary of Section 29, north of the seismic station. Scar was still visible during a recent field investigation.
GD31027	1974-1988	Two possible trenches just north of the toxic storage yard in Section 31.
GD31029	1974-1988	Possible trench on the western edge of the toxic storage yard.
GD31030 GD30132	1948-1974	Two irregularly shaped light toned areas located on the northern bank of First Creek in the SE quadrant of Section 31. Southern area is less clear in photos after 1974 because it contains standing water due to the extension of the dam.
GD31031	1954-1988	Small excavation north of the new dam on First Creek, just SW of the toxic storage yard.
GD31033	1948-1988	Circular light toned area located east of building 785 in the SW quadrant of Section 31.
GD31034	1948-1986	Pond of water present along ditch D10 midway between section boundary and ditch D19. Field investigation revealed that the pond is a temporary water storage facility.
GD32042	1962-1988	A dark toned area in the NW corner of Section 32. This north-south trending area was described as a possible surface burn in the Section-32 Nonsource Area CAR (EBASCO, 1988b/RIC 88196R10).
GD32044	1962-1986	A dark toned area in the west central part of Section 32. Disturbed area was still visible during a recent field investigation.
GD32045	1962-1988	Two open trenches located west of the burn pits in Section 32. Eastern trench was investigated as Site 32-6 (EBASCO, 1988b/RIC 88196R10). Western trench was sampled for this study.
GD32043 GD32046 GD32047 GD32048	1954-1988	Four storage pads in the SW quadrant of Section 32. The remaining 12 pads (16 total) were previously investigated as Sites 32-4 and 32-2 (EBASCO, 1988b/RIC 88196R10).

Table RISR D2.1-1 Description of Ground Disturbance Investigation Sampling Locations.

Sample Number	Date of Photos That Show Ground Disturbance	Description of Disturbed Area From Aerial Photographs and Field Investigation
GD32049 GD32050	1972-1988	Two trenches, a pit and a small excavation in the SW corner of Section 32. The eastern trench and a pit were previously investigated as part of Sites 32-4 and 32-2 (EBASCO, 1988b/R1C88196R10). The western trench and small excavation were sampled for this study.
GD34009	1948-1975	Ground scar parallel to C Street approximately 1000 ft north of December Seventh Avenue. Scar was still visible during a recent field investigation.
GD35010 GD35011 GD35012	1948-1988	Three scarred areas located along the western border of Section 35 just north of the ground scar parallel to C Street (GD34009) mentioned above.
GD35013	1948-1988	Scarred area located near the center of Section 35, west of the dry reservoir.
GD35014	1948-1988	Scarred area located in the NE quadrant of Section 35 south of the Sand Creek Lateral.

extract the desired sampling interval. The sample tube was then removed from the core barrel, sealed, and placed in a cooler to maintain a constant temperature at or below 4°C for shipping and handling. Sampling equipment was decontaminated between borings with trisodium phosphate solution and distilled water.

No unexploded ordnance were encountered during drilling but metal, wood, and brick debris were encountered around borings GD04007, GD04008, GD06038, GD19026, GD32044, GD32045, GD32046, GD32047, GD32048, GD32049, and GD35014. A shallow water table (3 to 4 ft deep) was encountered in borings GD06041 and GD31029, and samples from these borings were moist. In all sampling locations, the 1- to 4-ft depth interval was not sampled but was logged by the field geologist on site. No unusual coloring or staining was noted in any of the core samples.

D2.3 ANALYTICAL METHODS

All samples were analyzed for semivolatile organic compounds (SVOCs), arsenic, mercury, cadmium, chromium, copper, lead, and zinc. In addition, 50 samples from the 4- to 5-ft depth interval were analyzed for volatile organic compounds (VOCs). Data reporting procedures are described in the RMA Chemical Quality Assurance Plan (PMRMA, 1989).

The soil analytical methods were certified by the U.S. Army Program Manager for Rocky Mountain Arsenal (PMRMA). Samples were analyzed semiquantitatively for SVOCs by gas chromatography/mass spectrometry (GC/MS) based on U.S. Environmental Protection Agency (EPA) Methods 3540 and 8720 (DataChem, 1986c; EPA, 1982c). The 4- to 5-ft depth interval samples were analyzed semiquantitatively for VOCs by GC/MS based on EPA Method 624 (DataChem, 1986b; EPA, 1982a). All samples were analyzed quantitatively for cadmium, chromium, copper, lead, and zinc by inductively coupled argon plasma emission spectrometry (ICP) based on EPA Method 200.7 (EPA, 1983) and U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) Method 7S (DataChem, 1986a; EBASCO, 1985/RIC 86241R04; EBASCO, 1986/RIC 87006R02). These metals are collectively referred to as ICP metals. Samples were analyzed quantitatively for arsenic by graphite furnace atomic absorption spectroscopy (GFAA) based on EPA Method 3050 (DataChem, 1988b; EPA, 1982b). Mercury was analyzed for quantitatively by cold vapor atomic absorption spectroscopy (CVAA) based on EPA Method 245.5 (DataChem, 1988a; EPA, 1979). Table RISR D2.3-1 lists analytical methods and target analytes for the ground disturbance investigation.

D2.4 ANALYTICAL RESULTS

Table RISR D2.4-1a summarizes analytical data for the ground disturbance investigation, and includes certified reporting limits (CRLs) and indicator ranges (IRs). The IR is considered the range of concentrations indicative of natural or background occurrences. Table RISR D2.4-1b tabulates analytical results by sampling location.

D2.4.1 Organic Analytes

Neither SVOCs nor VOCs were detected in any of the ground disturbance samples.

D2.4.2 Inorganic Analytes

The distribution of inorganic analytes in ground disturbance areas in the 0- to 1-ft and 4- to 5-ft depth intervals are shown in Figures RISR D2.4-1 and D2.4-2, respectively.

Arsenic was detected in 15 ground disturbance samples, eight from the 0- to 1-ft depth interval and seven from the 4- to 5-ft depth interval. Arsenic detections ranged from 2.7 µg/g to 3.3 µg/g, well below the upper limit of the IR for arsenic (10 µg/g). The IR is the range of concentrations considered indicative of natural, background-level occurrences. Detections within the IR are, therefore, probably not attributable to RMA activities (ESE, 1987/RIC 88204R02).

Table RISR D2.3-1 Analytical Methods and Target Analytes for the Ground Disturbance Investigation at RMA

Analyte Groups/Analytes (Analytical Methods)

Volatile Organic Compounds (GC/MS)

1,1-Dichloroethane
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Benzene
Bicycloheptadiene
Carbon tetrachloride
Chlorobenzene
Chloroform
Dibromochloropropane
Dicyclopentadiene
Dimethyldisulfide
Ethylbenzene
m-Xylene
Methylene chloride
Methylisobutyl ketone
o- and p-Xylene
Tetrachloroethylene
Toluene
trans-1,2-Dichloroethylene
Trichloroethylene

Semivolatile Organic Compounds (GC/MS)

1,4-Oxathiane
2,2-bis(Para-chlorophenyl)-1,1-dichloroethane
2,2-bis(Para-chlorophenyl)-1,1,1-trichloroethane
Aldrin
Atrazine
Chlordane

Analyte Groups/Analytes (Analytical Methods)
Semivolatile Organic Compounds (GC/MS)
Chlorophenylmethyl sulfide
Chlorophenylmethyl sulfone
Chlorophenylmethyl sulfoxide
Dibromochloropropane
Dicyclopentadiene
Dieldrin
Diisopropylmethyl phosphonate
Dithiane
Endrin
Hexachlorocyclopentadiene
Isodrin
Malathion
Parathion
Supona
Vapona
Metals (ICP)
Cadmium
Chromium
Copper
Lead
Zinc
Arsenic (GFAA)
Mercury (CVAA)

Analyte Groups/Analytes (Analytical Methods)

GC/MS = Gas Chromatography/Mass Spectrometry

ICP = Inductively Coupled Argon Plasma Emission Spectrometry

GFAA = Graphite Furnace Atomic Absorption Spectroscopy

CVAA = Cold Vapor Atomic Absorption Spectroscopy

Table RISR D2.4-1a. Summary of Analytical Results for the Ground Disturbance Investigation at RMA.

Constituent Detected	Number of Samples*	Range	Median**	Mean**	Standard Deviation**	DataChem Certified Reporting Limit	Indicator Range
	Concentration (µg/g)						
<u>Volatile Organics (S=50)</u>							
None detected							
<u>Semivolatile Organics (S=100)</u>							
None detected							
<u>ICP Metals (S=100)</u>							
Cadmium	4	0.94 - 1.7	-	-	-	0.74	CRL-2.0
Chromium	58	8.9-48	25	25	9.3	6.5	CRL-40
Copper	54	5.9-120	12	14	15	4.7	CRL-35
Lead	45	11 - 52	20	24	10	8.4	CRL-40
Zinc	59	24-140	60	58	21	8.7	CRL-80
<u>Arsenic (S=100)</u>	15	2.7 - 3.3	2.9	3.0	0.17	2.5	CRL-10
<u>Mercury (S=100)</u>	2	0.053 - 0.083	-	-	-	0.050	CRL-0.10

CRL - The indicator level is the Certified Reporting Limit for DataChem laboratories, as appropriate.
µg/g-micrograms per gram
S - Number of samples analyzed
** - Number of samples in which constituent was detected; only these results were used in statistical analyses.*
*** - Median, mean, and standard deviation not calculated when constituent detected in fewer than 5 samples.*

RISR D.4-1a 9/25/90 bp

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD02016		GD04001		GD04002		GD04003		GD04004		GD04005	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	fine to crs. sand w/silt	fine to crs. sand, tr. silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to med. sand w/silt	fine to med. sand, tr. silt	fine to med. sand w/silt	fine to med. sand w/silt
% Fines (Visually determined)	20	5	15	15	10	10	15	15	15	5	10	10
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL*	NA	BCRL*	NA	BCRL*	NA	BCRL*	NA	BCRL*
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ
Copper	REJ	REJ	REJ	REJ	REJ	REJ	BCRL	BCRL	REJ	BCRL	REJ	REJ
Lead	REJ	REJ	REJ	BCRL	REJ	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Zinc	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD04006		GD04007		GD04008		GD06015		GD06035		GD06036	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	fine to med. silty sand	fine to med. sand, tr. silt	fine to med. sand, tr. silt	fine to med. sand, tr. silt	fine to med. sand w/silt	fine to med. sand, tr. silt	fine to crs. sand, tr. silt	fine to crs. sand, tr. silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to crs. sand w/silt	fine to med. sand w/silt
Percent Fines (Visually determined)	35	5	5	5	20	5	5	5	20	20	27	15
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL*	NA	BCRL*	NA	BCRL*	NA	BCRL*	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	REJ	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	25	17	30	15
Copper	REJ	REJ	BCRL	BCRL	REJ	REJ	REJ	REJ	11	6.8	14	7.6
Lead	BCRL	BCRL	BCRL	BCRL	REJ	BCRL	BCRL	BCRL	14	25	46	BCRL
Zinc	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ	53	40	75	35
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	2.8
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	0.053	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD06037		GD06038		GD06041		GD08028		GD12023		GD12024	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	fine to med. sand w/silt	fine to med. sand w/silt	fine to med. silty sand	fine to med. sand, tr. silt	fine to med. sand w/silt	fine to med. sand w/silt	fine to med. sand w/silt	fine to med. sand w/silt	clayey fine to med. sand	fine to med. sand w/silt	fine to med. sand w/silt	fine to med. sand w/silt
Percent Fines (Visually determined)	20	15	32	5	15	15	10	10	40	20	10	10
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL*	NA	BCRL*	NA	BCRL*
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	1.1	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	25	18	15	24	23	21	REJ	REJ	REJ	REJ	REJ	REJ
Copper	15	12	8.7	9.7	7.9	6.9	REJ	BCRL	REJ	REJ	REJ	REJ
Lead	45	BCRL	31	34	20	17	REJ	BCRL	REJ	REJ	REJ	BCRL
Zinc	76	49	47	57	59	49	REJ	REJ	REJ	REJ	REJ	REJ
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD12025		GD19026		GD24017		GD24018		GD25019		GD25020	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	v. fine to med. sand w/silt	v. fine to med. sand w/silt	clay w/fine sand and silt	fine to med. silty sand	fine to med. clayey sand	fine to med. sand, tr. clay	clay w/fine sand and silt	clay w/fine sand and silt	silty clay w/ fine sand	v. fine to fine clayey sand	clay w/fine sand and silt	clay w/fine sand and silt
Percent Fines (Visually determined)	10	10	85	35	30	5	89	93	80	40	90	85
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL*	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	0.94	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	REJ	REJ	25	18	23	12	35	9.8	38	29	23	35
Copper	REJ	REJ	13	8.6	11	6.0	13	BCRL	16	12	11	15
Lead	REJ	BCRL	17	16	20	19	20	BCRL	28	22	17	21
Zinc	REJ	REJ	61	44	54	32	74	24	92	60	58	77
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	3.0	2.7	BCRL	BCRL	BCRL	3.1
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD25021		GD25022		GD29039		GD29040		GD31027		GD31029	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	silty clay w/fine sand	silty, clayey fine sand	silty clay w/fine sand	fine to crs. clayey sand	fine to crs sand w/silt	fine to med. sand, tr. silt	clay w/fine sand and silt	fine to mod sand w/clay	silty v. fine to fine sand	silty v. fine to fine sand	clayey fine to med. sand	fine to med. sand w/silt
Percent Fines (Visually determined)	90	60	75	60	14	5	85	30	40	40	35	20
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	22	32	32	31	27	18	44	34	32	22	15	12
Copper	10	13	120	13	14	9.7	16	15	11	8.3	6.8	BCRL
Lead	34	20	25	45	52	BCRL	35	28	19	12	27	15
Zinc	60	69	70	68	77	41	90	71	66	52	41	28
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	3.0	2.8	BCRL	BCRL	BCRL	BCRL	BCRL
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ- Analytical results rejected by QA/QC

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD31030		GD31031		GD31032		GD31033		GD31034		GD32042	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	fine to med. sand w/silt	fine to med. sand w/silt	fine to med. sand, tr. silt	fine to v. crs. sand	fine to med. sand w/silt	fine to med sand, tr. clay	clay w/fine sand and silt	fine to crs. sand w/clay	silty clay w/fine to med.	fine to med. sand w/silt	silty clay w/fine sand	fine sandy silt w/clay
Percent Fines (Visually determined)	15	15	5	0	20	5	93	10	75	25	75	55
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	11	18	8.9	BCRL	14	12	37	BCRL	28	23	35	31
Copper	6.0	BCRL	6.3	BCRL	6.9	BCRL	13	32	14	12	18	15
Lead	18	21	BCRL	BCRL	BCRL	BCRL	20	BCRL	49	14	19	14
Zinc	32	39	31	BCRL	39	28	79	36	75	55	79	69
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	3.1	BCRL	BCRL	3.2
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-Background

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD32043		GD32044		GD32045		GD32046		GD32047		GD32048	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	clay w/fine sand and silt	silty fine to crs. sand	silty clay w/fine sand	fine to med. sand w/clay	silty clay w/fine sand	silty clay w/fine sand	fine to med. sand w/silt	clay w/fine sand and silt	silty fine to med. sand	clay w/fine sand and silt	fine to med. sand w/clay	fine to med. sand w/silt
Percent Fines (Visually determined)	65	30	75	10	80	35	80	25	80	45	80	10
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	1.1	BCRL	BCRL	BCRL	1.7	BCRL	BCRL	BCRL	BCRL	BCRL
Chromium	25	15	30	21	42	32	33	31	24	28	29	30
Copper	13	10	15	9.6	18	15	16	15	12	12	15	13
Lead	18	BCRL	26	BCRL	20	16	15	14	18	14	11	BCRL
Zinc	66	39	71	46	98	74	77	63	70	64	68	61
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL	2.9	2.8	2.9	BCRL	BCRL	BCRL	2.8	BCRL
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-BACKGROUND

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	SITE IDENTIFICATION											
	GD32049		GD32050		GD34009		GD35010		GD35011		GD35012	
Depth (feet)	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5	0-1	4-5
Geologic Material	fine to crs. sand w/silt	fine to crs. sand w/silt	silty clay w/fine sand	fine to crs. sand w/silt	clay w/fine sand and silt	fine to med. sand w/silt	silty clay w/fine sand	fine to med. sand w/silt	fine to crs. sand w/silt	fine to med. sand, tr. silt	clay w/fine sand and silt	fine to med. sand, tr. silt
Percent Fines	5	5	70	10	70	25	70	10	20	5	75	5
AIR MONITORING												
Volatile Organic Readings (ppm)												
HNU*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD	BKD
SOIL CHEMISTRY												
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL	NA	BCRL*	NA	BCRL	NA	BCRL	NA	BCRL
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)												
Cadmium	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	REJ	BCRL	BCRL	BCRL	REJ	BCRL
Chromium	10	11	48	9.4	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ
Copper	5.9	BCRL	30	6.1	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ
Lead	BCRL	BCRL	37	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	REJ	BCRL	BCRL
Zinc	29	30	140	31	REJ	REJ	REJ	REJ	REJ	REJ	REJ	REJ
Arsenic (µg/g)	BCRL	BCRL	3.3	BCRL	BCRL	BCRL	3.1	BCRL	BCRL	2.9	BCRL	BCRL
Mercury (µg/g)	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-BACKGROUND

BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*

Table RISR D2.4-1b. Analytical Results for the Ground Disturbance Investigation at RMA.

	GD35013		GD35014	
Depth (feet)	0-1	4-5	0-1	4-5
Geologic Material	clay w/fine sand and silt	clay w/fine sand and silt	clayey fine to med. sand	fine to med. sand w/clay
Percent Fines	90	50	40	10
AIR MONITORING				
Volatile Organic Readings (ppm)				
HNU*	BKD	BKD	BKD	BKD
OVA*	BKD	BKD	BKD	BKD
SOIL CHEMISTRY				
Volatile Organics (µg/g)	NA	BCRL	NA	BCRL*
Semivolatile Organics (µg/g)	BCRL	BCRL	BCRL	BCRL
ICP Metals (µg/g)				
Cadmium	BCRL	BCRL	BCRL	BCRL
Chromium	REJ	REJ	REJ	REJ
Copper	REJ	REJ	REJ	REJ
Lead	BCRL	REJ	BCRL	BCRL
Zinc	REJ	REJ	REJ	REJ
Arsenic (µg/g)	BCRL	BCRL	BCRL	BCRL
Mercury (µg/g)	BCRL	BCRL	0.083	BCRL

**As referenced to calibration standard of methane for OVA, and benzene for HNU; reading has been adjusted to account for background level.*

BKD-BACKGROUND

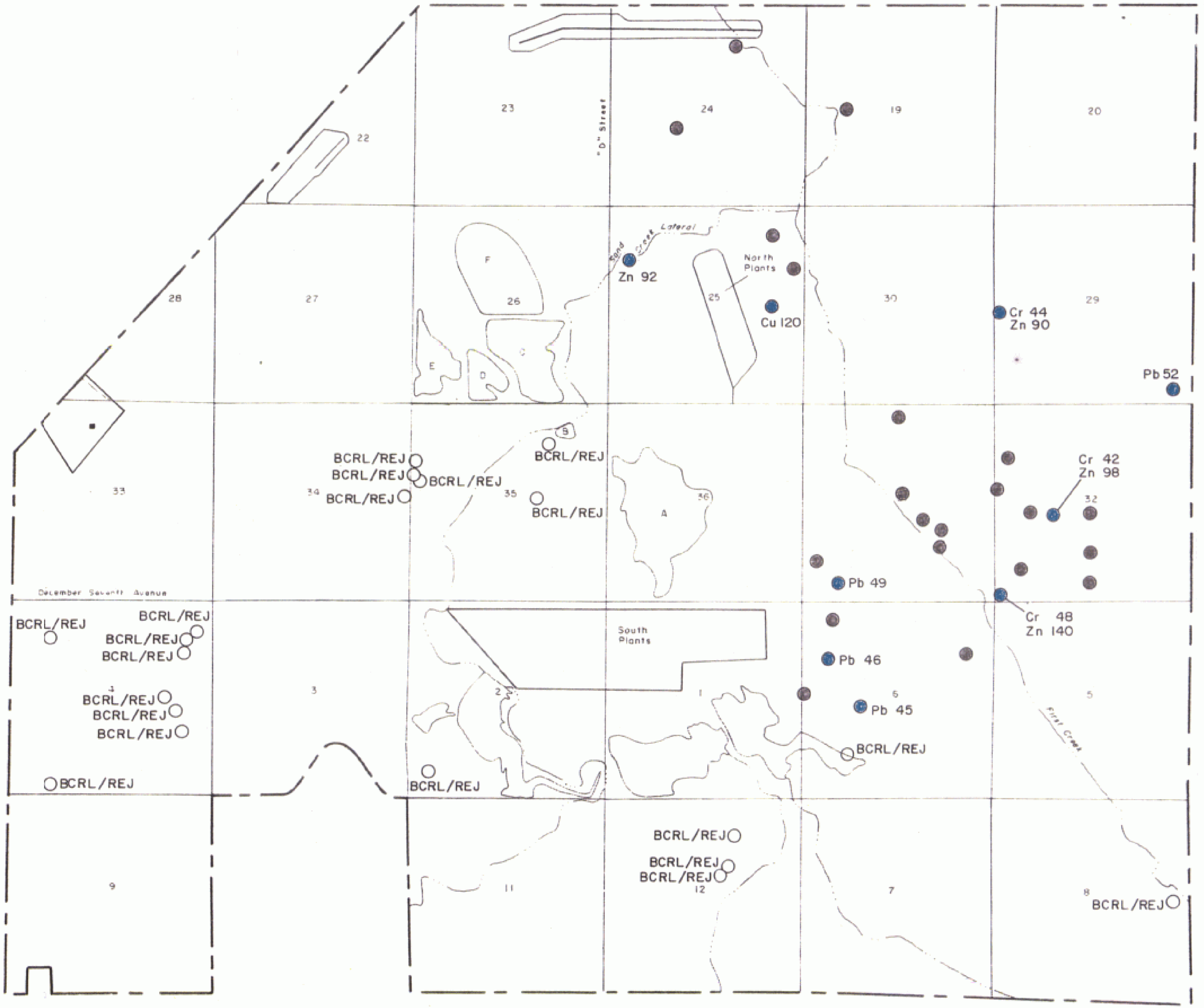
BCRL - Below certified reporting limit

µg/g-micrograms per gram

NA - Not analyzed

REJ-Analytical results rejected by QA/QC

BCRL - Analytical results have not yet been elevated to level 2*



Legend

- — - — Rocky Mountain Arsenal Boundary
- —— Road or Section Lines
- —··— Stream or Drainage Ditch
- ⬭ Lakes
- Ⓐ Waste Basins
- ● > Indicator Range (IR)
- ● Within Indicator Range
- ○ BCRL
- ○ REJ (Rejected by QA/QC)
- ○ BCRL/REJ
- ● Zn 98 — Concentration (ug/g) — Metal Detected Above IR

Indicator Ranges (ug/g)

Cadmium (Cd)	CRL - 2.0
Chromium (Cr)	CRL - 40
Copper (Cu)	CRL - 35
Lead (Pb)	CRL - 40
Zinc (Zn)	CRL - 80
Arsenic (As)	CRL - 10
Mercury (Hg)	CRL - 0.10

N

0 3000 Feet

Scale: 1" = 3000'

Prepared for:

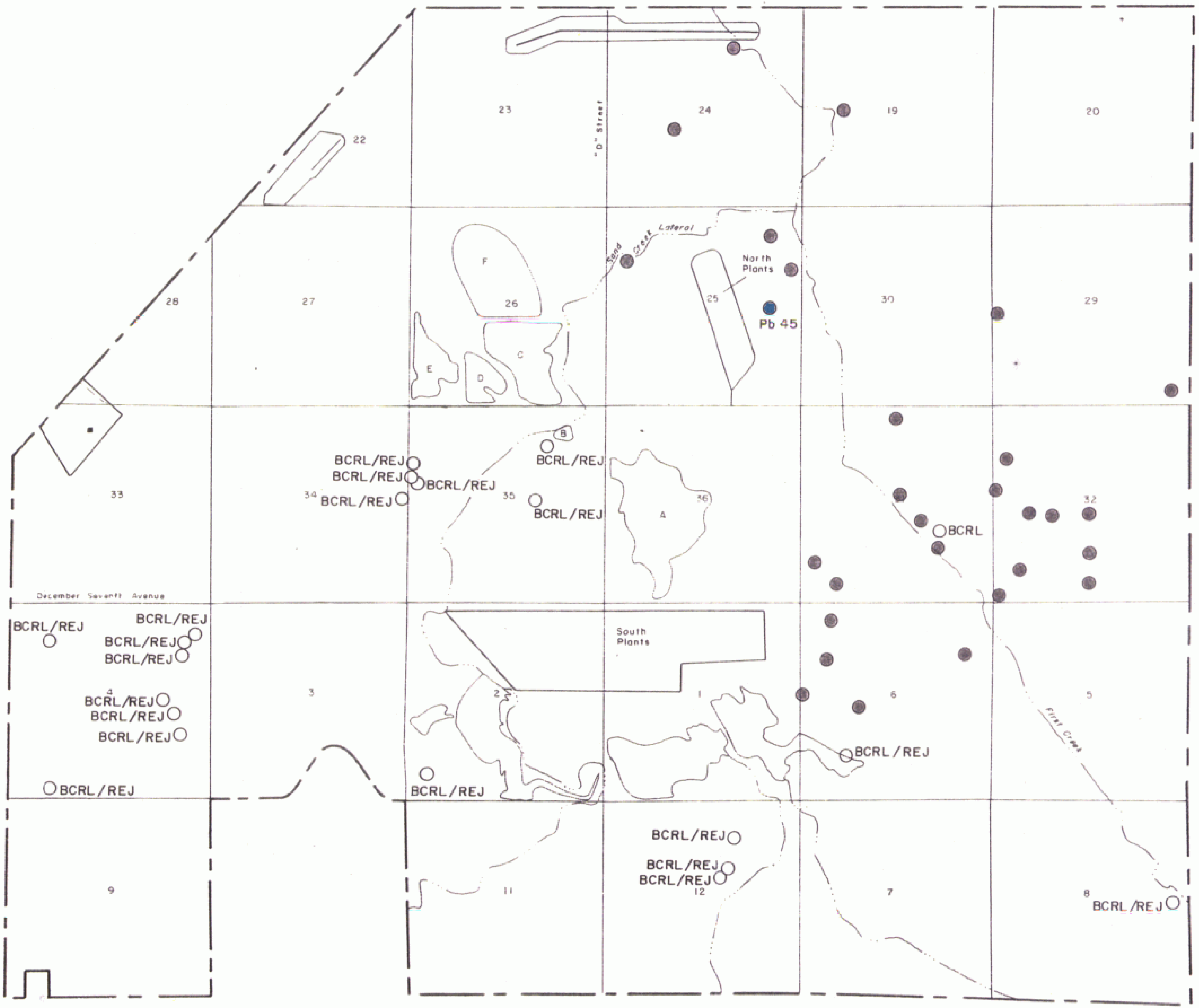
U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR D2.4-1

Distribution of Inorganic Analytes in Ground Disturbance Areas in the 0 to 1 ft Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend

— — —	Rocky Mountain Arsenal Boundary
———	Road or Section Lines
—··—	Stream or Drainage Ditch
⬭	Lakes
(A)	Waste Basins
●	> Indicator Range (IR)
●	Within Indicator Range
○	BCRL
○	REJ (Rejected by QA/QC)
○	BCRL / REJ
● Zn 98	Concentration (ug/g) Metal Detected Above IR

Indicator Ranges (ug/g)

Cadmium (Cd)	CRL - 2.0
Chromium (Cr)	CRL - 40
Copper (Cu)	CRL - 35
Lead (Pb)	CRL - 40
Zinc (Zn)	CRL - 80
Arsenic (As)	CRL - 10
Mercury (Hg)	CRL - 0.10

N

0 3000 Feet

Scale: 1"=3000'

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR D2.4-2
Distribution of Inorganic Analytes in Ground Disturbance Areas in the 4 to 5 ft Depth Interval

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

Mercury was detected in only two ground disturbance samples, both from the 0- to 1-ft depth interval. Mercury detections ranged from 0.053 μg/g to 0.083 μg/g, within the mercury IR (CRL - 0.10μg/g).

PMRMA quality assurance/quality control (QA/QC) personnel using criteria described in the Chemical Quality Assurance Plan (PMRMA, 1989) determined two lots of ICP metals to be unacceptable for values at or near the low spike values. These lots include the 0- to 1-ft and 4- to 5-ft depth intervals from sites GD02016, GD04001, GD04002, GD04003, GD04004, GD04005, GD04006, GD04007, GD04008, GD06015, GD080208, GD12023, GD12024, GD12025, GD34009, GD35010, GD35011, GD35012, GD35013, and GD35014. Only ICP metals data below the CRL (BCRL) and above the high spike concentration are considered acceptable for these lots. That is, analytical results reported as BCRLs are valid, and are posted in the figures if not rejected by the QA/QC procedures. CRLs and high spike concentrations for ICP metals are as follows:

ICP Metals	CRL (μg/g)	High Spike Concentration (μg/g)
Cadmium	0.74	25
Chromium	6.5	10
Copper	4.7	100
Lead	8.4	25
Zinc	8.7	250

Because all detections of ICP metals were between the CRL and the high spike concentration, all detections have been rejected for these lots.

For the 60 samples not rejected by QA/QC, ICP metals were detected in all but one, but were detected above their IR in only ten samples. Cadmium was detected in only four of the samples, at detections ranging from 0.94 μg/g to 1.7 μg/g. All were in the 0- to 1-ft interval and all were below the upper limit of the IR (2.0 μg/g). Chromium was detected in all but two of the samples. Chromium detections ranged from 8.9 μg/g to 48 μg/g, and chromium was detected above the upper limit of its IR (40 µg/g) in three of the samples. Copper was detected in all but six of the samples. Detections of copper ranged from 5.9 µg/g to 120 µg/g but copper was detected above the upper limit of its IR (35µg/g) in only one of the samples. Lead was detected in 45 samples at detections ranging from 11 µg/g to 52 µg/g. Five of these samples had concentrations of lead above the upper limit of its IR (40 µg/g). Zinc was detected in all but one of the samples. Detections of zinc ranged from 24 µg/g to 140 µg/g. Zinc was detected above the upper limit of its IR (80 µg/g) in four samples.

D2.5 INTERPRETATIONS AND CONCLUSIONS

Since neither SVOCs nor VOCs were detected in any of the samples analyzed, it is concluded that none of the ground disturbances sampled are either source or receptor areas for organic contaminants. Similarly, since mercury was detected in only two ground disturbance samples and both detections were within the IR for mercury, none of the ground disturbances sampled are considered either source or receptor areas for mercury contamination. All 15 arsenic detections were within the IR for arsenic, suggesting that all detections are of natural background-level occurrences. Consequently, none of the ground disturbances samples are considered either source or receptor areas for arsenic contamination.

ICP metals were detected in 59 of 60 ground disturbance samples not rejected by QA/QC, but were detected above their IR in only ten of these samples. ICP metal detections above IR are summarized in Table RISR D2.5-1, along with ICP metal detections from nearby soils/sewers RI borings, and information from the Contamination Assessment Reports (CARs) and Study Area Reports (SARs) regarding the origin of the ground scars and the likely source of contaminants. At some locations, ICP metal detections could be explained by a documented history of waste disposal. At other locations, some site history was known but did not provide an obvious explanation for metals detections. It is possible that detections above the IR may be anomalously high natural occurrences. The detections at all sites in the ground disturbance investigations are interpreted as isolated occurrences rather than contaminant

Table RISR D2.5-1 Summary of ICP Metal Detections Above Indicator Range.

Ground Disturbance Investigation Borings				Nearby Soils/Sewers Remedial Investigation Borings				Explanation
GD Boring Number	Detection > IR (µg/g) and Depth Interval (ft)			Phase I and II Boring Number	Detection > IR (µg/g) and Depth Interval (ft)			
		µg/g	ft			µg/g	ft	
GD06036*	Pb	46	(0-1)	None	None			Source of lead is unknown. Area of stressed vegetation is low marshland that is flooded periodically when Eastern Upper Derby Lake is full (Way, 1985).
GD06037	Pb	45	(0-1)	None	None			Source of lead is unknown. An area of Section 6 (possibly this site) was leveled off in 1946 for the purpose of storing M-47 bombs (EBASCO, 1988a/RIC 88196R08).
GD25019	Zn	92	(0-1)	I-5138 I-5138	Cu Zn	53 100	(0-1/4-5) (0-1/4-5)	Source of zinc is unknown. Detections of Cu and Zn at nearby site NCSA-9F (boring 5138) cannot be be attributed to any documented RMA activities (EBASCO, 1989b/RIC 89166R07). Metal concentrations at these levels are common in nonsource area soils composed of sandy silt (ESE, 1987/RIC 88204R02), and may be naturally derived.
GD25022	Cu Pb	120 45	(0-1) (4-5)	None	None			Source of copper and lead is unknown.
GD29039	Pb	52	(0-1)	None	None			Souce of lead is unknown.
GD29040	Cr Zn	44 90	(0-1) (0-1)	None	None			Source of chromium and zinc is unknown.

*Note: First two digits are Section number; last three digits are consecutive program boring number.
µg/g - micrograms per gram

Table RISR D2.5-1 Summary of ICP Metal Detections Above Indicator Range.

Ground Disturbance Investigation Borings				Nearby Soils/Sewers Remedial Investigation Borings				Explanation
GD Boring Number	Detection > IR (µg/g) and Depth Interval (ft)			Phase I and II Boring Number	Detection > IR (µg/g) and Depth Interval (ft)			
		µg/g	ft			µg/g	ft	
GD31034	Pb	49	(0-1)					Source of lead is unknown.
GD32045	Cr	42	(0-1)	I-10	Cd	19	(0-1)	Surface burn activity and metal debris were evident during Phase I field investigations (EBASCO, 1988c/RIC 88256R02). Detections of Cd, Cr, Cu, Pb, and Zn correspond to the historical burning of incendiary bombs (EBASCO, 1989a/RIC 89166R02). Bomb casings or other metal burned in the pits were probably constructed of alloys containing these metals.
	Zn	98	(0-1)	I-10	Cu	140	(0-1)	
				I-10	Pb	1400	(0-1)	
				I-10	Zn	2300	(0-1)	
				I-10	Zn	87	(2-3)	
GD32050	Cr	48	(0-1)	I-18	None			Boring GD32050 was placed in a small excavation in the SW corner of Section 32. Boring 18 investigated a nearby trench (EBASCO, 1988b/88196R10). Detections of Cr and Zn may be due to burial of metal debris, or to natural occurrence.
	Zn	140	(0-1)					

Abbrev.	Name	IR (µg/g)
Cd =	Cadmium	CRL-2.0
Cr =	Chromium	CRL-40
Cu =	Copper	CRL-35
Pb =	Lead	CRL-40
Zn =	Zinc	CRL-80

source areas. None of the ground disturbance areas are considered source areas for ICP metals.

Chromium was detected in the 0- to 1-ft depth interval of boring GD29040 at a concentration of 44 µg/g. The source of the chromium is unknown. Although the chromium concentration is just above the upper limit of the IR (40 µg/g), it may be naturally occurring. Chromium was also detected in the 0- to 1-ft depth interval of boring GD32045, at a concentration of 42 µg/g, and Boring 32050 at a concentration of 48 µg/g. Historical records indicate that burn pits of Section 32 have a documented history of munitions disposal. Metal detections in this area are most likely due to buried debris. However, the chromium detections are at or very near the upper limit of the IR and could reflect natural levels.

Copper was detected at a concentration of 120 µg/g in the 0- to 1-ft depth interval of boring GD25022. No borings from the RI are located near this ground disturbance and the source of the copper is unknown. The copper detection is interpreted as an isolated occurrence, rather than a contaminant source area, because it was detected only in the 0- to 1-ft depth interval.

Lead was detected in the 0- to 1-ft depth interval in boring GD06036 at a concentration of 46 µg/g. The ground disturbance is documented as an area of stressed vegetation, and is a low marshland that is periodically flooded when Eastern Upper Derby Lake is full (Way, 1985). Lead was also detected in the 0- to 1-ft depth interval in boring GD06037 at a concentration of 45 µg/g. In this case, the ground disturbance may correspond to an area of Section 6 that was leveled off in 1946 for the purpose of storing M-47 bombs (EBASCO, 1988a/RIC 88196R08), but the location of the storage area was not documented. Lead was detected at a concentration of 45 µg/g in the 4- to 5-ft depth interval of boring GD25022, 52 µg/g in the 0- to 1-ft depth interval of boring GD29039, and 49 µg/g in the 0- to 1-ft depth at interval of boring GD31034. No borings from the RI are located in proximity to these ground disturbance areas and the source of lead is unknown. Although the lead concentrations are slightly higher than the upper limit of the IR (40 µg/g), it is possible that lead detections in all three of these borings may be due to natural occurrences.

Zinc was detected at a concentration of 92 µg/g in boring GD25019, and a concentration of 90 µg/g in boring GD29040, both in the 0- to 1-ft depth interval. The source of zinc in these borings is unknown. Although the zinc concentration is slightly higher than the upper limit of the IR (80 µg/g), the zinc may be naturally derived. Metal concentrations at these levels are common in nonsource area soils composed of sandy silt (ESE, 1987/RIC 88204R02). Zinc was also detected at a concentration of 98 µg/g in the 0- to 1-ft depth interval of boring GD32045, placed in a trench just west of the Section 32 burn pits (Site ESA-2a6). Cadmium, copper, lead, and zinc were detected in a Phase I RI boring placed to investigate a nearby burn pit (Table RISR D2.5-1). Historical records indicated that the pits were used for burning incendiary bombs. Phase I field investigations documented surface burn activity and metal debris around the site (EBASCO, 1988c/RIC 88256R02). Metal detections in and around the burn pits are most likely due to bomb casings or other metal debris scattered around or buried in the pits. Zinc was detected in the 0- to 1-ft depth interval of boring GD32050 at a concentration of 140 µg/g. A nearby trench investigated during Phase I of the RI had detections of zinc within the IR, but not above it. Metal detections may be due to buried metal debris or to natural levels.

SVOCs and VOCs were not detected in any of the ground disturbance areas, arsenic and mercury were detected within their respective IRs in all ground disturbance areas, and ICP metals were detected within their respective IRs in most ground disturbance areas. Therefore, it is concluded that none of the ground disturbances samples are source areas for organic contaminants or metals. Most of the ICP metals detections above IR are probably anomalously high natural occurrences. The remainder are interpreted as isolated occurrences rather than contaminant source areas.

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Appendix E

Contaminant Fate and Transport

Text, Tables, and Figures

Remedial Investigation Summary Report

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Figure

APPENDIX E - LIST OF ABBREVIATIONS

Analyte Groups and Selected Analytes

DBCP	Dibromochloropropane
DDD	Dichlorodiphenyldichloroethane
DDT	Dichlorodiphenyltrichloroethane
DIMP	Diisopropylmethylphosphonate
DMMP	Dimethylmethyl phosphonate
GB	Nerve agent Sarin
ICP metals	Metals analyzed for by inductively coupled argon plasma spectroscopy; includes cadmium, chromium, copper, lead, and zinc
OCP	Organochlorine pesticides
ONC	Organonitrogen compounds
OPHGB	Organophosphorous compounds, GB-agent related
OPHP	Organophosphorous compounds, pesticide related
OSCH	Organosulfur compounds, herbicide related
OSCM	Organosulfur compounds, mustard-agent related
PAH	Polynuclear aromatic hydrocarbons
SHO	Semivolatile halogenated organic compounds
VAO	Volatile aromatic organics
VHC	Volatile hydrocarbons
VHO	Volatile halogenated organics
VOC	Volatile organic compounds

National Acts and Organizations

Army	U.S. Army
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
NAS	National Academy of Science
TDB	Toxicology Data Bank (Peer Review Committee)
USAMBRDL	U.S. Army Medical Bioengineering Research and Development Laboratory
USDA-SCS	U.S. Department of Agriculture-Soil Conservation Service
WHO	World Health Organization

Local Terminology

CRL	Certified Reporting Limit
CSA	Central Study Area
ESA	Eastern Study Area
IRA	Interim Response Action

APPENDIX E - LIST OF ABBREVIATIONS
(continued)

Local Terminology (continued)

MATC	Maximum allowable tissue concentration
NCSA	North Central Study Area
NPSA	North Plants Study Area
RI	Remedial Investigation
RMA	Rocky Mountain Arsenal
SAR	Study Area Report
SPSA	South Plants Study Area
SSA	Southern Study Area
WSA	Western Study Area

Companies

EBASCO	Ebasco Services Incorporated
ESE	Environmental Sciences and Engineering, Inc.
Shell	Shell Oil Company

Analytical Methods

GC/MS	Gas chromatography/mass spectrometry

Chemical Symbols

As	Arsenic
Cd	Cadmium
Fe^{+2}	Ferrous iron
Fe^{+3}	Ferric iron
Cr	Chromium
CrO_4^{2-}	Chromate
$Cr_2O_7^{2-}$	Dichromate
Cu	Copper
H^+	Hydrogen ion
Hg	Mercury
M^+	Metal cation
OH-	Hydroxyl radical
O_2	Oxygen
Pb	Lead
Zn	Zinc

APPENDIX E - LIST OF ABBREVIATIONS
(continued)

Measurements, Quantities, and Parameters

atm	Atmosphere
atm-m^3/mol	Atmosphere-cubic meters per mole
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BMF	Biomagnification factor
°C	Degrees Centigrade
C_s	Organic contaminant concentration in soil phase
C_l	Organic contaminant concentration in soil phase
Eh	Oxidation potential
°F	Degrees Fahrenheit
f_{oc}	Soil organic carbon content
ft	Foot, feet
g/cm^3	Grams per cubic centimeter
g/d	Grams per day
g/ml	Grams per milliliter
K	Degrees Kelvin
K_d	Soil-water partition coefficient
K_h	Henry's Law constant
K_{oc}	Organic carbon partition coefficient
K_{ow}	Octanol water partition coefficient
mg/l	Milligrams per liter
mi	Mile(s)
ml/g	Milliliters per gram
mm	Millimeters
mm Hg	Millimeters of mercury
n	Porosity
pH	A measure of acidity or alkalinity
R_f	Retardation factor
µg/g	Micrograms per gram (equivalent to parts per million)
µg/l	Micrograms per Liter
<	Less than
>	Greater than

E.1 INTRODUCTION

Observed contaminant distributions at the Rocky Mountain Arsenal (RMA) are a direct result of fate and transport mechanisms active since initial contaminant releases. Interpretations of contaminant fate and transport are derived from comparisons of observed contaminant distribution to theoretical contaminant behavior. This interactive approach to determining environmental persistence and migration has multiple benefits, including:

- Clarification of the "nature and extent" of contaminated media
- Identification of unrecognized source areas and secondary sources
- Development of conceptual models from which current and future contaminant dispersion, attenuation, alteration, and potential exposure routes may be estimated.

There are numerous complex factors influencing the transport of contaminants through the interactive media of RMA. The Remedial Investigation (RI) used a comprehensive approach for determining migration pathways and identifying potential exposure routes for biological receptors. This method involved development of conceptual models based on observed analyte distributions, historical information including known source areas and approximate dates of contaminant releases, relative contaminant mobilities, and RMA environmental transport processes.

The conceptual approach allows flexibility in developing conclusions, which is required due to the high degree of media heterogeneity observed at RMA. For example, unsaturated and saturated zone characteristics vary widely in such critical parameters as sorptive characteristics, permeability, hydraulic conductivity, and biological activity. Since, at best, the systems observed only approach ideal thermodynamic equilibrium conditions (ESE, 1988c/RIC 88344R01 and Mackay et al., 1985), the mobility of individual contaminants may display considerable variability under different environmental conditions (Mackay and Cherry, 1989). Numerical modeling of contaminant transport was, therefore, deemed inappropriate. Fortunately, multiple analytes maintain fairly consistent relative mobilities in the same environment, and a conceptual model is a meaningful and appropriate approach to understanding the complexities of contaminant fate and transport.

Theoretical contaminant behavior and relative mobility, outlined in the following sections, are derived from evaluating physical and chemical properties of individual analytes in the context of the physical and chemical properties of the specific media at RMA. Migration pathways and potential exposure to human and other biological receptors have been identified by evaluating theoretical contaminant behavior and transport mechanisms within surface water, saturated and unsaturated soils and bedrock, atmospheric, and biotic environments at RMA.

E.2 PHYSICAL AND CHEMICAL PROPERTIES THAT INFLUENCE CONTAMINANT MOBILITY

The efficiency of contaminant transport mechanisms and the ultimate fate of contaminants are largely controlled by the physical and chemical properties of the contaminants and the characteristics of the environment. Contaminant properties that influence behavior in saturated and unsaturated soil environments include physical state, density, aqueous solubility, vapor pressure, Henry's law constant (K_h), and soil-water partition coefficient. Retardation factors and bioconcentration factors are calculated parameters that are useful in estimating relative rates for saturated zone transport and relative biological accumulation, respectively. In addition, transformation and degradation reactions may have a significant impact on contaminant behavior.

Soil, water, and atmospheric environmental factors can have an effect on these chemical properties. Environmental factors that influence chemical properties include, but are not limited to, temperature, pressure, acidity or alkalinity (pH), oxidation potential (Eh), competing species in solution, moisture, organic carbon, and clay content in soil. Chemical properties presented in the literature are generally measured in carefully controlled laboratory environments under standard conditions of temperature and pressure, neutral pH, and at low concentrations in distilled water without competing species. Because these values are obtained under ideal conditions, chemical properties presented in the literature are often dissimilar to those in the environment and may not accurately reflect chemical properties observed in the field (Verschueren, 1983). Literature values used to assess field conditions should be interpreted as estimates for describing behavior in the field and should be used only as a tool to identify potential trends occurring in similar environmental settings (Lyman et al., 1982). Chemical and physical properties of organic analytes are listed in Table RISR E.2-1. Brief definitions and descriptions of important physical and chemical parameters and their effect on environmental mobility are provided below. Interpretations of chemical fate and transport and bioconcentration factors are primarily based on data presented in the Exposure Assessment (EBASCO, 1989i/RIC 89227R02,03), as well as in U.S. Environmental Protection Agency (EPA, 1982), Moore & Ramamoorthy (1984b), and Dragun (1988). Other references are cited as necessary.

For ease of discussion and understanding, the three most important chemical properties that control environmental mobility, organic carbon partition coefficient (K_{oc}), K_h, and aqueous solubility are described quantitatively as high, moderate, and low (Table RISR E.2-2). These informal subgroupings correspond to numerical criteria listed in Table RISR E.2-3. Guidance from the literature was used in selecting the ranges, although the reported criteria were modified in an attempt to divide each parameter into subgroups of approximately equal size. The groupings serve to emphasize the variability in these parameters for each compound.

E.2.1 PHYSICAL STATE

The physical state of a chemical contaminant is defined as its most commonly occurring or most stable form--solid, liquid, or gas--at ambient temperature and pressure. At RMA, ambient conditions are defined as average annual temperature of 50° F (USDA-SCS, 1974), with an atmospheric pressure of approximately 631 millimeters of mercury (mm Hg) at 5,280 feet (ft) above mean sea level. Chemicals released to the environment in solid form do not readily move through the soil matrix and are usually found in surficial soil layers or in

Table RISR E.2-1. Summary of Chemical and Physical Properties of Organic Analytes.

Analyte	Reference	Physical State (20°C, 1atm)	Density (g/ml)	Aqueous[a] Solubility (mg/l) (20-25°C)	Vapor[b] Pressure (mm Hg) (20-25°C)	Henry's Law[c] Constant (atm m³/mol)	Partition[d] Coefficient Log(K_{ow})	Partition[e] Coefficient Log(K_{oc})
Volatile Halogenated Organics								
1,1-Dichloroethane	•	liquid	1.18	5,500	180	4.31×10^{-3}	1.79	1.90
1,2-Dichloroethane	•	liquid	1.25	8,600	64	9.8×10^{-4}	1.45-1.79	1.20
1,1-Dichloroethylene	•	liquid	1.22	2,200	600	3.4×10^{-3}	1.84	2.02
1,2-Dichloroethylene	•	liquid	1.26	6,300	265	7.6×10^{-3}	1.48-1.53	1.74
1,1,2,2-Tetrachloroethane	EPA, 1982	liquid	1.59	2,900	5	3.8×10^{-4}	2.39	2.07
1,1,1-Trichlorethane	•	liquid	1.34	2,500	123	1.4×10^{-3}	2.47-2.50	2.34
1,1,2-Trichloroethane	•	liquid	1.44	4,500	30	1.17×10^{-3}	2.47	2.24
Carbon tetrachloride	•	liquid	1.6	810	90	2.4×10^{-3}	2.64-2.83	2.28
Chlorobenzene	•	liquid	1.11	450	11.7	3.72×10^{-3}	2.84-2.98	2.55
Chloroform	•	liquid	1.48	8,300	151	2.87×10^{-3}	1.90-1.97	1.65
Methylene chloride	•	liquid	1.33	18,000	362	2.03×10^{-3}	1.25-1.30	1.20
Tetrachloroethylene	•	liquid	1.63	252	18	2.6×10^{-3}	2.53-2.60	2.56
Trichloroethylene	•	liquid	1.46	950	58	9.1×10^{-3}	2.29-3.30	2.64
Trichloropropene	•	liquid	-	-	-	-	-	-
Volatile Hydrocarbons								
2-Butoxyethanol	Weast, 1975 Merck, 1983	liquid	0.90	50,000	-	-	-	-
4-Hydroxy-4-methyl-2-pentanone	Weast, 1975	liquid	0.94	-	-	-	-	-
2,2-Oxybisethanol	Merck, 1983	liquid	1.2	miscible	-	-	-	-
Bicycloheptadiene	•	liquid	0.91	228	50	2.6×10^{-3}	1.98	2.28
Dicyclopentadiene	•	solid	0.98	19.4	1.7	1.9×10^{-3}	3.14	2.99
1-Methyl-1,3-cyclopentadiene		liquid	0.75	-	-	-	-	-
Methylcyclohexane	Weast, 1975	liquid	0.77	-	-	-	-	-
Methylisobutyl ketone	•	liquid	0.798	19,000	16	1.1×10^{-4}	1.25	0.60
2-Pentanone	Weast, 1975	liquid	0.81	-	-	-	-	-

[a] = The geometric mean of multiple values was tabulated.

[b] = Where available, values reported by EPA, 1982 were tabulated. If an EPA value was not available, the geometric mean of reported values was presented.

[c] = Where available, values reported by EPA were tabulated. If an EPA value was not available, the geometric mean of values reported by EBASCO (1989i/RIC 89227R02,03) was presented.

[d] = Octanol/water partition coefficient from references listed in SAR appendices. If more than one value was reported, the range of reported values was tabulated.

[e] = Organic carbon partition coefficient from references listed in SAR appendices. If more than one value was reported, the Maximum Likelihood Estimate (MLE) value calculated by EBASCO (1989i/RIC 89227R02,03) was tabulated.

• = See Appendix C of SPSAR; or D of NPSAR, NCSAR, or WSAR; or E of ESAR or CSAR (EBASCO, 1989a-c, e-h/RIC 89166R01 through R07).

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Volatile Aromatic Organics								
Benzene	•	liquid	0.88	1,700	95	5.6 x 10^{-3}	2.0-2.1	1.62
Ethylbenzene	•	liquid	0.87	150	7	6.4 x 10^{-3}	3.1-3.2	2.75
m-Xylene	•	liquid	0.86	130	10	5.6 X 10^{-4}	3.2	3.02
o- and p-Xylene	•	liquid	0.86	180	10	5.6 x 10^{-4}	2.8-3.1	3.02
Toluene	•	liquid	0.87	520	28	6.4 x 10^{-3}	2.6-2.7	2.63
Organosulfur Compound, Mustard-Agent Related								
1,4-Oxathiane	•	liquid	1.1	20,000	4.4	-	-0.16	0.69
Chloroacetic acid	•	solid	1.6	850,000	0.80	-	0.22	-
Dithiane	•	solid	-	3,000	0.80	-	0.77	-
Thiodiglycol	• Merck, 1983	liquid	1.2	miscible	1.9 x 10^{-5}	-	-0.77	-
Organosulfur Compounds, Herbicide Related								
Benzothiazole	•	liquid	1.2	572	0.05	1.64 x 10^{-3}	1.45 - 1.67	1.95
Chlorophenylmethyl sulfide	•	liquid	1.2	16	0.05	6.4 x 10^{-4}	3.2	3.05
Chlorophenylmethyl sulfone	•	solid	-	910	3 x 10^{-5}	8.0 x 10^{-4}	1.3	1.80
Chlorophenylmethyl sulfoxide	•	solid	-	1.100	7.8 x 10^{-3}	1.5 x 10^{-3}	1.2	1.71
Dimethyldisulfide	•	liquid	1.1	360	15	5.1 x 10^{-3}	1.8	2.09
Organophosphorous Compounds, GB-Agent Related								
Diisopropylmethyl phosphonate	•	liquid	0.98	720	0.28	1.9 x 10^{-4}	1.73-1.82	2.09
Dimethylmethyl phosphonate	•	liquid	1.14	8 x 10^{6}	0.73	-	-1.88	-
Isopropylmethylphosphonic acid	•	liquid	1.1	48,000	-	-	-.54	-

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[a] = The geometric mean of multiple values was tabulated.

[b] = Where available, values reported by EPA, 1982 were tabulated. If an EPA value was not available, the geometric mean of reported values was presented.

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Methylphosphonic acid		-	-	-	-	-	-	-
Phosphoric acid, tributyl ester	Weast, 1975	liquid	0.92	-	-	-	-	-
Phosphoric acid, triphenyl ester	Weast, 1975	liquid	1.18	-	-	-	-	-
DBCP	•	liquid	2.09	1,100	1.0	3.11×10^{-4}	2.29-2.43	2.41
Organonitrogen Compounds								
Nitrosodimethylamine	Weast, 1975 EPA, 1982	liquid	1.05	miscible	8.1	3.3×10^{-5}	-0.67	-1.0
Nitrosodi-n-propylamine	Weast, 1975 EPA, 1982	solid	0.92	9,900	0.4	6.3×10^{-4}	1.49	1.18
Hydrazine	Merck, 1983[a]	liquid	1.0	miscible	14	-	-	-
Methylhydrazine	Merck, 1983[a]	liquid	0.87	miscible	49	-	-	-
Unsymmetrical dimethyl hydrazine	Merck, 1983[a]	liquid	0.79	miscible	167	-	-	-
Caprolactam	Merck, 1983	solid	-	miscible	-	-	-	-
Fluoroacetic Acid	•	solid	12.37	miscible	-	-		-
Polynuclear Aromatic Hydrocarbons								
Fluoranthene	Weast, 1975 EPA, 1982	solid	1.25	0.26	5×10^{-6}	6.5×10^{-4}	4.90	4.58
Methylnaphthalene	Weast, 1975	solid	1.02	-	-	-	-	-
Phenanthrene	EPA, 1982	solid	-	1.0	9.6×10^{-4}	2.6×10^{-4}	3.55	3.85
Pyrene	EPA, 1982	solid	-	0.13	2.5×10^{-6}	5.1×10^{-4}	3.10	3.42

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[a] = The geometric mean of multiple values was tabulated.

[b] = Where available, values reported by EPA, 1982 were tabulated. If an EPA value was not available, the geometric mean of reported values was presented.

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<u>Semivolatile Halogenated Organics</u>								
Dichlorobenzene	EPA, 1983	-	>1	-	-	-	-	-
Hexachlorobenzene	Weast, 1975 EPA, 1982	solid	1.6	0.006	1.09 x 10^{-5}	6.8 x 10^{-4}	6.41	6.08
Hexachlorobutadiene	Weast, 1975 EPA, 1982	liquid	1.7	2.0	0.15	2.6 x 10^{-2}	4.77	4.45
Hexachlorocyclopentadiene	*	liquid	1.7	1.59	0.08	1.4 x 10^{-2}	5.04	4.06
Pentachlorobenzene	Weast, 1975 Moore & Ramamoorthy, 1984a	solid	1.8	-	-	-	-	-
Tetrachlorobenzene	Weast, 1975 Moore & Ramamoorthy, 1984a	solid	1.8	-	-	-	-	-
Trichlorobenzene	Weast, 1975 EPA, 1982	liquid	1.4	30	0.29	2.3 x 10^{-3}	4.27	3.96
<u>Organochlorine Pesticides</u>								
Aldrin	*	solid	-	0.021	6.6 x 10^{-4}	1.6 x 10^{-5}	5.3-7.4	4.67
Chlordane	*	solid	1.6	0.13	1.0 x 10^{-5}	9.6 x 10^{-4}	2.78-5.48	5.15
Dichlorodiphenylethane (DDE)	*	liquid	-	0.08	6.5 x 10^{-4}	6.8 x 10^{-5}	4.86-7.1	4.93
Dichlorodiphenyltrichloroethane (DDT)	*	solid	-	0.002	5.5 x 10^{-4}	5.1 x 10^{-4}	3.98-7.48	5.48
Dieldrin	*	solid	1.75	0.084	1.78 x 10^{-7}	4.6 x 10^{-7}	3.5-6.2	3.86
Endrin	Weast, 1975 *	solid	1.7	0.082	2.0 x 10^{-7}	1.4 x 10^{-4}	3.5-5.6	3.87
Isodrin	*	liquid	-	0.17	<1.0 x 10^{-4}	3.3 x 10^{-4}	4.4-6.5	4.58

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[a] = The geometric mean of multiple values was tabulated.

[b] = Where available, values reported by EPA, 1982 were tabulated. If an EPA value was not available, the geometric mean of reported values was presented.

[c] = Where available, values reported by EPA were tabulated. If an EPA value was not available, the geometric mean of values reported by EBASCO (1989i/RIC 89227R02,03) was presented.

[d] = Octanol/water partition coefficient from references listed in SAR appendices. If more than one value was reported, the range of reported values was tabulated.

[e] = Organic carbon partition coefficient from references listed in SAR appendices. If more than one value was reported, the Maximum Likelihood Estimate (MLE) value calculated by EBASCO (1989i/RIC 89227R02,03) was tabulated.

* = See Appendix C of SPSAR; or D of NPSAR, NCSAR, or WSAR; or E of ESAR or CSAR (EBASCO, 1989a-c, e-h/RIC 89166R01 through R07).

Note: Dash inserted where information is not availble.

Table RISR E.2-1. Summary of Chemical and Physical Properties of Organic Analytes.

Analyte	Reference	Physical State (20°C, 1atm)	Density (g/ml)	Aqueous[a] Solubility (mg/l) (20-25°C)	Vapor[b] Pressure (mm Hg) (20-25°C)	Henry's Law[c] Constant (atm m^3/mol)	Partition[d] Coefficient $Log(K_{ow})$	Partition[e] Coefficient $Log(K_{oc})$
Organophosphorus Compounds, Pesticide Related								
Atrazine	◆	solid	1.19	48	3×10^{-7}	1.8×10^{-9}	2.32-2.75	2.21
Malathion	◆	liquid	1.23	145	4×10^{-5}	1.2×10^{-7}	2.36-2.89	3.25
Parathion	◆	liquid	1.26	21	5.7×10^{-5}	7.9×10^{-7}	3.81-3.90	3.40
Supona	◆	liquid	1.36	126	1.7×10^{-7}	7.3×10^{-10}	3.11	2.98
Vapona	◆	liquid	1.42	10,000	10×10^{-2}	2.9×10^{-7}	1.4	1.83

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[a] = The geometric mean of multiple values was tabulated.

[b] = Where available, values reported by EPA, 1982 were tabulated. If an EPA value was not available, the geometric mean of reported values was presented.

[c] = Where available, values reported by EPA were tabulated. If an EPA value was not available, the geometric mean of values reported by EBASCO (1989i/RIC 89227R02,03) was presented.

[d] = Octanol/water partition coefficient from references listed in SAR appendices. If more than one value was reported, the range of reported values was tabulated.

[e] = Organic carbon partition coefficient from references listed in SAR appendices. If more than one value was reported, the Maximum Likelihood Estimate (MLE) value calculated by EBASCO (1989i/RIC 89227R02,03) was tabulated.

◆ = See Appendix C of SPSAR; or D of NPSAR, NCSAR, or WSAR; or E of ESAR or CSAR (EBASCO, 1989a-c, e-h/RIC 89166R01 through R07).

Note: Dash inserted where information is not availble.

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Table RISR E.2-2. Relative Rank of Selected Physical Characteristics for Organic Analytes.

Analyte	Koc[a]	Henry's Law[b] Constant	Solubility[c]
Volatile Halogenated Organics (VHOs)			
Methylene chloride	Low	High	High
Chloroform	Low	High	Moderate
Carbon tetrachloride	Low	High	Moderate
1,1-Dichloroethane	Low	High	Moderate
1,2-Dichloroethane	Low	Moderate	Moderate
1,1,1-Trichloroethane	Low	High	Moderate
1,1,2-Trichloroethane	Low	High	Moderate
1,1,2,2-Tetrachloroethane	Low	Moderate	Moderate
1,1-Dichloroethylene	Low	High	Moderate
1,2-Dichloroethylene	Low	High	Moderate
Trichloroethylene	Moderate	High	Moderate
Tetrachloroethylene	Moderate	High	Moderate
Chlorobenzene	Moderate	High	Moderate
Trichloropropene	Moderate	High	Moderate
Volatile Hydrocarbons (VHCs)			
Methylisobutyl ketone	Low	Moderate	High
Bicycloheptadiene	Low	High	Moderate
Methylcyclohexane	Low	-	Moderate
2-Pentanone	Low	-	Moderate
2-Butoxyethanol	Low	-	High
2,2-Oxybisethanol	Low	-	High
Dicyclopentadiene	Moderate	High	Low
1-Methyl-1,3-cyclopentadiene	Moderate	-	-
4-Hydroxy-4-methyl-2-pentanone	Moderate	-	High
Volatile Aromatic Organics (VAOs)			
Benzene	Low	High	Moderate
Toluene	Moderate	High	Moderate
m-Xylene	Moderate	Moderate	Moderate
o- and p-Xylene	Moderate	Moderate	Moderate
Ethylbenzene	Moderate	High	Moderate

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[a] Low = <250 ml/g Moderate = 250 to 4000 ml/g High = >4000 ml/g

[b] Low = $<10^{-7}$ atm-m^3/mol Moderate = 10^{-7} to 10^{-3} atm-m^3/mol High = $>10^{-3}$ atm-m^3/mol

[c] Low = <50 mg/l Moderate = 50 to 10,000 mg/l High = >10,000 mg/l

Note: Dash inserted where information is not available.

Table RISR E.2-2. Relative Rank of Selected Physical Characteristics for Organic Analytes.

Analyte	Koc[a]	Henry's Law[b] Constant	Solubility[c]
Organosulfur Compounds, Mustard-Agent Related (OSCMs)			
1,4-Oxathiane	Low	Low	High
Dithiane	Low	Low	Moderate
Thiodiglycol	Low	Low	High
Chloroacetic acid	Low	Low	High
Organosulfur Compounds, Herbicide Related (OSCHs)			
Benzothiazole	Low	Moderate	Moderate
Chlorophenylmethyl sulfone	Low	Moderate	Moderate
Chlorophenylmethyl sulfoxide	Low	Moderate	Moderate
Chlorophenylmethyl sulfide	Moderate	Moderate	Low
Dimethyldisulfide	Low	High	Moderate
Organophosphorous Compounds, GB-Agent Related (OPHGBs)			
Diisopropylmethyl phosphonate	Low	Moderate	Moderate
Dimethylmethyl phosphonate	Low	Low	High
Isopropylmethylphosphonic acid	Low	Low	High
Methylphosphonic acid	-	-	-
Phosphoric acid, tributyl ester	-	-	-
Phosphoric acid, triphenyl ester	-	-	-
Organophosphorous Compounds, Pesticide Related (OPHs)			
Atrazine	Low	Low	Low
Malathion	Moderate	Moderate	Moderate
Vapona	Low	Moderate	High
Parathion	Moderate	Moderate	Low
Supona	Moderate	Low	Moderate
Dibromochloropropane (DBCP)	Moderate	Moderate	High
Organonitrogen Compounds (ONCs)			
Nitrosodimethylamine	Low	Moderate	High
Nitrosodi-n-propylamine	Low	Moderate	Moderate
Hydrazine	Low	Low	High
Methylhydrazine	-	Low	High
Unsymmetrical dimethylhydrazine	Low	Low	High
Caprolactam	-	-	High

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[a] Low = <250 ml/g Moderate = 250 to 4000 ml/g High = >4000 ml/g

[b] Low = $<10^{-7}$ atm-m^3/mol Moderate = 10^{-7} to 10^{-3} atm-m^3/mol High = $>10^{-3}$ atm-m^3/mol

[c] Low = <50 mg/l Moderate = 50 to 10,000 mg/l High = >10,000 mg/l

Note: Dash inserted where information is not available.

Table RISR E.2-2. Relative Rank of Selected Physical Characteristics for Organic Analytes.

Analyte	Koc[a]	Henry's Law[b] Constant	Solubility[c]
Fluoroacetic Acid	Low	Low	High
Polynuclear Aromatic Hydrocarbons (PAHs)			
Methylnaphthalene	Moderate	-	-
Phenanthrene	High	Moderate	Low
Pyrene	Moderate	Moderate	Low
Fluoranthene	High	Moderate	Low
Semivolatile Halogenated Organics (SHOs)			
Dichlorobenzene	-	-	Moderate
Trichlorobenzene	High	High	Low
Tetrachlorobenzene	-	-	-
Pentachlorobenzene	-	-	-
Hexachlorobenzene	High	Moderate	Low
Hexachlorobutadiene	High	High	Low
Hexachlorocyclopentadiene	High	High	Low
Organochlorine Pesticides (OCPs)			
Aldrin	High	Moderate	Low
Dieldrin	High	Moderate	Low
Endrin	High	Moderate	Low
Isodrin	High	Moderate	Low
Chlordane	High	Moderate	Low
DDE	High	Moderate	Low
DDT	High	Moderate	Low

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[a] Low = <250 ml/g Moderate = 250 to 4000 ml/g High = >4000 ml/g

[b] Low = $<10^{-7}$ atm-m^3/mol Moderate = 10^{-7} to 10^{-3} atm-m^3/mol High = $>10^{-3}$ atm-m^3/mol

[c] Low = <50 mg/l Moderate = 50 to 10,000 mg/l High = >10,000 mg/l

Note: Dash inserted where information is not available.

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Volatile Halogenated Organic Compounds						
1,1-Dichloroethane	5,500	EPA (1984f)	180	EPA (1986b)	4.31×10^{-3} 1.81×10^{-1} (Dimensionless)	EPA (1986b)
1,2-Dichloroethane	8,524	EPA (1984g)	64	EPA (1986b)	9.4×10^{-4} 3.95×10^{-2} (Dimensionless)	Mabey et al. (1981)
	8,700 at 20°C	TDB Peer Rev. Comm. (1984)			9.78×10^{-4} 4.11×10^{-2} (Dimensionless)	EPA (1986b)
	8,450	Chiou et al. (1979)			9.6×10^{-4} 4.03×10^{-2} (Dimensionless)	Geometric mean
	8,820	Valvani et al. (1980)				
1,1-Dichloroethylene	2.25×10^3	EPA (1986b)	600	EPA (1986b)	3.4×10^{-2} 1.4 (Dimensionless)	EPA (1986b)
1,2-Dichloroethylene	6,300 (trans-)	EPA (1984d)	265 at 29 °C (trans-)	EPA (1984d)	7.68×10^{-3} (cis-)	EPA (1985e)
	3,500 (cis-)	EPA (1984d)	180 at 20°C (cis-)	EPA (1984d)	6.56×10^{-3} (trans-)	EPA (1985e)
1,1,2,2-Tetrachloroethane	2,900	Mabey et al. (1981)	5	Mabey et al. (1981)	3.8×10^{-4}	Mabey et al. (1981)
1,1,1-Trichloroethane	1,360	Chiou et al. (1979)	123	EPA (1986b)	1.44×10^{-2} 6.05×10^{-1} (Dimensionless)	EPA (1986b)
	4,400	Verschueren (1977)				
	4,400	EPA (1984e)				
	1,500	EPA (1986b)				

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
1,1,2-Trichloroethane	4,400	TDB Peer Rev. Comm. (1984)	30	EPA (1986b)	1.17×10^{-3}	EPA (1986b)
	at 20°C				4.92×10^{-2}	
	4,500	EPA (1986b)			(Dimensionless)	
Carbon tetrachloride	930	Valvani et al. (1980)	100	Perry and Chilton (1973)	2.41×10^{-2}	EPA (1986b)
	780	Davies and Dobbs (1984)	at 23°C		1.01	
	800	Rogers et al. (1980) Table IV	115	Rogers et al. (1980) Table IV	(Dimensionless)	
	757	EPA (1986b)	at 25°C			
	800	Kenaga (1980b) Table I	90	EPA (1986b)		
Chlorobenzene	500	Verschueren (1977)	11.7	EPA (1986b)	3.72×10^{-3}	EPA (1986b)
	300	Tewari et al. (1982)			1.56×10^{-1}	
	625	Valvani et al. (1980)			(Dimensionless)	
	448	Mayo (1980); Kenaga (1980b)				
	466	EPA (1986b)				
Chloroform	7,500	Davies and Dobbs (1984)	200	Perry and Chilton (1973)	2.87×10^{-3}	EPA (1986b)
	9,200	Valvani et al. (1980)	at 25.9°C		1.21×10^{-1}	
	8,200	EPA (1986b)	151	EPA (1986b)	(Dimensionless)	
	7,840	Dilling (1977)	192	Dilling (1977)	1.3×10^{-1}	Dilling (1977)
			at 298K		at 298K	
Methylene chloride	13,200-20,000	EPA (1979)	436	Berkowitz et al. (1978)	2.03×10^{-3}	EPA (1986b)
	19,000	Valvani et al. (1980)	362	EPA (1986b)	8.53×10^{-2}	
					(Dimensionless)	
Tetrachloroethylene	150	EPA (1980b)	19	ACGIH (1980)	2.69×10^{-2}	EPA (1986b)
	200	Chiou et al. (1979)	17.8	EPA (1986b)	1.09	
	140-400	Berkowitz et al. (1978)			(Dimensionless)	
	500	Davies and Dobbs (1984) Table 2				
Trichloroethylene	1,100	Rogers et al. (1980) Table IV	57.9	EPA (1986b)	9.1×10^{-3}	EPA (1986b)
	825	Valvani et al. (1980)			3.82×10^{-1}	

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Trichloropropene	Not Located		13	estimated Lyman et al. (1982)	Not Located	
Volatile Hydrocarbons						
2-Butoxyethanol	50,000	Merck (1983), Weast (1981)	0.38	estimated Lyman et al. (1982)	Not Located	
4-Hydroxy-4-methyl-2-pentanone			1.8	estimated Lyman et al. (1982)	Not Located	
2,2'-Oxybisethanol	miscible	Merck (1983)	4.4×10^{-3}	estimated Lyman et al. (1982)	Not Located	
Bicycloheptadiene	228	Lyman et al. (1982)	49.7	Lyman et al. (1982) Method 1	2.64×10^{-2} 1.11 (Dimensionless)	(MW=92; VP=49.7; S=228)
Dicyclopentadiene	19.4	Lyman et al. (1982)	1.4 at 20° C 2.2 at 25°C	Rosenblatt et al. (1975a, 1975b) Rosenblatt et al. (1975a, 1975b)	1.97×10^{-2} 8.28×10^{-1} (Dimensionless)	(MW=132; S=19.4; VP=2.2)
Methylcyclohexane	Not Located		41	estimated Lyman et al. (1982)	Not Located	
Methylisobutyl ketone	19,000	Marochini (1984)	15.7 at 20°C	TDB Peer Rev. Comm. (1984)	1.1×10^{-4} 4.6×10^{-3} (Dimensionless)	(MW=100; S=19,000; VP=15.7)

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
<u>Volatile Aromatic Organics</u>						
Benzene	1,780	Kenaga (1980b)	95.2	EPA (1986b)	5.59 x 10^{-3}	EPA (1986b)
	1,750	EPA (1986b)			2.35 x 10^{-1} (Dimensionless)	
	1,700	Valvani et al. (1980)				
Ethylbenzene	140 at 15°C	TDB Peer Rev. Comm. (1984)	10 at 25.9°C	TDB Peer Rev. Comm. (1984)	6.43 x 10^{-3}	EPA (1986b)
	160	Valvani et.al.(1980)	7	EPA (1986b)	2.70 x 10^{-1} (Dimensionless)	
	152	EPA (1986b)				
Toluene	534.8	EPA (1980d)	28.1	EPA (1986b)	6.37 x 10^{-3}	EPA (1986b)
	515	Wilson et al. (1981)			2.68 x 10^{-1} (Dimensionless)	
o,m,p-Xylene	175 (ortho)	Sax (1986)	10	EPA (1986b)	7.04 x 10^{-3} (mixed)	EPA (1986b)
	130 (meta)	EPA (1986b)			2.96 x 10^{-1} (Dimensionless)	
	198 (para)	Sax (1986)				
	198 (mixed)	EPA (1986b)				
<u>Organosulfur Compounds, Mustard-Agent Related</u>						
1,4-Oxathiane	20,000	Berkowitz et al. (1978)	5.1 at 25°C	Merck (1983)	Not Applicable	
			3.9 at 20°C	Berkowitz et al. (1978)		

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Chloroacetic acid	Very soluble (sodium salt : 850 g/liter) at 20°C	Merck (1983)	0.791 at 25°C 0.0651 at 20°C	Jordan (1954) Freiter (1978)	Not Applicable	
Dithiane	3,000 at 25°C	estimated Lyman et al. (1982)	0.80 at 25°C	Berkowitz et al. (1978)	Not Applicable	
Thiodiglycol	Completely Soluble	Union Carbide Corp (1970)	1.9×10^{-5} at 25°C	Small (1984)	Not Applicable	
<u>Organosulfur Compounds, Herbicide Related</u>						
Benzothiazole	703; 441	Lyman et al. (1982) (Eqn 2-3; log K_{OW}=1.45; 1.67)	0.05	Lyman et al. (1982) Method 1	1.26×10^{-5} 5.31×10^{-4} (Dimensionless) 2.02×10^{-6} 8.48×10^{-4} (Dimensionless)	(MW=135; S=703; VP=0.05) (MW=135; S=441; VP=0.05)
Chlorophenylmethyl sulfide	16.4	Lyman et al. (1982) (Eqn. 2-3; log K_{OW}=3.22)	0.05	Lyman et al. (1982) Method 1	6.4×10^{-4} 2.7×10^{-2} (Dimensionless)	(MW=158.7; S=16.4; VP=0.05)
Chlorophenylmethyl sulfone	907	Lyman et al. (1982) (Eqn 2-3; log Kow=1.33)	0.003	Lyman et al. (1982) Method 1	8×10^{-6} 3.5×10^{-4} (Dimensionless)	(MW=190.6; S=907; VP=0.003)

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

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Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Chlorophenylmethyl sulfoxide	1,196	Lyman et al. (1982) (Eqn 2-3; log K_{OW}=1.20)	0.078	Lyman et al. (1982) Method 1	1.5×10^{-5} 6.3×10^{-4} (Dimensionless)	(MW=174.6; S=1,196; VP=0.078)
Dimethyl disulfide	356	Lyman et al. (1982) (Eqn 2-3; log K_{OW}=1.77)	14.8	Lyman et al. (1982) Method 1	5.1×10^{-3} 2.1×10^{-1} (Dimensionless)	(MW=94.2; S=356; VP=14.8)
<u>Organophosphorous Compounds, GB-Agent Related</u>						
Diisopropylmethyl phosphonate	1,500 349	(approximate) Rosenblatt et al. (1975a, 1975b) Lyman et al. (1982) (Eqn 2-3; log K_{OW}=1.78)	0.28	Rosenblatt et al. (1975a, 1975b)	1.9×10^{-4} 8.0×10^{-3} (Dimensionless)	(MW=180; S=349; VP=0.28)
Dimethylmethyl phosphonate	8×10^5	estimated Lyman et al. (1982)	0.62 at 25°C 0.87 at 25°C	Nowak (1983) Berkowitz et al. (1978)	Not Applicable	
Isopropylmethyl phosphonic acid	4.8×10^4	estimated Lyman et al. (1982)	Not Located		Not Applicable	
Methylphosphonic acid	Not Located		Not Located		Not Located	
Phosphoric acid, Tributyl ester	Not Located		Not Located		Not Located	
Phosphoric acid, Triphenyl ester	Not Located		Not Located		Not Located	

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
DBCP	1,230	Chiou et al. (1979)	1.0	EPA (1986b)	3.5×10^{-4} 1.47×10^{-2} (Dimensionless)	Burlinson et al. (1982)
	1,000	EPA (1986b)			3.11×10^{-4} 1.31×10^{-2} (Dimensionless)	EPA (1986b)
					3.3×10^{-4} 1.39×10^{-2} (Dimensionless)	Geometric mean
Fluoroacetic acid	Soluble	Merck (1983)	Not Located		Not Applicable	
Polynuclear Aromatic Hydrocarbons						
Fluoranthene	0.26	Mabey et al. (1981)	5×10^{-6}	Mabey et al. (1981)	6.5×10^{-6}	Mabey et al. (1981)
Methyl naphthalene						
Phenanthrene	1.0	Mabey et al. (1981)	9.6×10^{-4}	Mabey et al. (1981)	2.6×10^{-4}	Mabey et al. (1981)
Pyrene	0.13	Mabey et al.(1981)	2.5×10^{-6}	Mabey et al. (1981)	5.1×10^{-6}	Mabey et al. (1981)
Semivolatile Halogenated Organic Compounds						
Hexachlorobutadiene	Not Located		Not Located		Not Located	

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Hexachlorocyclopentadiene	2.1	Dal Monte and Yu (1977)	0.08	EPA (1986b)	2.7×10^{-2}	Atallah et al. (1980); Wolfe et al. (1982)
	1.8	Wolfe et al. (1982)			1.13 (Dimensionless)	
	0.805	Lu et al. (1975)				
	2.1	EPA (1986b)			1.37×10^{-2}	EPA (1986b)
					5.76×10^{-1} (Dimensionless)	
					1.92×10^{-2}	Geometric mean
					8.1×10^{-1} (Dimensionless)	
Tetrachlorobenzene			3.4×10^{-3}	estimated Lyman et al. (1982)		
Trichlorobenzene			4.7×10^{-4}	estimated Lyman et al. (1982)		
<u>Organochlorine Pesticidices</u>						
Aldrin	0.013	Kenaga (1980a) Table III	6×10^{-6}	EPA (1986b)	1.60×10^{5}	EPA (1986b)
	0.18	EPA (1986b)	5.12×10^{-5} at 290°K	Brammer and Blackwell (1967, 1970)	0.00335	Shell unpublished
	0.00735 at 290°K	Brammer and Blackwell (1967, 1970), Miller (1970), Salmon (unpublished)	1.39×10^{-4} at 298K	Brammer and Blackwell (1967, 1970)	6.72×10^{-4} (Dimensionless)	
	0.011 at 298°K	Brammer and Blackwell (1967, 1970), Salmon (unpublished)			0.141 at 290K	Shell unpublished
					0.248 at 298K	Shell unpublished
Dieldrin	0.2	EPA (1979)	1.78×10^{-7}	EPA (1986b)	4.58×10^{-7}	EPA (1986b)
	0.022	Kenaga (1980a) Table III			1.92×10^{-5} (Dimensionless)	
	0.25	Rosenblatt et al. (1975a, 1975b)				
	0.1	Rao and Davidson (1983) Table I				
	0.195	EPA (1986b)				

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Endrin	0.23	Rosenblatt et al. (1975)	2.0 x 10^{-7}	Rosenblatt et al. (1975a, 1975b)	4.2 x 10^{-6}	(MW=381; S=0.024; VP=2 x10^{-7})
	0.1	Rao and Davidson (1983) Table I			1.8 x 10^{-5} (Dimensionless)	
	0.024	Kenaga (1980a) Table III			4.4 x 10^{-7}	(MW=381; X=0.23; VP=2 x 10^{-7})
					1.8 x 10^{-6} (Dimensionless)	
Isodrin	1.4; 0.02	Lyman et al (1982) (Eqn 2-3 log K_{OW}=4.38; 6.51)	0.0001	Cogley and Foy (1978)	3.4 x 10^{-5}	(MW=365; S=1.4; VP=0.0001)
					1.4 x 10^{-3} (Dimensioless)	
					3.2 x 10^{-3}	(MW=365; S=0.015; VP=0.0001)
					1.3 x 10^{-1} (Dimensionless)	
Dichlorodiphenylethane	0.001 to 0.14	Range of literature values reported (1986) in Kadeg et al.	6.5 x 10^{-6}	EPA (1986b)	6.8 x 10^{-5} 2.86 x 10^{-3} (Dimensionless)	EPA (1986b)
	0.12	Burrows et al. (1979)				
	0.04	EPA (1986b)				
	0.10	Kenaga (1980b)				
Dichlorodiphenyl-trichloroethane	0.0017	Kenaga (1980a) Table III	5.5 x 10^{-6}	EPA (1986b)	5.13 x 10^{-4} 2.16 x 10^{-2} (Dimensionless)	EPA (1986b)
	0.001	Rao and Davidson (1983) Table I				
	0.0012	NAS (1977)				
	0.0017	Briggs (1981)				
	0.0012-0.0025	EPA (1980a)				
	0.004	Chiou et al. (1979)				
	0.005	EPA (1986b)				
Chlordane	0.056-1.85	Range of literature values reported in Kadeg et al. (1986)	1 x 10^{-5}	EPA (1986b)	9.63 x 10^{-6} 4.05 x 10^{-4}	EPA (1986b)

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Chlordane (continued)	0.009	NAS (1977)			(Dimensionless)	
	0.056	Kenaga (1980b)				
	0.56	EPA (1986b)				
<u>Arsenic</u>	Insoluble; some salts are soluble	EPA (1985f)				
<u>Mercury</u>	56.2 at 25°C	Merck (1983)	0.0012 at 20°C	EPA (1984h)		
			0.002 at 25°C	Merck (1983)		
<u>ICP Metals</u>						
Cadmium	Salts are water soluble; metal is insoluble	EPA (1985f)	1 at 394°C	EPA (1985f)		
Chromium	Insoluble; some compounds are soluble	EPA (1985f)				
Copper	Most copper salts are insoluble, with the exception of $CuSO_4$, $Cu(NO_3)_2$, and $CuCl_2$ (the more common copper salts). The metal is insoluble in water.	EPA (1985f)	1 at 1,628°C	EPA (1985f)		
Lead	Insoluble; some organic compounds are soluble	EPA (1985f)	1.77 at 1,000°C	Merck (1983)		

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes (Partition coefficient (Log K_{ow}, K_{oc}), and Bioconcentration factor are presented beginning on Page 12.)

Analyte	Aqueous Solubility Value (mg/l)	Aqueous Solubility Reference	Vapor Pressure Value (mm Hg)	Vapor Pressure Reference	Henrys Law Constant + (atm-m^3/mol)	Henrys Law Constant + Reference
Zinc	Insoluble; some salts are soluble	EPA (1985f)	1.0 at 487°C	EPA (1985f)		
Organophorous Compounds Pesticide Related						
Atrazine	70 33	TDB Peer Rev. Comm. (1984) Kenaga (1980b) Table 1	$3x10^{-7}$	TDB Peer Rev. Comm.(1984)	$1.8x10^{-9}$ $7.5x10^{-8}$ (Dimensionless)	(MW =216; VP =$3x10^{-7}$; S=4)
Malathion	145 145	Berg (1982); Marochini (1984) EPA (1986a)	$4x10^{-5}$ $4x10^{-5}$	Berg (1982) EPA (1986b)	$1.2x10^{-7}$ $5.0x10^{-6}$ (Dimensionless)	(MW=330;S=145; VP=0.00004)
Parathion	24	TDB Peer Rev.Comm. (1984)	$3.8x10^{-5}$	TDB Peer Rev. Comm. (1984)		
	20 20	Marochini (1984) Merck (1983)	$3.78x10^{-5}$ $5.7x10^{-5}$	Merck (1983) EPA (1975)	$7.9x10^{-7}$ $5.0x10^{-5}$ (Dimensionless)	(MW=291; S=21; VP=0000434)
Supona	110 at 20°C 145 at 23°C	Berg (1982) TDB Peer Rev. Comm.(1984)	$1.7x10^{-7}$	Edward (1973)	$7.3x10^{-10}$ $3.1x10^{-8}$ (Dimensionless)	(MW=360;S=110; VP=$1.7x10^{-7}$)
Vapona	10,000 10,000	Berg (1982) Marochini (1984)	0.01 at 30° C	TDB Peer Rev.Comm.(1984)	$2.9x10^{-7}$ $1.2x10^{-5}$ (Dimensionless)	(MW=221;S=10,000;VP=0.01)

+ - For Henry's Law Constant, where a reference is not cited, values were calculated from EBASCO, 1989i/RIC 89227R02, 03

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Partition Coefficient (Log K_{ow}) Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Partition Coefficient (K_{oc}) Reference	Bioconcentration Factor Value	Bioconcentration Factor Reference
<u>Volatile Halogenated Organic Compounds</u>						
1,1-Dichloroethane	1.8	EPA (1986b)	227	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.8)	16.95	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.92)
			73	Lyman and Loreti (1987) (log K_{ow}=1.8)	5.1	Davies and Dobbs (1984) Eqn A (S=5,000)
			30	EPA (1986b)	2.3	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.9)
					11	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.8)
					18	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.8)
					14	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.8)
1,2-Dichloroethane	1.48	Hansch and Leo (1979)	19	Chiou et al. (1979) Fig. 2	13.9	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.6)
	1.79		146; 224	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.45; 1.79)	7.8; 13.5	Lyman et al. (1982) Eqn 5-2;(log K_{ow}=1.48; 1.79)
	1.79	Veith et al. (1983)	39; 72	Lyman and Loreti (1987) (log K_{ow}=1.45; 1.79	7.45	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.45)
	1.45	Davies and Dobbs (1984)	14	EPA (1986b)	3.8	Davies and Dobbs(1984) Eqn A (S=8417)
					2	Davies and Dobbs (1984) Table 2 (experimental)
					8.8	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.6)
					9.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.6)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow})		Partition Coefficient (K_{oc})		Bioconcentration Factor	
	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
1,1-Dichloroethylene	1.84	Mabey et al. (1981)	239	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.84)	20.2	Davies and Dobbs (1984) Eqn C (log K_{ow}=2.18)
			78	Lyman and Loreti (1987) (log Kow=1.84)	26.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.18)
			65	EPA (1986b)	30.9	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.18)
1,2-Dichloroethylene	1.48 1.53	Lyman et al. (1982) Fragment Method	36-49	Lyman et al. (1982) Eqn 4-5 (S=3,500-6,300)	8.6	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.53)
			156	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.5)	6.2-4.4	Davies and Dobbs (1984) Eqn A (S=3,500 - 6,300)
			43	Lyman and Loreti (1987) Eqn I (log K_{ow}=1.5)	12.6	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.53)
			35	Lyman and Loreti (1987) Eqn II (log K_{ow}=1.5)	4.0; 1.58 8.08	EPA (1980b) Davies and Dobbs (1984) Eqn C (log K_{ow}=1.53)
			37	Lyman and Loreti (1987) Eqn III (log K_{ow}=1.5)		
			75	Kadeg et al. (1986) (log K_{ow}=1.5)		
1,1,2,2-Tetrachloroethane	2.39	Mabey (1981)	118	Mabey (1981)		
1,1,1-Trichloroethane	2.5 2.47	EPA (1986b) Davies and Dobbs (1984)	104	Chiou et al. (1979) Figure 2 (experimental)	95	Davies and Dobbs (1984) Eqn B (log K_{ow}=3.0)
			546	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =2.5)	8	Davies and Dobbs Table 2 (experimental)
			256	Lyman and Loreti (1987) (log Kow=2.5)	31.8	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.28)
			152	EPA (1986b)	32.4	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.29)
					40.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.42)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
1,1,1-Trichloroethane (continued)					190	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=3.3)
					19 -10.6	Davies and Dobbs (1984) Eqn A (S=480-1,360)
					23 - 82	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.3-3.3)
					46	Davies and Dobbs (1984) Eqn B (log K_{ow} =3.0)
					110	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=3.0)
1,1,2-Trichloroethane	2.47	EPA (1986b)	526	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=2.47)	22.0	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =2.07)
			242	Lyman and Loreti (1987) (log K_{ow}=2.47)	5.4	Davies and Dobbs (1984) Eqn A (S=4,400)
			56	EPA (1986b)	16	Davies and Dobbs (1984) Eqn C (log K_{ow}=2)
					24	Davies and Dobbs (1984) Eqn B (log K_{ow}=2)
					15.3	Davies and Dobbs (1984) Eqn C (log K_{ow}=2.07)
					26.5	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.07)
Carbon tetrachloride	2.64	Neely et al. (1974)	72	Sabljic (1984)	17	Neely et al.1974(experimental)
	2.73	Davies and Dobbs (1984)	45	Rogers et al. (1980) Table V	72	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.8)
	2.73; 2.83	Geyer et al. (1984)	328; 462	Lyman and Loreti (1987) (log K_{ow}=2.64; 2.83)	69.95	Lyman et al.(1982) Eqn 5-2 (log K_{ow}=2.73)
	2.83	Valvani et al. (1980)	650; 825	Lyman et al. (1982) Eqn 4-8 (K_{ow}=2.64; 2.83)	78.3	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.78)
	2.73	Rogers et al. (1980) Table IV				

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Carbon tetrachloride (continued)					83.3	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.83)
					13.7; 77	Davies and Dobbs (1984) Eqn 3 (S =855; 40)
					30	Davies and Dobbs (1984) Table 2 (experimental)
					36	Davies and Dobbs (1984) Eqn C (log K_{ow}=2.8)
					79	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.8)
					30	Barrows et al. (1980) (experimental)
Chlorobenzene	2.84	Valvani et al. (1980)	125	Sabljic (1984) Table 1	24.8-16.4	Davies and Dobbs (1984) Eqn 3 (S=300 -625)
	2.98	Tewari et al. (1982)	836; 996	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =2.84; 2.98)	10.3	EPA (1980b)
			470; 604	Lyman and Loreti (1987) (log K_{ow}=2.84; 2.98)	84.8; 108.3	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.84; 2.98)
			330	EPA (1986b)	83	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.9)
					41	Davies and Dobbs (1984) Eqn C (log K_{ow}=2.9)
					94	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.9)
Chloroform	1.90	Davies and Dobbs (1984)	45	Sabljic (1984)	16	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.9)
	1.96	Valvani et al. (1980)	257; 281	Lyman et al.(1982) Eqn 4-8 (log K_{ow}=1.90;1.97)	18.18	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.96)
	1.97	Moriguchi (1975)	87; 99	Lyman and Loreti (1987) (log K_{ow}= 1.90; 1.97)	3.59; 4.03	Davies and Dobbs (1984) Eqn A (S=7,500, 9,200)
					21	Davies and Dobbs (1984)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow})		Partition Coefficient (K_{oc})		Bioconcentration Factor	
	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
Chloroform (continued)						Eqn B (log K_{ow}=1.9)
					12	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.9)
Methylene chloride	1.25	EPA (1979)	27.5	Sabljic (1984) experimental	2.9 - 2.3	Davies and Dobbs (1984) Eqn A (S = 13,200 -20,000)
	1.30	EPA (1986b)	114; 121	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =1.25; 1.30)	5.25	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =1.25)
			27; 30	Lyman and Loreti (1987) (log K_{ow} =1.25; 1.30)	8.6	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.25)
			8.8	EPA (1986b)	5.81	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.25)
					16.4	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.9)
					21	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.9)
					14.2	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.9)
Tetrachloroethylene	2.6	Hansch and Leo (1979)	360	Chiou et al (1979)	49	Davies and Dobbs (1984) Table 2 (experimental)
	2.53	Veith et al.(1983)	567; 619	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=2.53; 2.60)	38-19	Davies and Dobbs (1984) Eqn A(S=140-500)
			270; 306	Lyman and Loreti (1987) (log K_{ow}=2.53; 2.60)	30.6	EPA (1980b)
			364	EPA (1986b)	55.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.6)
					49.3	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =2.53)
					26.9	Davies and Dobbs (1984) Eqn C (log K_{ow} =2.55)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Partition Coefficient (Log K_{ow}) Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Partition Coefficient (K_{oc}) Reference	Bioconcentration Factor Value	Bioconcentration Factor Reference
Tetrachloroethylene (continued)					51.3	Davies and Dobbs (1984) Eqn B (log K_{ow}=2.55)
					51.1	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.55)
Trichloroethylene	2.29 2.42	Hansch and Leo (1979) Veith et al. (1983)	188	Rogers et al. (1980) Table V (experimental)	95	Davies and Dobbs (1984) Eqn B (log K_{ow} =3)
	3.3 3.3	Valvani et al. (1980) Davies and Dobbs (1984)	420; 1,487	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=2.29; 3.30)	17	Kenaga (1980a,b) Table 3(experimental)
	3.24; 3.30 2.29	Geyer et al. (1984) Rogers et al ((1980) Table IV	175; 1,073	Lyman and Loreti (1987) (log K_{ow}=2.29; 3.30)	17	Davies and Dobbs Table 2 (experimental)
	2.53 2.38	Tewari et al. (1982) Table III EPA (1986b)	126	EPA (1986b)	31.8	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.28)
					32.4	Lyman et al. (1982) Eqn 5-2 (log Kow =2.29)
					40.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =2.42)
					189.7	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=3.3)
					14	Davies and Dobbs (1984) Eqn A (S=825)
					27.5	Davies and Dobbs (1984) Eqn C (log K_{ow} =2.57)
					52.8	Davies and Dobbs (1984) Eqn B (log K_{ow} =2.57)
					52.9	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.57)
<u>Volatile Hydrocarbons</u>						
Butoxyethanol						
4-Hydroxy 4 methyl 2-pentanone						

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Partition Coefficient (Log K_{ow}) Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Partition Coefficient (K_{oc}) Reference	Bioconcentration Factor Value	Bioconcentration Factor Reference
2, 2 -Oxybisethanol						
Bicycloheptadiene	1.98	Lyman et al. (1982) Fragment Method	284	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.98)	14.4; 29.6	Davies and Dobbs (1984) Eqn A (S=785; 219)
			101	Lyman and Loreti (1987) (log K_{ow}=1.98)	13.7	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.98)
Bicycloheptadiene (continued)					23.4	Davies and Dobbs (1984) Eqn B (log K_{ow}=1.98)
					18.8	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =1.98)
Dicyclopentadiene	3.14	Lyman et al. (1982) Fragment Method	1,217	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=3.14)	53	Bentley et al. (1976) (experimental)
			806	Lyman and Loreti(1987) (log K_{ow} =3.14)	114	Davies and Dobbs (1984) Eqn A (S =20)
					143	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =3.14)
					115	Davies and Dobbs (1984) Eqn B (log K_{ow} =3.14)
					53.9	Davies and Dobbs (1984) Eqn C (log K_{ow}=3.14)
Methylcyclohexane						
Methylisobutyl ketone	1.25	Lyman et al. (1982) Fragment Method	19	Lyman et al. (1982) Eqn 4-5 (S=19,000)	6.47	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.37)
			1.1	Lyman and Loreti (1987) (S=19,000)	2.4	Davies and Dobbs (1984) Eqn A (S=19,000)
					10.1	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.37)
					5.81	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.25)
					8.6	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.25)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Methylisobutyl ketone (continued)					5.25	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =1.25)
<u>Volatile Aromatic Organics</u>						
Benzene	2.01	Valvani et al. (1980)	18- 83	Sabljic (1984) Table II	5.2	EPA (1985a)(experimental)
	2.11	Geyer et al. (1984)	96	Rogers et al. (1980) Table V (experimental)	24	EPA (1980e)(experimental)
Benzene (continued)	2.13	Moriguchi (1975)	83	Kenaga (1980b)Table 1	24	Davies and Dobbs (1984) Eqn B (log K_{ow} =2)
	2.12	EPA (1986b)			19.8	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =2.01)
					23.6	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =2.11)
					24.5	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=2.13)
					18.5	Davies and Dobbs (1984) Eqn C (log K_{ow} =2.11)
					9.3	Davies and Dobbs (1984) Eqn A (S=1,700)
					16.4	Davies and Dobbs (1984) Eqn C (log K_{ow}=2.13)
					28.8	Davies and Dobbs (1984) Eqn B (log K_{ow} =2.13)
Ethylbenzene	3.13	Tewari et al.(1982)	95	Sabljic (1984) Table 1	109	Davies and Dobbs (1984) Eqn B (log K_{ow} =3.1)
	3.15	Hansch and Leo (1979)	1,217 ,	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =3.14)	37.5	EPA (1980c)
	3.15	Moriguchi(1975)	806	Lyman and Loreti (1987) (log K_{ow} =3.14)	67	Davies and Dobbs (1984) Eqn C (log K_{ow} =3.14)
			1,100	EPA (1986b)	141	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =3.13)

Analyte	Partition Coefficient (Log K_{OW})		Partition Coefficient (K_{OC})		Bioconcentration Factor	
	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
Ethylbenzene (continued)					146	Lyman et.al. (1982) Eqn 5-2 (log K_{OW}=3.14)
					36.6	Davies and Dobbs (1984) Eqn A (S=150)
					117	Davies and Dobbs (1984) Eqn B (log K_{OW} =3.15)
					54.6	Davies and Dobbs (1984) Eqn C (log K_{OW} =3.15)
Toluene	2.58	Valvani et al. (1980)	603; 728	Lyman et al. (1982) Eqn 4-8 (log K_{OW} =2.58; 2.73)	59	Davies and Dobbs (1984) Eqn B (log K_{OW} =2.65)
	2.65	Tewari et al. (1982)	295; 386	Lyman and Loreti (1987) (log K_{OW}=2.58; 2.73)	53.8	Lyman et. al. (1982) Eqn 5-2 (log K_{OW}=2.58)
	2.69	Geyer et al. (1984)	300	EPA (1986b)	60.8	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =2.65)
	2.69	Moriguchi(1975)			65.2	Lyman et.al. (1982) Eqn 5-2 (log K_{OW}=2.69)
	2.73	EPA (1986b)			18.1	Davies and Dobbs (1984) Eqn A (S=525)
					34	Davies and Dobbs (1984) Eqn C (log K_{OW}=2.6)
					29.9	Davies and Dobbs (1984) Eqn C (log K_{OW} =2.64)
					58.1	Davies and Dobbs (1984) Eqn B (log K_{OW} =2.64)
					59.8	Lyman et al. (1982) Eqn 5-2 (log K_{OW}=2.64)
o,m,p-Xylene	2.77; 3.20; 3.15	Moriguchi(1975) (ortho, meta, para)	1,157; 1,414	Lyman et al.(1982) Eqn 4-8 (log K_{OW} 3.10; 3.26)	95	Davies and Dobbs (1984) Eqn B (log K_{OW} =3)
	2.95; 3.20; 3.15;	Valvani et al. (1980) (ortho, meta, para)	750; 999	Lyman and Loreti (1987) (log K_{OW}=3.10; 3.26)	56	Davies and Dobbs (1984) Eqn C (log K_{OW} =3)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{OW}) Value (ml/g)	Reference	Partition Coefficient (K_{OC}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
o,m,p-Xylene (continued)	3.13; 3.20; 3.18	Tewari et al. (1982) Table 1 (ortho, meta,para)			34.7	Davies and Dobbs (1984) Eqn A (S=165)
	3.10	Geometric mean of all values for all isomers			75	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =2.77)
	3.26	EPA (1986b) mixed isomers			134	Lyman et al. (1982) Eqn 5-2 (log K_{OW}=3.10)
					146	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =3.15)
					159	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =3.20)
					8.7	Davies and Dobbs (1984) Eqn A (log K_{OW} =3.10)
					109	Davies and Dobbs (1984) Eqn B (log K_{OW}=3.10)
					51.4	Davies and Dobbs (1984) Eqn C (log K_{OW} =3.10)
<u>Organosulfer Compounds, Mustard-Agent Related</u>						
1,4-Oxathiane	-0.16	Lyman et al. (1982) Fragment Method	Not Applicable		Not Applicable	
Chloroacetic acid	0.22	Hansch and Leo (1981)	Not Applicable		Not Applicable	
Dithiane	0.77	Lyman et al. (1982) Fragment Method	Not Applicable		Not Applicable	
Thiodiglycol	-0.77	Small (1984)	Not Applicable		Not Applicable	

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Organosulfer Compounds Herbicide-Related						
Benzothiazole	1.45; 1.67	Lyman et al. (1982) Fragment Method; The two values presented represent two approaches to applying the method.	146; 193	Lyman et. al. (1982) Eqn 4-8 (log K_{ow} =1.45; 1.67)	9.02	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =1.56)
			39; 58	Lyman and Loreti (1987) (log K_{ow}=1.45; 1.67)	9.3	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.56)
					17.4; 16.3	Davies and Dobbs (1984) Eqn A (S=560; 632)
					13.2	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.56)
Chlorophenylmethyl sulfide	3.22	Brueggemann (1979)	1,345	Lyman et al (1982) Eqn 4-8 (log K_{ow}=3.22)	69.1	Davies and Dobbs (1984) Eqn C (log K_{ow}=3.35)
			930	Lyman and Loreti (1987) (log K_{ow} =3.22)	154	Davies and Dobbs (1984) Eqn B (log K_{ow}=3.35)
Chlorophenylmethyl sulfide (continued)					207	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=3.35)
Chlorophenylmethyl sulfone	1.33	Brueggemann (1979)	126	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.33)	5.54	Davies and Dobbs (1984) Eqn C (log K_{ow}=1.21)
			31	Lyman and Loreti (1987) Eqn 4-8 (log K_{ow} 1.33)	8.14	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.21)
					4.89	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.21)
Chlorophenylmethyl sulfoxide	1.20	Brueggemann (1979)	107	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =1.20)	5.88	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.26)
			25	Lyman and Loreti (1987) (log K_{ow}=1.20)	8.71	Davies and Dobbs (1984) Eqn B (log K_{ow}= 1.26)
					5.34	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.26)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Dimethyl disulfide	1.77	Hansch and Leo (1979)	219	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=1.77)	17.6	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.77)
			69	Lyman and Loreti (1987) (log K_{ow}=1.77)	22.7	Davies and Dobbs (1984) Eqn A (S=350)
					13.04	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =1.77)
					10.7	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.77)
<u>Organophosphorous Compounds, GB-Agent Related</u>						
Diisopropylmethyl phosphonate	1.73; 1.803; 1.823	Brueggemann (1979)	2.89; 4.2	Kd value reported in Wullschleger et al. (1980 & 1981)	0.6	Bentley et al.(1976) (experimental)
Diisopropylmethyl phosphonate (continued)			208; 234	K_{oc} estimated with Lyman et al. (1982) Eqn 4-8 (log K_{ow} =1.73; 1.82)	2.08	Lyman et al.(1982) Eqn 5-2 (log K_{ow} =0.72)
			64; 76	K_{oc} estimated with Lyman and Loreti (1987) (log K_{ow}=1.73; 1.82)	3.4 -1.8	Davies and Dobbs (1984) Eqn A (S=10,000-32,000)
					6.1	Davies and Dobbs (1984) Eqn B (log K_{ow} =1.0)
					4.3	Davies and Dobbs (1984) Eqn C (log K_{ow} =1.0)
					3.4	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=1.0)
Dimethylmethyl phosphonate	-1.88	Lyman et al. (1982) Fragment Method	Not Applicable		Not Applicable	
Isopropylmethyl-phosphoric acid	-0.54	Small (1984)	Not Applicable		Not Applicable	
Methylphosphonic acid						

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{OW})		Partition Coefficient (K_{OC})		Bioconcentration Factor	
	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
Phosphoric acid, Tributyl ester						
Phosphoric acid, Triphenyl ester						
DBCP	2.43	EPA (1985d)	130	Sabljic (1984) Table 1 (experimental)	41.4	Lyman et al. (1982) Eqn 5-2 (log K_{OW}=2.43)
	2.29	EPA (1986b)	420; 500	Lyman et al. (1982) Eqn 4-8 (log K_{OW} = 2.29; 2.43)	67.5	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =2.71)
			175; 225	Lyman and Loreti (1987) (log K_{OW} =2.29; 2.43)	11.2	Davies and Dobbs (1984) Eqn A (S=1,230)
					63	Davies and Dobbs (1984) Eqn B (log K_{OW} =2.71)
					43.5	Davies and Dobbs (1984) Eqn B (log K_{OW} =2.43)
					35.9	Davies and Dobbs (1984) Eqn B (log K_{OW} =2.29)
					19.8	Davies and Dobbs (1984) Eqn C (log K_{OW}=2.29)
					27.6	Davies and Dobbs (1984) Eqn C (log K_{OW} =2.43)
					32.4	Lyman et al. (1982) Eqn 5-2 (log K_{OW}=2.29)
Fluoroacetic Acid	Not Located		Not Applicable		Not Applicable	
Polynuclear Aromatic Hydrocarbons						
Fluoranthene	4.90	Mabey (1981)	$3.8x10^4$	Mabey (1981)		
Methyl naphthalene						

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Phenanthrene	3.55	Mabey (1981)	1.4×10^4	Mabey (1981)		
Pyrene	3.10	Mabey (1981)	3.8×10^4	Mabey (1981)		
<u>Semivolatile Halogenated Organic Compounds</u>						
Hexachlorobutadiene						
Hexachlorocyclopentadiene	5.04	Geyer et al. (1984)	13,140	Lyman et al. (1982) Eqn 4-8 (log K_{ow} =5.94)	29	Veith et al. (1979) (experimental)
			24,330	Lyman and Loreti (1987) (log K_{ow} =5.04)	11	EPA (1980b)
			4,800	EPA (1986b)	279	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=3.52)
					195	Davies and Dobbs (1984) Eqn B (log K_{ow} =3.52)
					107.6	Davies and Dobbs (1984) Eqn C (log K_{ow} =3.52)
					179	Davies and Dobbs (1984) Eqn A (S=9)
					717	Davies and Dobbs (1984) Eqn C (log K_{ow} =5.04)
					1,570	Davies and Dobbs (1984) Eqn B (log K_{ow} =5.04)
					3,980	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =5.04)
Tetrachlorobenzene						
Trichlorobenzene						

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
<u>Organochlorine Pesticides</u>						
Aldrin	5.66	Geyer et al. (1984)	76,000	Versar Inc. (1984)	1,555	Davies and Dobbs (1984) Eqn C (log K_{ow} =5.66)
	5.66	Kenaga (1980a) Table III	410	Kenaga (1980a) Table III		
	7.40	Briggs (1981)	28,200	Briggs (1981) Table III	13,640	Davies and Dobbs (1984) Eqn C (log K_{ow} =7.4)
	5.30	EPA (1986b)	40,000; 1,282,000	Kadeg et al (1986) (log K_{ow} =5.3; 7.4)	1,500	Lyman et al. (1982)
			96,000	EPA (1986b)	3,140	Kenaga (1980a) Table 3 (experimental)
			27,500	Brammer and Blackwell (1967, 1970)	10,800	Kenaga (1980a) Table 3 (experimental)
					3,690	Davies and Dobbs (1984) Eqn B (log K_{ow} =5.66)
					40,345	Davies and Dobbs (1984) Eqn C (log K_{ow}=7.4)
					11,792	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =5.66)
					247,742	Lyman et al (1982) Eqn 5-2 (log K_{ow} =7.4)
					1,810	Davies and Dobbs (1984) Eqn C (log K_{ow} =6.12)
Aldrin (continued)					6,940	Davies and Dobbs (1984) Eqn B (log K_{ow} =6.12)
					26,400	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=6.12)
Dieldrin	4.32	Davies and Dobbs (1984)	3,300; 12,880	Kadeg et al. (1986) Literature values	5,800; 4,420	Kenaga (1980a) Table 3 (experimental)
	6.2	Briggs (1981)			1,489	Davies and Dobbs(1984) Eqn B (log K_{ow}=5.0)
	3.69	Rao and Davidson(1983)	7,413	Briggs (1981) Table III (experimental)		
	5.48	Kenaga (1980a) Table III				
	3.5	EPA (1986b)	35,600	Kenaga (1980a) Table III (experimental)	12,590	Davies and Dobbs (1984) Table 2 (experimental)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Partition Coefficient (Log K_{ow}) Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Partition Coefficient (K_{oc}) Reference	Bioconcentration Factor Value	Bioconcentration Factor Reference
Dieldrin (continued)			1,700	EPA (1986b)	292	Davies and Dobbs (1984) Eqn C (log K_{ow} =4.32)
					1,130	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =4.32)
					30,339	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =6.2)
					1,350.7	Davies and Dobbs (1984) Eqn A (S=0.25)
					480	Davies and Dobbs (1984) Eqn C (log K_{ow} =5.0)
					3,700	Lyman et al. (1982) Eqn 5-2 (log K_{ow} =5.0)
Endrin	5.34	Kenaga (1980a) Table III	1,700; 7,590	Kadeg et al. (1986) (literature vlaues)	4,050	Kenaga (1980a) Table 3 (experimental)
	3.21	Rao and Davidson (1983) Table II				
	3.20 - 5.60	Kadeg et al. (1986)(range of six literature values)	1,312; 26,510	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=3.20; 5.60)	1,360	Kenaga (1980a) Table 3 (experimental)
			34,000	Kenaga (1980a) Table III (calculated value)	2,377	Davies and Dobbs (1984) Eqn B (log K_{ow}=5.34)
			897; 66,440	Lyman and Loreti (1987) (log K_{ow}=3.20; 5.60)	1,415.7	Davies and Dobbs (1984) Eqn A (S=0.23)
			1,249; 65,640	Kadeg et al. (1986) (log K_{ow}=3.20; 5.60)	5,012	Davies and Dobbs (1984) Table 2 (experimental)
					6,736	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=5.34)
					1,043	Davies and Dobbs (1984) Eqn C (log K_{ow} =5.34)
					250	Davies and Dobbs (1984) Eqn C (log K_{ow}=4.44)
					690	Davies and Dobbs (1984) Eqn B (log K_{ow}=4.44)
					1,390	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=4.44)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{ow}) Value (ml/g)	Partition Coefficient (Log K_{ow}) Reference	Partition Coefficient (K_{oc}) Value (ml/g)	Partition Coefficient (K_{oc}) Reference	Bioconcentration Factor Value	Bioconcentration Factor Reference
Endrin (continued)					1,640	Argyle (1973) (experimental)
					13,000	Hermanutz (1978) (experimental)
Isodrin	6.51	Lyman et al. (1982) Fragment Method (based on endrin log K_{ow}=5.34 as reported in Kenaga 1980a)	5751; 82,880	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=4.38; 6.51)	11,708	Davies and Dobbs (1984) Eqn B (log K_{ow}=6.5)
			7448; 339,900	Lyman and Loreti (1987) (log K_{ow}=4.38; 6.51)	51,286	Lyman et al. (1982) Eqn 5-2 ((log K_{ow}=6.5)
	4.38	Lyman et al. (1982) Fragment Method ; based on endrin log K_{ow}=3.21 as reported in Rao and Davidson (1983)	8759; 294,900	Kadeg et al. (1986) (log K_{ow}=4.38; 6.51)	4,436	Davies and Dobbs (1984) Eqn C (log K_{ow} =6.5)
	5.31	Lyman et al. (1982)Fragment Method (based on Endrin log K_{ow}=4.14; geometric mean of reported values)			1,737	Davies and Dobbs (1984) Eqn A (S=.16)
					233	Davies and Dobbs (1984) Eqn C (log K_{ow}=4.38)
					635	Davies and Dobbs (1984) Eqn B (log K_{ow}=4.38)
					1260	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=4.38)
Dichlorodiphenylethane	5.69	Rao and Davidson (1983)	19,350; 662,200	Kadeg et al. (1986) (log K_{ow}=4.86; 7.0)	13,900	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=7.07)
	4.86 - 5.89	Range of literature values reported in Kadeg et al. (1986)	50,100	Sabljic (1984)	12,430	Lyman et al. (1982) Eqn 5-2 (log K_{ow}=5.69)
	7.00	EPA (1986b)	10,490; 153,100	Lyman et al. (1982) Eqn 4-8 (log K_{ow}=4.86; 7.0)	2,043	Davies and Dobbs (1984) Eqn A (S=0.12)
			17,620; 818,500	Lyman and Loreti (1987) (log K_{ow}=4.86; 7.0)	25,362	Davies and Dobbs (1984) Eqn B (log K_{ow}=7.07)
			147,900	Kadeg et al. (1986) literature value	980	Davies and Dobbs (1984) Eqn C (log K_{ow}=5.60)
					3,400	Davies and Dobbs (1984) Eqn B (log K_{ow} =5.60)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{OW}) Value (ml/g)	Reference	Partition Coefficient (K_{OC}) Value (ml/g)	Reference	Bioconcentration Factor Value	Reference
Dichlorodiphenylethane (continued)					10,600	Lyman et al. (1982) Eqn 5-2 (log Kow=5.6)
					100,000	Davies and Dobbs (1984) Table 2 (experimental)
					366 - 9,659	Davies and Dobbs (1984) Eqn B (log K_{OW} =3.98; 6.36)
Dichlorodiphenyl -trichloroethane	5.98	Kenaga (1980a) Table III	23,800	Kenaga (1980a) Table III (experimental)	61,600; 84,500	Kenaga (1980) Table 3 (experimental)
	6.19	Rao and Davidson (1983)	140,000	Chiou et al. (1979) Experimental	623 - 29,800	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =3.98-6.19)
	3.98- 6.19	Hansch and Leo(1979)	243,000	Rao and Davidson (1983) Table I; mean of two soils	20,600	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =5.98)
	5.98	Lyman et al. (1982)	4 x10 ^{6}- 43,650	Range of 17 literature values reported in Kadeg et al. (1986)	40,100	Lyman et al. (1982) Eqn 5-2 (log K_{OW} =6.36)
	6.36	Davies and Dobbs (1984)	240,000	Sabljic (1984) Table 1	27,436-13,913	Davies and Dobbs (1984) Eqn A (S=0.0012-0.004)
	5.98; 6.19; 6.28 6.36	Geyer et al. (1984)			1,710	Davies and Dobbs (1984) Eqn C (log K_{OW}=6.07)
	4.0-7.48	Range of 20 literature values reported in Kadeg et al. (1986)			6,483	Davies and Dobbs (1984) Eqn B (log K_{OW}=6.07)
					24,200	Lyman et.al. (1982) Eqn 5-2 (log K_{OW} =6.07)
Chlordane	2.78; 3.32; 5.48	Kadeg et al. (1986) Literature values.	775; 22,810	Lyman et al. (1982) Eqn 4-8 (log K_{OW}=2.78; 5.48)		No values reported in Toxicity Assessment
			44; 53,570	Lyman and Loreti (1987) (log Kow=2.78; 5.48)		
			21,300	Kenage (1980a) Table III (Calculated value)		
			624; 53,850	Kadeg et al. (1986) (log K_{OW} =2.78; 5.48)		
			141,200	Kadeg et.al. (1986)		

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

Analyte	Partition Coefficient (Log K_{OW})		Partition Coefficient (K_{OC})		Bioconcentration Factor	
	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
Chlordane (continued)				(Literature value)		
			140,000	EPA (1986b)		
Arsenic						
Mercury						
ICP Metals						
Cadmium						
Chromium						
Copper						
Lead						
Organophosphorus Compounds, Pesticide Related						
Atrazine	2.32; 2.35	Rao and Davidson (1983) Table II	163	Rao and Davidson (1983) Table 1	3	Davies and Dobbs (1984)
			149	Kenaga (1980b) Table 1	37.4	Davies and Dobbs (1984)
					55	Davies and Dobbs (1984)
					34.13 -35.97	Lyman et al. (1982)
	2.64; 2.68; 2.75	Geyer et al. (1984)			56	Lyman et al. (1982)
					24-38	Davies and Dobbs (1984)
Malathion	2.89	Hansch and Leo(1979)			37.3	Davies and Dobbs (1984)
	2.36; 2.89	Rao and Davidson (1983)	1,797	Rao and Davidson (1983) Table 1	92.6	Lyman et al. (1982)
					49	Davies and Dobbs (1984)
Malathion (continued)	2.89	EPA (1985b)			82	Davies and Dobbs (1984)
Parathion					497	Lyman et.al. (1982)
					315	Davies and Dobbs (1984)
			2,961	Lyman et al. (1982)	453	Lyman et al. (1982)
	3.9	Briggs (1981)	600	Briggs (1981) Table III	571	Lyman et al. (1982)

Table RISR E.2-3 Chemical and Physical Properties of RMA Target Analytes.

	Partition Coefficient (Log K_{OW})		Partition Coefficient (K_{OC})		Bioconcentration Factor	
Analyte	Value (ml/g)	Reference	Value (ml/g)	Reference	Value	Reference
Parathion (continued)	3.8	Rao and Davidson (1983)	2,878	Lyman and Loreti (1987)	108	Davies and Dobbs (1984)
			3,651	Kadeg et al. (1986)	167	Davies and Dobbs (1984)
			10,650	Rao and Davidson (1983) Table I	132	Davies and Dobbs (1984)
					328	Davies and Dobbs (1984)
					542	Lyman et al. (1982)
					31-232	EPA (1986)
					33-201	EPA (1986)
					27	EPA (1986)
Supona	3.11	Briggs (1981)	1,172	Lyman et al. (1982)	135	Lyman et al. (1982)
			763	Lyman and Loreti (1987)	111	Davies and Dobbs (1984)
					65	Davies and Dobbs (1984)
					40	Davies and Dobbs (1984)
Vapona	1.4	Hansch and Leo (1979)	138	Lyman et al. (1982)	6.8	Lyman et.al. (1982)
			36	Lyman and Loreti (1987)	3.4	Davies and Dobbs (1984)
			64	Kadeg et al. (1986)	7.5	Davies and Dobbs (1984)
					11	Davies and Dobbs (1984)

the area where they had been disposed. Some contaminants at RMA, such as aldrin, endrin, and dieldrin, typically occur in solid form but are usually dissolved in an organic solvent during manufacture or use.

Contaminants in liquid form typically dissolve more readily in surface waters and infiltrate subsurface soils and aquifers more rapidly than do those in solid form. Liquid phases are also subject to volatilization from surface soils and waters. Volatilization, in turn, produces gaseous phases.

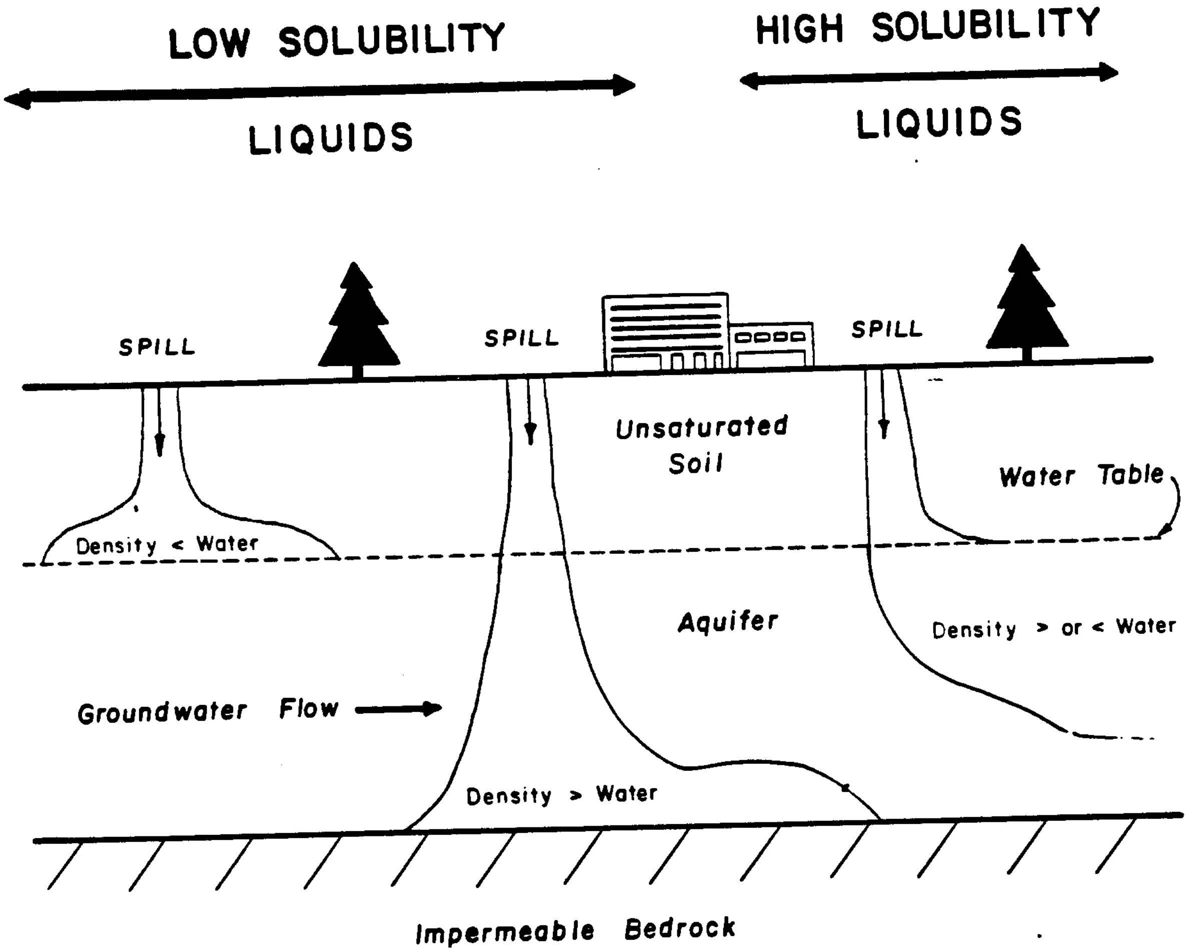
E.2.2 DENSITY

The density of a substance is the ratio of mass to unit volume. A related parameter, specific gravity, is the ratio of the mass of a given volume of a substance to that of an equal volume of water.

The density of a nonaqueous-phase liquid contaminant determines whether it will float or sink in an aqueous system. Where present in quantities in excess of solubility limits, pure phase liquid contaminants with a density less than that of water (1 gram per milliliter [g/ml] at 25°C) or specific gravity less than 1.0 will float on the water table surface, as shown in Figure RISR E.2-1. RMA target analytes that are less dense than water include diisopropylmethyl phosphonate (DIMP), dicyclopentadiene, benzene, toluene, and xylenes. Nonaqueous-phase contaminants with densities greater than that of water, when they reach the water table, tend to move downward in the aquifer until their progress is impeded by the degree of residual saturation of the contaminant within soil pores or until impermeable barriers are encountered (Figure RISR E.2-1). RMA target analytes that are more dense than water in their pure form include the volatile organohalogens, organosulfur compounds, and polynuclear aromatic hydrocarbons.

These pure phase contaminants will enter solution if a sufficient volume of water is encountered relative to the volume of pure contaminant. Although contaminants will tend to

Hypothetical Spills: Comparisons of Migration for Liquids of Varying Solubilities and Densities



Source: Modified from Kinzelback, 1986

Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR E.2-1

Aqueous Solubility and Density Effects on Contaminant Migration in Groundwater

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

diffuse throughout the water column, higher concentrations are generally encountered near the base of the permeable unit where pure-phase contaminants denser than water have settled, and near the water table surface where pure-phase contaminants less dense than water float. If a contaminant is dissolved in a nonaqueous solution, the density of the solution rather than the density of the pure contaminant controls transport. For example, a chemical that is heavier than water in its pure form may float in groundwater if dissolved in a solvent that is lighter than water.

E.2.3 SOLUBILITY

The aqueous solubility of a compound is defined as the maximum concentration that will dissolve in a unit volume of water under specified conditions. When water comes in contact with a compound, dissolution of the compound begins and continues until the solubility limit is reached or until all the compound has entered solution. If concentrations exceed aqueous solubility, the compound will exist as both a component of solution and as a separate solid, liquid, or gas phase. Variables in the groundwater environment such as temperature, pH, water hardness, concentrations of cations and anions, naturally occurring organic substances such as humic and fulvic acids, and the presence of other organic compounds all affect the water solubility of compounds. Solubility is also affected by the salinity of the water, although whether solubility increases or decreases with increased salinity is primarily dependent upon the electrolyte concentration and the molecular structure of the compound (Verschueren, 1983).

Aquatic solubility is a dominant characteristic for determining a contaminant's potential for environmental transport and distribution; compounds that are more soluble are generally subject to wider distribution in the environment than less soluble compounds as illustrated in Figure RISR E.2-1. However, even compounds with very low aquatic solubilities will eventually move entirely into solution given sufficient contact time, volume of water, and favorable environmental conditions. Aquatic solubility is related to adsorption and desorption reactions on soil and aquifer sediment surfaces. Highly soluble compounds are generally more likely to desorb from soils.

Organic compounds with solubilities of less than 50 milligrams per liter (mg/l) are considered slightly soluble; they include organochlorine pesticides, some purgeable hydrocarbons and organosulfur compounds, and dicyclopentadiene. Compounds with solubilities greater than 50 mg/l and less than 10,000 mg/l are considered moderately soluble and include benzene, dibromochloropropane (DBCP), DIMP, and most of the purgeable halogenated hydrocarbons and organosulfur compounds. Compounds with solubilities greater than 10,000 mg/l are considered highly soluble. Methylene chloride, dimethylmethyl phosphonate (DMMP), many chemical agents, agent degradation products, hydrazines, and organonitrogen compounds are highly soluble. Highly soluble compounds are less likely than slightly soluble compounds to be adsorbed onto soil or concentrate in the tissues of living organisms. Metallic cations and some inorganic anions, such as arsenic, chromium, fluoride, and sulfate, vary greatly in solubility depending on overall solution composition.

E.2.4 VAPOR PRESSURE

Vapor pressure is the pressure at which a pure solution of a compound and its vapor are in equilibrium at a given temperature. Vapor pressure can be used to predict the potential for a contaminant to volatilize from dry soils. Vapor-phase contaminants may be retained as vapors in the pore space of unsaturated soils, diffuse through the soil and into the atmosphere, or collect in subsurface structures such as sewers and basements. Diffusion through air in soil is affected by several variables such as the physical structure of the contaminant, the soil bulk density, soil moisture content, and soil adsorption potential (Dragun, 1988). The rate of diffusion through air in soil is typically a fraction of the diffusion rate through the atmosphere, which is discussed in the following section. For purposes of this report, vapor pressure is semiquantitatively described as volatile (>1 mm Hg) semivolatile (<1 but >1 x 10^{-3} mm Hg) or nonvolatile (<1 x 10^{-3} mm Hg). These descriptions should not be confused with analytical distinctions between volatile and semivolatile compounds or with the volatility ranking based on the Henry's law constant which is presented in Section E.2.6.

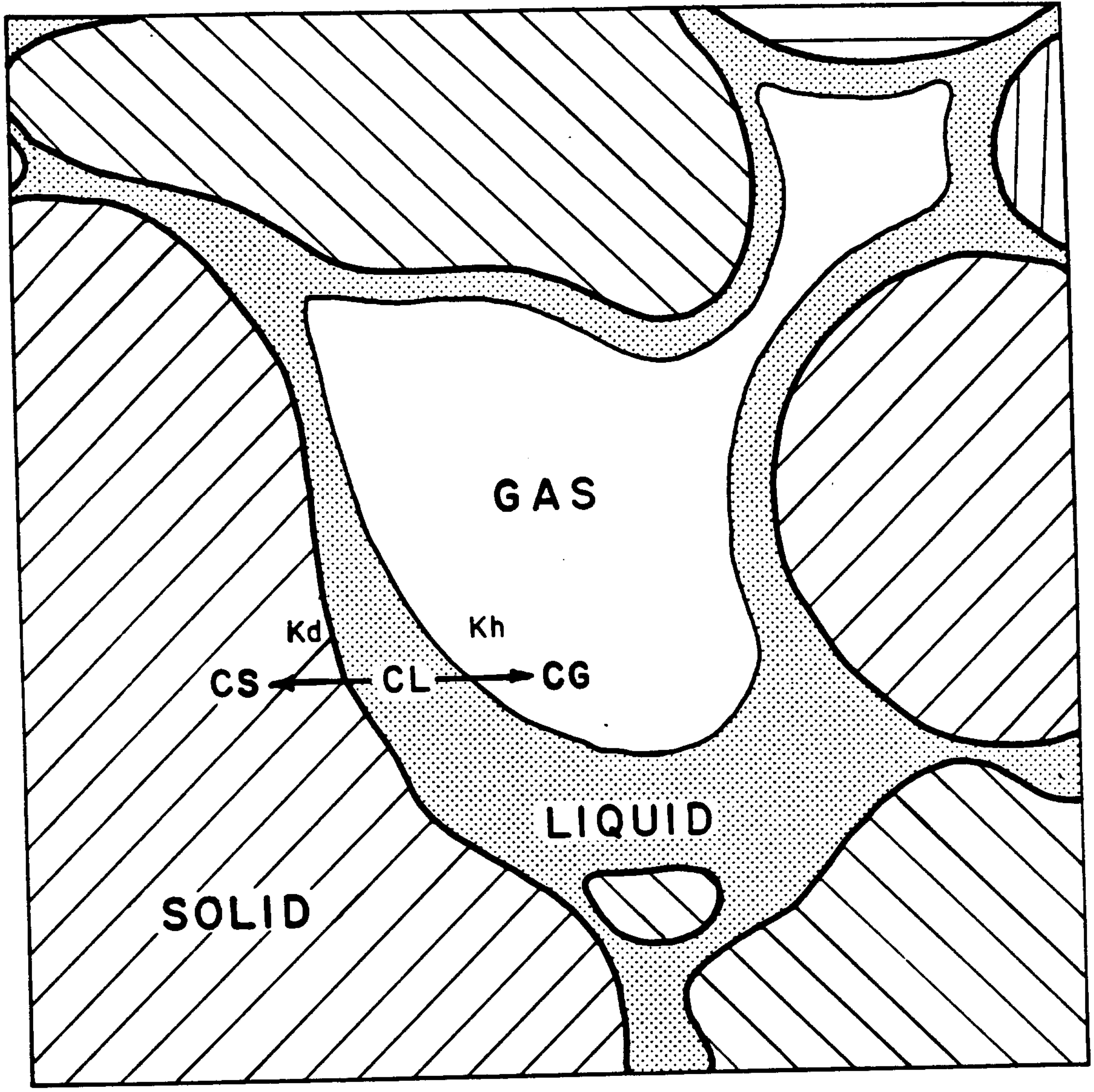
E.2.5 ATMOSPHERIC DIFFUSION

Atmospheric diffusion is the process in which gaseous molecules will mix and disperse within the atmosphere. Diffusion is caused by pressure, temperature, and concentration gradients in the atmosphere. These gradients are affected by the turbulent fluctuations of air motions created by the local weather system. In addition to meteorological effects, the rate of diffusion of individual vapor phase contaminants is influenced by their chemical structure, including molecular weight and intermolecular forces (Dragun, 1988).

E.2.6 HENRY'S LAW CONSTANT

For a vapor-liquid equilibrium system, the ratio of the concentration of a dilute compound in the vapor phase to the concentration of the compound in the aqueous phase is represented by Henry's Law constant (K_h), as illustrated in Figure RISR E.2-2. K_h provides a more reliable measure of the relative volatilization from a dilute solution than simple vapor pressure. K_h can be used to approximate environmental fate because it can be related to the degree of volatilization and persistence in the surface water.

If a compound has a K_h less than 10^{-7} atmospheres-cubic meters per mole (atm-m^3/mol), it is considered to have low volatility. Of RMA analytes for which data are available, dieldrin and organophosphorous pesticides, atrazine, malathion, and supona are considered to have low volatility. Moderately volatile compounds have K_h values in the 10^{-7} to 10^{-3} atm-m^3/mol range and are described as volatilizing slowly. RMA analytes in this moderate category include most organochlorine pesticides, DBCP, DIMP, herbicide-related organosulfur compounds. Some of the volatile halogenated and volatile aromatic compounds display K_h values at the upper end of this range. Highly volatile compounds have a value of K_h greater than 10^{-3} atm-m^3/mol and are readily volatilized from soils and surface water. This



LEGEND

CS - Solid Phase Concentration
CL - Liquid Phase Concentration
CG - Gas Phase Concentration
Kd - Solid-Liquid Partition Coefficients
Kh - Liquid-Gas Phase Partition Coefficients
(Henry's law constant)

Source: ESE, 1988

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Prepared August 1991	FIGURE RISR E.2-2 Enlarged Schematic Diagram of the Unsaturated Zone Rocky Mountain Arsenal Prepared by: Ebasco Services Incorporated

classification includes most volatile halogenated organics, most volatile aromatic organics, and many volatile hydrocarbons.

E.2.7 PARTITION COEFFICIENTS

In a two-phase system consisting of either liquid-liquid or solid-liquid phases, chemical species are usually detected at higher concentrations in one of the two phases. At equilibrium conditions, the chemical concentration will be distributed between the two phases at a specific ratio known as the partition coefficient. The octanol-water partition coefficient (K_{ow}) is defined as the ratio of equilibrium concentrations of a dissolved substance in a two-phase system of n-octanol and water. K_{ow} has been used to predict the tendency for chemicals to adsorb on soil organic matter, or to be subject to biological uptake and lipophilic storage. K_{ow} is often presented in the form of its base ten logarithm (Verschueren, 1983).

While K_{ow} is a readily determined and reproducible parameter in the laboratory, laboratory determinations do not directly apply to the partitioning of organic contaminants between soil or sediment and a coexisting water phase. However, the extent of adsorption of non-ionic organic chemicals onto soil organic carbon correlates well with K_{ow}. Empirical equations relate K_{ow} to the soil-water partition coefficient (K_d) and the soil organic carbon content (f_{oc}) through an intermediate parameter, the organic carbon partition coefficient (K_{oc}). K_{oc} of compounds is calculated from K_{ow}, or in some cases the solubility of the compound of interest (Lyman et al., 1982). K_{oc} is then related to the organic carbon content within a specific soil using the following equation:

$$K_d = K_{oc} \times f_{oc}$$

where: $f_{oc} > 0.0001$. Estimations of K_{oc} (and thus, K_d) involve empirical relationships that involve other properties of the chemical. Most commonly K_{oc} is derived using regression equations developed for limited classes of organic compounds. These equations are commonly expressed in logarithmic form, such as:

$$\log K_{oc} = a \log K_{ow} + b$$

where a and b are constants. The uncertainties associated with estimating K_{oc} by these different methods are reportedly less than one order of magnitude when applied to compounds that are chemically similar to those used to derive each equation. Uncertainties increase with the application of the equations to dissimilar compounds (Lyman et al., 1982).

As shown in Figure RISR E.2-2, K_d may then be used to relate organic contaminant concentrations in coexisting soil (C_s) and water (C_l) phases:

$$K_d = C_s/C_l$$

As with K_{ow}, compounds with high K_{oc} or K_d values are strongly partitioned into the solid phase, while compounds with low K_{oc} or K_d values are preferentially partitioned into the aqueous phase. Where organic carbon contents in sediments are greater than 0.01 percent, the relationship between K_{oc} and K_d indicates a direct correlation between the soil organic carbon content and the degree to which organic contaminants are partitioned into the soil phase. This is particularly true of sediments with high organic carbon contents, such as those present within well developed topsoils or in lake beds.

In an aquifer sediment, organic carbon contents may approach or exceed the lower level of applicability of the K_{oc}-K_d relationship, which is approximately 0.1 + 0.01 percent f_{oc} (Dragun, 1988). Sorption in sediments with low organic carbon contents becomes increasingly dominated by mineral surface interactions, and may be related to the surface area, grain size, cation exchange capacity, and percentage of silt and clay within the sediment. As a general rule, sorption of organic and inorganic compounds generally increases with increasing silt and clay content (Rhoades and Bernstein, 1971).

E.2.8 MEASURED SOIL-WATER PARTITION COEFFICIENTS

In order to evaluate the applicability of literature-derived partitioning data, an assessment of K_d values for samples collected in Section 36 of RMA was conducted (ESE, 1988c/RIC 88344R01). This study determined a range of K_d values for each analyte and compared these field-derived values to values reported in the literature. In addition, other geochemical parameters were determined, including organic carbon content, surface area, particle distribution, and mineralogy.

A review of the results of the field investigation and comparison with literature-derived partition coefficients suggest a good relative correlation between field K_d values and observed phased partitioning. Environmental contaminants characterized as having a strong affinity for the solid phase exhibit relatively high K_d values, while those with an affinity for the aqueous phase exhibit relatively low K_d values. However, there are significant discrepancies between field K_d values and those tabulated in the literature, suggesting a high degree of variability in the absolute partition coefficients. Reasons for discrepancies and high variability may include kinetic inhibition, nonequilibrium behavior, deviation from linear partitioning relationships, and the inherent heterogeneity of soils and sediments. Because of the high variability of partition coefficients, the data are considered more suitable for use in describing the relative behavior of a suite of contaminants in a similar environment rather than their absolute mobilities. Contaminants should be viewed as having relatively high, medium, or low affinities for solids in a given environment based on their relative partition coefficients. Mobilities of these compounds in the aqueous phase are inversely proportional to their Kd.

Organic compounds are grouped by the relative magnitude of their partition coefficients. Compounds with a K_{oc} value of less than 250 ml/g exhibit a relatively weak affinity for the solid phase and high degree of mobility in the aqueous phase. Compounds with a K_{oc} value of greater than 4,000 ml/g exhibit a strong affinity for the solid phase and limited mobility in the aqueous phase. Compounds with intermediate K_{oc} values exhibit moderate affinity for the solid phase and moderate mobility in the aqueous phase.

These categories should not be viewed as absolute, but rather as convenient indicators within a continuum of relative behavior. For example, dieldrin, which has a high K_{oc}, is nearly immobile in Basin C topsoil (ESE, 1988c/RIC 88344R01). The organochlorine pesticides, including dieldrin, remain in the upper few inches of soil despite storage and infiltration of clean water through these soils subsequent to using the basin for storage of liquid waste. However, dieldrin has also migrated in the alluvial groundwater system for a distance of over 2 miles (mi) along major flow paths from potential sources in the basins area (EBASCO, 1989d/RIC 89186R01). In both cases, dieldrin appears to be relatively less mobile than most of the other contaminants present, yet in an absolute sense its mobility is highly variable. The source of this variability is believed to be inherent in the heterogeneity of naturally occurring soils, sediments, and waters. It may also be related to little-understood complexities such as transport of colloidal materials to which contaminants may be adsorbed.

E.2.9 RETARDATION FACTORS

The rate of contaminant migration can be retarded with respect to groundwater flow velocities through interactions with aquifer solids. The more strongly a constituent is attracted to aquifer solids, the more slowly it will migrate with respect to groundwater flow velocities (Figure RISR E.2-3). The relative migration rate can be described in terms of a retardation factor (R_f), which relates the affinity of an organic compound for naturally occurring sediments through an empirically derived K_{oc}:

$$R_f = 1 + \frac{(D_b)(K_{oc})(f_{oc})}{n}$$

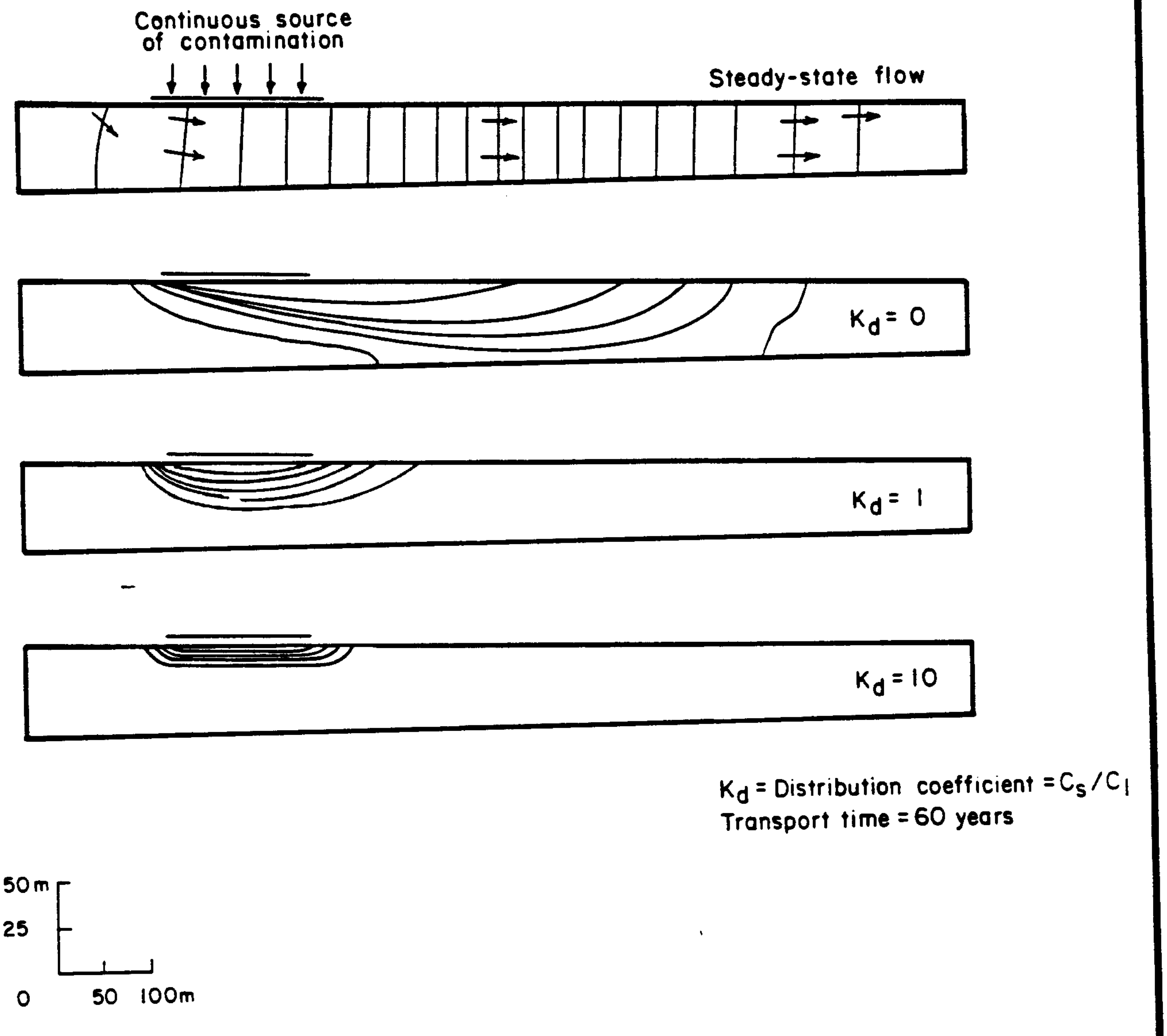
where:

D_b = aquifer sediment bulk mass density

n = aquifer porosity

f_{oc} = fraction organic carbon in the aquifer sediment.

A retardation factor of 1.0 implies that a contaminant will migrate at a rate equivalent to groundwater flow velocities; whereas a retardation factor of 2.0 indicates a rate of migration that is only half the rate of groundwater flow. Using porosities of 30 and 40 percent and a bulk density of 1.5 grams per cubic centimeter (g/cm^3) for surficial sediments and 1.8 g/cm^3 for aquifer sediments, ranges of retardation factors within saturated sediments below basins



Source: Freeze and Cherry, 1979

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U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR E.2-3

Effect of the Distribution Coefficient on Contaminant Retardation During Transport in a Shallow Groundwater Flow System

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

and ponds and the alluvial aquifer have been calculated (Tables RISR E.2-4 and RISR E.2-5). Given the potential for high variability in K_{oc} and f_{oc} values, these retardation factors should be used only in a relative sense. There may be large differences in mobility for a given compound in different environments. In addition, mobility may be enhanced by facilitated transport, which includes cosolvent effects and particle transport (EPA, 1989).

E.2.10 BIOCONCENTRATION, BIOACCUMULATION, AND BIOMAGNIFICATION FACTORS

In a food web representing the feeding relationships among species in an ecosystem, large numbers of organisms at low trophic, or feeding, levels are consumed by fewer organisms at the next higher level. These organisms, in turn, may be consumed by a predator in yet a higher trophic level. Through this process contaminants that are accumulated in biota may be systematically concentrated or biomagnified in successively higher trophic level species. Contaminant concentrations have a potential to reach levels that produce adverse or lethal effects on populations of high trophic level or particularly sensitive species. The specific aspects of bioaccumulation include bioconcentration and biomagnification, which are discussed in the following paragraphs.

The bioconcentration factor (BCF) is indicative of the degree to which contaminants may accumulate in aquatic organisms, and is defined as the ratio of contaminant concentrations in an organic (C_o) to the corresponding concentration in water:

$$BCF = \frac{C_o}{C_w}$$

BCF values may be measured using bioassay tests, or may be estimated from empirical relationships based on solubility, K_{ow} and K_{oc}. Bioconcentration factors have been estimated in Table RISR E.2-6 for RMA analytes using empirically derived regression equations referenced in Table RISR E.2-3. These regression equations are based on data from flow

Table RISR E.2-4. Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Saturated Lakebed Sediments and Soils at RMA.

Analyte	Log K_{oc}	R_f[a]
Volatile Halogenated Organics (VHOs)		
1,1-Dichloroethane	1.90	2.5 - 8.7
1,2-Dichloroethane	1.20	1.3 - 2.5
1,1-Dichlorethylene	2.02	3.0 - 11
1,2-Dichloroethylene	1.74	2.0 - 6.4
1,1,2,2-Trichloroethane	2.07	3.2 - 12
1,1,1-Trichloroethane	2.34	5.1 - 22
1,1,2-Trichloroethane	2.24	4.3 - 18
Carbon tetrachloride	2.55	7.7 - 36
Chlorobenzene	2.28	4.6 - 20
Chloroform	1.65	1.8 - 5.4
Methylene chloride	1.20	1.3 - 2.5
Tetrachloroethylene	2.56	7.8 - 36
Trichloroethylene	2.64	9.2 - 44
Trichloropropene	-	-
Volatile Hydrocarbons (VHCs)		
2-Butoxyethanol	-	-
4-Hydroxy-4-methyl-2-pentanone	-	-
2,2-Oxybisethanol	-	-
Bicycloheptadiene	2.28	4.6 - 20
Dicyclopentadiene	2.99	19 - 96
Methylcyclohexane	-	-
Methylisobutyl ketone	0.60	1.1 - 1.4
2-Pentanone	-	-
1-Methyl-1,3-cyclopentadiene	-	-
Volatile Aromatic Organics (VAOs)		
Benzene	1.62	1.8 - 5.1
Ethylbenzene	2.75	11 - 56
m-Xylene	3.02	21 - 100
o- and p-Xylene	3.02	21 - 100
Toluene	2.63	9.0 - 43

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[a] $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:
D_b = Bulk Density = 1.5 g/cm^3
Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR A.2-1.
f_{oc} = Organic Carbon Content, f_{oc} = 0.5% to 2.6% (J.P. Walsh, 1988; EBASCO, 1989b/RIC 89166R01).
Range of R_f reflects range of f_{oc}.
n = Porosity = 0.40.

Note: Dash inserted where no information is available.

Table RISR E.2-4. Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Saturated Lakebed Sediments and Soils at RMA.

Page 2 of 3

Analyte	Log K_{oc}	R_f^{a}
<u>Organosulfur Compounds, Mustard-Agent Related (OSCMs)</u>		
1,4-Oxathiane	0.69	1.1 - 1.5
Chloroacetic acid	-	-
Dithiane	-	-
Thiodiglycol	-	-
<u>Organosulfur Compounds, Herbicide Related (OSCHs)</u>		
Benzothiazole	-	-
Chlorophenylmethyl sulfide	3.05	22 - 110
Chlorophenylmethyl sulfone	1.80	2.2 - 7.2
Chlorophenylmethyl sulfoxide	1.71	2.0 - 6.0
Dimethyldisulfide	2.09	3.3 - 13
<u>Organophosphorous Compounds, GB-Agent Related (OPHGBs)</u>		
Diisopropylmethyl phosphonate	2.09	3.3 - 13
Dimethylmethyl phosphonate	-	-
Isopropylmethylphosphonic acid	-	-
Methylphosphonic acid	-	-
Phosphoric acid, tributyl ester	-	-
Phosphoric acid, triphenyl ester	-	-
<u>Dibromochloropropane (DBCP)</u>	2.41	5.8 - 26
<u>Organonitrogen Compounds (ONCs)</u>		
Nitrosodimethylamine	-1.00	1.0 - 1.0
Nitrosodi-n-propylamine	1.18	1.3 - 2.5
Hydrazine	-	-
Methylhydrazine	-	-
Unsymmetrical dimethylhydrazine	-	-
Caprolactam	-	-
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>		
Fluoranthene	4.58	710 - 3,700
Methylnaphthalene	-	-
Phenanthrene	3.85	130 - 690
Pyrene	3.42	50 - 260

(a) $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:

D_b = Bulk Density = 1.5 g/cm^3

Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR A.2-1.

f_{oc} = Organic Carbon Content, f_{oc} = 0.5% to 2.6% (J.P. Walsh, 1988; EBASCO, 1989b/RIC 89166R01).

Range of R_f reflects range of f_{oc}.

n = Porosity = 0.40.

Note: Dash inserted where no information is available.

Table RISR E.2-4. Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Saturated Lakebed Sediments and Soils at RMA.

Analyte	Log K_{oc}	$R_f^{(a)}$
Semivolatile Halogenated Organics (SHOs)		
Dichlorobenzene	-	-
Hexachlorobenzene	6.08	23,000 - 120,000
Hexachlorobutadiene	4.45	530 - 2,700
Hexachlorocyclopentadiene	4.06	220 - 1,100
Pentachlorobenzene	4.06	220 - 1,100
Tetrachlorobenzene	-	-
Trichlorobenzene	-	-
Organochlorine Pesticides (OCPs)		
Aldrin	4.67	880 - 4,600
Chlordane	5.15	2,600 - 14,000
Dichlorodiphenylethane (DDE)	4.93	1,600 - 8,300
Dichlorodiphenyltrichloroethane (DDT)	4.58	710 - 3,700
Dieldrin	3.86	140 - 710
Endrin	3.87	140 - 720
Isodrin	4.58	710 - 3,700
Organophosphorous Compounds, Pesticide Related (OPHPs)		
Atrazine	2.21	4.0 - 17
Malathion	3.25	34 - 170
Parathion	3.40	48 - 250
Supona	2.98	19 - 94
Vapona	1.83	2.3 - 7.6

(a) $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:
D_b = Bulk Density = 1.5 g/cm^3
Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR A.2-1.
f_{oc} = Organic Carbon Content, f_{oc} = 0.5% to 2.6% (J.P. Walsh, 1988; EBASCO, 1989b/RIC 89166R01).
Range of R_f reflects range of f_{oc}.
n = Porosity = 0.40.

Note: Dash inserted where no information is available.

Table RISR E.2-5 Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Unconfined Aquifer Sediments at RMA.

Analyte	Log K_{oc}	R_f*
Volatile Halogenated Organics (VHOs)		
1,1-Dichloroethane	1.90	1.3 - 4.2
1,2-Dichloroethane	1.20	1.1 - 1.6
1,1-Dichlorethylene	2.02	1.4 - 5.3
1,2-Dichloroethylene	1.74	1.2 - 3.2
1,1,2,2-Trichloroethane	2.07	1.5 - 5.8
1,1,1-Trichloroethane	2.34	1.9 - 9.9
1,1,2-Trichloroethane	2.24	1.7 - 8.1
Carbon tetrachloride	2.55	2.5 - 15
Chlorobenzene	2.28	1.8 - 8.8
Chloroform	1.65	1.2 - 2.8
Methylene chloride	1.20	1.1 - 1.6
Tetrachloroethylene	2.56	2.5 - 15.8
Trichloroethylene	2.64	2.8 - 18.8
Trichloropropene	-	-
Volatile Hydrocarbons (VHCs)		
2-Butoxyethanol	-	-
4-Hydroxyl-4-methyl-2-pentanone	-	-
2,2-Oxybisethanol	-	-
Bicycloheptadiene	2.28	1.8 - 8.8
Dicyclopentadiene	2.99	5.1 - 41
Methylcyclohexane	-	-
Methylisobutyl ketone	0.60	1.0 - 1.2
2-Pentanone	-	-
1-Methyl-1,3-cyclopentadiene	-	-
Volatile Aromatic Organics (VAOs)		
Benzene	1.62	1.2 - 2.7
Ethylbenzene	2.75	3.4 - 24
m-Xylene	3.02	5.4 - 44
o- and p- Xylene	3.02	5.4 - 44
Toluene	2.63	2.8 - 18

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* $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:
D_b = Bulk Density = 1.8 g/cm^3
Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR E.2-1.
f_{oc} = Organic Carbon Content, f_{oc} = 0.07% to 0.68% (ESE, 1988c/RIC 88344R01).
Range of R_f reflects range of f_{oc}.
n = Porosity = 0.30.

Note: Dash inserted where no information is available.

Table RISR E.2-5 Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Unconfined Aquifer Sediments at RMA.

Analyte	Log K_{oc}	R_f^*
<u>Organosulfur Compounds, Mustard-Agent Related (OSCMs)</u>		
1,4-Oxathiane	0.69	1.0 - 1.2
Chloroacetic acid	-	-
Dithiane	-	-
Thiodiglycol	-	-
Organosulfur Compounds, Herbicide Related (OSCHs)		
Benzothiazole	-	-
Chlorophenylmethyl sufide	3.05	5.2 - 47
Chlorophenylmethyl sulfone	1.80	1.3 - 3.6
Chlorophenylmethyl sulfoxide	1.71	1.2 - 3.1
Dimethyldisulfide	2.09	1.5 - 6
<u>Organophosphorous Compounds, GB-Agent Related (OPHGBs)</u>		
Diisopropylmethyl phosphonate	2.09	1.5 - 6
Dimethylmethyl phosphonate	-	-
Isopropylmethylphosphonic acid	-	-
Methylphosphonic acid	-	-
Phosphoric acid, tributyl ester	-	-
Phosphoric acid, triphenyl ester	-	-
<u>Dibromochloropropane (DBCP)</u>	2.41	2.1 - 11
<u>Organonitrogen Compounds (ONCs)</u>		
Nitrosodimethylamine	-1.00	1.0 - 1.0
Nitrosodi-n-propylamine	1.18	1.1 - 1.6
Hydrazine	-	-
Methylhydrazine	-	-
Unsymmetrical dimethylhydrazine	-	-
Caprolactam	-	-
<u>Polynuclear Aromatic Hydrocarbons (PAHs)</u>		
Fluoranthene	4.58	160 - 1,600
Methylnaphthalene	-	-
Phenanthrene	3.85	31 - 290
Pyrene	3.42	12 - 110

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* $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:
D_b = Bulk Density = 1.8 g/cm^3
Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR E.2-1.
f_{oc} = Organic Carbon Content, f_{oc} = 0.07% to 0.68% (ESE, 1988c/RIC 88344R01).
Range of R_f reflects range of f_{oc}.
n = Porosity = 0.30.

Note: Dash inserted where no information is available.

Table RISR E.2-5 Partition Coefficients (K_{oc}) and Retardation Factors (R_f) for Unconfined Aquifer Sediments at RMA.

Page 3 of 3

Analyte	Log K_{oc}	R_f*
Semivolatile Halogenated Organics (SHOs)		
Dichlorobenzene	-	-
Hexachlorobenzene	6.08	5,100 - 49,000
Hexachlorobutadiene	4.45	120 - 1,200
Hexachlorocyclopentadiene	4.06	49 - 470
Pentachlorobenzene	4.06	49 - 470
Tetrachlorobenzene	-	-
Trichlorobenzene	-	-
Organochlorine Pesticides (OCPs)		
Aldrin	4.67	200 - 1,900
Chlordane	5.15	590 - 5,800
Dichlorodiphenylethane (DDE)	4.93	360 - 3,500
Dichlorodiphenyltrichloroethane (DDT)	4.58	160 - 6,600
Dieldrin	3.86	31 - 300
Endrin	3.87	32 - 300
Isodrin	4.58	160 - 1,600
Organophosphorous Compounds, Pesticide Related (OPHPs)		
Atrazine	2.21	1.7 - 7.6
Malathion	3.25	8.5 - 74
Parathion	3.40	12 - 100
Supona	2.98	5 - 40
Vapona	1.83	1.3 - 3.8

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* $R_f = 1 + (D_b)(K_{oc})(f_{oc})/n$, where:
D_b = Bulk Density = 1.8 g/cm^3
Log K_{oc} = Organic Carbon Partition Coefficient from Table RISR E.2-1.
f_{oc} = Organic Carbon Content, f_{oc} = 0.07% to 0.68% (ESE, 1988c/RIC 88344R01).
Range of R_f reflects range of f_{oc}.
n = Porosity = 0.30.

Note: Dash inserted where no information is available.

Table RISR E.2-6. Bioconcentration and Biomagnification Factors for Selected[a] RMA Analytes. Page 1 of 2

Analyte	Bioconcentration[b] Factor	RMA Biomagnification[c] Factor
Volatile Halogenated Organics (VHOs)		
1,1-Dichloroethane	9.0	-
1,2-Dichloroethane	7.2	-
1,1-Dichloroethylene	26	-
1,2-Dichloroethylene	5.5	-
1,1,1-Trichloroethane	43	-
1,1,2-Trichloroethane	16	-
Carbon tetrachloride	45	-
Chlorobenzene	48	-
Chloroform	11	-
Methylene chloride	8.5	-
Tetrachloroethylene	41	-
Trichloroethylene	38	-
Volatile Hydrocarbons (VHCs)		
Bicycloheptadiene	19	-
Dicyclopentadiene	88	-
Methylisobutyl ketone	5.9	-
Volatile Aromatic Organics (VAOs)		
Benzene	18	-
Ethylbenzene	78	-
m-Xylene	68	-
o- and p-Xylene	68	-
Toluene	45	-
Organosulfur Compounds, Herbicide Related (OSCHs)		
Chlorophenylmethyl sulfide	130	-
Chlorophenylmethyl sulfone	6.0	-
Chlorophenylmethyl sulfoxide	6.5	-
Dimethyldisulfide	15	-
Organophosphorous Compounds, GB-Agent Related (OPHGBs)		
Diisopropylmethyl phosphonate	2.6	-

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[a] Applicable Bioconcentration and RMA Biomagnification Factors not available for other RMA analytes.

[b] The geometric mean of reported values was tabulated from Table RISR E.2-3.

[c] Range of values reported for selected species (mallard, bluegill, pike, and eagle) determined by pathways analysis at RMA. Values available only for Biota RI Contaminants of Concern (ESE, 1989/RIC 89173R02).

Table RISR E.2-6. Bioconcentration and Biomagnification Factors for Selected[a] RMA Analytes. Page 2 of 2

Analyte	Bioconcentration[b] Factor	RMA Biomagnification[c] Factor
Dibromochloropropane (DBCP)	34	0.25 - 31.88
Semivolatile Halogenated Organics (SHOs)		
Hexachlorobenzene	12,000	-
Hexachlorocyclopentadiene	225	-
Pentachlorobenzene	1,800	-
Tetrachlorobenzene	1,800	-
Trichlorobenzene	182	-
Organochlorine Pesticides (OCPs)		
Aldrin	5,100	-
Dichlorodiphenylethane (DDE)	8,100	-
Dichlorodiphenyltrichloroethane (DDT)	19,000	-
Dieldrin	2,400	6,600-290,000
Endrin	2,000	350-11,000
Isodrin	2,600	-
Organophosphorous Compounds, Pesticide Related (OPHPs)		
Atrazine	27	-
Malathion	61	-
Parathion	210	-
Supona	79	-
Arsenic	limited	1.6-19
Mercury	insignificant	1,300-50,000

(a) Applicable Bioconcentration and RMA Biomagnification Factors not available for other RMA analytes.

(b) The geometric mean of reported values was tabulated from Table RISR E.2-3.

(c) Range of values reported for selected species (mallard, bluegill, pike, and eagle) determined by pathways analysis at RMA. Values available only for Biota RI Contaminants of Concern (ESE, 1989/RIC 89173R02).

through laboratory experiments with a variety of fish species. ASTM (1985) indicates that chemicals with BCFs less than approximately 100 have low potentials for causing harm to wildlife and human health as a result of biomagnification of contaminants up the food chain.

The biomagnification factor (BMF) represents the direct accumulation of contaminants originating in sediment, soil, or water by lower organisms, and subsequent accumulation of contaminant residues by higher organisms due to exposure in the food chain. Biomagnification factors are calculated by summing appropriate BCFs and accounting for species-specific bioaccumulation effects to predict the fate of contaminants as they as transformed from abiotic environments, up the food chain, to selected target species.

In terrestrial systems, plants may accumulate inorganic and organic constituents through their root zones, although some adsorption may also occur through their leaves. For some chemicals, phytotoxic effects limit bioaccumulation by eliminating susceptible plant species from the food chain. Although generalities are presented, the unique effects of bioaccumulation in different species is based in part on their geographic location, trophic level, physiology, and life processes. Contaminants of concern are addressed in greater detail specifically as they affect sensitive biota at RMA in the Biota RI (ESE, 1989/RIC 89173R02).

The Biota RI used RMA field data and multiple pathways analyses to develop species-specific BMFs for five contaminants of concern at RMA which are presented in Table RISR E.2-6. However, reported values for BCFs and BMFs may vary greatly for each species due to variations in susceptibility, chemical accumulation, feeding habits, physical environments, and biota assessment methodology. These numbers are presented only for use in examining relative degrees of concentration and magnification in biotic systems.

E.2.11 TRANSFORMATION AND DEGRADATION

Transformation and degradation processes determine whether a chemical will persist in the environment. Key processes include both chemical and biological mechanisms, such as hydrolysis, photolysis, oxidation-reduction, and biotransformation. Contaminants are generally reduced to less hazardous components, such as carbon dioxide and water. However, degradation products may, in certain instances, be of greater concern due to increased toxicity, persistence, or mobility. Specific rates at which these processes occur are dependent on individual chemical and environmental characteristics. In general, surface processes occur at faster rates than subsurface processes. Therefore, a chemical that is buried will generally degrade at a slower rate than the same chemical exposed at the soil surface. Exceptions would include compounds more susceptible to reduction or anaerobic processes.

Several chemical reaction mechanisms potentially contribute to the overall process of chemical transformation. Hydrolysis, photolysis, oxidation-reduction, and biological reactions are the primary components of chemical transformation in soils, although other reactions may be significant for individual compounds of interest. EPA (1979) assessed potential transformations affecting priority pollutants in aqueous systems. A brief description of each major class of reactions follows.

During hydrolysis, an organic compound reacts with water, which results in the introduction of a hydroxyl group into the molecule and subsequent elimination of another functional group, such as a halogen. Hydrolysis may be catalyzed by acid (H+), base (OH^-), or metal (M+) ions; thus, the rate of hydrolysis is dependent on pH and metal-ion concentration. Sorption effects may also influence the rate of hydrolysis. Hydrolysis of some pesticide derivatives is more rapid in the presence of humic materials.

Photochemical processes include both direct photolysis and sensitized photolysis. In direct photolysis, a compound adsorbs solar radiation and is transformed, while in sensitized photolysis, the energy that transforms the compound is derived from another species in solution. Photolysis reactions may occur in either air, near-surface soils, or surface water.

Oxidation-reduction (redox) reactions involving both inorganic and organic compounds are important in soil and water environments. Inorganic chemists define oxidation as the loss of electrons and increase in oxidation number, while reduction is the gain of electrons and decrease in oxidation number. Organic oxidation reactions generally involve a gain in oxygen and loss of hydrogen, while the reverse is frequently true for organic reduction. Oxidation often requires the presence of molecular oxygen (O_2), but the reaction usually involves free radicals, especially OH, RO_2, RO, and singlet oxygen as the oxidant (where R = carbon chain or ring). Redox reactions are often biologically mediated but can also occur in abiotic systems.

Reductive dehalogenation involves the removal of a halogen atom via a redox reaction. This reaction is most likely to occur in low-redox state groundwaters where oxygen has been depleted. This reaction requires mediators, such as ferric iron (Fe^{+3}) or naturally occurring biological products, to accept electrons generated by oxidation of reduced organics and to transfer these electrons to the halogenated organic compound to bring about dehalogenation (Mackay et al., 1985).

Biotransformation occurs as a result of the metabolic activity of microorganisms through the action of enzymes that catalyze chemical reactions. These reactions generally lead to the production of energy or some essential nutrient for the organism, although some chemicals may be transformed even though the specific reaction does not promote growth. Rates of biotransformation are dependent on microbial tolerance to specific contaminant compounds and the availability of groups of compounds, such as oxygen and nitrate, as nutrient sources. Therefore, rates of biodegradation are dependent upon microbial population, environment, and the physical-chemical properties of the compound. Although only limited information is available on rates of biodegradation, historical data and field studies may be helpful in evaluating the importance of biodegradation.

E.3 CONTAMINANT BEHAVIOR

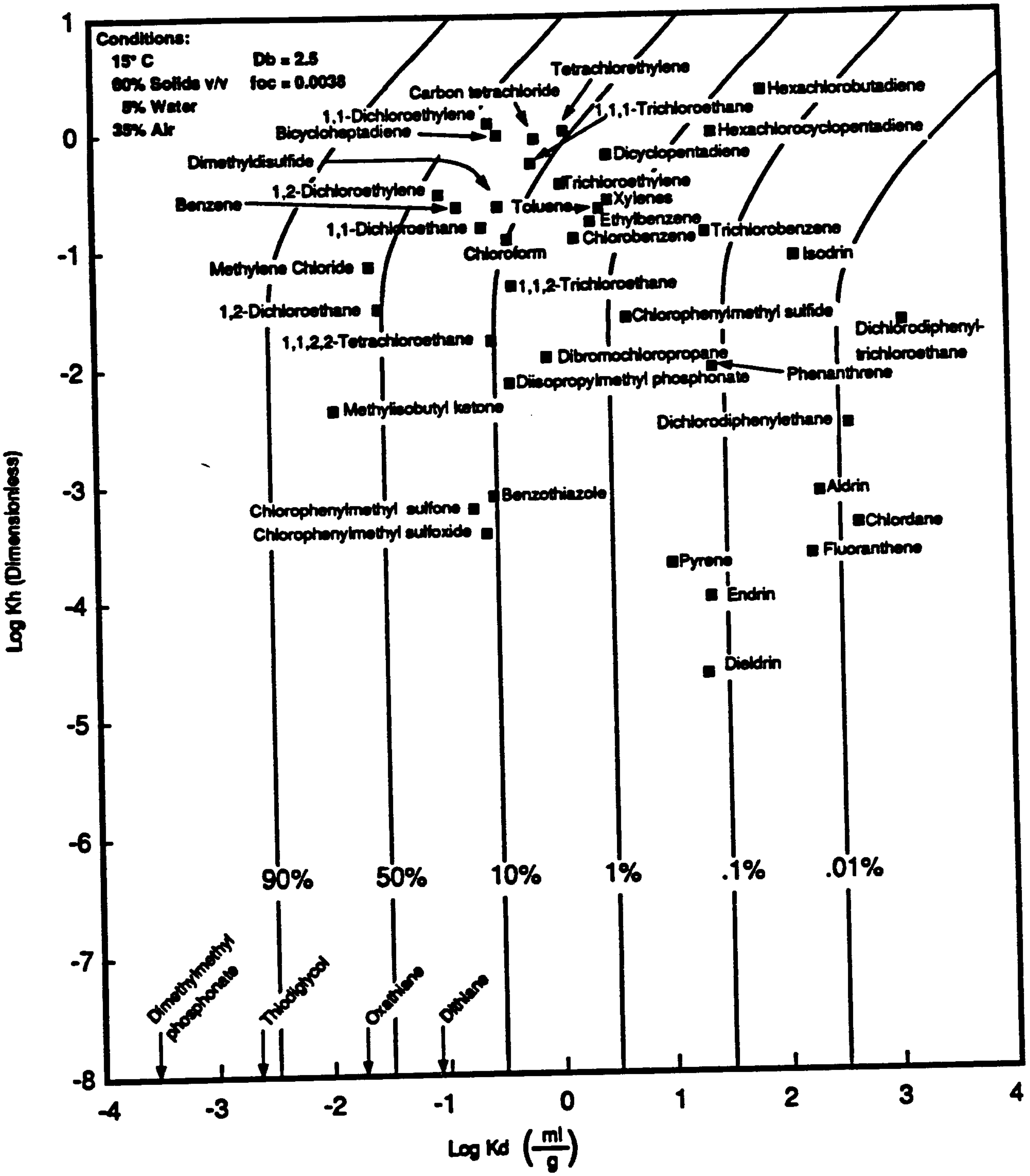
Physical-chemical properties of organic analytes at RMA have been summarized in Table RISR E.2-1. These properties may be used to describe the relative fate and mobility of these contaminants in the soil, air, surface water, and groundwater environments. The relative magnitude of the K_{oc} and K_h and solubility of RMA contaminants are directly proportional to each compound's affinity for the solid, gas, and liquid phases, respectively.

The relationships between volatility and K_d partition coefficient in the soil environment are demonstrated through the use of a compartment model, which is discussed below and illustrated in Figures RISR E.3-1 and RISR E.3-2. In addition, the general environmental behavior of RMA analyte groups is summarized below.

E.3.1 COMPARTMENT MODEL

A valuable use for equilibrium partition coefficients is determining the relative distribution of contaminants between the phases present. Given the partition coefficients and the quantity of the solid, liquid, and gas phases per unit volume of environment, the fraction of contaminant in each phase, or environmental compartment, can be calculated. The equations, derived in the Determination of Partition Coefficients for the Primary Contaminant Sources of Section 36 (ESE, 1988c/RIC 88344R01), are used to describe these partitioning relationships, which are applicable to either two- or three-phase systems.

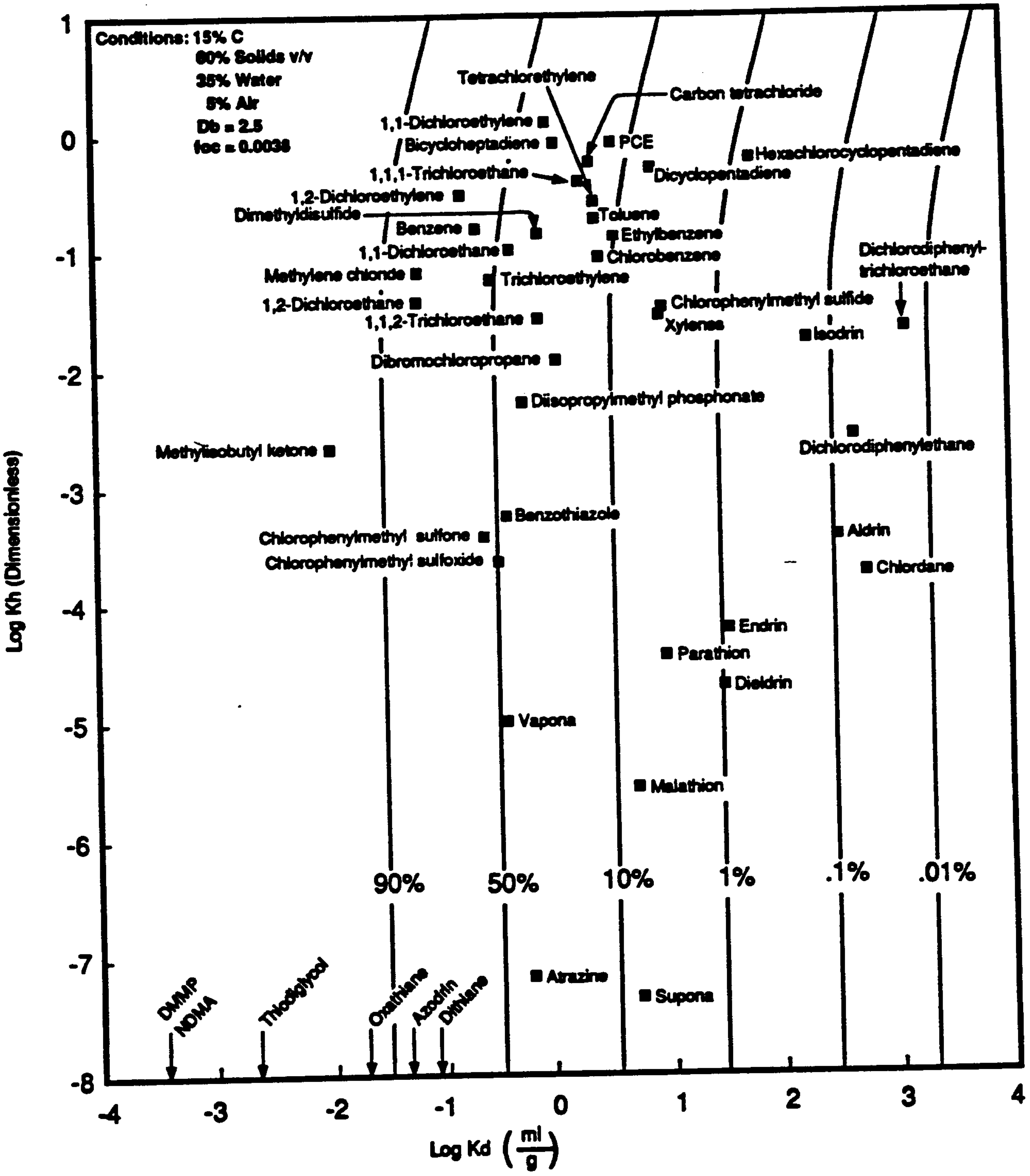
The equations can be used to assess the potential for mobility of a contaminant in a given system by calculating the fraction of contaminant in the mobile air and water phases as a function of K_d and K_h. Figure RISR E.3-1 plots the values of K_h and K_d for RMA target analytes. Superimposed on these values are lines denoting the total percentage of each contaminant expected in the potentially mobile water and gas phases. The environmental



Note: Db = Density of solids
foc = Organic carbon fraction

Source: ESE, 1988c

Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Prepared August 1991	**Figure RISR E.3-1** **Percent of Contaminant in Mobile Phase - 5% Water and 35% Air** Prepared by: Ebasco Services Incorporated



Note: Db = Density of solids
foc = Organic carbon fraction

Source: ESE, 1988c

Prepared for:	Figure RISR E.3-2
U.S. Army Program Manager for Rocky Mountain Arsenal	Percent of Contaminant in Mobile Phase - 35% Water and 5% Air
Prepared August 1991	Prepared by: Ebasco Services Incorporated

conditions are representative of the unsaturated zone, where solids occupy 60 percent of the volume, water 5 percent, and air 35 percent. These same relationships are determined for conditions representative of the saturated zone in Figure RISR E.3-2, where solids occupy 60 percent of the volume, water occupies 35 percent, and air occupies 5 percent. The values of K_d and K_h used in this plot were derived from data presented in Table RISR E.2-1.

Figures RISR E.3-1 and E.3-2 depict some important environmental characteristics of the contaminants. The curvature in the percent mobile phase lines above log K_h = -2.0 indicates that the gas phase becomes an increasingly important reservoir for volatile contaminants with higher K_ds. The contaminants exhibiting log K_h values greater than -2.0 demonstrate an increasing mobility in the gas phase and can be volatilized to the atmosphere. For contaminants exhibiting log K_h values less than -2.0, the gas phase is relatively insignificant, and liquid-solid phase interactions will control their behavior. Contaminants lying to the left of the log K_d = 0 line (negative K_d) are relatively mobile in the aqueous phase, while contaminants to the right (positive K_d) demonstrate decreasing mobility in the aqueous phase.

E.3.2 ANALYTE GROUP BEHAVIOR

The environmental mobility of each of the RMA target analytes or composite groups of compounds can be bracketed into general categories such as relatively immobile, moderately mobile, and highly mobile. This is accomplished by evaluating contaminant properties, media properties, and transport and fate processes acting in the environment. The following discussion presents a relative description of the mobility of each composite analyte group in air, soil, water, and biotic environments. In addition, general observations regarding transformation processes, biodegradation, and bioconcentration are also provided. These descriptions have been primarily based on data presented in the RMA Exposure Assessment (EBASCO, 1989i/RIC 89227R02,03). Other sources include EPA (1982), Moore and Ramamoorthy (1984a; 1984b), and Dragun (1988).

These descriptions of analyte behavior should be used in a relative sense to compare compounds or groups of compounds in similar environmental settings. For example, in an organic-rich soil environment that is subject to moderate infiltration, DBCP will be transported much more readily than the organochlorine pesticides (OCPs). Therefore, in comparison with the organochlorine pesticides and for a given period of time, a DBCP contaminant plume would migrate farther and be more dispersed in groundwater.

E.3.2.1 Volatile Halogenated Organics

All of the volatile halogenated organic compounds (VHOCs) have moderate to high aqueous solubilities, moderate to high volatilities, and moderate to low affinities for organic matter. Therefore, these chlorinated solvents are readily mobilized from shallow soils by volatilization and infiltration. Once dissolved in surface waters and groundwaters, these compounds are transported at moderate to high rates. In general, mobility decreases with increasing halogenation within each of the chloromethane, chloroethane, and chloroethylene groups. The chloromethanes generally exhibit a greater mobility than the chloroethanes or chloroethylenes.

In surface water systems, VHOs are readily volatilized to the atmosphere, where they are rapidly photo-oxidized by hydroxyl radicals. Half lives for the volatilization process in flowing surface water range from hours to days for the group (Moore and Ramamoorthy, 1984a). Although this process is relatively rapid, potential transport distances may still be significant in most streams and rivers.

In groundwater systems, photolysis is insignificant, and losses due to volatilization are minimized as a result of slow upward diffusion rates within the unsaturated zone. Abiotic transformation by hydrolysis, reduction, or dehydrohalogenation occurs at relatively slow rates for most compounds within the group, resulting in successive degradation to decreasingly halogenated compounds. Rates of transformation increase in biologically mediated systems, although reaction mechanisms are uncertain. Dehalogenation has been reported in both microbial and mammalian systems (Vogel et al., 1987). Transformation of the halogenated alkanes and alkenes to vinyl chloride (chloroethylene) is possible following the depletion of oxygen in the groundwater.

Although trichloroethylene is readily absorbed by all routes of exposure, there is no evidence of bioaccumulation in biotic systems. In general, BCFs for the group suggest that appreciable bioconcentration or biomagnification is unlikely.

E.3.2.2 Volatile Hydrocarbons

The volatile hydrocarbon (VHC) group contains a wide variety of compounds exhibiting a range of behaviors. For most compounds within the group, environmental behavior is evaluated on the basis of approximate solubility measurements (Merck, 1983; Weast, 1975) and vapor pressure estimates (Lyman et al., 1982). Other properties are inferred from relative solubility and vapor pressure. Therefore, the following discussion of volatile hydrocarbon migration focuses on general trends and characteristics.

The environmental behavior of the VHCs is subdivided into compounds exhibiting high solubility and those exhibiting moderate to low solubility. The high solubility group includes 2-butoxyethanol, 2,2-oxybisethanol, 4-hydroxy-4-methyl-2-pentanone (diacetone alcohol), and 4-methyl-2-pentanone (methylisobutyl ketone). These compounds are characterized by both their high solubility and moderate vapor pressure. Volatilization from soils may be a significant loss mechanism, particularly for methylisobutyl ketone. However, the least volatile of these compounds, 2,2-oxybisethanol, will not readily volatilize in the environment. The affinity of these high solubility compounds for adsorption to soil organic carbon or mineral surfaces is inferred to be low, resulting in a high potential for leaching from soils and high mobility in groundwater with respect to flow rates. Transport in surface water will be predominantly in the dissolved phase. Degradation of these alcohols and ketones by chemical and biological transformations in soil and water is likely (EPA, 1985c; USAMBRDL, 1985). Information regarding uptake in plants, biomagnification, and bioconcentration is currently unavailable.

The moderate to low solubility group of hydrocarbons includes dicyclopentadiene, bicycloheptadiene, methyl cyclohexane, and 2-pentanone. These compounds exhibit moderate to high vapor pressures, resulting in potential losses to the atmosphere from surface soils and surface water by volatilization. Available data regarding the behavior of dicyclopentadiene and bicycloheptadiene indicate low to moderate affinity for adsorption on soil organic carbon and mineral surfaces. Their overall mobility in soil and groundwater is considered moderate. Chemical and biological transformations will degrade these hydrocarbons in soil and water with half lives on the order of months. Photolysis is a potential degradation mechanism in the atmosphere, surface soils, and surface water (Cogley and Foy, 1978).

Dicyclopentadiene is not significantly accumulated in terrestrial plants (USAMBRDL, 1985). For this group, appreciable bioconcentration or biomagnification is unlikely, although available data are limited.

E.3.2.3 Volatile Aromatic Organics

The volatile aromatic organics (VAOs) exhibit moderate solubilities, moderate to high volatilities, and low to moderate affinities for soil organic carbon. These characteristics result in a moderate mobility for the group.

Volatilization is the major transport process in surface soils and surface water, followed by photo-oxidation by hydroxy radicals in the atmosphere. Half lives of these compounds in flowing surface water are on the order of hours (Moore and Ramamoorthy, 1984a). Although this process is relatively rapid, potential transport distances may still be significant in most streams and rivers (Dragun, 1988).

Biodegradation by fungi and microorganisms present in soil or water is significant in the presence of oxygen. Half lives of the VAOs range from days to months in soils. The potential for leaching of these compounds into groundwater is least significant for the xylenes, which exhibit the strongest affinity for soil organic carbon. These compounds are transformed through incorporation of molecular oxygen into the aromatic structure to form dihydroxybenzene degradation products, with aliphatic acid or benzoic acid derivatives as products. References for degradation of these compounds include EPA (1985a), Dragun (1988), USAMBRDL (1985), and Overcash et al. (1982).

In groundwater systems, volatilization is limited by slow upward diffusion rates within the unsaturated zone. Oxidation and hydrolysis are relatively unimportant fate processes. Once introduced into the groundwater system, migration will be moderately retarded with respect to groundwater flow rates.

Bioconcentration factors for the group indicate that limited bioconcentration of xylene residues may occur up through food chains. Bioconcentration and biomagnification are unlikely for the remainder of the group.

E.3.2.4 Organosulfur Compounds, Mustard-Agent Related

The mustard-agent related organosulfur compounds (OSCMs) consist of mustard degradation products that include 1,4-oxathiane, dithiane, and thiodiglycol, as well as chloroacetic acid, which is reportedly used primarily as a preemergent herbicide and defoliant.

The mustard degradation products are moderately to highly soluble, exhibit low volatility in water, and are weakly adsorbed to soil organic matter. As a result, they are considered highly mobile in the environment and will be readily leached from soils and transported in surface water and groundwater with little attenuation. Volatilization may also provide a transport pathway in soils, although the high water solubility of these compounds minimizes the significance of volatilization from water. Persistence and uptake data are generally unavailable, but oxidation and biodegradation are reported as potential degradation mechanisms. High aqueous solubility and low organic partitioning behavior indicates that bioconcentration is not likely.

For most of these compounds, available literature does not provide data regarding chemical stability or degradation processes. Available information on dithiane is described below. Dithiane is reported to readily oxidize to sulfoxides and sulfones (Berkowitz et al., 1978). It is readily photo-oxidized to sulfoxide in nonaqueous solvents (Foote and Peters, 1971); however, the presence of water may facilitate photo-oxidation (Berkowitz et al., 1978). Although data on biodegradation of OSCMs were not found in available literature, this process is suspected due to the microbial nutrients (carbon and sulfur) contained in dithiane.

Chloroacetic acid has been linked to mustard manufacturing and demilitarization and to herbicide production at RMA. Chloroacetic acid is also reported to be a degradation product generated by the oxidation of 1,2-dichloroethane, 1,2-trichloroethane, chloroethane, and 1,1-dichloroethene (Vogel et al., 1987). Chloroacetic acid is likely to occur in its dissociated anionic form at normal soil and water pH values. It is highly soluble, exhibits high volatility, and has little affinity for soil organic matter. This compound is also considered highly mobile in the environment and will be readily leached from soils and transported in migrating surface and groundwater.

Based on studies of a related compound (trichloroacetate), uptake of chloroacetic acid in plants, followed by degradation, is suspected (Chow, 1970). The potential for bioconcentration or food chain transfer is expected to be negligible.

E.3.2.5 Organosulfur Compounds, Herbicide Related

The herbicide related organosulfur compounds (OSCHs) have low to moderate solubility, moderate to high volatility, and low to moderate affinity for soil organic matter. The resulting mobilities, therefore, range from moderate to high, depending on the particular compound of interest. Dimethyldisulfide is the most mobile compound of the group, with volatilization from soils being a major transport pathway. Chlorophenylmethyl sulfide is the least mobile compound of the group, exhibiting a limited potential for leaching from soils and subsequently retarded rates of transport with respect to groundwater flow. Limited volatilization of chlorophenylmethyl sulfide from soils may also occur. The remainder of this group is moderately mobile in groundwater and may also be transported in surface water and suspended sediment.

Microbial degradation of these OSCHs has been reported, although data regarding the rate and extent of degradation and the resulting products are unavailable. Chlorophenylmethyl sulfide has been reported to chemically oxidize to chlorophenylmethyl sulfoxide. Other types of degradation have not been identified in available literature. Half lives in soil range from months to years for the group (Cogley and Foy, 1978; Guenzi et al., 1979). Data on the persistence of benzothiazole or dimethyldisulfide in environmental media were not located in available literature.

Uptake in plants occurs in both the roots and leaves of corn and sugarbeets, with residues concentrated to the greatest degree within the leaves (Guenzi et al., 1979). Significant bioconcentration and biomagnification are unlikely for the group.

E.3.2.6 Organophosphorous Compounds, GB-Agent Related

Limited information is available for most GB-Agent related organophosphorus compounds (OPHGBs) within this group. Studies have investigated the behavior of DIMP and DMMP, which are relatively well characterized as by-products of GB manufacture. Available data indicate that the compounds within this group exhibit moderate to high solubility, low to moderate volatility, and low affinity for solid organic carbon. Therefore, these compounds are considered mobile in the environment, readily leached from soils, and transported with minimal attenuation in groundwater and surface water. The potential exists for limited volatilization from surficial soils and surface water.

These OPHGB compounds hydrolyze slowly in water, with half lives for DIMP and DMMP of 530 years and 12 years, respectively. Measurements on loss of DIMP and DMMP in soils suggest half lives on the order of 2 years and 12 days, respectively. Data indicate the potential for biodegradation of isopropylmethylphosphonic acid. The degradation sequence of GB reportedly progresses through a series of hydrolysis reactions from isopropylmethylphosphonic acid and isopropylmethylphosphonate to methyl phosphonic acid, and ultimately, phosphate. References for degradation include Rosenblatt et al. (1975a, 1975b), Howard et al. (1986), Howells et al. (1973), and Cook et al. (1978).

Uptake of DIMP into plant tissues occurs, with highest concentrations observed in the leafy tissues (O'Donovan and Woodward, 1977). Bioconcentration of compounds within the group is not expected to occur.

E.3.2.7 Organophosphorous Compounds, Pesticide Related

The pesticide-related organophosphorous compounds (OPHPs) have solubilities ranging from low to high. They exhibit low to moderate volatilities and low to moderate affinity for soil organic matter. These properties indicate that the group is moderately mobile and may be leached from soils and transported by surface or groundwater. Retardation in groundwater due to adsorption will be moderate. Volatilization to the atmosphere is a notable migration pathway for some members of the group, particularly vapona and parathion.

Hydrolysis is an important degradation mechanism and is directly related to pH. Half lives in water at a pH greater than seven range from days to weeks, but in acidic solutions these values increase to years (NAS, 1977; Mabey and Mill, 1978; and TDB Peer Review Committee, 1984). Hydrolysis in soil is also pH dependent, with reported half lives ranging from weeks to years (Menzie, 1969; Menzie, 1980; Warnock and Leary, 1978; and TDB Peer Review Committee, 1984). Degradation rates in soil increase with increasing pH and decreasing organic carbon content.

Uptake of Supona has been observed in carrots (Edward, 1973). Appreciable bioconcentration and biomagnification are unlikely for most of the group, although magnification of parathion residues in higher vertebrates may occur (EBASCO, 1989b/RIC 89166R01).

E.3.2.8 Dibromochloropropane

This compound has a high aqueous solubility, moderate volatility, and a moderate affinity for organic matter in soil. DBCP is lost from near-surface soils and surface water by volatilization; therefore, detectable concentrations in shallow soil horizons are present only for short periods of time following disposal. Although the volatilization process in surface water is moderately rapid, potential transport distances in rivers and streams are significant. Once flushed from shallow soils, DBCP is moderately retained by soil organic matter and transported at moderate rates by groundwater. DBCP is relatively persistent in subsurface soils and groundwater, but is decomposed slowly by hydrolysis and microbial action. Dibromochloropropane can be converted to n-propanol, bromide, and chloride by soil-water culture (Berkowitz et al., 1978).

Plant uptake can occur, with the highest residues generally present within the root portion (EBASCO, 1989i/RIC 89227R02,03). The bioconcentration factor suggests that appreciable bioconcentration or biomagnification is not likely to occur.

E.3.2.9 Organonitrogen Compounds

The organonitrogen compound (ONC) group includes hydrazines, nitrosamines, and caprolactam. The hydrazines and nitrosamines exhibit somewhat dissimilar properties and behavior, despite their relatively consistent mobility in groundwater and surface water. Although the RI sampling program conducted Phase I and Phase II investigations in the vicinity of the hydrazine blending facility in the South Plants Study Area, a USATHAMA-certified analytical method for hydrazines was not available. Descriptions of the ONCs and their fate and transport behavior are derived from EPA (1982), Schmidt (1984), and Stone and Wiseman (1988).

The hydrazines are characterized by high solubility and low volatility in water. The hydrazines are readily leachable from inorganic mineral sediments, although they become irreversibly bound to organic matter. As a result, their mobility in soils is strongly related to the form and availability of organic carbon in the soil horizon. Retardation in organic-poor aquifer sediments will be dominated by cation exchange processes and correspondingly high mobility. Volatilization from soil is a potential migration pathway, particularly for unsymmetrical dimethyl hydrazine, but will decrease in importance in the presence of organic carbon.

The hydrazines degrade rapidly in the environment. Degradation mechanisms include photolysis and oxidation by hydroxyl radicals in the atmosphere, oxidation by dissolved oxygen in water, and biodegradation by nitrogen-fixing bacteria in soil. Oxidation of unsymmetrical dimethylhydrazine yields n-nitrosodimethylamine as a degradation product.

The nitrosamines are characterized by high solubility, low affinity for soil organic carbon, and low volatility. They are moderately mobile and will be leached from soils by infiltrating water. Transport is likely to occur in the dissolved phase in association with groundwater and surface water flow. The nitrosamines are reportedly unstable in sunlight and are biodegradable. Data are currently unavailable regarding uptake in plants, bioconcentration, or biomagnification.

Caprolactam was tentatively identified in groundwater at RMA based on gas chromatography/mass spectroscopy (GC/MS) scans. It is a cyclic ONC described as hexahydro-2H-azepin-2-one. It is a solid at room temperature and is freely soluble in water and organic solvents (Merck, 1983). Vapor pressure calculated from the caprolactam boiling point indicates a moderate volatility for this compound in soil. High solubility and moderate vapor pressure indicate a preference for the aqueous phase, with a low potential for loss through volatilization or through attenuation by adsorption on soil and aquifer solids. Overall mobility is considered high.

E.3.2.10 Fluoroacetic Acid

Limited information is available regarding the behavior of fluoroacetic acid in the environment. Both the acid and its sodium salt, sodium fluoroacetate, are highly soluble in water. Under normal environmental pH conditions, dissociated anionic fluoroacetate species will predominate over fluoroacetic acid. Sodium fluoroacetate is nonvolatile, and consequently, will not be lost from soil or surface water through volatilization. The high solubility of both the acid and sodium salt indicates a limited potential for adsorption to soils and high mobility in groundwater and surface water.

Data are unavailable regarding the stability of fluoroacetic acid in air, soil, or water, or its potential for bioaccumulation. However, given the soluble nature of fluoroacetic acid and its sodium salt, bioconcentration is not anticipated.

E.3.2.11 Polynuclear Aromatic Hydrocarbons

Polynuclear aromatic hydrocarbons (PAHs) are characterized by low solubility, moderate volatility, and moderate to high affinity for soil organic carbon. As a result, these compounds are considered relatively immobile. Primary transport pathways are limited to suspended sediment or colloids in surface or aquifer waters or as wind-blown dust. Leaching from soils by infiltration is minimal, and subsequent transport by groundwater flow would be strongly attenuated due to the group's affinity for solid surfaces. Volatilization is unimportant for these 3- and 4-ring PAHs.

The PAHs are degraded through photo-oxidation in the atmosphere, surface water, and surficial soils. They vary in their sensitivity to this process, although compounds adsorbed to particulates are more susceptible. Micro-organisms present in soil and sewage sludge are capable of degrading these compounds. Breakdown products from photolysis are either endoperoxides, which undergo secondary reactions to yield various products, or diones. Photo-oxidation yields quinones. Lower molecular weight PAHs can be degraded completely to carbon dioxide and water, whereas higher molecular weight PAHs form various phenolic and acidic metabolites (Dragun, 1988; Moore and Ramamoorthy, 1984a).

Although half lives are short in aquatic biota, BCFs for this group indicate the potential for significant bioconcentration. Uptake from water is rapid and increases with exposure concentration, which results in rapid, but short-term, accumulation in fish tissues.

E.3.2.12 Semivolatile Halogenated Organics

The semivolatile halogenated organics (SHOs) contained within this group are characterized by low solubility, moderate to high volatility, and high affinity for solids. Similar to the VHOs, these compounds tend to volatilize rapidly from surface water. Half lives in flowing water are hours (Moore and Ramamoorthy, 1984a). In contrast to the VHOs, however, they are low in solubility and exhibit a strong affinity for soil organic carbon and mineral surfaces. These characteristics limit their rates of volatilization and transformation in the soil environment, as well as their potential for leaching. Mobility in groundwater is also low.

Degradation mechanisms vary with each compound. The chlorinated benzenes are photodegraded in the presence of humic substances, while biodegradation is slow to insignificant. Chlorobenzene is reportedly biotransformed to 3-chlorocatechol (Moore and Ramamoorthy, 1984a). Hexachlorocyclopentadiene exposed to atmospheric photolysis results in releases of carbaryl chloride, diacychlorides, ketones, and free chlorine radicals (EPA, 1984b). Hexachlorocyclopentadiene is rapidly transformed under favorable conditions through photolysis, hydrolysis, and biodegradation. Other degradation products were not found in available literature. Detailed discussions of SHO degradation processes are found in Moore and Ramamoorthy (1984a) and EPA (1984b).

Bioconcentration factors for the group suggest that appreciable bioconcentration and biomagnification may occur. Experimental studies indicate that increasing substitution in the chlorobenzenes leads to increasing uptake and stability in both plants and animals.

Experimental results also indicate, however, that hexachlorocyclopentadiene is not appreciably bioconcentrated.

E.3.2.13 Organochlorine Pesticides

Organochlorine pesticides (OCPs) are generally very persistent in soil environments and exhibits low mobility in the aqueous environment. Their distribution is a result of relatively low aqueous solubilities, a high affinity for soil organic matter, and moderate volatility. Therefore, OCPs present in unsaturated zone soils as solid or aqueous wastes would strongly partition to naturally occurring organic matter and would be leached from these soils at very low rates. However, leaching of these compounds may be significantly enhanced by the presence of organic solvents.

Affinity for solid substrates results in transport of OCPs as windblown particulates and as suspended sediment in runoff and surface water. Volatilization of endrin and chlordane may be a significant loss process from surface waters, and rates of volatilization for dieldrin are reported to increase with evaporation of surface waters (Jury, 1986). In groundwater, transport is strongly retarded with respect to groundwater flow, although significant migration may occur in coarse-grained, organic-poor sediments that present little opportunity for sorption and retardation.

Once mobilized in the subsurface, OCPs may accumulate as secondary sources at optimal locations along their migration pathways. Partitioning between soil and water phases will tend to remain constant as long as subsurface conditions do not vary. An increase in clay or organic carbon content or a reduction in available pore water may cause OCPs to sorb to saturated or unsaturated zone sediments. Secondary sources formed under these conditions may be responsible for the slow release of OCPs significant distances from their original disposal areas (Mackay and Cherry, 1989).

In agricultural soils, the OCPs are resistant to chemical and biological degradation, with half lives ranging from 1 to 46 years (Rosenblatt et al., 1975a, 1975b; Berkowitz et al., 1978; EPA, 1984a; and EBASCO, 1991). Photolysis and biodegradation, the principal transformation mechanisms, occur slowly. Volatilization may also be responsible for losses from the soils. Degradation products are similar to the original compounds. Aldrin is converted to dieldrin by oxidation, while isodrin degrades to endrin. Similarly, metabolites of DDT include p,p'-DDE and o,p'-DDD.

Residues of these pesticides in crops grown on treated soils vary, but generally appear to accumulate in root crops. Accumulation in pasture crops has not been observed. The magnitude of BCFs for the OCPs, as well as direct measurements, indicate that appreciable bioconcentration and biomagnification will occur in the food chain. The results of biota studies at RMA agree with expected biomagnification of OCPs in both aquatic and terrestrial environments (ESE, 1989/RIC 89173R02).

E.3.2.14 Arsenic

Arsenic is a naturally occurring metalloid that is present in the environment in a number of oxidation states. The indicator range for arsenic in RMA soils was selected as the certified reporting limit (CRL) to 10 micrograms per gram (µg/g). Toxicity and environmental mobility for arsenic are dependent on the valence state, which is in turn controlled by the Eh, pH, and overall composition of the system.

Arsenic can occur as arsenate (+5), arsenite (+3), elemental (0), or arsenide (-3) species. The elemental metal is extremely rare, while the arsenide form is present under strongly reducing conditions generally characterized by the presence of sulfide. Under oxidizing conditions, arsenite is oxidized to arsenate, which can be anticipated in oxygenated systems. In addition, microbial action can convert arsenite to arsenate in well-oxygenated soils. Arsenite can be found in moderately reducing systems generally characterized by the absence of both oxygen and sulfide. Arsenic also combines strongly with sulfur and carbon, forming numerous organoarsenical compounds.

Arsenate and arsenite can be expected to predominate under environmental conditions commonly encountered at RMA. These anionic species generally exhibit low solubilities and are moderately mobile (Korte et al., 1976; and WHO, 1981); however, arsenite is more soluble than arsenate. Arsenate or arsenite may be leached from soils and transported at low levels in the dissolved phase (WHO, 1981). Their migration will be moderately retarded with respect to groundwater flow rates. Transport in the dissolved phase may be enhanced by complexation with dissolved organic matter (Moore and Ramamoorthy, 1984b).

Sorption of arsenate and arsenite is controlled primarily by inorganic and iron-manganese oxyhydroxides and clay minerals contained in the silt- and clay-sized sediment fraction (Korte et al., 1976; Huang and Liaw, 1979; Moore and Ramamoorthy, 1984b; and Dragun, 1988). Soil organic matter is a less important sorptive phase. The presence of these arsenic species in the fine sediment fractions makes wind-blown dust and suspended surface water sediment important migration pathways. Under moderately reducing conditions, arsenic present in sediments can be resolubilized, primarily as the more toxic arsenite species (Moore and Ramamoorthy, 1984b; Clement and Faust, 1981).

The concentration of arsenic in solution can also be controlled by the solubility of various arsenate solids that may be precipitated. Minor concentrations of metals in solution, such as iron, copper, and barium, can limit the solubility of arsenic. The reaction of adsorbed arsenate with iron oxyhydroxides may result in the formation of ferric hydroxyarsenate, which has a very low solubility (Hem, 1970).

Methylation of arsenic can occur in soil or water environments through the action of fungi and bacteria (Chau and Wong, 1978; McBride et al., 1978; and WHO, 1981). The resulting methylated arsenic compounds can be either volatile or nonvolatile, creating a potential loss mechanism for shallow soil and surface water arsenic. For a more detailed description of these parameters and their influence on migration, see Dragun (1988), Moore and Ramamoorthy (1984b), and Faust and Aly (1981).

Although arsenic has been found to be phytotoxic to plants, evidence for significant bioaccumulation of arsenic has not been found at RMA or elsewhere. RMA biota and other studies to date indicate that arsenic bioconcentrates at lower levels, but higher predators are not at significant risk (EPA, 1985c).

E.3.2.15 Mercury

Mercury is a naturally occurring metal that is found in the environment in a number of oxidation states. The indicator range for mercury at RMA was selected to include levels from the CRL to 0.1 µg/g. The prevailing species and corresponding behavior are dependent on environmental conditions.

Mercury can occur in three oxidative states in the environment, including elemental (0), mercurous (+1), and mercuric (+2) species. Mercuric species will predominate in oxygenated environments. Under reducing conditions, elemental mercury should be the dominant oxidation state. High concentrations of dissolved sulfide may stabilize the mercuric ion as sulfide and bisulfide complexes even at very low redox potentials. The mercurous state is restricted to low pH and moderate Eh conditions. Strong complexes are formed with chloride, hydroxide, bisulfide ions, and organic ligands (Moore and Ramamoorthy, 1984b).

At RMA, the mercuric species will predominate in most soil and surface water environments, as well as in oxygenated groundwater. Mercurous and elemental forms may also exist in moderately reducing groundwater, as characterized by the absence of oxygen. The solubility of inorganic mercury in all of its potential oxidation states is low, and as a result, mercury in soils is considered relatively immobile. Mercury binds strongly to both organic and inorganic particulates (Rosenblatt et al., 1975a; 1975b), resulting in minimal leaching from soils and sediments and high retardation in groundwater. Solubility and subsequent transport in the dissolved phase may be significantly enhanced by the presence of dissolved organic carbon or by conversion to organic forms (Ramamoorthy and Rust, 1976; Ramamoorthy and Rust, 1978; and Moore and Ramamoorthy, 1984b).

Sorption of mercury is correlated with both the organic carbon content and the grain size or surface area of soils and sediments. Desorption from sediments is slow (Reimers and Krenkel, 1974; and Moore and Ramamoorthy, 1984b). Migration of mercury is likely to occur in association with sediment transport, either as windblown dust or suspended sediment and bed load in surface water.

Inorganic mercury may be transformed in the environment to a group of compounds called organomercurials. These compounds may be produced through either biological or abiotic processes. Characteristics of organomercurials vary widely, ranging in the aquatic environment from water soluble and persistent to nearly insoluble and extremely volatile (Moore and Ramamoorthy, 1984b). The biological and chemical cycling of mercury is a complex process dependent on the nature of mercury input, physical-chemical composition of the environmental system, and the metabolic state of various types of biota. However, these processes are not completely understood, and virtually any mercury compound can be remobilized in aquatic systems by conversion to methyl and dimethyl forms. Conditions reported to enhance biomethylation include high concentrations of mercury, large bacterial populations, absence of complexing agents, neutral pH, and aerobic environments (EBASCO, 1989i/RIC 89227R02,03).

Mercury in organic and inorganic forms can volatilize to the atmosphere from both aquatic and terrestrial environments. Precipitation subsequently removes mercury from the atmosphere. Rates of volatilization are reduced by conversion of elemental mercury to complexed or solid species. Additional discussions of mercury behavior may be found in Moore and Ramamoorthy (1984b).

Uptake of mercury by plants has been demonstrated, with highest concentrations generally found in bulb and root crops (Rosenblatt et al., 1975a; 1975b). Turf grass does not accumulate mercury compounds exposed to the root zone (EPA, 1984c). Mercury is also bioaccumulated by numerous aquatic organisms (EPA, 1984d). Large BCFs are observed in aquatic systems and BCFs increase with increasing trophic level. The magnitude of reported BCFs indicates that appreciable bioconcentration or biomagnification of mercury can occur. However, the extent and severity of effects from mercury bioaccumulation at RMA are significantly less than for the OCPs (ESE, 1989/RIC 89173R02).

E.3.2.16 ICP Metals

The occurrences of the five inductively coupled plasma (ICP) metals at RMA, cadmium, chromium, copper, lead, and zinc, are generally ubiquitous in soils at RMA. After review of published information regarding naturally occurring metals concentrations in soils, and consultations with the organizations and state, the following indicator ranges were selected as a best estimate of background concentrations:

- Cadmium (Cd) - CRL to 2 μg/g
- Chromium (Cr) - CRL to 40 μg/g
- Copper (Cu) - CRL to 35 μg/g
- Lead (Pb) - CRL to 40 μg/g
- Zinc (Zn) - CRL to 80 μg/g.

Cadmium, copper, lead, and zinc behave similarly in the environment. Although specific behavior is strongly related to the chemical environment of interest, numerous generalizations may be made for the group. These metals occur in the divalent state under Eh-pH conditions encountered at RMA. The free divalent cations form aqueous complexes with hydroxide at neutral to basic pH, as well as with chloride and dissolved organic matter. Cadmium, copper, lead, and zinc readily precipitate as sulfides in reducing environments. In oxidizing systems, they may form solid carbonates, sulfates, and phosphates with varying solubilities (Moore and Ramamoorthy, 1984b; Faust and Aly, 1981; and EBASCO, 1989i/RIC 89227R02, 03).

Although solubilities of these metals vary widely under commonly encountered environmental conditions, their aqueous mobility is limited by sorption to mineral and organic solids. In solution, cadmium, copper, lead, and zinc exhibit a strong affinity for iron and manganese oxyhydroxides, organic matter, carbonates, and clays (Moore and Ramamoorthy, 1984b; and EBASCO, 1989i/RIC 89227R02, 03). As a result, they are generally associated with soil or sediment, rather than the surface water or groundwater phase.

Leaching of these four ICP metals from soils is difficult due to the abundance of sorptive solids, particularly in soils with a pH of 7 or greater. In general, partitioning measurements indicate an increasing affinity for the solid phase in the following order: Cd < Zn < Cu < Pb (Dragun, 1988). The range of partitioning coefficients for these metals is shown in Table RISR E.3-1. Although cadmium is considered the most mobile of this group of metals, it is also relatively difficult to leach from soils. ICP metals transport is most likely to occur in the form of wind-blown dust or as suspended and bed load sediments in surface water. Remobilization of adsorbed metals in sediments may occur by desorption and solubilization as a result of complexation with dissolved organics such as humic and fulvic acids.

Table RISR E.3-1. Ranges of K_d Values for ICP Metals and Arsenic in Soils and Clays.

Element	Observed Range
Cd	1.3 - 27
Cr	1.2 - 150,000
Cu	1.4 - 333
Pb	4.5 - 7,640
Zn	0.1 - 8,000
As	1.0 - 18

Source: Dragun, 1988.

Copper and zinc are incorporated by plants and animals as essential nutrients, and are bioconcentrated even where these elements are naturally occurring. However, they are generally not biomagnified. Lead has similarly been shown to bioconcentrate in a variety of organisms, although microcosm studies indicate that it is not biomagnified through the food chain. Cadmium is readily concentrated in plants, but incorporation is generally offset by phytotoxic effects. Measured BCFs suggest that appreciable bioconcentration and biomagnification of cadmium may occur.

Chromium occurs in two oxidation states in natural systems. The hexavalent state (+6) is thermodynamically stable in well-oxygenated waters and exists as complex oxyanions such as chromate (CrO_4^{-2}) and dichromate ($Cr_2O_7^{-2}$). The anionic hexavalent species are moderately soluble and weakly adsorbed, resulting in considerable environmental mobility in groundwater and surface water (EBASCO, 1989i/RIC 89227R02, 03). Chromium contained in chemical manufacturing wastes is generally in the hexavalent state. Trivalent chromium (+3) is thermodynamically stable under moderately to strongly reducing conditions, and occurs as a trivalent cation or hydroxide complex. The cationic trivalent species exhibit a low solubility and are strongly adsorbed by soils and sediments, resulting in a low environmental mobility in the dissolved state (EBASCO, 1989i/RIC 89277R02, 03). Transport occurs as wind-blown dust and as suspended or bed load sediments in surface water. Remobilization of trivalent chromium following complexation with dissolved organic compounds may occur. Most naturally occurring chromium exists in the trivalent state. Where present in minerals, it is mobilized to different degrees depending on the solubility of the mineral in which it is contained.

Hexavalent chromium species are readily reduced to the trivalent state by ferrous iron (Fe^{-2}), dissolved sulfides, and certain organic compounds such as those present in soils. Trivalent chromium, by contrast, is oxidized slowly by oxygen under natural conditions due to kinetic inhibition of the reaction (Moore and Ramamoorthy, 1984b). Kinetic inhibition allows thermodynamically unstable trivalent chromium species to persist, particularly in the adsorbed state, even in well-oxygenated waters. Certain conditions, however, will allow interconversion of the trivalent and hexavalent states. Elemental chromium (Cr^O), used as an electroplated protective coating, is relatively inert in the environment.

None of the plants used as food or animal feed are chromium accumulators. Chromium absorbed by certain plants tends to remain primarily in the roots and is poorly translocated to the leaves. Bioconcentration factors calculated from experimental observations indicate a moderate potential for bioconcentration, but much lower than that for either mercury or cadmium. Chromium is rapidly eliminated from higher organisms, suggesting little potential for biomagnification.

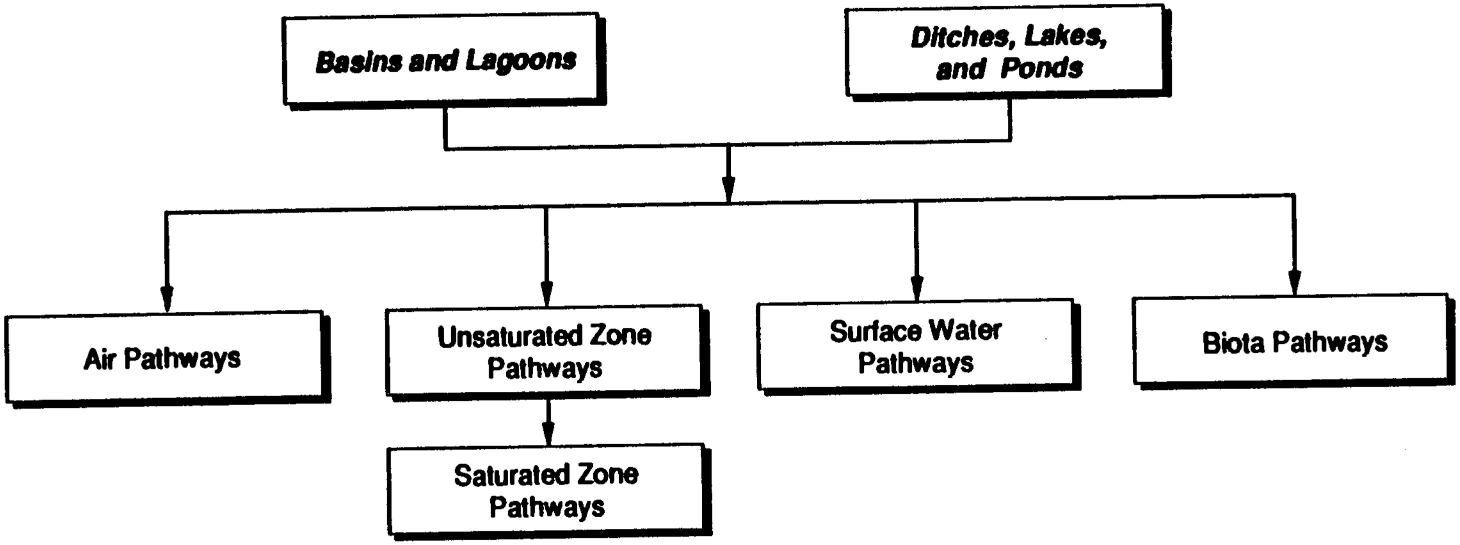
E.4 ENVIRONMENTAL FATE AND TRANSPORT PROCESSES

To aid in the understanding of the multitude of transport and migration processes affecting more than 100 analytes at 178 RMA sites, the following discussion addresses the dominant migration processes in surface water, unsaturated zone, saturated zone, air, and biota media. These transport processes comprise the most significant migration pathways in both surface and subsurface environments. A brief discussion of anthropogenic transport is also included, followed by a summary of predominant migration pathways for each RMA site type. The conclusions presented in the following sections reflect a summary and synthesis of the overall effort. Major conclusions have been emphasized here in order to convey the most important and widespread recurring trends at RMA. Discussion of exceptions and additional detail may be found in the documents listed below or referenced in the text. Flow charts are provide or schematic illustration (Figures RISR E.4-1 through RISR E.4-7), and Table RISR E.4-1 lists individual Study Area Report (SAR) sites and pathways most conducive to analyte transport. The bulk of the information was compiled from the individual SARs and media RI reports, with additional references provided where appropriate.

E.4.1 SURFACE WATER PROCESSES

Surface water may transport a wide variety of contaminants relatively rapidly by two mechanisms. Contaminants may be dissolved in the aqueous phase or they may travel in solid phase as suspended material or bed load sediments. Material may be entrained by erosion processes including wave and channel erosion, rainsplash erosion, and overland flow. These dissolved and suspended chemicals may be carried by surface flow to channels, ditches, lakes, or basins where they subsequently volatilize, infiltrate the soil column, remain in solution, or collect on the bottom sediments.

Physical properties of the contaminants and environmental conditions control the solution, stratification, and persistence of chemicals in surface water environments. In addition, cosolvent relationships and particle transport may enhance migration of compounds not readily soluble in water. Large surface areas facilitate atmospheric interaction, optimizing volatilization of dissolved compounds with high K_h values, including many VHOs, VAOs,



Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

Figure RISR E.4-1

Predominant Migration Pathways for Basins, Lagoons, Ditches, Lakes, and Ponds

Prepared by: Ebasco Services Incorporated

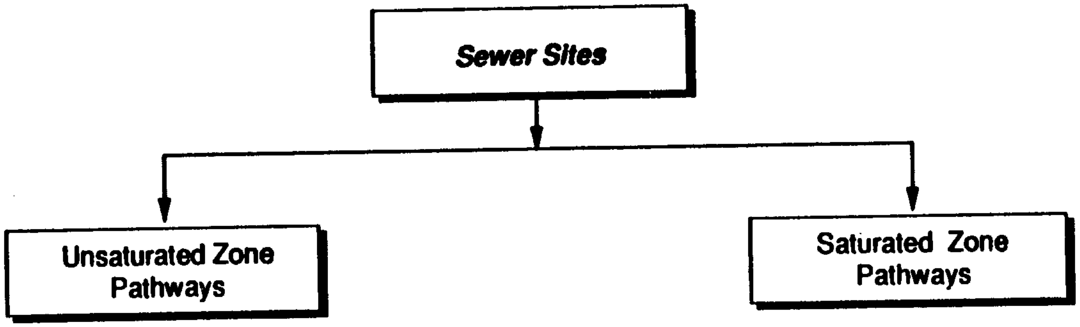


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Figure RISR E.4-2

Predominant Migration Pathways for Sewer Sites

Prepared by: Ebasco Services Incorporated

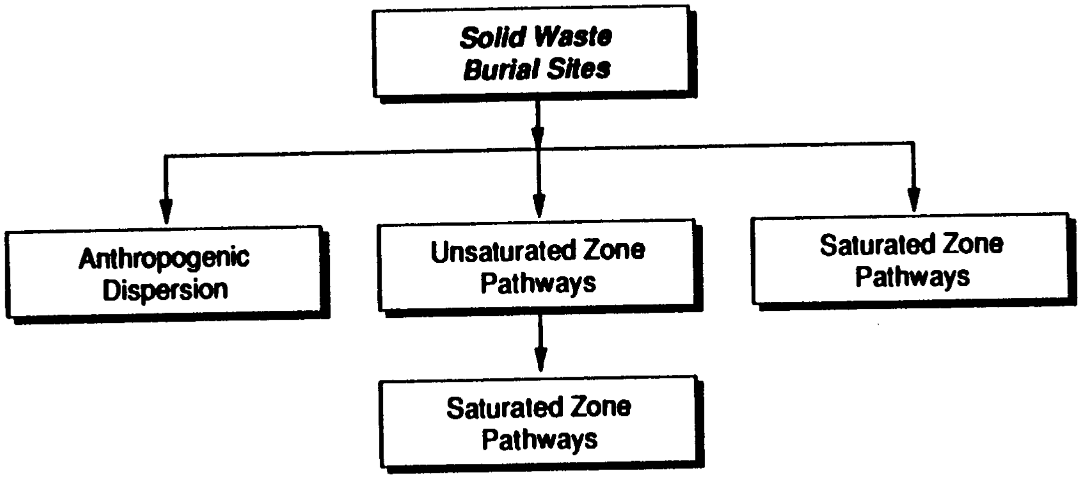

Figure RISR E.4-3

Predominant Migration Pathways for Solid Waste Burial Sites

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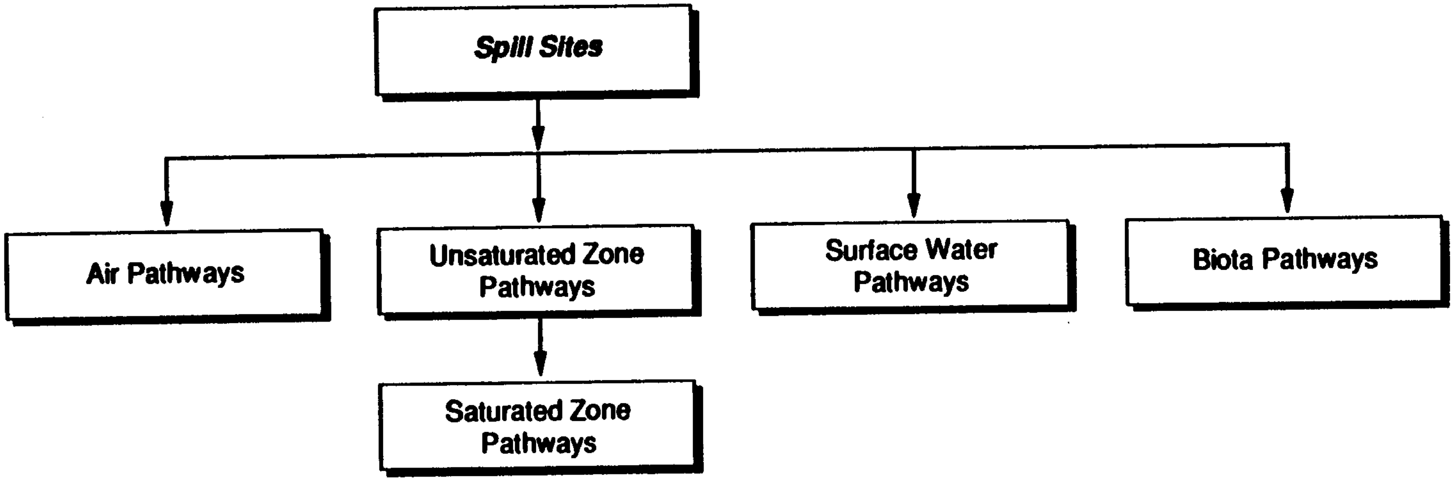

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Figure RISR E.4-4

Predominant Migration Pathways for Spill Sites

Prepared by: Ebasco Services Incorporated

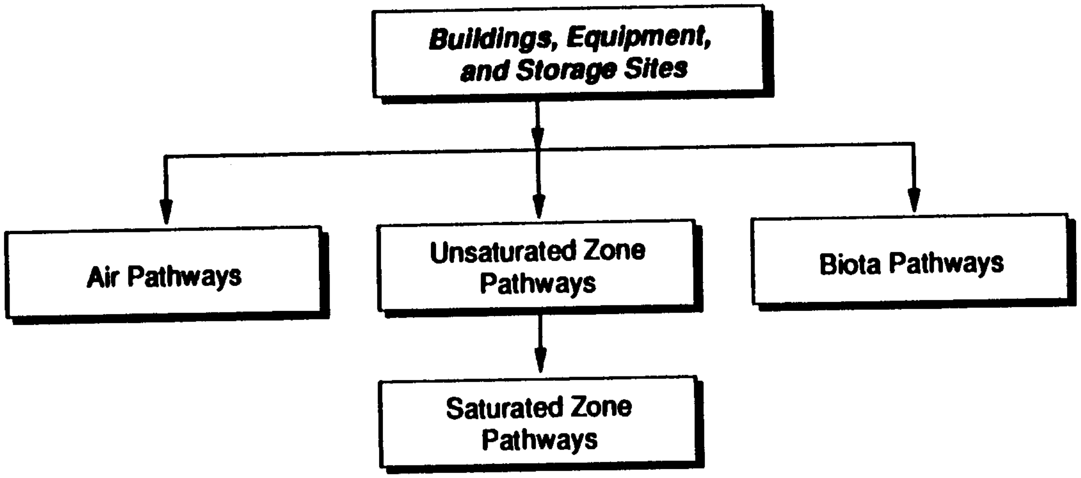

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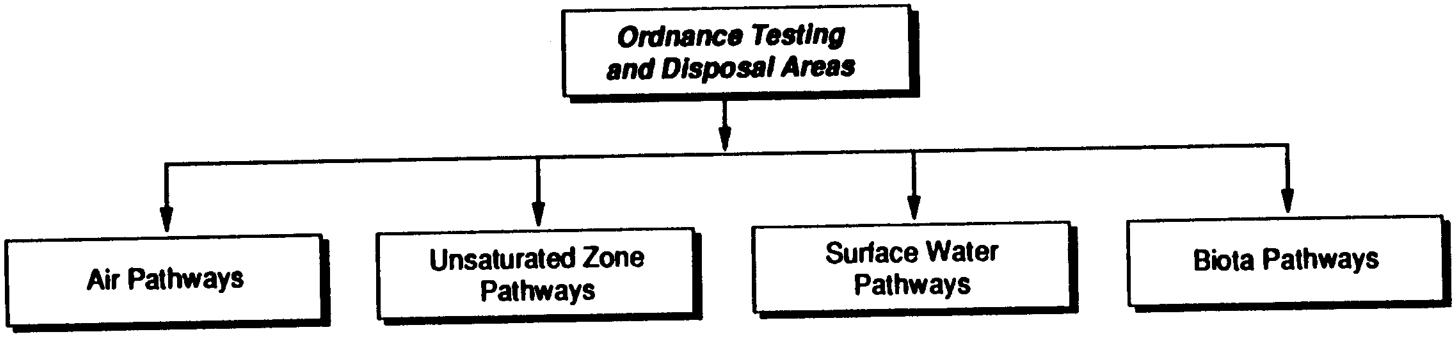
Figure RISR E.4-5

Predominant Migration Pathways for Buildings, Equipment, and Storage Sites

Prepared by: Ebasco Services Incorporated



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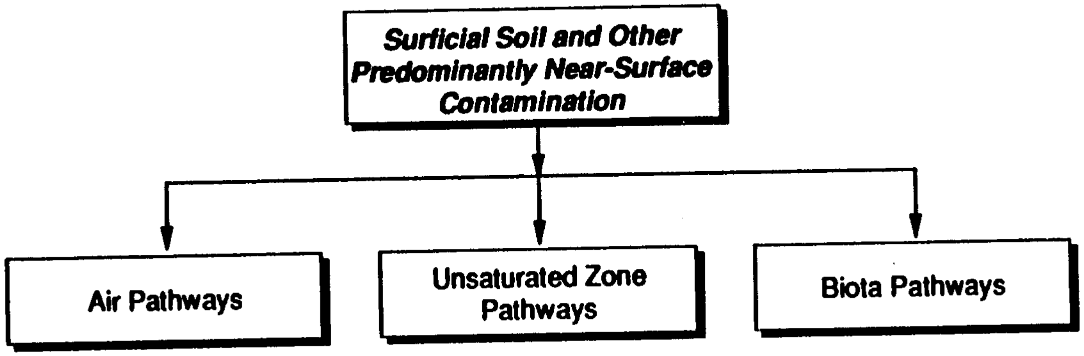
Prepared August 1991

Figure RISR E.4-6

Predominant Migration Pathways for Ordnance Testing and Disposal Areas

Prepared by: Ebasco Services Incorporated



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Prepared August 1991

Figure RISR E.4-7
Predominant Migration Pathways for Surficial Soil and Other Predominantly Near-Surface Contamination

Prepared by: Ebasco Services Incorporated

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

Site	Site Type	Spatially Analytes Detected	Predominant Modes of Environmental Transport				Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
			Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes			
NCSA-1a	Basins, Lagoons	VHO, MECL, VHC, OSCM, OSCH, OPHGB, DBCP, FC2A, SHO, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
NCSA-1b	Basins, Lagoons	VHO, VAO, VHC, OSCH, OPHGB, DBCP, FC2A, PAH, SHO, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
NCSA-1d	Basins, Lagoons	VHO, DBCP, SHO, OCP, AS, HG, ICP	No	Yes	X	X	X	X	X
NCSA-2a	Basins, Lagoons	VAO, OPHGB, FC2A, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
NCSA-2b	Basins, Lagoons	OSCH, OPHGB, FC2A, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
NCSA-2c	Basins, Lagoons	VHC, OSCH, OPHGB, FC2A, OCP, AS, ICP	Yes	Yes	X	X	X	X	X
NCSA-3	Basins, Lagoons	VHO, MECL, VAO, VHC, OSCM, OSCH, OPHP, GB, DBCP, PAH, SHO, OCP, AS, ICP	Yes	Yes	X	X	X	X	X
NCSA-5a	Basins, Lagoons	OSCM, OPHGB, FC2A, OCP, AS, HG, ICP	No	Yes			X	X	
NCSA-9s	Basins, Lagoons	HG	No	Yes	X	X	X		X
SPSA-12a	Basins, Lagoons	VHO, SHO, OCP, HG	No	Yes	X	X	X		X
SPSA-12b	Basins, Lagoons	OCP, HG, ICP	Yes	Yes	X	X	X	X	X
SPSA-1c	Basins, Lagoons	VHO, OCP, AS, HG	No	Yes	X	X	X		X
SPSA-1e	Basins, Lagoons	VHC, SHO, OCP, AS, HG,	Yes	Yes	X	X	X	X	X
SPSA-7b	Basins, Lagoons	VHO, OCP, AS	No	No	X	X	X		X
ESA-3h	Ditches, Lakes, Ponds	OSCM	Yes	No	X	X	X	X	X
ESA-3i	Ditches, Lakes, Ponds	VHO, HG, ICP	Yes	No	X	X	X	X	X
ESA-6c	Ditches, Lakes, Ponds	FC2A, AS, ICP	No	No	X	X	X		X
NCSA-1c	Ditches, Lakes, Ponds	OPHGB, OCP, AS, HG	Yes	Yes	X	X	X	X	X
NCSA-1f	Ditches, Lakes, Ponds	VHO, OPHGB, OCP, AS, HG	Yes	Yes	X	X	X	X	X
NCSA-2d	Ditches, Lakes, Ponds		No	Yes	X	X	X		X

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

Site	Site Type	Spatially Analytes Detected	Predominant Modes of Environmental Transport						
			Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes	Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
NCSA-5b	Ditches, Lakes, Ponds	VHC, OSCM, OPHGB, FC2A, SHO, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
NCSA-5c	Ditches, Lakes, Ponds	SHO, OCP, ICP	Yes	Yes	X	X	X	X	X
NCSA-5d	Ditches, Lakes, Ponds	OCP, ICP	No	Yes	X	X	X		X
NCSA-7	Ditches, Lakes, Ponds	OPHGB, OCP, ICP	Yes	Yes	X	X	X	X	X
NCSA-8b	Ditches, Lakes, Ponds	VHO, MECL, DBCP, OCP, AS, HG, ICP	No	Yes	X	X	X		X
NPSA-8a	Ditches, Lakes, Ponds	HG, ICP	No	No	X	X	X		X
NPSA-8b	Ditches, Lakes, Ponds	VHO, HG	No	Yes	X	X	X		X
NPSA-8c	Ditches, Lakes, Ponds	VHO, PAH, AS, HG, ICP	No	Yes	X	X	X		X
NPSA-1d	Ditches, Lakes, Ponds	OCP, HG	No	Yes	X	X	X		X
NPSA-2d	Ditches, Lakes, Ponds	HG	Yes	Yes	X	X	X	X	X
SPSA-3a	Ditches, Lakes, Ponds	VHO, OSCH	No		X	X	X		X
SPSA-4a	Ditches, Lakes, Ponds	HG, ICP	Yes	Yes	X	X	X	X	X
SPSA-5a	Ditches, Lakes, Ponds	PAH, ICP	No	No	X	X	X		X
SPSA-7a	Ditches, Lakes, Ponds	VHO	No	No	X	X	X		X
SPSA-8b	Ditches, Lakes, Ponds	OCP, HG, ICP	Yes	No	X	X	X	X	X
SPSA-9a	Ditches, Lakes, Ponds	HG, ICP	Yes	Yes	X	X	X	X	X
SSA-1a	Ditches, Lakes, Ponds	OCP, AS, HG	Yes	No	X	X	X	X	X
SSA-1b	Ditches, Lakes, Ponds	VHO, SHO, OCP, AS, HG, ICP	Yes	No	X	X	X	X	X
SSA-1c	Ditches, Lakes, Ponds	DBCP, OCP, HG, ICP	Yes	No	X	X	X	X	X

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

			Predominant Modes of Environmental Transport						
Site	Site Type	Spatially Analytes Detected	Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes	Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
SSA-1d	Ditches, Lakes, Ponds	VHO, OCP, HG	Yes	No	X	X	X	X	X
SSA-1e	Ditches, Lakes, Ponds	VHO, MECL, DBCP, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
SSA-1f	Ditches, Lakes, Ponds	MECL, OCP, HG	No	No	X	X	X		X
SSA-2a	Ditches, Lakes, Ponds	OCP, HG, ICP	No	No	X	X	X		X
SSA-2b	Ditches, Lakes, Ponds	SHO, OCP, HG, ICP	Yes	Yes	X	X	X	X	X
SSA-2c	Ditches, Lakes, Ponds	VHO, MECL, OCP, AS, HG	Yes	No	X	X	X	X	
SSA-5b	Ditches, Lakes, Ponds	VHO, OCP, AS, HG, ICP		No	X	X	X	X	X
SSA-5e	Ditches, Lakes, Ponds	DBCP, ICP		No	X	X	X	X	X
WSA-6a	Ditches, Lakes, Ponds	VHO, VAO, OSCH, DBCP, PAH, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
WSA-6d	Ditches, Lakes, Ponds	ICP	Yes	Yes	X	X	X	X	X
WSA-6e	Ditches, Lakes, Ponds	HG, ICP	No	Yes	X	X	X		X
CSA-3	Sewer	OPHGB, HG	No	Yes			X		
NCSA-4a	Sewer	VHO, MECL, DBCP, PAH, OCP, HG, ICP	No	Yes			X		
NCSA-6a	Sewer	VHO, VAO, VHC, OSCH, DBCP, SHO, OCP	Yes	Yes			X	X	
NCSA-6b	Sewer	OSCH, OPHGB, OCP, HG	No	Yes			X		
NCSA-8a	Sewer	VHO, OCP, ICP	No	Yes			X		
NPSA-1	Sewer	OPHGB, HG	Yes	Yes			X	X	
SPSA-10	Sewer	VHO, VAO, VHC, OSCM, OPHP, DBCP, SHO, OCP, AS, HG, ICP	Yes	Yes			X	X	
SPSA-11	Sewer	OCP	No	Yes			X		
SPSA-12	Sewer	OCP, AS, HG	Yes	Yes			X	X	
WSA-7a	Sewer	HG, ICP	No	Yes					
CSA-1a	Solid Waste Burial	VHO, MECL, VAO, OSCM, OPHGB, DBCP, FC2A, PAH, SHO, OCP, AS, HG, ICP	Yes	Yes			X	X	
CSA-1b	Solid Waste Burial	MECL, VAO, OSCM, OPHGB, DBCP, FC2A, SHO, OCP, AS, HG	Yes	Yes			X	X	

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA. Page 4 of 7.

			Predominant Modes of Environmental Transport						
Site	Site Type	Analytes Detected	Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes	Unsaturated Zone Processes	Saturated Zone Processes	Spatially Biota Processes
CSA-1c	Solid Waste Burial	VHO, MECL, VAO, OSCM, OPHGB, DBCP, FC2A, PAH, SHO, OCP, AS, HG, ICP	Yes	Yes			X	X	
CSA-1d	Solid Waste Burial	MECL, OPHGB, FC2A, PAH, OCP, AS, HG, ICP	Yes	No			X	X	
ESA-2b	Solid Waste Burial	VHO, VAO, OSCH, OCP, HG	Yes	No			X	X	
ESA-3k	Solid Waste Burial	OSCM, ICP	No	No					
NCSA-1e	Solid Waste Burial	OSCM, SHO, OCP, AS, HG, ICP	Yes	Yes			X	X	
SPSA-1f	Solid Waste Burial	SHO, OCP, HG	Yes	Yes			X	X	
SPSA-8a	Solid Waste Burial	SHO, OCP, AS, HG, ICP	Yes	No			X	X	
SSA-3a	Solid Waste Burial	OCP, HG, ICP	No	No			X		
SSA-3b	Solid Waste Burial	DBCP, SHO, OCP, HG	No	No			X		
WSA-2	Solid Waste Burial	VHO, PAH, SHO, OCP, AS, HG, ICP	Yes	Yes			X	X	
WSA-3b	Solid Waste Burial	SHO	No	Yes			X		
WSA-3c	Solid Waste Burial	VHO, ICP	No	Yes			X		
WSA-5a	Solid Waste Burial	VHO, VHC, SHO, OCP, AS, HG	No	Yes			X		
WSA-5b	Solid Waste Burial	VHO, HG, ICP	No	Yes			X		
WSA-5c	Solid Waste Burial	VHO, VHC, SHO, OCP, AS, HG	No	Yes			X		
WSA-5d	Solid Waste Burial	VHO, VHC, SHO, OCP, AS, HG	No	Yes			X		
ESA-3f	Spill	VHO, OSCM, FC2A, ICP	No	No					
ESA-3g	Spill	OSCM	Yes	No	X		X	X	X
NCSA-8c	Spill	HG	No	No	X				X
NPSA-6	Spill	VAO, OPHGB, OCP, AS, HG, ICP	Yes	Yes	X		X	X	X
NPSA-7	Spill		No	Yes	X		X		X
NPSA-9a	Spill	VAO, PAH	No	No	X		X		X
NPSA-9d	Spill	VAO, ICP	No	Yes	X		X		X
NPSA-9e	Spill	VHC	No	No	X		X		X
WSA-1a	Spill	PAH	No	No	X		X		X
WSA-1b	Spill	VHO, VAO, PAH	No	No	X		X		X
WSA-1c	Spill	PAH	No	No	X		X		X
WSA-1e	Spill	DBCP	Yes	Yes	X		X	X	X
WSA-7b	Spill	HG	No	No	X		X		X
CSA-2b	Buildings, Equipment, Storage	VAO, PAH, OCP, HG, ICP	No	No	X	X	X		X
ESA-3a	Buildings, Equipment, Storage	OSCM	Yes	No	X	X	X	X	X
ESA-3b	Buildings, Equipment, Storage	VHC, OSCM, AS, ICP	Yes	No	X	X	X	X	X

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

		Spatially	Predominant Modes of Environmental Transport						
Site	Site Type	Analytes Detected	Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes	Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
ESA-3c	Buildings, Equipment, Storage	VHO, ICP	No	No	X	X	X		X
ESA-3d	Buildings, Equipment, Storage	VHC, OSCM, OSCH, ICP	Yes	No	X	X	X	X	X
ESA-3e	Buildings, Equipment, Storage	VHO, OPHGB	No	No	X	X	X		X
ESA-5	Buildings, Equipment, Storage	FC2A	No	No	X	X	X		X
ESA-6a	Buildings, Equipment, Storage	ICP	No	No	X	X			X
NPSA-2	Buildings, Equipment, Storage	VHO, VAO, ICP	Yes	Yes	X	X	X	X	X
NPSA-3	Buildings, Equipment, Storage	VHO, OPHGB, OCP, ICP	Yes	Yes	X	X	X	X	X
NPSA-4	Buildings, Equipment, Storage	OSCM, ICP	No	Yes	X	X	X		X
NPSA-5	Buildings, Equipment, Storage	VHO, VAO, OPHGB, AS, HG, ICP	No	Yes	X	X	X		X
SPSA-1a	Buildings, Equipment, Storage	VHO, VAO, VHC, OSCM, OSCH, OPHP, DBCP, PAH, SHO, OCP, AS, HG, ICP	Yes	Yes	X	X	X	X	X
SPSA-1b	Buildings, Equipment, Storage	VHO, VHC, OSCM, OSCH, OCP, HG, ICP	No	Yes	X	X	X		X
SPSA-2a	Buildings, Equipment, Storage	VHO, VAO, VHC, DBCP, SHO, OCP, ICP	Yes	Yes	X	X	X	X	X
SPSA-2b	Buildings, Equipment, Storage	VHO, VAO, VHC, SHO, OCP, ICP	Yes	Yes	X	X	X	X	X
SPSA-2c	Buildings, Equipment, Storage	VHO, VHC, SHO, OCP, HG, ICP	Yes	Yes	X	X	X	X	X
SPSA-3b	Buildings, Equipment, Storage	VHO, VHC, OSCH, OPHGB, OPHP, DBCP, SHO, OCP, AS, HG, ICP	No		X	X	X		X
SPSA-3c	Buildings, Equipment, Storage	VHO, VHC, SHO, OCP, HG, ICP	No	Yes	X	X	X		X
SPSA-3d	Buildings, Equipment, Storage	VHC, SHO, OCP, ICP	No	No	X	X	X		X
SPSA-6	Buildings, Equipment, Storage	VHC, SHO, OCP, AS, HG, ICP	No	No	X	X	X		X
SSA-4	Buildings, Equipment, Storage	VHO, SHO, OCP, HG	No	No	X	X	X		X
WSA-4b	Buildings, Equipment, Storage	VHO, VAO, HG, ICP	Yes	Yes	X	X	X	X	X

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

Site	Site Type	Spatially Analytes Detected	Predominant Modes of Environmental Transport				Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
			Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes			
WSA-6b	Buildings, Equipment, Storage	VAO, VHC, PAH, ICP	No	Yes	X	X	X		X
WSA-6c	Buildings, Equipment, Storage	VHO, AS	Yes	Yes	X	X	X	X	X
CSA-2a	Ordnance Testing	FC2A, OCP, HG, ICP	No	Yes	X				X
CSA-2c	Ordnance Testing	VAO, HG	No	No	X		X		X
CSA-2d	Ordnance Testing	VHO, VAO, PAH, ICP	No	No	X		X		X
ESA-1a	Ordnance Testing	VAO, OSCH, PAH, ICP	No	No	X	X	X		X
ESA-1b	Ordnance Testing	PAH, ICP	No	No	X	X			X
ESA-1c	Ordnance Testing	PAH, AS, HG, ICP	No	No	X	X			X
ESA-1d	Ordnance Testing	AS, ICP	No	No	X	X			X
ESA-2a	Ordnance Testing	VHO, VAO, PAH, ICP	Yes	No	X		X	X	X
ESA-2c	Ordnance Testing	FC2A, OCP, HG, ICP	No	No	X		X		X
ESA-4a	Ordnance Testing	ICP	No	No	X		X		X
ESA-4b	Ordnance Testing	HG, ICP	No	No	X				X
ESA-4c	Ordnance Testing	VHO, ICP	No	No	X		X		X
CSA-4	Windblown/Other	SHO, OCP, HG, ICP	No	Yes	X				X
NCSA-1g	Windblown/Other	OCP, HG, ICP	No	Yes	X				X
NCSA-4b	Windblown/Other	MECL, VHC, OSCH, OPHGB, FC2A, PAH, SHO, OCP, HG, ICP	Yes	Yes	X		X	X	X
SPSA-1g	Windblown/Other	VHO, VAO, VHC, OSCH, SHO, OCP, AS, HG, ICP	No	Yes	X		X		X
SPSA-2e	Windblown/Other	VAO, VHC, DBCP, SHO, OCP, AS, HG, ICP	No	Yes	X		X		X
SPSA-3e	Windblown/Other	VHO, VAO, VHC, PAH, SHO, OCP, AS, HG, ICP	No	Yes	X		X		X
SPSA-4b	Windblown/Other	VHO, VHC, PAH, SHO, OCP, AS, HG, ICP	No	Yes	X		X		X
SPSA-5b	Windblown/Other	VHO, VAO, VHC, PAH, SHO, OCP, AS, HG, ICP	No	Yes	X	X	X		X
SPSA-7c	Windblown/Other	VAO, PAH, OCP, AS, HG, ICP	No	Yes	X		X		X
SPSA-8c	Windblown/Other	VAO, SHO, OCP, AS, HG	No	Yes	X		X		X
SPSA-9b	Windblown/Other	OCP, AS, HG, ICP	No	Yes	X				X
ESA-3j	Isolated	OSCH	No	No					
ESA-6b	Isolated	SHO	No	No					
ESA-6d	Isolated	ICP	No	No		X			
NCSA-9a	Isolated	OPHGB	No	Yes					
NCSA-9b	Isolated	ICP	No	No					
NCSA-9c	Isolated	ICP	No	No					
NCSA-9d	Isolated	VHO, ICP	No	Yes					
NCSA-9e	Isolated	ICP	No	Yes					
NCSA-9f	Isolated	ICP	No	No					

Table RISR E.4-1. Predominant Analyte Transport Processes Associated with Individual Sites at RMA.

Site	Site Type	Spatially Analytes Detected	Predominant Modes of Environmental Transport: Potential Groundwater Source	Associated Plume	Air Processes	Surface Water Processes	Unsaturated Zone Processes	Saturated Zone Processes	Biota Processes
							NCSA-9h	Isolated	ICP Yes
NCSA-9g	Isolated	MECL, ICP	No	Yes					
NCSA-9i	Isolated	VHC	No	Yes					
NCSA-9j	Isolated	HG	No	Yes					
NCSA-9k	Isolated	VHO	No	Yes					
NCSA-9l	Isolated	AS	No	No	X				
NCSA-9m	Isolated	ICP	No	Yes					
NCSA-9n	Isolated	VHO	No	No					
NCSA-9o	Isolated	AS	No	No					
NCSA-9p	Isolated	AS, HG	No	No					
NCSA-9q	Isolated	HG	No	Yes	X				
NCSA-9r	Isolated	ICP	No	Yes					
NPSA-9b	Isolated	ICP	No	No					
NPSA-9c	Isolated	ICP	No	No					
NPSA-9f	Isolated	AS	No	No					
SSA-5a	Isolated	DBCP	No	No					
SSA-5c	Isolated	ICP	No	No					
SSA-5d	Isolated	ICP	No	No					
WSA-1d	Isolated	ICP	No	Yes					
WSA-1f	Isolated	OCP	No	Yes					
WSA-1g	Isolated	HG	No	Yes					
WSA-3a	Isolated	VHO, VAO, ICP	No	Yes					
WSA-3d	Isolated	VHC	No	Yes					
WSA-4a	Isolated	VHC	No	Yes					
WSA-8a	Isolated	ICP	No	No					
WSA-8b	Isolated	ICP	No	No					
WSA-8c	Isolated	VHO	No	Yes					
WSA-8d	Isolated	OPHGB	No	No					
WSA-8e	Isolated	OPHGB	No	No					
WSA-8f	Isolated	PAH		No					

Note: There is no evidence available to determine if isolated detections are due to migration from some source of contamination so no modes of transport are listed.

Abbreviations:

VHO	Volatile Halogenated Organics	SHO	Semivolatile Halogenated Organics
MECL	Methylene Chloride	OCP	Organochlorine Pesticides
VHC	Volatile Hydrocarbon Compounds	As	Arsenic
VAO	Volatile Aromatic Organics	Hg	Mercury
OSCM	Organosulfur Compounds, Mustard Related	ICP	ICP Metals
OPHGB	Organophosphorus Compounds, GB-Agent Related		
OPHPH	Organophosphorus Pesticides		
DBCP	Dibromochloropropane		
FC2A	Fluoroacetic Acid		
PAH	Polynuclear Aromatic Hydrocarbons		

VHCs, and several SHO compounds. Photolysis, oxidation, hydrolysis, and biotransformation may also decrease the persistence of compounds within this environment.

Transport in surface water may ultimately lead to subsequent migration of contaminants by groundwater, air, and biota migration pathways. In addition, surface water provides a major exposure pathway to both aquatic and terrestrial biota. Once ingested or absorbed, these contaminants are subject to transport by various biotic processes.

Analyte migration potential in surface water is limited by the hydrologic aspects of the various study areas at RMA. The influence of surface water on contaminant migration is further discussed on a more source-specific basis in the latter part of this section.

E.4.2 UNSATURATED ZONE PROCESSES

The unsaturated zone is both a critical pathway and a retarding medium between surface sources and underlying groundwater systems at RMA. Contaminants are predominantly transported by infiltration of liquid wastes, wastewater, or surface water containing dissolved or suspended contaminants. In addition, vapor migration in soils allows upward, lateral, and downward diffusion of gas phases, and may significantly contribute to the attenuation of many volatile organic compounds. Infiltration and volatilization processes in the unsaturated zone are further described below.

For organic compounds, infiltration potential is primarily a function of aqueous solubility, K_d, and permeability of the underlying soil. Consequently, compounds such as OCPs and PAHs, which display an affinity for solid phases, tend to leach less readily through the soil column than other organic compounds. This results in limited mobility in the unsaturated zone. In contrast, the VHOs, VHCs, VAOs, OSCMs, OPHGBs, DBCP, fluoroacetic acid, and SHOs, which have moderate to high aqueous solubilities and moderate to low K_d, tend to partition into soil water and infiltrate the soil column until environmental conditions cause interruption of transport. The migration of inorganic compounds is complex and influenced by numerous factors. In general, arsenic, mercury, and the ICP metals tend to remain near source areas, exhibiting highly retarded migration in the unsaturated zone at RMA.

The nature of the host material strongly influences transport. Parameters such as Eh, pH, permeability, moisture content, and composition affect processes such as sorption and desorption, degradation and transformation, and inorganic specification. Clay layers tend to increase sorption and cation exchange capacity, which further retards transport. Relatively high organic carbon contents, generally found in shallow soils or lake bed sediments, also tend to increase sorption of organic and inorganic constituents. Organic carbon contents may range from 2.6 percent in topsoil and root zone layers (J.P. Walsh and Associates, 1988) to less than 0.01 percent in aquifer sediments (ESE, 1988a/RIC 88243R01). It should be noted that primary contaminant sources, as well as secondary sources resulting from transport and subsequent deposition of contaminants in favorable subsurface horizons, result in releases to the environment that vary spatially and temporally with changes in local conditions.

Cosolvency has appeared to facilitate transport of many organic compounds that are not readily mobilized in the unsaturated zone. The historical practice of disposing solvents with pesticides and other products provides a possible explanation for wide distribution of analytes that normally display low mobility. Reductions in analyte retardation resulting from sediment heterogeneity may also increase analyte mobilities, most notably for those that normally exhibit limited movement in the unsaturated zone. Despite these local variabilities in contaminant mobility between sites, the relative mobility of most contaminants is fairly predictable.

Vapor migration can result in transport of volatile organic compounds in contaminated soils or permeable sediments that overlie volatile contaminant plumes. The degree of vapor movement is determined not only by chemical volatility of the contaminant but also by the adsorptive properties of the affected soil and the vapor gradients established between the contaminated horizon and the ground surface.

In addition to volatilization, attenuation and transformation in unsaturated sediments may occur by a number of other mechanisms that vary depending upon local environmental conditions. In surficial and shallow soils, hydrolysis, photolysis, oxidation, and biotransformation may result in significant attenuation of organic compounds that are amenable to these processes. Generally, the rate and effectiveness of these processes decrease with depth as a result of limited sunlight, water, and atmospheric exchange. The upper unsaturated zone provides a critical exposure pathway to terrestrial biota. Analytes present in the root zone are available for plant uptake, and terrestrial animals risk exposure by incidental ingestion, dermal contact, and inhalation. Exposure to analytes in the unsaturated zone may result in contaminant accumulation and transport in biotic systems.

In summary, the significant migration pathways for contaminant transport in the unsaturated zone include processes of infiltration and leaching and, to a lesser extent, vapor migration and plant uptake. Transport in the unsaturated zone may ultimately lead to migration within the saturated zone, air, or biota pathways.

E.4.3 SATURATED ZONE PROCESSES

Groundwater functions as the primary migration pathway for many contaminants at RMA. Groundwater transport is controlled primarily by the processes of advective flow and dispersion. Advective flow is the process by which solutes are transported by the bulk motion of flowing groundwater. It is the dominant process by which dissolved contaminants migrate in granular sediments. Dispersion results from the processes of molecular diffusion due to the thermal-kinetic energy of the solute particles and mechanical mixing during fluid advection (Freeze and Cherry, 1979). Dilution tends to result from dispersion, thereby reducing maximum concentrations of analytes with increasing distance from the source.

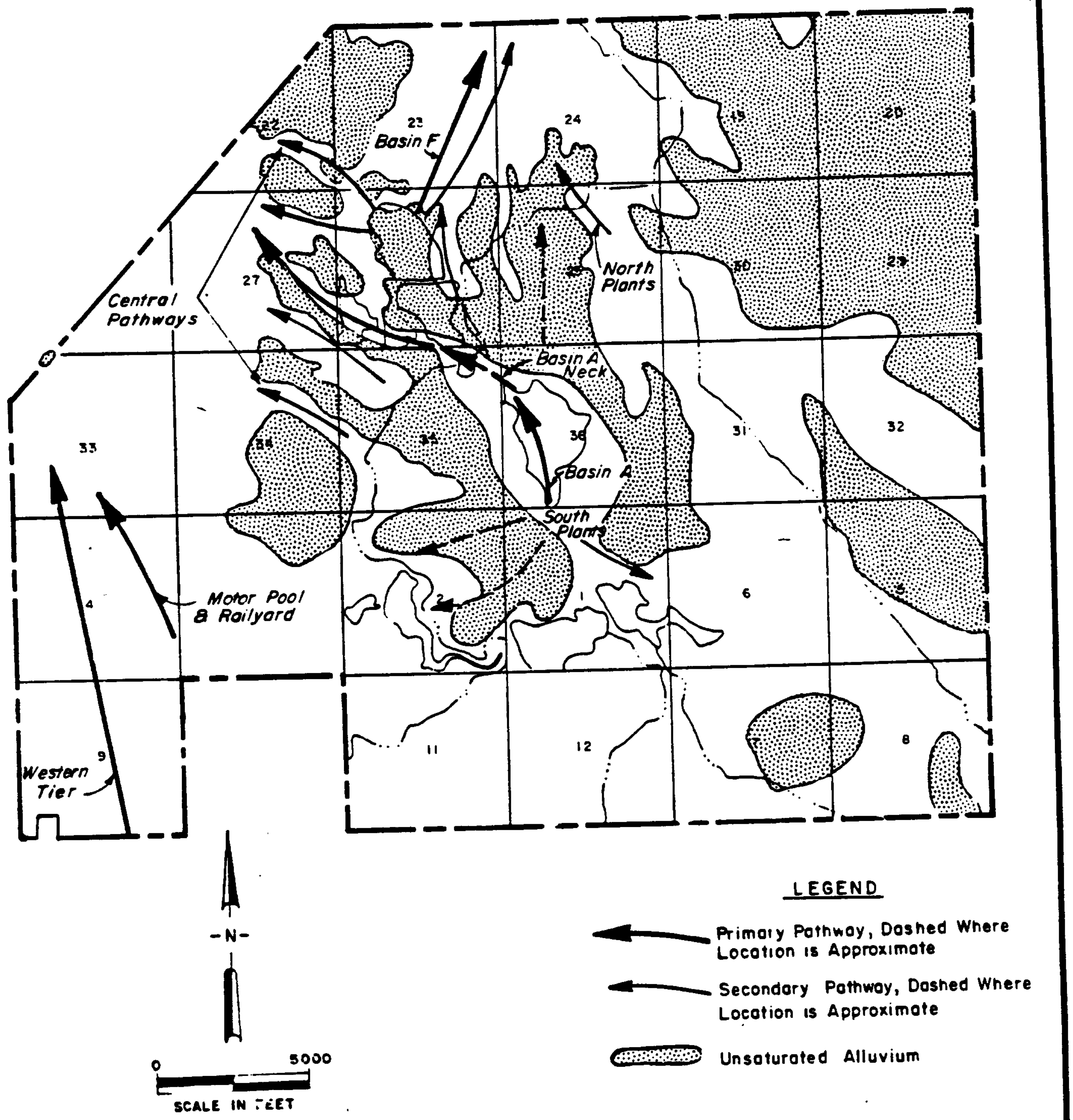
Two types of saturated zones, which vary in their effectiveness as migration pathways, exist at RMA. Artificial impoundments commonly create downward hydraulic gradients, thereby generating saturated and semisaturated zones that extend variable depths from the basin floor toward the water table. These phenomena may diminish and even eliminate unsaturated zones in some areas, thus greatly reducing transport time relative to migration through a comparable thickness of unsaturated sediments. The second type exists below the water table, where the unconfined flow system provides relatively efficient migration pathways that are responsible for the extensive distribution of many analytes. Both types of saturated conditions are spatially and temporally variable due to annual, seasonal, and local climatic variations, as well as engineered controls.

Locally, sandy soils and closed depressions allow surface water infiltration that results in recharge to the unconfined aquifer. In addition, wastewater discharges, sewer leaks, and chemical spills are capable of infiltrating directly to the water table. Contaminant sources located below the water table are in direct hydraulic connection with the groundwater system. Examples of sources for direct migration may include underground storage tanks, transfer pipelines, sewers, sumps, basins, ditches, and disposal pits. Once introduced to the unconfined flow system, these contaminants are transported laterally over significant distances at RMA and parts of the off-post area. Well-defined flow paths identified by hydrologic assessments and contaminant plume configurations are described in the water RI (EBASCO, 1989d/RIC 89186R01), and are shown in Figure RISR E.4-8. Data from this same report generally show poor correlation between analyte concentrations from adjacent wells within the deeper confined flow system. Although subject to local recharge from the unconfined flow system, the confined groundwater system in the Denver Formation shows limited potential for lateral contaminant transport.

Most target analytes exhibit some degree of retardation with respect to groundwater flow rates. Retardation rates are subject to changes in organic carbon and clay contents, grain size, and iron or manganese oxide concentrations. The heterogeneity of saturated zone sediments and their resulting impact on analyte transport at RMA has been discussed by Mackay and Cherry (1989).

Biological and chemical processes that transform contaminants in the surface environment are generally less efficient in the subsurface. Available sunlight, atmospheric exchange, and nutrients become significant rate-limiting factors for degradation processes in groundwater. Volatilization of volatile organic compounds (VOCs) is capable of attenuating concentrations in groundwater, although the effectiveness is controlled by the thickness of the overlying unsaturated zone, soil permeability, and moisture content, and by VOC vapor concentration gradients. Henry's law constants indicate the ability of each dissolved contaminant to volatilize from groundwater, and vapor pressure controls the volatilization of nonaqueous phase liquids. Thus, rates of volatilization are dependent on individual chemical properties, permeability, and VOC vapor concentration gradients in the unsaturated zone.

In summary, migration pathways in the unconfined flow system dominate lateral and vertical transport in the saturated zone. Isolated saturated zones extending below surface water bodies are capable of efficiently transporting analytes in a dominantly vertical direction. Once



Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR E.4-8

RMA Contaminant Migration Pathways

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

introduced to the unconfined flow system, these analytes may be transported in both lateral and vertical directions. The potential for lateral contaminant migration in confined water-bearing zones of the Denver Formation is considered substantially less than in the alluvium of the unconfined flow system.

E.4.4 AIR PROCESSES

Eolian (wind blown) transport appears to be the most important atmospheric migration pathway at RMA. However, volatilization from surface water and soils has accounted for detectable concentrations of volatiles and semivolatiles, particularly peripheral to disposal basins in the North Central Study Area (NCSA). Such detections occurred sporadically in close proximity to sources during periods in which atmospheric conditions were considered favorable for elevated concentrations of volatiles and semivolatiles (ESE, 1988b/RIC 88263R01).

Surficial soil contaminants exhibiting a high affinity to solid surfaces are candidates for eolian transport, including OCPs, PAHs, chlorophenylmethyl sulfide, ICP metals, arsenic, and mercury. Contaminants transported by this pathway are dispersed and redistributed in surface soil. Distribution is controlled largely by high-event winds because wind speed influences the entrainment of particles and also the momentum with which airborne particles will travel (Hartley and Graham-Bryce, 1980). High wind speed events are dominantly from the west and south at RMA. Particle size and bulk density are two key factors in controlling eolian transport of surficial soil. Finer particles travel farther than coarser, heavier grains. The most erodible particles are considered to be approximately 0.1 millimeter (mm) in diameter or smaller.

Volatilization from surface water, soil moisture, or groundwater is significant for compounds with high K_h values such as the VHOs, VAOs, and some VHCs. Evaporation of water may also enhance the volatilization of some semivolatile compounds such as dieldrin (Jury, 1986).

Volatilization, photolysis, oxidation, and hydrolysis are responsible for transformation and attenuation of many RMA analytes that are transported by air pathways. The relative importance of these mechanisms and their rates may vary considerably for different analytes. Most volatile compounds do not persist in surface soils long enough to be dispersed by eolian transport. In the atmospheric environment, exposure to biota is primarily by inhalation and skin contact. Some analytes such as lead may be absorbed through the leaves of sensitive plant species.

In summary, eolian transport is considered the primary air pathway for less mobile constituents at RMA, although volatilization may also be significant for volatile and semivolatile compounds near spills and surface water bodies. Contaminants that are transported by blowing dust typically display a strong affinity for solid phases and generally exhibit limited migration in the unsaturated zone.

E.4.5 BIOTA PROCESSES

Results of the RI and previous biota investigations at RMA have indicated that bioaccumulation has occurred for some analytes and has resulted in toxic effects to both plants and animals. Pathways analyses show that bioaccumulation occurs for all selected contaminants of concern (see Biota RI Report, ESE, 1989/RIC 89173R02), particularly the OCPs. Exposure resulting from ingestion, inhalation, or skin contact produces varying degrees of accumulation and transformation for individual analytes in sensitive species. Many factors affect the tendency for plants and animals to absorb and concentrate contaminants, including: soil and water characteristics; contaminant concentrations, solubilities, and partition coefficients; and species and tissue types, vegetative cover, and animal migratory patterns (EPA, 1983; Rouchaud and Meyer, 1982; Kaufman, 1983). Contaminant transport and accumulation in biological systems generally do not lead to significant accumulation in abiotic systems.

E.4.6 ANTHROPOGENIC TRANSPORT

Anthropogenic transport is defined, for the purposes of the RI, to include any human activities that result in contaminant migration that would otherwise not occur. Examples of anthropogenic transport include transport of potentially contaminated soil, mud, or dust adhering to vehicles, and ground surface modifications including excavations, grading, or fill placement of potentially contaminated materials.

The significance of the first anthropogenic mechanism is difficult to assess but is expected to be limited to roadways or heavily traveled tracks. However, restricted access and present decontamination and health and safety practices at RMA are specifically designed to prevent or reduce further spread of contaminants by this mechanism. Ground surface modifications are a factor to consider when assessing historical contaminant fate and transport. Routine and emergency actions (such as filling basins, lakes, and ditches with runoff or other surface water; solid waste burial practices; or regular ditch maintenance activities) historically had the potential for spreading contaminants into uncontaminated media.

E.5 CONTAMINANT MIGRATION PATHWAYS

The following section presents discussions of contaminant migration pathways, summarized by analyte group, for the various media at RMA. Emphasis is placed on major contaminant sources, pathways and exposure routes that were determined from the SARs for each of the 16 contaminant groups described in Section E.3.2. Generally, the distribution of contaminants is consistent with conceptual models developed by evaluating disposal history, predicted behavior, and site-specific environmental parameters. Discussions here have been generalized and simplified to highlight the most significant sources and pathways; however, exceptions do occur. Additional detail is provided in the individual SARs and media reports.

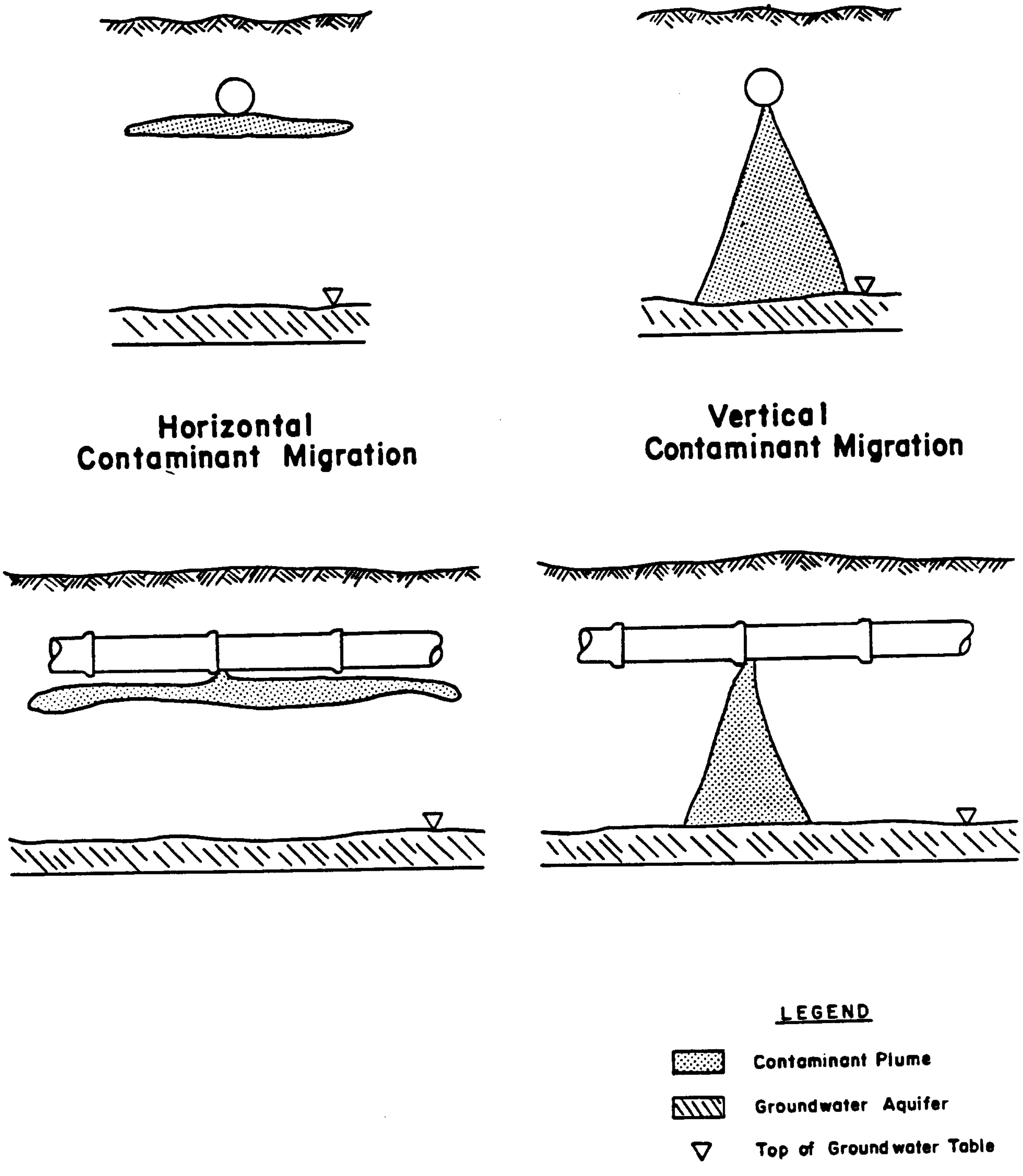
E.5.1 VOLATILE HALOGENATED ORGANICS

The VHOs exhibit a relatively widespread distribution throughout RMA, with occurrences in all study areas and within all site types. VHOs were detected in all media sampled, with repeated occurrences of all target analytes within the group. In accordance with their expected behavior, the VHOs were most widely distributed in surface and groundwaters, with less frequent occurrences detected in soil and air media.

The South Plants, Basin A, and Basin F have released the largest mass of VHOs to the environment. Spills and disposal of VHOs from the chloroform manufacturing plant, as well as other process facilities in the South Plants, are responsible for contamination of five groundwater plumes emanating from the groundwater mound below the South Plants complex. VHOs concentrations in the Basin F Pathway and Basin A/Basin A Neck Pathways are attributed to release from the respective basins. The North Plants facility was also a source of VHO releases; most notably, the tank farm used to store solvents for chemical agent manufacture. Additional sources of VHOs include landfills in the Western Study Area (WSA), disposal trenches in the Central Study Area (CSA) and Eastern Study Area (ESA), and other disposal basins and interconnecting ditches of the NCSA. Leaking portions of the chemical sewer apparently released significant quantities of VHOs into sediments and groundwater in the southwestern corner of Section 36 and adjacent to Basin F and the deep well area. The lakes in the Southern Study Area (SSA) received VHO-contaminated surface water and groundwater from the South Plants complex, thereby causing these lakes to act as a secondary source of VHO contamination. In addition, storage and building sites, spills, and isolated sites exhibiting VHO contamination occur in manufacturing, storing, and disposal areas at RMA. In addition to on-post sources, a major influx of trichloroethylene enters the unconfined aquifer in the Western Study Area from off-post sources south of RMA.

The most significant releases of VHOs to the environment historically involved migration from disposal basins, underground storage tanks, solid waste burial trenches, and leaking sewer lines. VHOs dissolved in surface water infiltrated the underlying sediments, reaching the unconfined aquifer below many of the basins. Although this pathway accounts for relatively low volume of recharge to groundwater flow, it provides an effective transport pathway for VHO compounds. Migration from the bottom of disposal trenches, underground tanks, and leaking sewer lines both above and below the water table has also led to relatively efficient VHO migration and minimal retardation prior to reaching the unconfined aquifer. Possible contaminant migration pathways resulting from sewer leakage are illustrated in Figure RISR E.5-1. Once introduced to the unconfined flow system, VHOs are capable of migrating significant distances in both lateral and vertical directions.

Limited retardation in alluvial sediments has permitted VHOs to migrate efficiently through the unsaturated soil column. High volatilization and moderate to high solubility rates have attenuated these concentrations, resulting in surficial soils nearly void of VHO contamination. Efficient vadose zone transport has generally produced the highest VHO concentrations at or near the water table. This environmental transport and fate has repeatedly produced secondary sources of VHOs where fine-grained sediments historically occurred near the top of the water table below basins, disposal trenches, and other sites. Because of the deep occurrences of VHOs, exposure to potential receptors is relatively limited in unsaturated soils. Exposure is possible in areas of persistent, shallow water table conditions and where plants and animals penetrate deeper portions of the soil column. Thus, plant uptake and incident ingestion by animals are potential, but somewhat limited, exposure pathways.



Prepared for:

U.S. Army Program Manager
for Rocky Mountain Arsenal

Prepared August 1991

FIGURE RISR E.5-1

Possible Contaminant Migration Patterns Resulting from Sewer Leakage

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

The most important migration pathways for VHO migration from sources to receptors are surface water and groundwater pathways. Due to their relatively low affinity for solids and relatively high solubilities, the compounds of this group are most mobile and widespread in aqueous environments. Volatilization and abiotic degradation processes effectively limit their persistence in surface waters, with half lives expected to range from hours to days (Vogel et al., 1987). However, VHOs have been repeatedly detected in drainage basins near the South Plants and in SSA lakes that receive recharge of VHO-contaminated groundwater (EBASCO, 1989b/RIC 89166R01). The surface water pathway currently provides the greatest risk of VHO exposure to biota at RMA, particularly to species that have developed habitats within or near the SSA lakes. The current land use restrictions at RMA are designed to eliminate exposure to humans along this pathway.

In groundwater at RMA, VHO compounds commonly define the extent of contaminant plumes, due in part to their relatively high environmental mobilities. Analyte mobility varies within the group, with chloroform exhibiting the highest mobility, and often-exhibiting broader lateral and longitudinal distribution than other analytes within groundwater plumes. In contrast, chlorobenzene exhibits considerably slower migration with respect to the other VHOs within the group. VHO plumes occur extensively in all of the major groundwater flow paths shown in Figure RISR E.4-8, most notably the South Plants, Basin A, Basin A Neck, and Basin F Pathways. Although volatilization, and to a lesser extent abiotic and biotic transformation processes, are collectively expected to decrease VHO concentrations in groundwater, migration in the unconfined flow system continues to be the most prominent migration pathway for this group. These compounds occur only sporadically in the confined flow system. The current land use restrictions at RMA essentially eliminate exposure of biota and humans to VHOs along the groundwater pathway. The exception is exposure to deep-rooted plants and burrowing animals in areas of shallow water table conditions, near basins, lakes, the North Bog, and First Creek.

Contaminant migration along air pathways has been mitigated by removal of Basin F liquids in conjunction with the Basin F Interim Response Action (IRA). The Air RI reported occurrences of chloroform and methylene chloride peripheral to Basin F prior to containment of the Basin F liquid (ESE, 1988b/RIC 88263R01). VHO compounds were not detected elsewhere during the RI air sampling program at RMA. Very low levels of VHOs may be entering the atmosphere as a result of volatilization from soils, groundwater, and surface water at RMA, although this route is not expected to result in detectable levels or significant exposure to potential receptors.

The VHO compounds, including chloroform, chlorobenzene, trichloroethylene, and methylene chloride, have been detected in various biota species at RMA. Although these compounds range in toxicity from low to high, only chlorobenzene is known to bioaccumulate. Therefore, contaminant migration along biota pathways involving transport to higher trophic levels is expected to be relatively minor in comparison to other pathways. Land use restrictions relating to hunting and fishing on post are designed to eliminate exposure to humans by this route. However, migratory habits may result in distribution of contaminated waterfowl to other wetlands.

E.5.2 VOLATILE HYDROCARBON COMPOUNDS

Although the VHCs exhibit a widespread distribution at RMA, their occurrences are not as frequent or widespread as the VHOs. All target and significant nontarget VHCs were detected, although not all were detected within a single study area. Dicyclopentadiene, bicyclopentadiene, and methylisobutyl ketone were the most frequently detected compounds in the group. Their occurrences in soil, surface water, and groundwater are related to primary sources at all site types except wind-blown contamination.

The most important sources of VHC contamination are the basins, drainages, and chemical sewer in the NCSA; building, storage areas, sewers, and drainages in the South Plants Study Area (SPSA); and the insecticide pits in the CSA. Smaller releases including spills and isolated occurrences predominate in the ESA and WSA. Dicyclopentadiene is the only VHC commonly detected in groundwater. It comprises contaminant plumes that tend to mimic VHO plumes, but displays less extensive migration patterns.

In soils, VHCs were detected most frequently in the 2- to 5-ft sampling interval, with highest concentrations occurring at or near the water table. This distribution indicates that downward migration through the vadose zone is more significant than surface redistribution. Volatilization is assumed to be the dominant transport mechanism in shallow soils, with infiltration and leaching to the water table significant in the central and lower parts of the unsaturated zone. Deeper soil occurrences continue to persist as secondary sources of VHCs, particularly in fine-grained soils. Degradation and transformation of VHCs due to photolysis, oxidation, hydrolysis, biodegradation, and volatilization are expected to have attenuated concentrations in shallow soils. Exposure to biota is minimal due to the limited occurrence of VHCs in shallow soils as well as sparse population by biota communities near major VHC occurrences.

Surface water pathways are second in significance only to groundwater pathways for these compounds at RMA. VHC detections in soils of basin and drainage sites represent transport by historical surface water processes. This transport has been minimized by the discontinued use of the surface water storage system. VHCs in surface water ditches draining the South Plants appear to be effectively mitigated by natural processes prior to reaching basins and lakes (EBASCO, 1989b/RIC 89166R01). However, seepage through the ditch sediments may contribute to contamination of the unconfined flow system and subsequent discharge into the lakes of the SSA. Surface water transport by overland flow is minimal because of the limited persistence of VHCs in surface soils. Sporadic VHC detections in the North Bog are attributed to discharge of contaminated groundwater that occurred when Basin C was in use. Biota that inhabits areas adjacent to the North Bog and south lakes are the only potential receptors of VHCs in surface water. Current land use restrictions serve to protect humans from VHC exposure at RMA. Dicyclopentadiene, the most common VHC, reportedly does not accumulate in plants or animals (EBASCO, 1989i/RIC 89227R02,03).

Three dominant dicyclopentadiene plumes persist along the Basin F, Basin A, and Basin A Neck Pathways in the NCSA. Several smaller plumes originating at the South Plants facilities and tank farm flow from the SPSA south, southwest, and southeast into the SSA. Current data indicate that VHCs were not detected in SSA lakes. Dicyclopentadiene and other VHCs were not detected in confined Denver Formation wells during sampling events conducted by the Water RI. The moderate environmental mobility of dicyclopentadiene is displayed by its pervasive, but limited groundwater distribution with respect to the VHO compounds. Exposure to potential human and wildlife receptors is minimal along this pathway, given the current land use restrictions at RMA.

Sources of detectable VHCs in air have been controlled by the initial stages of the Basin F IRA. Prior to implementation of the IRA, acetone was the only VHC-related compound detected in air, and these detections were suspect based on the potential for laboratory contamination (ESE, 1988b/RIC 88263R01). Theoretically, VHC compounds are expected to volatilize from surface water, sediments, and groundwater, but at essentially undetectable concentrations. There is not evidence to suggest that VHCs persist in surface soils long enough to be distributed by windblown sediments. Therefore, exposure to receptors along air pathways are considered nominal.

Significant migration of VHCs in biota is not anticipated. Biota exposure to VHCs at RMA is minimal, and these compounds are not expected to appreciably bioconcentrate or biomagnify.

E.5.3 VOLATILE AROMATIC ORGANICS

Similar to the VHCs, VAO compounds exhibit a sporadic but relatively widespread distribution in soils and groundwater at RMA. Repeated surface water detections have also been observed but are confined to a few sampling locations. The VAOs commonly display a notable co-occurrence with the halogenated compounds, although VAO occurrences are less frequent. The VAOs occur at all site types. They are most frequently associated with basins and lagoons, storage, sewer, solid waste burial, and spill sites. These analytes were identified in all study areas at RMA. Consistent with occurrences of other volatile organics in soil, VAO occurrences tend to increase with depth.

The largest VAO releases are attributed to historical manufacturing, storage, and disposal practices at the South Plants. The underground tank farm and chemical sewer in the SPSA are sources of accidental VAO releases that resulted in free-phase hydrocarbons and concentrations in groundwater as high as 1,000,000 µg/l in the southern and northern South Plants plumes, respectively. Estimates of contaminant flux in groundwater from the SPSA to the SSA range from 3,782 grams per day (g/d) to 380 g/d (EBASCO, 1989b/RIC 89166R01; EBASCO 1989e/RIC 89166R04). VAOs spills along roads, railroad tracks, and in storage areas were identified in the SPSA, WSA, CSA, and the North Plants Study Area (NPSA). Soil beneath the disposal basins in the NCSA persists as a secondary source of VAO contamination. Historical infiltration from these basins resulted in VAO plumes along the

Basin A and F flow paths. Isolated occurrences of benzene, ethylbenzene, toluene, and xylenes resulted from spills, surface water transport, and sediments contaminated by VAO-bearing groundwater.

Although VAO liquids were predominantly disposed at or near the surface, migration pathways including volatilization, leaching, and infiltration effectively eliminated most of these compounds from shallow unsaturated zone soils and surface water. The VAOs are readily biodegraded by microorganisms within soils (Barker and Patrick, 1985; Zoetman et al., 1981). The more frequent VAO occurrences at depth resulted in part from the decreased efficiency of volatilization and transformation processes of photolysis, oxidation, and biodegradation. Transport by groundwater pathways not only produced mappable contaminant plumes, but secondary sources of residual soil contamination where VAOs sorbed to aquifer sediments. This process is most likely for xylenes, which display a greater affinity for solid phases than the other constituents of the group.

Presently, groundwater provides the primary migration pathway for VAOs at RMA. The alluvial aquifer has widely distributed these compounds from sources in the SPSA, NCSA, CSA, and southern off-post areas along Basin A, F, and South Plants flow paths. Sporadic and very low-level benzene detections in Denver Formation groundwater in the WSA, CSA, and ESA cannot be attributed to RMA sources and are suspected to represent detectable, naturally occurring background concentrations in the confined flow system. Detectable background levels for benzene, toluene, and other naturally occurring hydrocarbons are reported by Simonart and Batistic (1966). Human and biota exposure to VAOs in groundwater is not expected to occur due to current land use restrictions at RMA and the lack of bioaccumulation expected for VAOs in plants and animals.

Surface water transport is the only other notable migration pathway for VAOs evident at RMA. All VAO group compounds were detected repeatedly in surface waters, but confined to drainage ditches close to the South Plants. Volatilization and other degradation mechanisms sufficiently reduced concentrations below detection limits as distances from the sources in the SPSA increased. Suspended sediment transported by overland flow was also presumably minimal due to rapid degradation of VAOs in shallow soils. Therefore, contaminant migration in surface water is considered minimal due to the limited persistence of these compounds in surface environments. Potential for biota exposure to VAO contaminated surface water exists with the risk of exposure confined to a very few ditches and small pools near the SPSA.

Volatilization is expected to continue as an ancillary pathway in air, although at concentrations that are not expected to result in detections of these compounds. Because of the short half lives of VAO compounds in surface environments, eolian transport is not considered a viable migration pathway.

Biota pathways are not considered significant due to limited population density in contaminated areas and limited uptake and persistence of VAO compounds in biota systems. The VAO compounds are not considered contaminants of concern for biota.

E.5.4 ORGANOSULFUR COMPOUNDS, MUSTARD-AGENT RELATED

All four OSCM compounds were detected in soil and groundwater, although their overall distribution and concentrations were generally low compared to the volatile suites discussed above. Soil occurrences were sporadic, and generally confined to a limited number of sites including basins, solid waste burial trenches, and buildings or storage sites. At least one compound from the group was detected in NCSA, CSA, NPSA, and SPSA soils, although occurrences were generally infrequent. Detections of chloroacetic acid in samples collected from within the WSA and NCSA sanitary sewer lines were suspected to have resulted from the use of commercial cleaning agents. The only repeated surface water detections were in Basin A and the inflow ditch from the SPSA. OSCM plumes in the unconfined flow system extended from source areas to the north and northwest boundaries. Sporadic detections were noted in the confined flow system as well. These compounds were not observed in air or biota sampled at RMA during the RI effort.

The OSCM compounds are readily leached through permeable soils because of their high solubilities and preferences for the aqueous phase. Some original OSCM sources exhibit sporadic occurrences in unsaturated zone soils, although other suspected sources show little in the way of OSCM contamination. Limited degradation is expected to occur and volatilization is the primary loss mechanism in soils, surface water, and shallow groundwater. Current soil distributions reflect OSCM compounds adsorbed to soils or trapped in pore spaces. A comparison of OSCM distribution in groundwater and soils suggests that most OSCM sources in the unsaturated zone have been significantly depleted. This phenomena, coupled with the limited population density of resident species in most areas of OSCM contamination, suggests that exposure to biota by incidental ingestion is currently minimal.

Groundwater provides the dominant migration pathways for OSCMs at RMA. Their hydrophilic nature encourages relatively rapid transport in this environment. Dithiane is the least mobile and appears to exhibit greater residence time in soils relative to the other OSCMs. The largest OSCM plume lies below Basin A and Basin A Neck, where it bifurcates and follows the North Boundary and the Northwest Boundary Pathways. The SPSA North Plume, which lies upgradient of the aforementioned plume, also contains OSCM compounds. Major sources for these plumes have been identified as the South Plants chemical sewer, the NCSA disposal basins, and burial trenches in the CSA. The CSA burial trenches currently persist as the most critical sources of these compounds because of their proximity to the water table. Engineering controls applied to the other sources have significantly reduced their flux of contaminants. Although OSCM migration in groundwater is extensive, the only on-post receptors to contaminated groundwater are plants and burrowing animals that may encounter saturated sediments. Chloroacetic acid is expected to be phytotoxic, limiting its exposure to herbivores. Current biological and geochemical data indicate that potential exposure to OSCM compounds in groundwater at RMA is minimal.

The OSCM compound thiodiglycol was detected in a sample of building liquid collected from the NPSA. Although the Sump 1727 IRA addressed contaminated liquids associated with these buildings (ESE, 1988a/RIC 88243R01), potential for human exposure remains until these buildings are fully remediated.

In addition to groundwater, surface water provides a limited exposure pathway for OSCMs. The presence of these compounds in Basin A and the SPSA drainage ditch can be indicative of potential sites for surface water ingestion and dermal contact by resident animal species. Exposure to humans is not anticipated due to current land use restrictions at RMA.

Air and biota pathways provide very limited opportunities for OSCM exposure. Because OSCM compounds are considered semivolatile, they may be present in the atmosphere or soil in very low concentrations. These compounds were not detected during air monitoring, and are not expected to provide a significant exposure pathway to human or other biological receptors. Because OSCMs were not detected in biota and are not expected to bioaccumulate, migration along biota pathways is not expected to impact the food chain.

E.5.5 ORGANOSULFUR COMPOUNDS, HERBICIDE RELATED

A very specific and somewhat predictable distribution of OSCH compounds resulted in readily identified source areas and pathways for this group. These compounds were detected in soils at manufacturing, storage, or disposal sites in the SPSA, CSA, and NCSA, and at isolated locations in the ESA. The moderate mobility of the OSCH compounds is reflected in extensive contaminant plumes and in a fairly widespread surface water distribution. The most common analytes in the group include the chlorophenylmethyl sulfide-sulfoxide-sulfone series, which has also been detected in air and biota samples at RMA.

The majority of OSCH contamination observed at RMA was linked to major sources in basins and lagoons of the NCSA, the chemical sewer in the NCSA and SPSA, building, storage, and ditches in the SPSA, and solid waste burial sites in the CSA. Isolated occurrences at storage and landfill sites in the ESA do not appear to impact groundwater quality. Soil occurrences are variably located with respect to depth. The variable behavior for members of this group, as well as environmental heterogeneities, are presumably responsible for this type of distribution in soils. In addition, chemical transformation, such as oxidation of chlorophenylmethyl sulfide to more oxidized forms, complicates the pathways analysis of OSCH migration.

Infiltration, leaching, and to a lesser extent vapor migration, are the notable migration pathways for OSCHs in the unsaturated zone. Liquid wastes containing OSCHs, which infiltrated the soil column below basins, ditches, sewers, trenches, basements, and spills are dominantly responsible for OSCH occurrences in groundwater at RMA. Leaching of these compounds from burial sites and contaminated soils has also impacted groundwater. This is particularly significant in parts of the CSA where historical and current water table conditions are expected to have intersected buried waste materials. Infiltration below all sites except burial sites is expected to be minimized under current conditions where local precipitation remains as the only source of leaching solution. Vapor migration provides only an ancillary pathway for OSCH migration from soils. The half lives for OSCH compounds in soil range from months to years, with attenuation expected to result from the combined effects of oxidation, volatilization, biodegradation, and plant uptake.

Migration of OSCHs in groundwater is notably the most significant migration pathway for the OSCH group. These compounds were transported by the unconfined flow system from sources in the NCSA, SPSA, and CSA to the north and northwest boundaries of RMA. Sporadic detections in the confined flow system in the ESA and NPSA were not associated with OSCH plumes or known sources. In the WSA and southern SSA, such occurrences appear to have been introduced by off-post sources. These sporadic occurrences in the confined flow system are generally not accompanied by detections in adjacent wells or repeated by successive sampling. Degradation and transformation of OSCHs in groundwater are not well documented. Oxidation and reduction, the predominant transformation reactions, are expected to produce related analytes within the same group. Volatilization and biodegradation may also be active in decreasing contaminant concentrations. Although it is difficult to identify relative migration rates and transformations between the-OSCH compounds, collectively they tend to exhibit similar environmental behavior and follow the same migration pathways. The only known potential receptors to groundwater contamination at RMA are plants with root zones that contact the capillary fringe. Plant uptake is known to occur for these compounds and was substantiated by detections in a number of plant species at RMA (U.S. Army, 1983).

Surface water transport is responsible for migration of OSCH compounds from SPSA sources to ditches and pools in the SPSA and NCSA. A major component of surface water accumulations are presumably introduced by discharge of contaminated groundwater and storm runoff in areas of contaminated surface soils. Plants and animals that contact these waters may risk exposure to OSCHs by uptake or ingestion.

Data collected for the Air RI indicated that chlorophenylmethyl sulfoxide was present in detectable quantities peripheral to Basins A and F. Volatilization from Basin F is no longer a pathway due to removal of Basin F liquids during the Basin F IRA. Volatilization from liquids in Basin A may continue to be detected sporadically under optimal conditions. This pathway is not expected to impact biota or humans due to the low sporadic detections, lack of nearby biological communities, and restrictions on access for humans.

Although OSCH compounds were observed in numerous plant and wildlife species, significant biomagnification is not expected. These compounds were detected primarily in plants and herbivores (Thorne et al., 1979; U.S. Army, 1983; Berry, 1984; McNeill, 1981a; McNeill, 1981b) and are not expected to migrate to higher trophic levels. Although information on bioconcentration and biomagnification is limited, biota migration pathways are not expected to account for significant contaminant transport.

E.5.6 ORGANOPHOSPHOROUS COMPOUNDS, GB-AGENT RELATED

The distribution of the OPHGB compounds repeatedly identifies OPHGB source areas despite variable distribution patterns for individual analytes. DIMP and DMMP are clearly the most widespread analytes in the group, perhaps as a result of their greater environmental persistence when compared to the other OPHGB compounds. Detection of OPHGBs are generally restricted to contaminated soils, groundwater, and surface water related to sources in the NCSA, NPSA, CSA, and SPSA. Although soil occurrences are sporadic, well-defined groundwater plumes define the extent of contamination for these relatively hydrophilic compounds.

The dominant source areas for OPHGB migration include CSA solid waste burial sites, basins and ditches in the NCSA, and buildings and spills in the North and South Plants. Surface water processes and groundwater transport have apparently produced secondary sources of OPHGBs in saturated, or formerly saturated soils adjacent to sites, most notably the disposal basins.

Organophosphorous, GB-agent related compounds exhibit limited distribution in soils, tending to cluster in the vicinity of sources described above. Surface occurrences are rare, with the most frequent and concentrated occurrences exhibiting a preference for soils near the water table. These compounds may be sorbed to solids or may persist as a dissolved phase in pore fluids. The relatively sporadic occurrences of OPHGBs in soils relative to groundwater presumably results from their affinity for the aqueous phase and their greater persistence in aqueous environments. Half lives for DIMP in soil range from 12 days to 2 years, while the same degree of degradation is estimated to be 580 years in water environments (Bel'skii et al., 1969; Howard et al., 1986). Hydrolysis is the dominant degradation mechanism for the group as a whole, due in part to minimal effects of photolysis, oxidation, biodegradation, and volatilization. Degradation products are expected to include other OPHGB analytes, methanol, and ultimately, phosphate.

As expected for these hydrophilic compounds, groundwater transport by the unconfined flow system is the primary migration pathway. Historically, leaching and infiltration through the vadose zone carried significant quantities of these compounds to the water table. The resulting contaminant plumes originated below the North and South Plants, CSA burial trenches, and NCSA basins, and flowed to the north and northwestern RMA boundaries. Under present conditions of low precipitation and high evaporation, recharge through the unsaturated zone is not expected to mobilize OPHGB compounds from current sources in unsaturated soil. However, a rising water table is capable of transporting OPHGBs from sources in deep unsaturated zone soils. Groundwater contaminated with OPHGBs poses little risk of exposure to potential receptors, with the exception of deep-rooted plants and burrowing animals. Plant uptake is known to occur at RMA (U.S. Army, 1983), although phytotoxic effects serve to limit migration along this pathway.

Surface water provides a secondary migration pathway for OPHGB compounds. Isolated detections in Basin A, overflow Basin B, and ditches draining the SPSA indicate current storage and transport of water containing these compounds. Long half lives in surface water indicate that natural attenuation in this environment is minimal. Surface water bodies continue to allow limited zones of subsurface infiltration and transport. Although the quantities of OPHGB-contaminated surface water are small compared to groundwater, surface water presents a far greater risk to biological receptors by ingestion and dermal contact. Historical evidence of exposure is documented by DIMP detections in aquatic snails, earthworms, mallards, pheasants, deer mice, and other creatures (Thorne et al., 1979; U.S. Army, 1983; McNeill, 1981a).

Although OPHGB compounds are not expected to significantly bioaccumulate or biomagnify, they have been detected in lower trophic levels at RMA, as described above. Biota exposure to contaminated food sources is possible, particularly in the northern and central portions of

RMA. Biological pathways persist at RMA, but are not expected to result in significant concentrations at higher trophic levels.

Air pathways are not significant routes for OPHGB migration. Because these compounds do not tend to persist in surface soils, their potential for eolian transport is negligible. Volatilization is not significant for these compounds, and is confirmed by the lack of detections at air monitoring stations.

E.5.7 ORGANOPHOSPHOROUS COMPOUNDS, PESTICIDE RELATED

The relatively limited distribution of OPHP compounds in soil, surface water, and groundwater is confined to the SPSA. These compounds were detected in air during the RI program. All of the OPHP compounds were detected in soil and groundwater; only atrazine was detected in surface water samples.

The OPHP occurrences in soil appear to be confined to the chemical sewer and building and storage sites. Historical spills in these areas are suspected, but were not clearly identified. These historical spills are apparently responsible for sporadic OPHP occurrences in soil, which range in depth from 0 to more than 20 ft. Infiltration and soil leaching, along with leakage from the chemical sewer, are responsible for three small OPHP plumes that flow north, south, and southeasterly from the central part of the SPSA. Contamination of OPHPs along these flow paths exhibits limited lateral distribution. Risk of exposure to biota through contaminated soils is possible but considered low because of the sparse distribution of these compounds and low biota population densities near OPHP occurrences. Organophosphorous pesticides in soil may enter biotic systems by plant uptake or incidental soil ingestion. These compounds reportedly do not exhibit significant bioaccumulation (ESE, 1989b/RIC 89173R02).

Groundwater is the primary migration pathway for the OPHP compounds, although their distribution is limited by their moderately retarded migration rates and relatively short half lives in slightly alkaline aqueous environments. Consequently, OPHP plumes have migrated only short distances from their sources. They are limited to the unconfined aquifer and presently do not provide a significant risk of exposure to potential receptors in this media.

Occurrences of OPHP analytes in surface water is limited to a single site, which is the northern drainage ditch leaving the South Plants. Although this distribution is minimal, it does pose risk of exposure to animals through ingestion and skin contact. Plant uptake is possible, potentially creating a secondary exposure pathway to consumers.

Although historical studies note that parathion was detected in rainbow trout from the lower lakes at RMA (U.S. Army, 1981; 1982), more recent occurrences have not been observed.

Organophosphorous, pesticide-related compounds were not detected in air samples collected in the vicinity of the South Plants, Basin A, or Basin F. Volatilization and vapor transport is limited for these compounds, and thus air pathways are considered negligible.

OPHP compounds are not considered biota contaminants of concern due to their sparse distribution and limited tendency to bioaccumulate or biomagnify (EBASCO, 1989i/RIC 89227R02,03). Therefore, migration pathways through biotic systems at RMA are considered insignificant.

E.5.8 DIBROMOCHLOROPROPANE

DBCP was detected in soil, groundwater, surface water, and biota at RMA during the RI program. Soil occurrences are sporadic and generally restricted to a limited number of sites, which include basins in the NCSA, solid waste burial trenches in the CSA, buildings or storage sites in the SPSA, and isolated occurrences and spills elsewhere. Groundwater plumes extend from these sources to the north and northwest boundaries. An additional plume extends from a spill area near the railyard in the WSA to the northwest boundary. In surface water, DBCP was detected predominantly in ditches that drain the SPSA. DBCP was not detected in air or biota during the RI; however, previous studies have reported DBCP in several bird species (McNeill, 1981a). Concentrations of DBCP in shallow lake bed sediments may be a source of contamination to aquatic species.

The dominant sources of DBCP contamination are fairly well constrained to areas of product manufacture, storage, transport, and disposal. Manufacturing and storage areas in the SPSA are responsible for DBCP releases to soil, surface water, and liquid that collected in basements. The WSA railyard spill is the most striking example of a product release associated with DBCP transport. Disposal of DBCP-contaminated water and wastes by the chemical sewer and ditches to the disposal basins of the NCSA account for large releases to unsaturated zone sediments and groundwater. Disposal in CSA trenches near the shallow water table also contributed observable DBCP to the unconfined flow system. The sources described above account for the dominant occurrences of DBCP; however, numerous other isolated detections were observed at RMA.

The mobility of DBCP at RMA appears to be controlled to a large degree by its combined organic carbon and clay contents in soil and sediment. In undisturbed RMA soils, DBCP tends to concentrate at depths greater than 5 ft. This behavior is not unexpected for DBCP, which is known to exhibit moderate mobility in unsaturated soils. Volatilization, hydrolysis, and biodegradation may also account for DBCP loss in shallow soils. However, in clay-rich and often organic-rich shallow lake bed and basin sediments, DBCP tends to concentrate, exhibiting only limited mobility. Thus, DBCP leaching and transport in the unsaturated zone is strongly dependent upon the sorptive properties of the host material. As a result, secondary sources of DBCP contamination may develop in fine-grained sediments within the unsaturated or saturated zones. This behavior has significant consequences for groundwater transport as described below.

Groundwater provides the dominant migration pathways for DBCP at RMA. DBCP has migrated downgradient from sources in the central and western portions of RMA to the north and northwest boundaries. Sporadic detections are not uncommon in the unconfined flow system in the ESA. Relatively rapid transport and limited retardation is expected for DBCP in the coarse paleochannel deposits of the unconfined flow system. In contrast, fine-grained, clay-rich sediments in the Denver Formation and similar alluvial strata are expected to significantly retard DBCP migration as well as groundwater flow rates. This behavior explains the very limited migration of DBCP in the confined flow system.

Secondary sources may form where DBCP has sorbed to fine sediments and slowly desorbs in an effort to maintain equilibrium conditions. In many cases, DBCP sources in the unsaturated zone appear to be depleted. The main portion of a plume may migrate downgradient; however, fine-grained sediments may slowly release DBCP, producing a tailing effect. This type of distribution is apparent in the railyard spill in the WSA. Degradation in saturated sediments is fairly slow, resulting predominantly from hydrolysis and biotransformation. Exposure to potential receptors is very limited, due to the predominance of DBCP in deep subsurface media. Deep-rooted plants and burrowing animals may be exposed to groundwater contaminated with DBCP, particularly in areas of pervasive, shallow water table conditions.

Surface water provides a limited migration pathway but a significant exposure pathway for DBCP. Repeated detections in ditches draining the SPSA indicate that DBCP is currently migrating by surface water processes in selected areas. The SPSA ditches carry surface runoff from the South Plants and may receive recharge from shallow groundwater as well. Although migration distances are limited, these ditches are capable of transporting DBCP to lakes and basins. Volatilization from surface water is expected to attenuate, but not eliminate, DBCP concentrations in surface water. Exposure to biota is possible, predominantly resulting from surface water ingestion and plant uptake. Land use restrictions at RMA control surface water exposure to humans.

Biota do not appear to provide a significant migration pathway for DBCP. Information on DBCP in animal tissue at RMA is limited and was reported in only one study (McNeill, 1981a). The distribution of DBCP in biota does not appear to be widespread, probably because of the high loss rate from animal tissues. DBCP is known to accumulate in root crops, but metabolizes rapidly in animals (ESE, 1989/RIC 89173R02). In addition, DBCP does not bioaccumulate to a significant extent. Laboratory studies reported in the literature and RMA pathways analyses in aquatic and terrestrial ecosystems support this conclusion. Therefore, although biota may be exposed to DBCP by ingesting contaminated food and water, significant migration is not anticipated to result from biological pathways.

E.5.9 ORGANONITROGEN COMPOUNDS

Although sampling was conducted in the vicinity of the hydrazine blending facility, a USATHAMA-certified analytical method for the hydrazines in soils was not available prior to implementation of the RI program. None of the ONCs on the target analyte list that were analyzed for were detected in soil, water, or air at RMA during the RI program. However, caprolactam was tentatively identified in 45 groundwater samples collected at RMA between 1986 and 1987. Caprolactam occurs sporadically in both the unconfined and confined flow systems, and was detected in all study areas except the ESA and SSA. Caprolactam is highly soluble and is expected to migrate readily in groundwater. Apparently, caprolactam was released from undetermined on-post and off-post sources. Because caprolactam was not detected in soils, source areas can only be suggested based on groundwater distribution and historical waste disposal practices. Caprolactam may have been released as a degradation product of nylon and other plastics. Likely on-post sources are solid waste burial sites and basins where plastics were burned or codisposed with solvents. Because caprolactam is present only in groundwater, significant risk of exposure to biota or humans in highly unlikely.

E.5.10 FLUOROACETIC ACID

Scattered occurrences of fluoroacetic acid were observed in soils in the NCSA, CSA, and ESA. Detections were limited to surface and subsurface soils and occurred primarily in unlined basins, ditches, and solid waste disposal areas. No fluoroacetic acid was detected in surface water, groundwater, air, or biota.

Several potential sources are suggested by the distribution and expected behavior of the compound. Fluoroacetic acid is highly soluble in water and consequently migrates readily in surface water and groundwater. Based on this expected behavior, the distribution of fluoroacetic acid in unlined basins and connecting drainages of the NCSA presumably resulted from wastewater discharges from South Plants. Detections in soil surrounding Basin F and sporadic occurrences in the CSA and ESA may be the result of rodenticide applications. Fluoroacetic acid detected in solid waste disposal sites in the CSA and ESA may be related to disposal of this compound or to degradation of the chemical agent GB. Surface detections in a localized area of the CSA probably resulted from decontamination of GB-contaminated materials.

Detections of fluoroacetic acid at RMA occur primarily in soil from moderate depths down to the water table. In the unlined basins, fluoroacetic acid typically occurs in soil below ponding areas in the basins. This depth distribution and the high solubility of fluoroacetic acid identify wastewater infiltration and leaching as the dominant transport mechanisms. In the disposal trenches, fluoroacetic acid may have resulted from degradation of chemical mixtures in the trenches. Detections of fluoroacetic acid in soil just above the water table indicate transport to the groundwater. The absence of detections in groundwater may be related to dilution or attenuation of highly soluble fluoroacetic acid to levels below detection.

Exposure to fluoroacetic acid is currently limited to surface and subsurface soils in scattered locations. The greatest risk occurs in exposure to subsurface soils in Basin A and adjacent areas where concentrations are highest. There is the potential for leaching of fluoroacetic acid present in soil to the groundwater. However, this does not currently appear to be an active process and, therefore, exposure to groundwater is not expected to pose a significant risk. Potential biota receptors include plants and burrowing animals. Based on the solubility of fluoroacetic acid, bioconcentration is not anticipated.

E.5.11 POLYNUCLEAR AROMATIC HYDROCARBONS

The four PAH compounds were tentatively identified in all RMA study areas except the SSA. Although they were not part of the target analyte suite, they were identified by the nontarget analytical program. PAHs were detected sporadically in surficial soils where they are frequently associated with various combustion activities. These low-mobility compounds were not detected in groundwater or surface water during the RI sampling programs. Phenanthrene was detected in air and may be associated with Basin F prior to implementation of the IRA, or to atmospheric fallout. PAH compounds were not analyzed as part of the biota RI.

Limited occurrences indicate minor areas of PAH contamination in RMA soils, which include building, equipment, and storage sites, chemical sewer sites, surface and subsurface burn sites, basins and ditches, and ordnance test sites. PAHs were frequently detected near rail lines where creosote was used to preserve wooden railroad ties. Because PAHs are a common product of combustion, they are commonly distributed throughout burn sites at RMA. In soils, however, PAHs do not exhibit signs of significant migration from their source areas. Detections are confined to points of discharge, such as surficial soils, soil in the vicinity of sewer lines, and burn horizons within solid waste burial sites. There is no evidence to suggest that PAHs have migrated noticeably from their sources in shallow soils. This distribution is consistent with predicted behavior for these relatively insoluble compounds.

The only notable migration pathways for PAHs at RMA involve transport of contaminated surface soil by wind or storm runoff. Volatilization and photo-oxidation are limited loss mechanisms for PAHs in surficial soils or entrained particles. Conduct of the Basin F IRA has eliminated the only source of likely PAH contamination detected during the Air Media RI. Other atmospheric PAH concentrations fall within normal urban background levels caused by gasoline combustion and vegetation. Because of their sparse distribution, which is confined to surficial soils, PAHs present only a very limited risk of exposure to plants and terrestrial animals. Although these compounds may occur naturally in plants, uptake is possible and is expected to result in only short-term tissue accumulation.

E.5.12 SEMIVOLATILE HALOGENATED ORGANICS

The distribution of SHO compounds at RMA is primarily confined to surficial soils or subsurface horizons associated with SHO disposal or release. At least one of these low-mobility compounds was detected sporadically in every study area except the NPSA. SHO compounds were also observed to occur sporadically or in small plumes confined to the unconfined flow system in the NCSA and SPSA. Single, isolated groundwater occurrences were noted in both the WSA and the CSA during the RI sampling programs. The only SHO occurrences in surface water were observed in ditches draining the SPSA. These compounds were not detected in air or biota during the RI.

Sources of SHO contamination at RMA include basins and the chemical sewer in the NCSA; solid waste burial sites in the CSA, WSA, and SPSA; and ditches that drain the SSA.

Consistent with their predicted behavior, migration in unsaturated or saturated soils is strongly retarded for these compounds. Overall, migration of SHOs from source areas appears limited, due predominantly to their relatively low solubility and high affinity for fine-grained and organic-rich soils. Facilitated transport may have enhanced migration through the vadose and saturated zones below the basins, chemical sewer, and some solid waste burial sites. The SHOs are persistent in shallow soils, showing little observable attenuation by photolysis, hydrolysis, or biodegradation. Loss due to volatilization may be more significant, particularly in surface waters.

Migration pathways are limited for SHO compounds at RMA. Surficial sediment transport by winds or surface runoff is capable of transporting SHOs at the surface. Groundwater transport is limited and expected to exhibit significant retardation in all but medium- to coarse-grained aquifer sediments. Sparse SHO occurrences in surface water are subject to transport along ditches draining the SPSA. In summary, a number of pathways are viable, although none are expected to contribute to significant mass flux for SHOs. Appreciable bioconcentration of hexachlorocyclopentadiene, the most abundant SHO at RMA, is not expected to occur. The very sparse occurrences of the more highly chlorinated SHOs, which tend to bioaccumulate in biota, should limit migration along biota pathways. Exposure to biota is restricted to incidental soil ingestion or exposure to contaminated surface water in the SPSA. The low biota populations and the sparse SHO concentrations in soil elsewhere provide little risk of exposure to biota at RMA.

E.5.13 ORGANOCHLORINE PESTICIDES

The OCP compounds are distributed widely at RMA with detections reported in all media, all site types, and all study areas. Each of the seven analytes were detected in soils and groundwater, and several OCP compounds were repeatedly observed in surface water, air, and biota sampled during the RI.

The South Plants has a long history of OCP manufacture and storage and thus exhibits the most pervasive OCP contamination in shallow soils and surface water. Disposal and storage of OCP-contaminated wastewater in chemical sewers, ditches, and basins of the NCSA and SPSA appear to have produced the most extensive OCP impacts to groundwater quality. Solid waste burial sites in the CSA and SPSA were also major sources of OCP releases to groundwater. In addition, secondary OCP sources were observed at depth where OCPs in groundwater have sorbed to relatively fine-grained aquifer sediments. These contaminated sediments may continue to slowly release OCPs to aqueous phases by desorption. This type of occurrence was observed at the North Boundary Containment System (EBASCO, 1989h/RIC 89166R07) and is suspected to occur elsewhere at RMA. Large areas of contaminated surface soils containing OCPs at concentrations typically less than a few µg/g appear to have resulted from eolian transport.

The strong tendency for OCP compounds to bind to clays and organic carbon has resulted in their widespread distribution in shallow soils and basin or lake bed sediments. Infiltration of wastewater below disposal basins is responsible for extensive vertical distribution of OCPs in soils that are currently unsaturated. Leaching has generally not been significant except in areas where cosolvent transport, coarse-grained and organic-poor sediment, or shallow water table conditions have enhanced transport and mass transfer. Such areas were identified in Basin F, Basin A, the chemical sewers, and the solid waste burial sites in the CSA. Consequently, these areas have historically been primary sources for subsurface migration. Under current conditions, which have eliminated large bodies of contaminated wastewater, transport in the unsaturated zone is significantly reduced. As a result, leaching of OCPs in clayey soils at RMA by natural precipitation is expected to proceed very slowly. Degradation and attenuation in soils can be expected to proceed slowly by volatilization, photolysis, and biotransformation. Frequently, the degradation of one analyte produces a closely related analyte within the group.

The potential for exposure of biota to contaminated soil is significant and is possible by plant uptake and incidental ingestion. RMA areas that are highly contaminated with OCPs are not presently accessible to the public; hence potential exposure of humans to contaminated soil is remote.

Groundwater provides a primary migration pathway for OCPs despite the fact that these compounds are considered relatively hydrophobic. Coincident disposal of OCPs with VHOs, VAOs, or VHCs has presumably resulted in enhanced OCP transport as solutes in these more mobile compounds. Once OCPs reach the coarse-grained paleochannels, that comprise the dominant flow paths in the unconfined flow system and have little attenuating capability, OCP transport by groundwater may proceed relatively rapidly. Hence, OCPs are widely distributed along major unconfined flow paths between sources in the SPSA, CSA, and NCSA and the leading edges of plumes near the north and northwest boundaries. Increased retardation of OCPs in groundwater may be generally correlated to the abundance of fine-grained material and organic carbon in the aquifer sediments. Consequently, transport in the finer-grained sediments that dominate the confined flow system is restricted. As described above for soils, degradation is slow and is not expected to produce noticeable mitigating effects. Because groundwater is relatively inaccessible from the surface, biota receptors are generally confined to deep-rooted plants and burrowing animals. Generally, exposure is expected to be most significant in areas of shallow water table conditions.

Although surface water flow is limited at RMA, this medium still provides several significant transport mechanisms for OCPs. Channel flow in ditches draining the SPSA continues to provide a migration pathway, transporting OCPs downstream from their sources in ditch sediments to lakes, ponds, and basins. OCPs have accumulated in lake bottom sediments since dredging in 1964-1965. Repeated OCP detections in surface water from these ditches and receiving basins in the NCSA confirm that OCPs may currently migrate in surface water ditches. Overland flow, resulting when precipitation exceeds the infiltration capacity of the soil, is also a significant mode of transport for OCPs. Their persistence in surface soils allows sediment transport during runoff to collect OCPs in natural and manmade channels and depressions. Degradation and transformation in surface water environments are slow, as seen in other environments. Contaminated surface water provides a major exposure pathway to plants and animals by ingestion and other forms of uptake. Aquatic organisms, marsh plants, and waterfowl risk the greatest exposure.

Because OCPs tend to concentrate in surface soils and degrade very slowly, they are readily entrained by wind. During the RI, broad areas of surficial soils were observed to be contaminated by low concentrations of OCPs. These areas are attributed to contaminant migration by eolian transport. Limited volatilization was also identified by the Air RI downwind of Basin F. Exposure to biota due to OCP volatilization is currently negligible due to implementation of the Basin F IRA. Exposure to OCPs as wind-transported dust and the resulting dispersion, however, may be significant. Biota are most likely to be exposed by plant uptake, incidental ingestion, and inhalation.

The OCPs are known to accumulate in biotic systems to a higher degree than other analytes at RMA. For this reason, along with their acute toxicity, OCPs have been determined as the most significant contaminants of concern for biota. At RMA, OCPs may be found in a range of aquatic and terrestrial organisms, from the lower life forms to the top of the food chain. Considerable uptake in plants, along with high BCFs and BMFs, serve to present the greatest risk to higher level predators. The current distribution of OCPs in biota may spread widely within the ecosystem and continue to increase in the higher trophic levels. The dominant exposure pathways in lower life forms occur by plant uptake, ingestion, and aquatic exposure. At higher levels, ingestion of contaminated food and water are the major routes of exposure, with ancillary pathways provided by soil ingestion, inhalation, and dermal contact. Land use restrictions on fishing and hunting at RMA are designed to eliminate any risk of exposure to humans by consuming contaminated foods. However, contamination in game species presents a chance of exposure to persons hunting these species off post. Levels of OCPs detected in fish and game have been identified as exceeding action levels established by the Food and Drug Administration (FDA) (ESE, 1989/RIC 89173R02).

E.5.14 ARSENIC

Arsenic occurrences above the upper end of the indicator range in soils (10 µg/g) are sporadic and relatively widespread at RMA. As discussed in Appendix A, arsenic concentrations within the indicator range are considered indicative of naturally occurring background concentrations. Indicator ranges were established based on published literature values of naturally occurring concentrations in similar soils, and on an evaluation of data collected at RMA and in off-post areas. Supporting documentation concerning selection of the indicator ranges, including literature references, is provided in the Introduction to the Contamination Assessment Report (ESE, 1987a/RIC 88204R02). More recent studies conducted near RMA have established a higher background concentration of 28 µg/g for arsenic (TRC, 1988).

Arsenic releases at RMA are predominantly associated with sites where army and riot control agents were manufactured, stored, decontaminated, or disposed. Consequently, arsenic source areas are primarily buildings and sewers in the SPSA; storage and solid waste burial sites in the ESA, WSA, and CSA; and basins, lakes, ditches, and sewers in the NCSA and SSA. Ditches and buildings are also contaminated with arsenic in the NPSA; however, building contamination has been controlled by the Sump 1727 IRA. Arsenic has been detected in all media at RMA; however, shallow soils and lake bed sediments contain the greatest frequency of detections and concentrations above inferred background levels. Isolated soil occurrences, whether natural or man-induced, are distributed widely throughout RMA as well. Arsenic occurrences have formed plumes within the unconfined flow system, and were also detected sporadically in groundwater samples from both the unconfined and confined flow systems. Arsenic in surface water is generally limited to ditches and basins and exhibits a less widespread distribution than many of the organic analytes. Arsenic has also been detected sporadically at air monitoring stations near Basin F and in many biota species.

The arsenate species is expected to predominate in RMA soils. The distribution of total arsenic above indicator levels occurs preferentially in shallow soils. Arsenic in surficial soils may be subject to erosion and transport by wind or surface water. Except in devegetated areas of the Arsenal such as disposal basins, these pathways are expected to be limited. Plants exposed to arsenic in shallow soils may exhibit limited uptake or phytotoxic effects, which contributes to devegetation and erosion-prone areas. Animals may be exposed by incidental ingestion of soil, with only limited exposure expected to result from ingestion of contaminated foods.

Migration of arsenic in groundwater is complex and influenced by many parameters such as chemical speciation, aquifer characteristics, and particle transport. Arsenic was identified in the unconfined flow system in the CSA and NCSA. Extensive plumes have developed in the unconfined flow system, extending from the South Plants towards the north and northwest boundaries. Thin vadose zones and historical disposal of the more mobile arsenate species may also account for arsenic influxes to the unconfined flow system. In addition, sites that lie only a short distance above coarse paleochannel deposits of the alluvial aquifer provide only limited retarding media. Although many detections in Denver Formation wells are considered natural occurrences, elsewhere, such as in the NCSA, arsenic in groundwater in the upper Denver Formation appears to have migrated downward from the overlying unconfined aquifer. Many other occurrences of arsenic in groundwater are limited in lateral and vertical extent. These phenomena are frequently attributed to sporadic natural occurrences that have resulted from aquifer inhomogeneities. There are few potential receptors of arsenic in groundwater. Concentrations in plants are not readily distinguishable as resulting from exposure to contaminated soils or groundwater. Existing controls and restrictions at RMA serve to control significant exposure pathways for animals and humans to arsenic in groundwater.

Arsenic was detected at relatively low concentrations in numerous species of plants and animals during the RI program. These results are not surprising in light of the widespread natural arsenic distribution, in addition to contamination associated with RMA source areas.

Although arsenic may significantly bioconcentrate, it reportedly does not significantly biomagnify. Therefore, exposure to arsenic-contaminated soils and surface waters are expected to have a far greater impact on biota than ingestion of arsenic in food sources. The importance of biota migration pathways should not be ruled out for arsenic although transport from lower to higher trophic levels is expected to be minor.

E.5.15 MERCURY

Mercury is present as a naturally occurring constituent of bedrock and soils and as a contaminant associated with numerous activities at RMA. Results of the RI show that mercury occurrences are dominantly confined to soils and biota at RMA. Primary sources of mercury at concentrations above indicator levels (0.1 µg/kg) are shallow sediments in basins in the NCSA, lakes in the SPSA, and various ditches where mercury was introduced by direct disposal or sediment transport by surface water. Solid waste burial sites and isolated occurrences associated with storage areas and the sanitary and chemical sewers in the CSA and NPSA comprise the majority of other detections at RMA. Mercury was detected in isolated groundwater samples from both the unconfined and confined flow systems in all study areas except the WSA and ESA. Mercury in various plants and animals at RMA has been reported in either current or historical studies (ESE, 1989/RIC 89173R02). Mercury was not detected in surface water or air samples.

The solubility of inorganic mercury is low, and as a result, mercury in soils is considered relatively immobile. Mercury binds strongly to both inorganic and organic particulates, so that leaching from soils and sediments will be minimal and retardation will occur in groundwater. Current and historical mercury migration has predominantly occurred in association with sediment transport, either as wind-blown dust or suspended and bed load sediment in surface water. Overall, relative rates of mercury migration are very slow compared with most other analytes at RMA.

Mercury tends to bioaccumulate and can be transported along biotic pathways. Historical and recent detections of mercury in many plant and animal species at RMA, both aquatic and terrestrial, support this conclusion. Although mercury was selected as a biota contaminant of concern, pathways analyses performed during the RI indicate that mercury bioaccumulation is far less critical than OCP accumulation, particularly in terrestrial ecosystems. Where mercury is present in surface soils, a potential does exist for incidental soil ingestion by animals or uptake by plants. Bioaccumulation in the food web is expected to follow exposure by ingestion of contaminated food.

E.5.16 ICP METALS

The ICP metals were frequently detected in soil, air, and groundwater samples collected throughout RMA. This widespread distribution, in part, reflects their natural occurrences in the environment. As discussed in Appendix A, the indicator range includes concentrations of analytes considered indicative of naturally occurring background concentrations. These ranges were established based on published literature value and on soils collected from RMA and from off-post areas (ESE, 1987/RIC 88204R02). More recent data from an area near RMA suggest higher soil background concentrations of 8, 413, and 820 µg/g for cadmium, lead, and zinc, respectively (TRC, 1988).

Concentrations above the respective indicator range for each metal in soils are generally associated with designated sites or may be associated with natural occurrences in soil or bedrock. Where multiple ICP detections were identified in shallow soils, concentrations are generally attributed to waste disposal, munitions testing, or chemical spills. Deeper detections, which cannot be related to RMA activities, may be attributed to natural occurrences.

Generally, ICP metals detected at air monitoring stations are attributed to ambient, urban conditions. However, data collected during the RI program also indicate that Basins A and F were probably sources of ICP metals dispersed as fugitive dust. The ICP metals cadmium and copper were detected by historical studies in aquatic and terrestrial biota (Thorne et al., 1979; U.S. Army, 1983). None of the ICP metals have been designated contaminants of concern by the Biota RI (ESE, 1989/RIC 89173R02).

Anomalous metal concentrations that cannot be attributed to natural occurrences are primarily restricted to a limited number of site types. Most apparent sources of ICP metals are the disposal basins in the NCSA and burn sites or solid waste burial trenches throughout RMA. Leaks in the chemical sewer have contributed to ICP metal distribution, as has storage of metal equipment where it was exposed to the elements and allowed to oxidize. Munitions testing areas are commonly designated sites strictly based solely on the occurrence of ICP metals in surface soils.

Wind and surface water transport, although relatively minor, represent the principal migration pathways for ICP metals at RMA. Wind erosion and eolian transport is greatest for sparsely vegetated sources, and were formerly attributed to Basins A and F. However, the use of a dust suppressant on Basin A and the current extent of the Basin F IRA are expected to minimize future transport of ICP metals from the basin areas to on-post receptors downwind at RMA. The highest concentrations of metals were detected at the western and southern RMA boundaries and appear to reflect off-post automobile emissions and ambient urban air quality. Surface water is capable of transporting ICP metals in dissolved or suspended phases by overland and channelized flow. Optimal conditions for surface water transport are dependent on precipitation and occur only sporadically at RMA. Plant uptake of lead may occur through the leaves of some plants, and exposure to humans and animals may result from inhalation of fugitive dust. Under current conditions the limited flux of metals from RMA sources is considered minor in comparison to natural occurrences and off-post emissions. Potential receptors include aquatic and terrestrial plants and animals that risk sporadic exposure by plant uptake or ingestion of contaminated surface water.

ICP metals exhibit very limited mobility in the subsurface. They have a strong tendency to bind to soil constituents and aquifer solids. Consequently, their distribution is generally limited to the immediate vicinity of contaminant releases. Metals disposed in landfills, burial trenches, and burn pits have not migrated appreciably below the limit of excavation. At munitions testing sites and drainage ditches, ICP metals are generally confined to surficial soils. Therefore, leaching and unsaturated zone transport is considered negligible.

Groundwater transport is a restricted migration pathway for ICP metals. Sporadic occurrences of all five metals in both confined and unconfined aquifers are attributed to natural occurrences. Where present, they may migrate as dissolved phases or by particle transport. Only the distribution of chromium, which exhibits spatially and temporally related occurrences in the unconfined aquifer, is suspected to have resulted from RMA activities. Presumably, chromium was introduced at or near the water table by infiltration below Basin A or leaks in the chemical sewer. Receptors to sporadic chromium in this media are considered negligible due to its limited occurrence and tendency to sorb readily to the solid substrate of the aquifer.

Biological uptake and accumulation is possible to varying degrees for all the ICP metals. Only cadmium is expected to biomagnify and result in migration along biota pathways. Chromium is phytotoxic and may result in devegetation, thereby limiting chromium contaminated plants as a potential food source. In the hexavalent state, chromium can exhibit toxicologic effects on humans. Although the metals exhibit varying degrees of toxicity and bioaccumulation, they are not expected to biomagnify and thus are not considered primary contaminants of concern to biota at RMA.

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APPENDIX F
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TECHNICAL SUPPORT FOR

ROCKY MOUNTAIN ARSENAL

FINAL
REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX F
COMMENTS AND RESPONSES
VERSION 3.2

January 1992

Contract Number DAAA15-88-D-0024

PREPARED BY:

EBASCO SERVICES INCORPORATED
APPLIED ENVIRONMENTAL, INC.
CH2M HILL DATACHEM, INC.
R.L. STOLLAR AND ASSOCIATES

PREPARED FOR:

U.S. ARMY PROGRAM MANAGER FOR
ROCKY MOUNTAIN ARSENAL

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

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APPENDIX F - LIST OF ABBREVIATIONS

Analyte Groups and Selected Analytes

As	Arsenic
Cr	Chromium
Cd	Cadmium
Cu	Copper
DBCP	Dibromochloropropane
DCPD	Dicyclopentadiene
DDE	Dichlorodiphenylethane
DDT	Dichlorodiphenyltrichloroethane
DIMP	Diisopropylmethyl phosphonate
GB	Nerve agent Sarin
HC	Hydrocarbons
ICP metals	Metals analyzed for by inductively coupled argon plasma spectroscopy; includes cadmium, chromium, copper, lead, and zinc
OCP	Organochlorine pesticides
ONC	Organonitrogen compounds
OPHGB	Organophosphorous compounds, GB-agent related
OPHP	Organophosphorous compounds, pesticide related
OSCH	Organosulfur compounds, herbicide related
OSCM	Organosulfur compounds, mustard-agent related
PAH	Polynuclear aromatic hydrocarbons
Pb	Lead
PCB	Polychlorinated Biphenyl
SHO	Semivolatile halogenated organics
SVOC	Semivolatile organic compounds
TCE	Trichloroethylene
TDG	Thiodiglycol
TOA	Total organic analytes
TOC	Total organic carbon
UDMH	Unsymmetrical dimethylhydrazine
VAO	Volatile aromatic organics
VHC	Volatile hydrocarbons
VHO	Volatile halogenated organics
VOC	Volatile organic compounds
VX	Nerve Agent
Zn	Zinc

APPENDIX F - LIST OF ABBREVIATIONS
(continued)

National Acts and Organizations

AMCCOM	U.S. Army Munitions and Chemical Command
CERCLA	Comprehensive Environmental Response, Compensation, and Recovery Act
CFR	Code of Federal Regulations
DOD	U.S. Department of Defense
EPA	U.S. Environmental Protection Agency
LDR	Land Disposal Restrictions
NAAQS	National Ambient Air Quality Standards
NCP	National Contingency Plan
TVA	Tennessee Valley Authority
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USDA-SCS	U.S. Department of Agriculture - Soil Conservation Service
USFWS	U.S. Fish and Wildlife Service

Local Terminology

ARARs	Applicable or Relevant and Appropriate Requirements
BDL	Below detection limit
CAR	Contamination Assessment Report
CDH	Colorado Department of Health
CFS	Confined flow system
CMP	Comprehensive Monitoring Program
COC	Contaminant of concern
CRL	Certified reporting limit
CSA	Central study area
DNAPL	Dense nonaqueous-phase liquid
EA	Endangerment assessment
EI	Exposure index
ESA	Eastern study area
FS	Feasibility Study
GT	Greater than
HBSF	Hydrazine Blending and Storage Facility
ICS	Irondale Containment System
IEA	Integrated Endangerment Assessment
IRA	Interim response action
IRDMIS	Installation Restoration Data Management Information System
ISV	*In Situ* vitrification

APPENDIX F - LIST OF ABBREVIATIONS
(continued)

JARDF	Joint Administrative Records and Document Facility
LNAPL	Light nonaqueous-phase liquid
LOAEL	Lowest observed acceptable exposure limit
MATC	Maximum allowable tissue concentration
NA	Not analyzed
NAPL	Nonaqueous-phase Liquid
NBCS	North Boundary Containment System
NCSA	North central study area
NS	Not sampled
NWBCS	Northwest Boundary Containment System
OAS	Organizations and State
OTSP	Organics (Organochlorine Pesticides) in Total Suspended Particulates
PM-10	Respirable particulates
PMRMA	Program Manager for Rocky Mountain Arsenal
QA/QC	Quality assurance/quality control
RC	Risk Characterization
RI	Remedial Investigation
RIC	Rocky Mountain Arsenal Information Center
RI/FS	Remedial Investigation/Feasibility Study
RISR	Remedial Investigation Summary Report
RMA	Rocky Mountain Arsenal
RMACCPMT	Rocky Mountain Arsenal Contamination Control Program Management Team
SACWSD	South Adams County Water and Sanitation District
SAR	Study area report
SPSA	South Plants study area
SSA	Southern study area
STF	South Tank Farm
SVE	Soil vapor extraction
TCLP	Toxicity Characteristic Leaching Procedure
TIC	Tentatively identified compound
TSP	Total suspended particulates
UFS	Unconfined flow system
UNC	Uncontaminated area (Usage Replaced by Nonsource Area)
USCS	Unified Soil Classification System
VEC	Vertical extent of contamination (Database)
WBZ	Water-bearing zone
WRIR	Water Remedial Investigation Report
WSA	Western study area

APPENDIX F - LIST OF ABBREVIATIONS
(continued)

Companies

CAL	California Analytical Laboratories, Inc.
DataChem	DataChem, Inc. (formerly Utah Biomedical Test Laboratory, UBTL)
EBASCO	Ebasco Services Incorporated
ENSE	ENSECO Inc. (formerly Rocky Mountain Analytical Laboratories)
ESE	Environmental Sciences and Engineering, Inc.
HB&A	Harland Bartholomew and Associates, Inc.
HITT	Hittman-Ebasco
MKE	Morrison-Knudsen Engineering
MRI	Midwest Research Institute
RCI	Resource Consultants, Inc.
RLSA	R.L. Stollar & Associates, Inc.
Shell	Shell Oil Company
WWE	Wright Water Engineers

Measurements, Quantities, and Parameters

AGM	Adjusted geometric mean
BCF	Bioconcentration factor
b.c.y.	Bank cubic yards
BMF	Biomagnification factor
cfs	Cubic feet per second
F_{oc}	Organic carbon fraction
ft	Foot, feet
Fy	Fiscal year
in	Inch, inches
K_d	Soil-water partition coefficient
K_{oc}	Octanol-carbon partition coefficient
K_{ow}	Octanol-water partition coefficient
µg/l	Micrograms per liter (equivalent to parts per billion)
µg/g	Micrograms per gram (equivalent to parts per million)
µg/m^3	Micrograms per cubic meter
mg/l	Milligrams per liter
ml/g	Milliliters per gram, a measure of aqueous solubility
mph	Miles per hour

APPENDIX F - LIST OF ABBREVIATIONS
(continued)

Analytical Methods

GC/ECD	Gas chromatography/electron capture detector
GC/FID	Gas chromatography/flame ionization detector
GC/FPD	Gas chromatography/flame photometric detector
GC/HECD	Gas chromatography/Hall electrolytic conductivity detector
GC/MS	Gas chromatography/mass spectrometry
HPLC	High pressure liquid chromatography
ICP	Inductively coupled argon plasma spectroscopy

Appendix F1

Responses to the Environmental Protection Agency's Comments on the Draft Final Remedial Investigation Summary Report, Version 2.3

Remedial Investigation Summary Report

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
999 18th STREET - SUITE 500
DENVER, COLORADO 80202-2405

JUL 1 1991

Ref: 8HWM-FF

Kevin Blose, Chairman
RMA Committee
ATTN: AMXMR-PM
Rocky Mountain Arsenal
Commerce City, Colorado 80022-2180

Re: Rocky Mountain Arsenal (RMA)
Draft Remedial Investigation
Summary Report, May 1991.

Dear Mr. Blose:

We have reviewed the above referenced document and have the enclosed comments. The Army is to be commended for the quality of the graphical presentations. They aid greatly in the understanding of the nature and extent of contamination at RMA. The document, which for the most part is well done, is in need of a few clarifications. We particularly wish to highlight the following areas in need of clarification:

1) Figure RISR 2.1-1. The area indicated in yellow does not include the 1989-1990 surficial soils data. A figure should be constructed showing the extent of surficial soils contamination to avoid the erroneous impression that the windblown contamination is limited to Sections 26 and 36.

2) Plate RISR 2.1-1. This plate, which is an excellent graphic presentation of the spatial relationship between the arsenal and the groundwater contamination, should indicate the CRL used for the preparation of the contours in the saturated alluvium and bedrock surface.

3) The text should be amended in several sections to clarify that Army agents were found in several areas other than the Army trenches, including one lewisite detection in Section 35.

4) Page 2-21, the text should be amended to indicate that "direct" human exposure to the top few inches of soil is one of the most important exposure pathways.

5) Page 2-30, the text needs to clarify that, although the degree of contamination and migration in the Denver Formation are less than in the unconfined aquifer, the contamination in the Denver Formation is never the less significant, given concentrations of up to 10,000 ug/l found in several areas, including Section 23.

6) Appendix A, the text should be expanded to include a summary of the investigations performed to date of the LNAPLs, DNAPLs, and/or adsorbed contamination in saturated soils, rather than focusing on water quality only. The text should further indicate that additional investigation of these contaminants will be performed as needed during the FS.

7) Appendix A, the report should use the most recent QA/QC data, rather than relying on data that is two years old.

8) Table RISR A2.5-1, this table presents CRLs that are up to an order of magnitude lower than those used in the Biota RI. This discrepancy, which could impact the CMP and the values used in the biota model, should be clarified.

9) Appendix A, Section A3.1.1. We request a listing that states what specific sites have been grouped into each generic category. This would help in cross-referencing with FS documents.

10) Appendix B, Vertical Extent of Contamination, the text needs to indicate that the information and analysis presented in this Appendix will be fully incorporated into the FS, including any further sampling that may be needed to address remediation alternatives for the Denver Formation.

11) Appendix D, this appendix should provide a discussion of soil sampling QA/QC procedures or a reference to another document which contains these procedures.

Our contact on this matter is Linda Jacobson at 294-1977.

Sincerely,

Connally Mears

Connally E. Mears
EPA Coordinator for RMA Cleanup

Enclosure

cc: Glenn Tucker, ATSDR
Major John Fomous
Brad Bridgewater, DOJ
David Shelton, CDH
Jeff Edson, CDH
Vicky Peters, CAGO
George Roe, Shell
Bill McKinney, Shell

ENVIRONMENTAL PROTECTION AGENCY'S
COMMENTS ON THE
DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
MAY 1991

Cover Letter Comments

Comment 1: Figure RISR 2.1-1. The area indicated in yellow does not include the 1989-1990 surficial soils data. A figure should be constructed showing the extent of surficial soils contamination to avoid the erroneous impression that the windblown contamination is limited to Sections 26 and 36.

Response: Two figures depicting the extent of organic and inorganic contamination in surficial soils (0-2 in) for which analyses were performed were included in Appendix D1 of the Draft Final Remedial Investigation Summary Report (RISR). The overall extent of detected organic surficial soil contamination is shown in Figure RISR D1.4-1, Distribution of Total Organics in Surficial Soils (0-2 in). Figure RISR D1.4-2, Distribution of Arsenic and Mercury in Surficial Soils (0-2 in) Greater than the Indicator Range presents the extent of detected inorganic contamination exceeding levels indicative of background concentrations. Figure RISR 2.1-1 has been revised to clarify the extent of surficial soil contamination. In addition, the data from the surficial soils study (summarized in Appendix D1) have been incorporated into Table RISR A3.1-8 and Figure RISR A3.1-10, both supporting the discussion of the Surficial Soil and Other Predominantly Near-Surface Contamination site type in the proposed final version of the RISR. This site type was referred to as the Inferred Windblown and Other Contamination site type in the Draft Final version of the RISR.

Comment 2: Plate RISR 2.1-1. This plate, which is an excellent graphic presentation of the spatial relationship between the arsenal and the groundwater contamination, should indicate the CRL used for the preparation of the contours in the saturated alluvium and bedrock surface.

Response: Because certified reporting limits (CRLs) depend on the individual analyte, laboratory, and analytical method used, no single CRL value was used to plot the contours shown for the total organic analytes in the unconfined flow system on Plate RISR 2.1-1. Rather, the CRL contour encloses the area within which detections of any target organic analytes exceeded their respective CRLs. A clarifying note has been added to the plate, and to all other graphics depicting contoured total contaminant concentrations.

Comment 3: The text should be amended in several sections to clarify that Army agents were found in several areas other than the Army trenches, including one lewisite [sic] detection in Section 35.

Response: In Section 2.2, Potential for Occurrence of Chemical Warfare Agents and Unexploded Ordnance, Figure RISR 2.2-1 presents a map of areas with a potential for agent occurrences. As is clear from inspection of this figure, other areas, in addition to the Army trenches, are included.

Records in the Installation Restoration Data Management Information System (IRDMIS) Rocky Mountain Arsenal (RMA) database indicating detections of agents in soils outside the areas shown on Figure RISR 2.2-1 are suspect, or were not confirmed by subsequent sampling. The Lewisite method in use at the time was known to give false positive results. The following bores show agent detections in soils in the RMA database:

Bore	Depth (ft)	Agent	Concentration µg/g	Julian Date Sampled	CRL	Method
						29Y
3092	5	Mustard	0.844	85175	2.1	29Y
3092	7	Mustard	0.22	85176	2.1	29Y
3094	5	Mustard	0.22	85175	2.1	29Y
3599	0	Mustard	0.882	88014	2.1	29Y
3500	3	Lewisite	12.8	87280	5.0	29X
3504	3	Lewisite	>5.0	87272	5.0	29X
3629	1	Lewisite	55.4	88049	5.0	29X
3629	3	Lewisite	38.9	88049	5.0	29X
3629	4	Lewisite	5.9	88049	5.0	29X
4114	4	Lewisite	5.0	87294	5.0	29X
NRS06122	5	Lewisite	5.0	87265	5.0	29X
Limefix 1	0.0	Lewisite	18.5	89261	5.0	29V
Limefix 2	0.0	Lewisite	12.9	89261	5.0	29V
Limefix 3	0.0	Lewisite	5.5	89261	5.0	29V
Limesoil	0.0	Lewisite	14.9	89254	5.0	29V
RTP317T	0.0	VX	5.9	89086	5.9	29U
RTP318T	0.0	VX	5.9	89086	5.9	29U
RTP319T	0.0	VX	5.9	89086	5.9	29U
RTP337T	0.0	VX	5.9	89086	5.9	29U
RTP338T	0.0	VX	5.9	89086	5.9	29U
RTP339T	0.0	VX	5.9	89086	5.9	29U

Review of the data files, the Contamination Assessment Reports (CARs), lab analytical data packets form the RMA Surety Lab, where all these and other agent analyses were performed, and communications with Army and contractor personnel reveals the following:

Mustard:

1) All the mustard detections are at concentrations less than one-half of the method CRL, therefore, were never positively identified, and should not have been entered into the database.

2) All the field test kit (M8 alarm and M18A2) results were negative for the mustard locations (Final Phase I CAR, Site 36-17: Complex Disposal Activity, Version 3.2; ESE, 1988/RIC 88013R05).

3) With the exception of Bore 3599, no second column confirmation analysis was available at the time to confirm the mustard detections. Second column analysis on Bore 3599 indicated a mustard detection below the method CRL but just above the lowest calibration standard.

4) All the mustard detections are within Section 36, in the Complex Disposal Areas.

5) All the mustard detections are within the area shown in Figure RISR 2.2-1 as having a potential for agent occurrences.

Lewisite:

1) The Lewisite methods were highly susceptible to false positives, since the methods actually measured for acetylene resulting from reaction of the sample extract with NaOH. Plastic debris and combustion byproducts were noted to be present in some samples analyzed for Lewisite, which could have caused false positive readings (Elijah Jones, Laboratory Support Division - Program Manager Rocky Mountain Arsenal (PMRMA), oral communication with James Bush - EBASCO, August 8, 1991).

2) The Lewisite detection in Bore 3500 in Basin A was investigated for verification by collection and analysis of a sample from Bore 3733, located within a 3 ft radius circle of Bore 3500. Agent was not detected in that sample using a more reliable certified method (Final Phase II Data Addendum, Site 36-1: Basin A, Version 3.1, pp 1-2; ESE, 1988/RIC 87203R07A).

3) Bore 3504 in Basin A was also reinvestigated during the Remedial Investigation (RI). Analysis of a sample from Bore 3734, located within 3 ft of Bore 3504, indicated no detections for agents, using a more reliable RMA Laboratory certified analysis (Ibid.).

4) Agent was not detected in a sample from Boring 3738, drilled 3 ft north of Bore 3629 in the Complex Disposal Sites North in Section 36 for verification purposes (Final Phase II Data Addendum, Site 36-17: Complex Disposal Activity, Version 3.1, p. 17; ESE, 1988/RIC 88013R05A).

5) Bore 4114 was investigated further by collection of a sample from Bore 4138, located within 2 ft east of it in Basin B in Section 35. Lewisite was not detected in this sample using a more reliable analytical method (Final Phase II Data Addendum, Site 35-3: Basin B, Version 3.1, p. 1; ESE, 1988/RIC 87203R05A).

6) Bore NRS06122 was drilled by Shell's contractor in the vicinity of the Former Toxic Gas Storage Yard in Section 6. According to the "Final Phase I CAR, Site 6-6, Former Toxic Gas Storage Yard, Version 3.2 (EBASCO, 1988/RIC 88196R02), this bore was located in the vicinity of Boring 5, a Phase I bore with high arsenic concentrations. The vicinity of Boring 5 was investigated in Phase II by three bores, Borings 23, 24, and 25. Two of these bores also had high arsenic concentrations (97 and 130 µg/g); however, the M8 and M18A2 field test kits used to monitor for agent during both Phase I and Phase II investigations did not indicate any agent detections (Final Phase I CAR, Site 6-6, Former Toxic Gas Storage Yard, Version 3.1, EBASCO, 1988/RIC 88196R02A).

7) Bores Limefix 1, Limefix 2, Limefix 3, and Limesoil were all collected as part of the Remediation of Other Contamination Sources ("Hot Spots") Interim Response Action (IRA), in the immediate vicinity of the Lime Settling Basins in Section 36. They were collected from areas known to have high levels of various contaminants. While no evidence of additional sample collection to verify these detections is available, these samples are within the Lime Settling Basins area, shown in Figure RISR 2.2-1 as having the potential for agent occurrences.

VX (Nerve Agent):

1) Bores RTP317T, 318T, 319T, 337T, 338T, and 339T with VX detections in the RMA database all show the same concentration value. According to Elijah Jones, Laboratory Support Division - PMRMA, all these records should have "LT" (Less than) in the boolean field preceding the concentration value (oral communication with James Bush - EBASCO, August 12, 1991).

Summary:
With the exception of Bore 4114 and the RTP bores, all the bores showing detections of agent in the RMA database are within the areas shown in Figure RISR 2.2-1 as being areas with a potential for agent occurrences. It is the conclusion of the RI that the Lewisite detection in Bore 4114 was a false positive, as evidenced by nondetects for agent in the sample from Bore 4138.

All areas shown in Figure RISR 2.2-1 will be addressed by the Feasibility Study (FS) as part of the evaluation of remedial alternatives with respect to agents.

In addition to the records for agent detections in soils discussed above, agent contamination in certain structures is recognized by the Army. The text of Section 2.2 has been revised to distinguish between soils and structures contaminated with agents.

Comment 4: Page 2-21, the text should be amended to indicate that "direct" human exposure to the top few inches of soil is one of the most important exposure pathways.

Response: The text has been amended to reflect the importance of potential direct human exposures associated with surficial soil contamination.

Comment 5: Page 2-30, the text needs to clarify that, although the degree of contamination and migration in the Denver Formation are less than in the unconfined aquifer, the contamination in the Denver Formation is never the less [sic] significant, given concentrations of up to 10,000 ug/l found in several areas, including Section 23.

Response: The text has been revised to indicate that contaminant concentrations in the confined flow system in isolated locations may equal or exceed those in the overlying unconfined flow system.

Comment 6: Appendix A, the text should be expanded to include a summary of the investigations performed to date of the LNAPLs, DNAPLs, and/or adsorbed contamination in saturated soils, rather than focusing on water quality only. The text should further indicate that additional investigation of these contaminants will be performed as needed during the FS.

Response: The text in Section A2.2.2 has been expanded to include a summary of investigations regarding light nonaqueous-phase liquids (LNAPLs) and dense nonaqueous-phase liquids (DNAPLs), and absorbed contamination. Future investigations are noted in the text.

Comment 7: Appendix A, the report should use the most recent QA/QC data, rather than relying on data that are 2 years old.

Response: The RISR is intended to summarize the RI Program and its findings. Data collection under the RI was essentially completed by March 1989. It is beyond the scope of the RISR to attempt to summarize the findings of the many other investigations conducted at RMA under various programs outside the RI. However, CMP data have been considered where appropriate. For example, references to the Comprehensive Monitoring Program (CMP) are included as appropriate throughout the RISR to inform the reader of the existence of additional data collected outside or subsequent to the RI program. Readers are encouraged to explore these other program results. Results of the surficial soils and ground disturbance programs are appended to the RISR because these two programs were agreed to by the parties as a part of the finalization and acceptance process for the Study Area Reports (SARs).

Comment 8: Table RISR A2.5-1, this table presents CRLs that are up to an order of magnitude lower than those used in the Biota RI. This discrepancy, which could impact the CMP and the values used in the biota model, should be clarified.

Response: With the exception of endrin, the CRL values shown on Table RISR A2.5-1 are the same as those shown of Table 4.3-3 of the Final Biota RI Report. The lower CRL value for endrin was 0.040 µg/g, not 0.40 µg/g as shown. This typographical error has been corrected. Some CRLs in the CMP program are different than those in the Biota RI. CMP reports have compared CRLs used by both the Biota RI and CMP programs. Where CRLs are lower, this should serve to decrease the uncertainty associated with the pathways model by providing more and lower detections. All variations in CRLs are considered in data manipulations which may be affected by CRL values.

Comment 9: Appendix A, Section A3.1.1. We request a listing that states what specific sites have been grouped into each generic category. This would help in cross-referencing with FS documents.

Response: Tables RISR 1.2-2 and 2.1-1 in sections 1.2 and 2.1 present such lists.

Comment 10: Appendix B, Vertical Extent of Contamination, the text needs to indicate that the information and analysis presented in this Appendix will be fully incorporated into the FS, including any further sampling that may be needed to address remediation alternatives for the Denver Formation.

Response: The information presented in Appendix B will be considered in the FS. The text has been modified to reflect this.

Comment 11: Appendix D, this appendix should provide a discussion of soil sampling QA/QC procedures or a reference to another document which contains these procedures.

Response: Appendix D does contain general descriptions of the soil sampling procedures used for both the surficial soil and ground disturbance investigations, as well as references to the final data summary reports for both programs, wherein the quality assurance/quality control (QA/QC) procedures are further explained or referenced. In addition, please see response to EPA Appendix D General Comment 1, wherein references to the Procedures Manual and the Quality Assurance Program Plan are provided.

General Comments

Comment 1: This document is generally acceptable, but is in need of clarification in several places. Realizing that this document is a summary of a massive amount of data, it must necessarily omit some detail. Since the technical information in this document is of limited value to detailed technical evaluation, this document is most likely to be used by less technical readers. Therefore, accuracy and some additional detail is essential to the readers' accurate understanding of the arsenal.

Response: Comment noted.

Comment 2: The Army is to be commended for the quality of the graphical presentations. They aid greatly in the understanding of the nature and extent of contamination at the arsenal.

Response: The Army appreciates the comment.

Specific Comments

Comment 1: Executive Summary, page xxxii. The text should be amended to state that contaminants were also introduced from emissions from permitted air stacks and the use of commercial chemical products during normal facility operation.

Response: The text has been revised.

Comment 2: Page 1-1, Section 1.0. Please amend the text to state that the RI/FS is being developed in conformance with the requirements of the National Contingency Plan as revised.

Response: The text has been modified as requested.

Comment 3: Page 1-3, Section 1.0. Please amend the text to specifically identify the parties or signatories to the Federal Facility Agreement, not included in the preceding text.

Response: The text has been amended to specifically identify the signatories to the Federal Facility Agreement.

Comment 4: Page 1-18, Section 1.3. This section does not indicate that numerous spills of raw material or products occurred at RMA. It implies that spills occurred as isolated incidents. This is inconsistent with the Chemical Index. It is important to indicate that many spills occurred because this helps the reader to understand the widespread contamination. For example, also note page 2-16, paragraph 2.

Response: Statements indicating the importance of spills have been added to Sections 1.3.3 and 2.1.3.

Comment 5: Page 1-21, Section 1.3.1. The text states that storage bunkers in Sections 5, 6, 7, and 8 were used for storage of cluster and incendiary bombs, which contain white phosphorus. As a separate matter, we need to discuss how these storage bunkers might be incorporated into the Surety IRA, which is assessing the contamination and decontamination of the White Phosphorus building in the South Plants.

Response: Comment noted. This action is known as the Chemical Process Related Activities.

Comment 6: Page 1-24, Section 1.3.1. Please provide a reference to the hazardous [sic] abatement work that has been performed at the HBSF, referred to in the text.

Response: According to the Final Phase I CAR for Site 1-7, Hydrazine Blending and Storage Facility: "RMA implemented hazard abatement plans to eliminate potential sources of [nitrosodimethylamine] (RMA,1983; Smith, 1983). The abatement plans included the removal of all fuel from the facility and the decontamination of the entire facility. An Air Force contractor submitted a bid for this work in late September 1983 (RMA, 1983)."

RMA. 1983, September 30. Rocky Mountain Arsenal annual historical review, October 1, 1982, through September 30, 1983. Microfilm RMA196, Frames 1216-1217.

Smith, R. W. 1983, July 22. Fact sheet to commanding general AMCCOM hydrazine blending and storage program status, Rocky Mountain Arsenal. Microfilm RMA023, Frame 0516.

Comment 7: Page 1-24, Section 1.3.2. The text indicates that Shell is a current lessee of the South Plants facilities. If this statement is incorrect, please amend the text.

Response: The text has been amended to show that Shell's lease on the South Plants facilities expired in 1987.

Comment 8: Page 1-27, Section 1.3.3. The text should be expanded to discuss the historic production and discharge of arsenic-containing compounds in both Army and Shell manufacturing.

Response: The Army handled arsenic-containing compounds Lewisite and Adamsite. The manufacture of Lewisite is already mentioned in Section 1.3.1. A statement about the Army's demilitarization of Adamsite in Building 1611 has been added to Section 1.3.1.

According to Shell Comments #26 and #32 to the RMA Chemical Index (EBASCO, 1988c/RIC 90326R01), and the Army's responses to those comments, the only arsenic-containing compound associated with Shell was a fuel oil in which arsenic was detected.

Comment 9: Page 1-30, Section 1.3.3. Please expand the text to mention the later closure of the deep well and to provide specifics on the pump testing program conducted in 1968 that may relate to well integrity.

Response: Additional information on the well closure and the pumping tests, including a reference, has been added to the text. Reference for the information provided is found in the Final Phase I Contamination Assessment Report Site 26-1: Deep Disposal Well and Chemical Sewers (Version 3.2), March 1988 (ESE, 1988/RIC 88103R02). A report on the 1968 pump tests was prepared by Dr. H.K. Van Poollen for the U.S. Corps of Engineers in January 1969. That report contains specific information and data obtained during the pump tests. The purpose of the pumping tests was to determine the feasibility of a full-scale pumping program and determine whether removal of fluid from the deep disposal well would reduce seismic activity in the vicinity.

Van Poollen, H.K. January 1969. Report of Pumping Tests, Rocky Mountain Arsenal Disposal Well, September - October 1968. Microfilm RMA145, Frames 0003-0111, 0010-0019.

Comment 10: Page 1-30, Section 1.3.3. Please state the current status of the Denver Effluent Treatment Facility, constructed by Shell in 1975.

Response: Like other production and support facilities in South Plants, the Denver Effluent Treatment Facility is currently inactive, and has been since 1982.

Comment 11: Page 1-61, Section 1.4.1.2. The second paragraph should be expanded to mention the construction of the Klein Water Treatment Facility on RMA, completed in 1989, to treat multisource TCE contamination.

Response: The purpose and construction completion date for the Klein Water Treatment Facility on RMA have been added to the text in Section 1.3.4.

Comment 12: Page 2-2, Paragraph 2, sixth sentence. This sentence states that low levels of OCPs are found throughout most of RMA. Without any qualifying statement to indicate what these low levels are, the reader is free to use his own imagination regarding the significance of these low levels of contamination. The same can be said for the statement that the contamination covers most of the arsenal. Some indication of the significance of the low levels of contamination and its areal extent would prevent the reader from drawing erroneous conclusions.

Response: The text has been modified to indicate the range of contaminant concentrations detected by the surficial soil program outside of designated site areas. Within designated site areas the maximum total organic concentration was 920 µg/g on the east side of and near former Basin F. An exposure assessment of the surficial soils contamination is being prepared as part the addendum to the Human Health Exposure Assessment.

Comment 13: Figure RISR 2.1-1. This figure shows the windblown soils as being very limited, primarily around Basin F and South Plants. This contradicts the statement made on Page 2-2 (see comment page 2-2, paragraph 2, sixth sentence) which states that most of the arsenal is contaminated.

The area indicated in yellow also does not include the 1989-1990 surficial soils data and should be so qualified. We recommend that a similar figure, drawn from Figure RISR D1.4-1, showing the extent of surficial soils contamination be added to this section to avoid an erroneous impression that the windblown contamination is limited to Sections 26 and 36.

It would be useful if the figure and/or text indicated what concentration levels were used to delineate the boundaries of the Inferred Windblown and Other Contamination areas.

Response: See response to EPA Cover Letter Comment 1. Figures RISR 2.1-1, A3.1-1, and A3.1-2 have been modified to better indicate the extent of surficial soil contamination.

Comment 14: Page 2-11, Paragraph 1, last sentence. This sentence states that the volume of soils requiring remediation is based on detections only and may not be indicative of actual volumes that will require remediation. This statement requires additional clarification as it leaves open the question of what is the value of these volume estimates.

Response: These volume estimates represent first-order approximations of the soil volumes that may require remediation. The FS will make refined estimates of the soil volumes requiring remediation, based on numerous factors including data developed by other programs, the exposure assessment and risk characterization results, and land-use and other policy decisions.

Comment 15: Plate RISR 2.1-1. This plate is an excellent graphic presentation of the spatial relationship between the arsenal and the groundwater contamination. However, this plate should indicate what CRL was used for the preparation of the contours in the Saturated Alluvium diagram. Without knowing the value that was used, it is impossible to determine by what standard the extent of the groundwater contamination is being measured. It would also be very useful if the plate identified which contaminants were used to create this plate.

Response: The Army appreciates EPA's opinion of Plate RISR 2.1-1. No single CRL value was used to contour contaminant concentrations in the unconfined alluvium. The RI analyzed literally thousands of samples and many thousands of analyte concentrations from several different laboratories using several different U.S. Army Toxic and Hazardous Materials Agency (USATHAMA)-certified methods with different CRLs. Therefore, it would be impossible to select a single CRL value that adequately presented the analytical results without undesirable bias. Instead, Plate RISR 2.1-1 as well as all other graphic presentations of multiple analyte occurrences, incorporates all target analyte concentrations in excess of their respective CRLs for the sampling period shown. The effect of this approach is conservative; that is, a positive detection of a single analyte at any given location will be represented even if all other analytes, including those with more sensitive reporting limits were below their CRL values. Similarly, if less sensitive methods did not show detections, positive results from more sensitive methods would still be shown. For the 1989 Total Organic Analytes Plume in the unconfined flow system (UFS), all RI target analyte results (see Section A2.2) were incorporated.

Comment 16: Page 2-14, Section 2.1.2, second to last sentence. This section indicates that potentially, Army agents may be found only in the Army trenches. This presentation implies that Army agents will only be found in the Army trenches. Data on the RMA database clearly shows that Army agents have been detected in several other areas in addition to the Army trenches, including one lewisite [sic] detection in section 35. Also, the second paragraph on page 2-16 states that lewisite [sic] was detected in the M-1 settling basins. This sentence needs to be modified to indicate that the presence of detectable Army agents exists in several areas, not just the Army trenches.

Response: Please see response to EPA Cover Letter Comment 3. The cited passage does not indicate that potential Army agent occurrences may be found only in Army trenches. It does indicate that a potential for Army chemical agent occurrences exists in the Army trenches, despite geophysical, analytical, and exploratory excavation evidence which did not support the conclusion that Army agents are present in the trenches. The reported detection of Lewisite contamination in the M-1 settling basins (site SPSA-1e) is also not in contradiction with the cited passage. Figure RISR 2.2-1 shows areas with a potential for agent occurrences.

Comment 17: Page 2-18, Paragraph 1, last sentence. While the Army has concluded that the potential for groundwater migration of OCPs from lake sediments should be reduced due to the proclivity of these compounds to sorb onto soil particles, this conclusion has not yet been positively demonstrated. A statement to this effect would serve to avoid misleading the reader.

Response: The paragraph in question has been revised in response to the U.S. Fish and Wildlife Service (USFWS) Comment 6. The passage notes that the data from the RMA lakes "suggests that aldrin and dieldrin are so strongly sorbed to sediment materials that normal conversion mechanisms may not operate (Cushing, 1990)." Use of the term "suggests" was deliberate to indicate that this conclusion is a reasonable hypothesis.

Comment 18: Page 2-18, Paragraph 2, last sentence. Please qualify "considerably less." Considering the volume of contaminated material at the larger sites, the sewers could still contribute a significant percentage to the volume of the contaminated soils.

Response: The statement in question refers to ditches, not sewers. The volume estimates in Table RISR 2.1-1 show that most ditch sites have a few thousand to a few tens of thousands of bank cubic yards (b.c.y.) of contaminated soil associated with them, while contaminated volumes associated with lake and pond sites range from under 100,000 b.c.y. to over 400,000 b.c.y. Therefore, the term "considerably less" in this context indicates that the volume of contaminated soil assigned to ditches is approximately an order of magnitude less than that associated with lakes and ponds.

Comment 19: Page 2-21, Paragraph 2, last sentence. The word "limited" is incorrect and should be replaced with "direct." Direct human exposure to the top few inches of soil is one of the most important exposure pathways.

Response: The passage has been modified to indicate that direct human exposure is considered an important potential exposure pathway.

Comment 20: Page 2-21, Paragraph 3, first sentence. Please explain what parameters were used to judge the on-post air quality to be superior to off-post air quality.

Response: The paragraph discussing the relative quality of air onpost and offpost has been deleted from the text.

Comment 21: Page 2-23, Section 2.2. The detection of Army agents, as evidenced by data on the RMA database, includes lewisite [sic] as well as mustard, contradicting the Army's position as stated in this paragraph. Please modify the text to indicate that agents have been detected on the arsenal and the detections are not limited to mustard only. Furthermore, EPA does not consider agent detections of 55 µg/g to be insignificant.

Response: The statement that "agents generally have short half-lives when exposed to the natural elements and, with the exception of mustard that may have been trapped in voids beneath buildings, are not persistent" is not contradicted by the records on the RMA database. Agents do generally have short half-lives and, unless protected from the elements, tend not to be persistent in the natural environment. The mustard detections on the RMA database are all at concentrations less than 50 percent of their CRL for the analytical method used (please see response to EPA Cover Letter Comment 3). Nevertheless, the potential for mustard occurrences and the presence of a Lewisite detection were previously noted in the text (Sections 2.1.1 and 2.1.3). The text of Section 2.2 has been modified to include reference to the data for Lewisite and mustard on the RMA database.

Comment 22: Page 2-24, Paragraph 1, second sentence and Figure RISR 2.2-1. According to data filed in the RMA database, a lewisite [sic] detection has been noted in Section 35. This contradicts the Army's statement that the map shows a worst case scenario. The map does not include this detection in the areal extent of agent contamination. Please modify the text and the map to accurately depict the extent of agent contamination.

Response: Please see response to EPA Cover Letter Comment 3. Lewisite detections outside the M-1 pits (Site SPSA-1e) in South Plants, as evidenced by data on the RMA database, are suspect. The analytical method for Lewisite was known to give false positives, as it is actually a measure of the presence of acetylene formed by reaction of NaOH with the sample extract. Analysis of a Phase II sample taken at the location of a Phase I Lewisite detection in Basin B was negative for Lewisite (Final Phase II Data Addendum, Section 35-UNC, Nonsource Area, Version 3.1/RIC 87313R01A). As noted in the previous response, the text has been modified to include reference to Lewisite detections outside of the South Plants area.

Comment 23: Page 2-30, Paragraph 2. Many spatially related detections involve different analytes. Differences in analytes are often the results of degradation/transformation processes. The correlation between various analytes should be clarified before the detections in the Denver Formation are said to be "not spatially related."

Response: The text has been revised to refer only to the detections within the Denver Formation as not appearing spatially related. The spatial relationship between individual analytes detected in the Denver Formation are not discussed.

Comment 24: Page 2-32, Paragraph 2. This states that arsenic levels in plants near Basin A were within the range that could produce phytotoxic effects, "however, no such effects were noted." This statement appears to be in error, because no plants grow in large portions of Basin A. We submit that significant phytotoxicity exists, given the lack of vegetation in portions of Basin A and believe that the statement should be deleted.

Response: Details of the study from which this conclusion was drawn are presented in the Biota RI Report (Section 3.2.2, Methods; Section 4.3.2, Contaminants in Terrestrial Ecosystems, and Section 5.3, Contaminant Effects). Section 5.3.2.1 (Effects of Contaminant

Levels in Terrestrial Plants) of the Biota RI reports that signs of obvious phytotoxicity were not observed and acknowledges that arsenic may have contributed to the low diversity of species in Basin A. The high level of disturbance and soil compaction, factors that could also affect plant species diversity, made this hypothesis difficult to evaluate. The text has been revised to clarify these points. The statement "however, no such effects were noted" is correct.

Comment 25: Page 2-30, Paragraph 2, last sentence. This indicates that the degree of contamination and migration in the Denver Formation are "less than" the unconfined aquifer. This is not a sufficient statement because the unconfined system contamination is high and extensive. The last sentence should be revised to state that "although less than ... the unconfined system, contamination in the Denver Formation is never the less [sic] significant, given concentrations of up to 10,000 µg/l found in several areas, including Section 23."

Response: The text has been revised to clarify the range of contaminant concentrations detected in the confined flow system (CFS).

Comment 26: Page 2-32, Paragraph 4. This section should also indicate that significant wildlife management practices have been implemented to attract wildlife to uncontaminated areas of RMA and also to eliminate contaminated biota in contaminated areas.

Response: A statement about wildlife management has been added to the first paragraph of Section 2.4.

ENVIRONMENTAL PROTECTION AGENCY'S
COMMENTS ON THE
DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX A - ENVIRONMENTAL SETTLING, RI APPROACH, NATURE AND EXTENT OF CONTAMINATION
MAY 1991

General Comments

Comment 1: This document was well written and generally did an excellent job of evaluating and summarizing a very large body of data, from a very complex site.

Response: The Army appreciates the EPA's comment.

Comment 2: The level of investigation into contamination of the confined aquifer has been disproportionately small compared to investigation of the unconfined aquifer, since the unconfined aquifer contains the bulk of contamination that has migrated downward. The potential for remediation of the confined aquifer should be addressed in the FS.

Response: The Army believes, because of the restricted contaminant migration potential of the Denver Formation, the typically reduced contaminant concentrations within the Denver Formation, and the limited potential receptors of Denver Formation contamination, that in general sufficient characterization of the Denver Formation has been developed to conduct the FS. Additional site-specific investigations in limited areas will be considered in the FS.

Comment 3: The text should be expanded to include a summary of the investigations performed to date of the LNAPLs, DNAPLs, and/or adsorbed contamination in saturated soils, rather than focusing on water quality only. The text should further indicate that additional investigation of these contaminants will be performed as needed during the FS.

Response: Please see response to EPA Cover Letter Comment 6.

Specific Comments

Comment A1: Page A1-3, partial paragraph at top of page, last sentence. It is stated that the highest wind speed recorded as a 1-minute average was 65 mph. It is unclear if this refers to only the time period during the RI activities or the maximum ever recorded over a larger historical time period.

Response: The statement is in error and has been revised. The highest windspeed recorded at Stapleton in the time period of 1951 to 1980 as a 1-minute average was 44 mph from the northwest.

Comment A2: Page A1-3, last paragraph, last sentence. Even a very brief description of the Basin F IRA would be helpful here. For example, "An interim response action (IRA) for Basin F to containerize the liquids and stabilize soils and sludges in a waste pile was completed in May, 1989." As written it is assumed that the reader is familiar with the Basin F IRA. At the very least, a reference to a document with a description of the past Basin F activities should be included.

Response: The text has been revised. In addition, a summary of the Basin F IRA is presented in Appendix C and a list of reports pertaining to the Basin F liquids, sludges and soils remediation are provided in Table C.1-4 of this report.

Comment A3: Page A1-4, first paragraph, first sentence. Again, a reference, or very brief description of the purpose of the containment systems would be helpful. For example, "Three groundwater interception/treatment systems ...., are present at RMA to capture contaminant plumes before they migrate off post."

Response: The text has been revised as indicated.

Comment A4: Page A1-9, partial paragraph at top of page, last sentence. A word or words appear to be missing from this sentence. Please amend the text.

Response: The text has been amended.

Comment A5: Page A1-14, Section A1.5.3. Please expand the text to provide more information on the Confined Flow System production wells in use on RMA, including their location, depth, pumping rates, contamination levels, and use(s) of the water.

Response: The word "no" was inadvertently omitted from the last sentence of the second paragraph on page A1-14. There are no production wells that obtain water from the CFS on RMA. This is in keeping with the Federal Facilities Agreement which prohibits the use of groundwater located under the Arsenal as a source of potable water.

Comment A6: Page A2-12, first paragraph. Are there any instances when criterion 4 was met, but not criterion 3? If so, the analyte under consideration would not have been included as a target analyte. Because criterion 4 includes consideration of the persistence of an analyte, it seems that any analyte meeting criteria 2, 3, and 4 should have been emphasized.

Response: In general, analytes meeting criteria 2, 3, and 4 were included in the target list. In addition to inclusion of likely degradation products and manufacturing by-products of Army agents in the target analyte list, other methods were used to ensure that even those agents or related compounds that were unlikely to be present would be detected. These methods include field screening for chemical agent residues during sample collection, RMA laboratory analysis of all soil samples for chemical agents prior to shipment to the contract laboratories, and identification of nontarget compounds during Phase I gas chromatography/mass spectroscopy (GC/MS) soil analysis. The use of these combined strategies has resulted in a thorough analysis of Army agent compounds at RMA.

Comment A7: Page A2-51, Section A2.2.1, first paragraph, last sentence. Were the stream gaging stations that were installed starting in 1982 all located on post? The sentence should be rewritten to clarify this.

Response: The stations were installed at on-post locations. The sentence has been modified to include this description.

Comment A8: Page A2-54, first paragraph. To assist the reader in locating the results of the study, a reference identifying where the results of Task 39 are presented is needed in this paragraph.

Response: The text has been revised to include a reference for the Task 39 investigation. The results of Task 39 are presented in the Off-Post Operable Unit Remedial Investigation and Chemical Specific Applicable or Relevant and Appropriate Requirements Final Report (ESE, 1988f/RIC 89173R01).

Comment A9: Page A2-57, first full paragraph, last sentence. As stated, this sentence detracts from the credibility of the document. This report is using data that are 2 years old when more recent data exists. If there is a reason that data collected after 1989 are not discussed, the reason should be stated here.

Response: See response to EPA Cover Letter Comment 7.

Comment A10: Table RISR A2.5-1. This table presents CRLs in animals that are up to an order of magnitude lower than those used in the Biota RI. For example, the Biota CMP gives a CRL for aldrin in animal tissue as 0.103 µg/g and the RISR gives a lower CRL for animal tissue as 0.020 µg/g. The same situation is also observed for other compounds listed in the RISR, such as dieldrin, endrin, DDT, and arsenic. Please explain these discrepancies between the two documents. This could have a significant impact on the CMP if the lower CRL presented in this report were applied to the Biota CMP data. The number of detections would be increased significantly. This change in CRLs could also impact the confidence of the values used in the biota model.

Response: See response to EPA Cover Letter Comment 8. It is unclear whether EPA is referring to discrepancies between the RISR and the Biota RI or the CMP. As previously stated, the CMP is not a subject of the RISR.

Comment A11: Page A3-2, top of page, second sentence. This sentence is incomplete. Text appears to have been omitted from this sentence. Please clarify so the meaning may be understood.

Response: The sentence has been corrected to include the words "were used."

Comment A12: Table RISR A3.2-1. This table appears to be in error in that it completely omits the positive detections of agent, thereby creating the impression that agents were either not analyzed for or not detected. We recommend that all agent detections be included.

Response: This comment should probably refer to Table RISR A3.1-1, Summary of Analytical Results for Soils in Basins and Lagoons rather than Table RISR A3.2-1 Summary of Detections in Surface Water. The soils data tables are compilations of the information developed in the RI program for target compounds and significant tentatively identified compounds. Agent (surety compounds) analyses were not included in the target analytes reported in the CARs or SARs and, consequently, are not included on the data summary tables in the RISR. Verification sampling did not confirm most of the reported detections. In addition, most reported detections were below the CRL value (but, due to the extremely conservative nature of the surety lab program, were erroneously reported). Finally, most of the reported detections are suspect due to the susceptibility of the analytical technique to generate false positives. For further discussion of agent detections, please see response to EPA Cover Letter Comment 3.

Comment A13: Page A3-6, Section A3.1.1. Since sites are grouped in generic categories, it is not possible to ascertain for many sites exactly where they fit. Therefore, we request a listing stating what specific sites (i.e., NCSA-2a, WSA-3e, etc.) fit into each category. This would help cross-referencing with FS documents and facilitate use of this RISR.

Response: Tables RISR 1.2-2 and 2.1-1 in Sections 1.0 and 2.0 provide a lists of the sites that are included in each site type.

Comment A14: Page A3-31, last paragraph, sixth sentence. This sentence appears to be missing depth information. Were the high concentrations of OCPs, DBCP, and arsenic detected in the uppermost samples or at some greater depth?

Response: Depth information has been added to the sentence. High concentrations (>10,000 µg/g) of organochlorine pesticides (OCPs), dibromochloropropane (DBCP), and arsenic were detected in the 0- to 2-ft interval; high OCP concentrations were also detected in the 2- to 5-, and 5- to 20-ft intervals.

Comment A15: Page A3-73, Section A3.2.1. Please include information on the location and use of the South Plants sedimentation pond, referred to in this section.

Response: The South Plants sedimentation pond is Site SPSA-12b, which is included in the Basins and Lagoons site type. The pond was a part of the South Plants process water system and received overflows and purge water from the cooling tower. The location of the South Plants sedimentation pond with respect to other surface water features is shown in Figure RISR A1.5-1.

Comment A16: Page A3-75, top of page, second sentence. The word "Table" should be deleted from this sentence.

Response: The sentence has been corrected.

Comment A17: Page A3-127, first full paragraph, second to last sentence. It is stated that the total depth of contamination could not be inferred in Sections 22 and 26, the southeast corner of Section 35, and the NBCS. Further clarification is needed to explain why the depth of contamination could not be inferred in these areas. This is one of the data gaps that should be addressed in the FS.

Response: The total depth of contamination could not be inferred in these areas because organics were detected in the deepest wells in these areas. This explanation has been added to the text. The Army believes, because of the restricted contaminant migration potential of the Denver Formation, the typically reduced contaminant concentrations within the Denver Formation, and the limited potential receptors of Denver Formation contamination, that in general sufficient characterization of the Denver Formation has been developed to conduct the FS. Additional site-specific investigations in limited areas will be considered in the FS.

Comment A18: Page A3-129, Section A3.3, first paragraph, last sentence. The text states that ". . . the Structures Survey Report (EBASCO, 1988c/RIC 88306R02) below." The word "below" should be deleted.

Response: The sentence has been corrected to indicate that the results of the programs are presented in the Structures Survey Report.

Comment A19: Page A3-133, Section A3.3.4. The text states that asbestos was "only detected in buildings from the South Plants". Does this statement refer only to the RI Structures sampling effort? EPA has received notification of asbestos abatement work at other structures than South Plants buildings.

Response: The text has been revised slightly to clarify this point. The statement in the text refers only to the Task 24 RI Structures sampling investigation. The Asbestos Removal IRA is currently addressing the need for additional assessment and removal of asbestos at RMA.

Comment A20: Page A3-133, Section A.3.3.5. The annual program of air monitoring in agent operations buildings is not part of the Air CMP program. For what purpose is this data being collected? Please provide reference to documentation on this program.

Response: These data are collected by the Army as part of their internal health and safety program. Reference to the program has been included in Section A3.3.5.

Comment A21: Page A3-145, Paragraph 2. This states that "similar associations could not be made for OCPs" at other trophic levels. It appears that this statement was prepared without the benefit of the 1990 surficial soils data. If so, it should be qualified, as it could appear to be misleading.

Response: The information summarized herein is from the Final Biota RI report. Additional data from CMP, surficial soils, and subsequent programs will be incorporated into the Endangerment Assessment (EA) and FS documents. The paragraph has been modified to clarify the potentially misleading statement.

Comment A22: Figures A3.5-1 and A3.5-2.[sic] The units for contaminant concentrations are incorrect. They should be µg/g of animal tissue rather than µg/l.

Response: This comment incorrectly references Figure RISR A3.5-1, which does not present any contamination concentrations, and should refer to Figure RISR A3.5-3 as well as Figure RISR A3.5-2. Both Figures RISR A3.5-2 and -3 have been corrected.

ENVIRONMENTAL PROTECTION AGENCY'S
COMMENTS ON THE
DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX B - VERTICAL EXTENT OF GROUNDWATER CONTAMINATION IN THE DENVER AQUIFER
MAY 1991

Specific Comments

Comment B1: Page B-1, first paragraph, second and fourth sentences. The text should specify ranges of values for "low" hydraulic conductivities and well yields or at least refer to that part of the document where these characteristics are discussed. It would also be informative to state that hydraulic conductivity and well yield are "low" with respect to values measured for the alluvial aquifer. The use of the term "low" is very subjective and may mean different things to different readers.

Response: The estimated ranges of hydraulic conductivities for the Denver aquifer sediments, a comparison to hydraulic conductivities, and a reference to the sections in Appendix A that include more detail regarding this information have been added to the text.

Comment B2: Page B-6, Section B.2.2. This section discusses how data were selected for inclusion in the VEC data base. Only one value was selected for each well. However, a review of any temporal trends, as appropriate, would also be helpful to characterize the vertical extent of contamination. If the data are insufficient to evaluate temporal trends, the text should clearly explain this.

Response: A review of temporal trends was conducted in selecting the values for the Vertical Extent of Contamination (VEC) database. Please note the discussion in Section B.2.3, Data Evaluation Criteria.

Comment B3: Pages B-7 and B-8, fifth, sixth, and seventh bullets. The values comprising the category A, B, and C exclusions should be briefly discussed in the text.

Response: A brief discussion of the categories A, B, and C exclusions has been added to the text. The number of detections, ranges of values, and dates of samples for each category are discussed.

Comment B4: Page B-10, second paragraph, last sentence. The text states that Table RISR B.3-1 lists the organic analytes summed for the total organics maps. DIMP is supposedly mapped separately, yet this compound is listed on the table. Please clarify whether the total organics maps also include DIMP.

Response: A sentence has been added to the text to clarify that diisopropylmethylphosphonate (DIMP) is also included on the total organics maps.

Comment B5: Page B-11, second paragraph, fourth sentence. To someone not intimately familiar with past RMA analytical practices, this statement is not clear. A clear explanation of how the CRL's [sic] have varied would help the reader to understand why such a map would be misleading.

Response: An explanation that CRLs have varied by up to three orders of magnitude has been added to the discussion of CRLs in Section B.2.1, where they are first discussed in Appendix B.

Comment B6: Page B-17, Section B.3.1.2. Possible explanations for dissimilar contamination distributions between the unconfined flow system and the Denver aquifer should be provided in the text. For example, why would organics be detected in Section 22 in the Denver aquifer at a depth of 106 feet below the alluvium-bedrock contact and not in the overlying unconfined flow system? Such explanations should also be provided for similar observations noted in Sections 3.2.2., 3.4.2 (Fluoride - why higher in the Denver aquifer?), and 3.5.2 (Chloride - why higher in Denver aquifer?)

Response: Based on minutes of the June 28, 1989 Water Assessment Working Group Subcommittee meeting on the Vertical Extent of Groundwater Contamination at RMA, the Army and the organizations and State agreed that a migration mechanisms analysis was difficult to perform on a regional basis, and that the results of this study (Vertical Extent of Groundwater Contamination in the Denver Aquifer) would be integrated into the FS in order to determine what additional investigations or analyses may be required. Additional information regarding Well 22002 has been added to Section B.3.1.2 of Appendix B. Speculation regarding higher concentrations in the Denver aquifer than in overlying UFS groundwaters is presented here.

Generally, contaminant concentrations in groundwater decrease with depth throughout most of RMA. Locally, contaminant concentrations in the Denver aquifer may exceed those found in the overlying UFS. Two possible explanations for these local reversals in contaminant concentrations are related to the dissimilar average linear flow velocities between the two aquifers and the unequal degree of dilution within each aquifer. Groundwater flow rates are considerably faster in the UFS than in the underlying Denver aquifer. In addition, conditions at many contaminant sources have changed markedly over time, as have hydrologic conditions within the UFS. In each of the instances noted by the EPA, it appears that contaminants detected in the Denver aquifer may represent "relics" of contaminant plumes that have passed by in the UFS. Following the introduction of contaminants into the UFS and Denver aquifer, contaminant migration has proceeded at a much greater rate within the UFS than in the Denver aquifer. Over time, many former sources of contamination have been eliminated or so altered that the mass of contaminants entering groundwater from them has been greatly reduced. In addition, the groundwater head pressures driving contaminant migration from sources such as basins and ditches has in most areas declined dramatically or ceased altogether. Consequently, there are areas through which the highest concentrations of contaminant plumes have passed, and less contaminated groundwater is now present. Contaminant plumes have also become diluted to some extent by dispersion, mixing with uncontaminated or less contaminated groundwater, and the infiltration of uncontaminated or less contaminated water from precipitation, surface water bodies, and possible water facilities leakage such as fire systems, potable water systems, and sewer systems. In the Denver aquifer concentrations of contaminants introduced when concentrations were much higher in the overlying UFS have not had time to attenuate to lower levels and may, therefore, reflect the higher concentrations present in the UFS in the past. In addition, in some areas such as the South Plants and the North Boundary Containment System (NBCS) contaminants probably become diluted as they migrate from low porosity alluvial and Denver Formation sediments into more porous and permeable alluvial materials.

Comment B7: Page B-18, Section B.3.2.1, third paragraph, last sentence. This sentence appears to be out of place with respect to the discussion of North Plants. It appears to contradict the previous paragraph and Figure B.3-6 which shows DIMP in the 50 to 100 foot depth interval existing near Basin C.

Response: The sentence in the text is incorrect; it has been changed to reflect that no wells in the immediate area of North Plants are completed below the 0- to 50-ft depth interval.

Comment B8: Page B-20, third paragraph, first sentence. Text should say "calculated mean background fluoride concentration."

Response: The sentence has been changed to describe the calculated mean background fluoride concentration.

Comment B9: Page B-24, Section B.4, second paragraph, third sentence. Some explanation for the "unexpectedly high frequency" of OCPs in the Denver aquifer should be provided. Also, in this paragraph is the first discussion of individual analytes in the Denver aquifer. Without distribution maps for individual compounds or at least for classes of organic compounds, discussion of their distribution is difficult to review. If these figures cannot be provided in this document, a reference to where they may be found should be provided.

Response: Possible explanations for the frequent detections of OCPs have been added to the text. References to maps showing the recent distribution of individual contaminants have been added to the text. These references include the 1989 CMP ground-water report (RLSA, 1990) and the Water Remedial Investigation Report (EBASCO, 1989).

Comment B10: Page B-24, Section B.4, General Comment. A more expanded discussion of why contaminant concentrations are typically lower in the Denver aquifer and why concentrations typically decrease as depth increases should be provided in the text. This discussion should address both hydrogeologic and chemical factors.

Response: The text of Section B.4 has been expanded to include a discussion of processes acting on contaminant concentrations in the Denver Formation.

Comment B11: Page B-28, Section B.5.1, second paragraph, last sentence. The meaning of this statement is unclear. How do the high concentrations in the upper Denver aquifer relate to the poorly characterized migration mechanisms? Further explanation should be provided.

Response: The sentence has been clarified by deleting reference to migration mechanisms. For further discussion of possible relationships, please see response to EPA Specific Comment B6.

Comment B12: Page B-30, first paragraph. Is the conclusion therefore that the vertical extent of contamination in the Basin A area has not been defined?

Response: The conclusion that the vertical extent of contamination has not been defined in the Basin A area has been added to the paragraph. The Army believes, because of the restricted contaminant migration potential of the Denver Formation, the typically reduced contaminant concentrations within the Denver Formation, and the limited potential receptors of Denver Formation contamination, that in general sufficient characterization of the Denver Formation has been developed to conduct the FS. Additional site-specific investigations in limited areas will be considered in the FS.

ENVIRONMENTAL PROTECTION AGENCY'S
COMMENTS ON THE
DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX C - INTERIM RESPONSE ACTIONS, VERSION 2.3
MAY 1991

General Comments

Comment 1: This appendix provides a brief synopsis or overview of the various IRAs at RMA and their status. The appendix could be greatly improved by providing reference to the Joint Administrative Record and Documents Facility (JARDF) where documentation can be found on items such as action levels in various media, treatment levels and effluent concentrations, and summary schematics of the IRA implementations (including groundwater extraction and injection, treatment process flow diagrams, etc.).

Response: A reference indicating that IRA documentation may be obtained at the JARDF, located at RMA, has been added to the text.

Specific Comments

Comment C1: Page C-44, first full paragraph. The proposed action for the South Tank Farm Plume Hot Spot IRA is not indicated in the text. Please correct this omission.

Response: The text has been revised to indicate that groundwater monitoring was the alternative selected for the South Tank Farm Plume Hot Spot IRA. For further details see the Final Decision Document (MKE, 1991) and the Draft Implementation Document for this IRA.

RIC 91122R02
MKE, 1991. Final Decision Document for Other Contamination Sources, IRA South Tank Farm Plume.

ENVIRONMENTAL PROTECTION AGENCY'S
COMMENTS ON THE
DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
APPENDIX D - OTHER SPECIAL INVESTIGATIONS, VERSION 2.3
MAY 1991

General Comments

Comment 1: This appendix lacks any discussion of soil sampling QA/QC procedures. Since that is discussed in another document, the section and report should be referenced in this document.

Response: Soil sampling procedures for the surficial soils investigation are presented in the Final Surficial Soil Investigation Data Summary, Version 3.1 (EBASCO, April 1991/RIC 91121R01). Soil sampling procedures for the ground disturbance investigation are presented in the Final Ground Disturbance Investigation Data Summary, Version 3.1 (EBASCO, August 1990/RIC 90247R01). Laboratory analysis and data validation QA/QC programs followed during these investigations are described in the Procedures Manual to the Technical Plan, Volume II (EBASCO, 1985/RIC 86241/R02), and in the Chemical Quality Assurance Plan (PMRMA, 1989).

Comment 2: Although the text on page D2-24 indicates that QA/QC personnel determined that two lots of ICP metals should be rejected, the criteria and methods used for this determination should be described or referenced.

Response: The text has been revised to indicate that the criteria used for determining acceptance or rejection of the two lots of inductively-coupled plasma analysis (ICP) metals are described in Section 7 of the Chemical Quality Assurance Plan, Version 1.0 (PMRMA, July 1989).

Specific Comments

Appendix D1 - Surficial Soils Investigation

Comment D1: Page D1-1, paragraph 2, third to last sentence. Please state when this surficial soil sampling program was conducted.

Response: Surficial soil samples were taken in the first two weeks of October 1989.

Comment D2: Page D1-1, paragraph 2, last sentence. Please identify when the summary report described in the text will be prepared.

Response: The text has been modified to state that the Surficial Soil Data Summary Report was released in April 1991.

Comment D3: Page D1-2, Figure RISR D1.1-1. Please include the sample identification numbers on this surficial soil sample locations map. The results of the analyses shown in Table RISR D1.4-1a and 2a (beginning on page D1-16) are of limited value without a map indicating where the individual samples were collected.

Response: Sample identification numbers have been included in Figure RISR D1.1-1.

Comment D4: Page D1-3, paragraph 3, sentence 4. The text mentions that areas downwind from Basin A are being monitored and that "dust suppressants will be reapplied on an as-needed basis." It would help to provide reference to the JARDF where documents containing further information on this IRA may be found.

Response: The text has been revised to include a reference to the JARDF.

Comment D5: Page D1-4, Section D1.3, paragraph two, sentence 2. Please explain how one sample was accidentally destroyed.

Response: The jar containing sample SS30095 was accidentally dropped and broken by lab personnel before an analysis could be performed.

Comment D6: Page D1-8, Paragraph 1. This states that dieldrin has a half-life of 7 years in soils while aldrin has a half-life of 4 to 5 years in soils. We are unaware of any scientific data which supports this conclusion. Please note that this statement is at substantial variance with the document titled Position Paper on the Degradation of Contaminants of Concern at Rocky Mountain Arsenal (EBASCO, 1991) which indicates a possible range of half-lives for aldrin up to 10 years and 46 years for dieldrin.

Therefore, we recommend that this statement be revised to indicate that the possible range of half-lives for aldrin and dieldrin is quite wide, subject to much uncertainty, and varies substantially whether field or literature values are considered.

Response: We agree that the disappearance rate of aldrin and dieldrin are expected to vary greatly based on soil and environmental factors. The text has been revised as recommended. However, some studies on the disappearance of dieldrin in agricultural soils have found a half-life of 7 to 12 years (Nash and Woolson, 1967; Nash and Harris, 1973; Freeman et al., 1975). These studies were performed in soils and climates differing from RMA and the results are not directly applicable, but the results do provide an order of magnitude estimate of the disappearance rates of these compounds.

Nash, R.G. and E.A. Woolson. 1967. Persistence of Chlorinated Hydrocarbon Insecticides in Soils in Science, Volume 157, p. 924-927.

Nash, R.G. and W.G. Harris. 1973. Chlorinated Hydrocarbon Insecticide Residues in Crops and Soil. In: Journ. Environ. Quality, Volume 2, No. 2, p. 269-273.

Freeman, H.P., A.W. Taylor, and W.M. Edwards. 1975. Heptachlor and Dieldrin Disappearance from a Field Soil Measured by Annual Residue Determinations. In: Journ. Agric. Food Chem., Volume 23, No. 6, p. 1101-1105.

Appendix D2 - Ground Disturbance Investigation

Comment D7: Page D2-24, first three paragraphs. The criteria used for assessing quality control and quality assurance of the sample results should already be specified elsewhere. Please provide reference to that documentation.

Response: Please see the response to EPA's Appendix D General Comment 2 above.

ENVIRONMENTAL PROTECTION AGENCY'S COMMENTS ON THE DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT APPENDIX E - CONTAMINANT FATE AND TRANSPORT, VERSION 2.3

MAY 1991

General Comments

Comment 1: In general, this appendix is well written; explanations of contaminant pathways and natural processes that affect the contaminants of interest are concise, correct and inclusive, with the exceptions noted below.

Response: The Army appreciates the EPA's comment.

Comment 2: Since the material presented in Appendix E-2 appears to be identical to material provided in recent parameter data packets, all EPA comments on the parameter data packets are hereby incorporated by reference.

Response: The parameter data packets referred to by EPA are part of the Risk Characterization program. Responses to comments regarding that program are not part of the RISR. EPA comments on the referenced data packets that may have relevance to the information presented in Appendix E have been considered in preparation of the proposed final RISR. The information presented in Appendix E2 is provided only to inform the reader of the physical and chemical properties that influence contaminant mobility, transport mechanisms, and effect the ultimate fate of the contaminants. The information and data presented in Appendix E2 are representative values obtained from EPA and other sources, as indicated in the footnotes of the various data tables in this section. The narrative discussions, data presentation formats, and data sources cited differ in many regards from those in the referenced data packets. Due to the range of reported values in the literature for the various parameters presented in Appendix E2, the data values, while similar, are rarely identical to those in the data packets. In addition, the purposes for which the data were compiled differ. As noted above, the RISR provides this information for general informational purposes only. The parameter data packets will be used where applicable in all EA and FS analyses.

Specific Comments

Comment E1: Page E-46, paragraph 3. The Henry's Law constant does not relate vapor pressure (as defined in paragraph 2, same page) with aqueous solubility. By definition, Henry's Law is valid for dilute solutions and the vapor pressure of a compound is related to a pure solution of the compound. The term vapor pressure should be deleted in this paragraph and a definition of Henry's Law (as used in this appendix) should be included.

Response: The text has been modified accordingly.

Comment E2: Page E-77, Paragraph 3. This paragraph indicates that hydrazines and nitrosamines "were not detected." Please note that 1986 data in the RMA database show positive detection, while analytical work performed in 1988-1989 had exceedingly high detection levels. Therefore, we recommend that the statement be revised to indicate that the sampling yielded inconclusive results.

Response: The text has been modified to clarify that USATHAMA-certified analytical methods for the hydrazines were unavailable during the RI program. Additional characterization of the hydrazine blending and storage facility (HBSF) is being conducted (HLA, 1991/RIC 91222R01). Information developed by this investigation will be considered by the FS.

Reference: HLA, 1991, July 15. Final Letter Work Plan for the Hydrazine Blending and Storage Facility Groundwater Investigation (RIC 91222R01).

Comment E3: Page E-81, Paragraph 4. This paragraph indicates that the half-lives for OCPs range from 1 to 15 years. This appear [sic] to be in error. Please refer to EPA's specific comment for page D1-8, paragraph 1, of this report. At a minimum the upper end of the range may extend to 46 years.

Response: The text has been revised and a reference to the document cited by EPA in the referenced comment has been included.

Comment E4: Page 82, Section E3.2.14. A discussion of the arsenic oxyanions should be included in this section. Also a discussion of the mineral phases of arsenic (such as scorodite) that may influence the fate of arsenic in the soils and groundwater at RMA.

Response: The arsenate and arsenite oxyanion species, which are the forms of arsenic likely to be present at RMA, are already featured in this section. A discussion of solid phase equilibria has been added.

Comment E5: Page E-119, Section E5.4. This section omits any indication that actual agents (mustard, lewisite, [sic] etc.) were actually positively identified. We recommend that the database be searched for agent hits and a summary be presented. We also recommend that the first sentence be revised to indicate agent detections. (See our earlier comments on Volume 1, pages 2-14, 2-23, and 2-24, and Appendix A, Table RISR A3.2-1.)

Response: The database has been reviewed, and a review of the reported agent occurrences in soils is summarized in response to EPA comments on Section 2 of this report, specifically EPA Cover Letter Comment 3. Some reported agent occurrences were investigated by collection of additional field samples, and no agent occurrence was verified by these data. Occurrences within the areas shown in Figure RISR 2.2-1 were not typically field-verified; however, many reports of their detection within the areas shown in Figure RISR 2.2-1 are considered suspect. Inclusion of these reported occurrences in the RMA database does not indicate positive identification in all cases for these compounds. The Army continues to routinely monitor for agents where appropriate as a health and safety precaution during the conduct of on-site activities.

Comment E6: Page E-136, paragraph 1. The suspected background concentration of arsenic should be included in this paragraph, along with reasons for selecting the value and references used in the decision.

Response: The paragraph referred to is a discussion of arsenic in groundwater. Background concentrations for arsenic in groundwater have not been established at RMA. The text has been edited with respect to background concentrations of arsenic in soil.

Comment E7: Page E-137, paragraph 4. The same comments as above (page E-136, paragraph 1) also apply to Cd, Cr, Cu, Pb, and Zn.

Response: The text has been edited with respect to background concentrations of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn) in soil.

Appendix F2

Responses to the Colorado Department of Health's Comments on the Draft Final Remedial Investigation Summary Report, Version 2.3

Remedial Investigation Summary Report

COLORADO
DEPARTMENT
OF HEALTH

ROY ROMER
Governor

JOEL KOHN
Interim Executive Director

4210 East 11th Avenue
Denver, Colorado 80220-3716
Phone (303) 320-8333

Telefax Numbers:
Main Building/Denver
(303) 322-9076

Ptarmigan Place/Denver
(303) 320-1529

First National Bank Building/Denver
(303) 355-6559

Grand Junction Office
(303) 248-7198

July 1, 1991

Mr. Kevin Blose
Rocky Mountain Arsenal
Building 111
Commerce City, CO 80022-0116

Re: State Comments Draft Remedial Investigation Summary Report

Dear Mr. Blose:

Enclosed are State Comments on the above-referenced document. We have not reiterated past comments on the Study Area and Media reports in this submittal; nor have we repeated our previously transmitted requests for data gap rectification. Those comments and proposals are merely incorporated by reference. We look forward to meetings in the near future to discuss Army responses to those requests.

The State is concerned about information contained in Appendix B regarding the vertical extent of contamination. It appears from the report that ground water contaminants exceeding State and/or Federal standards are migrating off the Arsenal in the Denver Formation, for example, chloride migrating from Section 23. The State believes an evaluation must be performed to characterize all chemical plumes migrating around and beneath the boundaries. A technical meeting is necessary to discuss alternatives to minimize these contaminants.

We note also that the Remedial Investigation is merely a summary of prior, more detailed data reports. Therefore, in assessing risks posed by the site, or in developing remedial alternatives, this report must not be relied upon to the exclusion of such other more complete information.

If you have any questions regarding the attached comments, please call.

Sincerely,

Jeff Edson

Jeff Edson
RMA Project Manager
Hazardous Materials and Waste
Management Division

Enclosure

RMA 91-1011

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cc: Vicky Peters, AAG
Bradley Bridgewater, Esq.
Bill Clemmens, Esq.
George Roe
Edward J. McGrath, Esq.
Connally Mears, EPA
Maj. John Fomous
Janet Yanowitz

COLORADO DEPARTMENT OF HEALTH'S COMMENTS ON THE DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
JULY 1991

General Comments

Comment 1: The State has previously transmitted extensive comments regarding its perceived data gaps in the Army's Remedial Investigation (RI). These comments were submitted in response to the six study area draft reports (Data Gaps for The North Plants Study Area will be forthcoming), and in response to the Draft Final Task Plan Feasibility Study Data Collection. To the extent they have not been previously addressed, those comments are hereby incorporated by reference. We look forward to resolving these matters in the near future.

Response: Responses to the comments on the six study areas referred to by the State are included at the end of Appendix F of the Proposed Final RISR. Comments on the North Plants Study Area had not been received at the time these responses were prepared. Responses to the comments on the Phase I Feasibility Study Field Data Collection Program Draft Final Task Plan will be transmitted under separate cover to the organizations and State. Responses to the State's North Plants comments will also be transmitted under separate cover.

Comment 2: The document should clearly acknowledge that it constitutes only a summary of more detailed information that has previously been compiled in the various contamination assessment reports, study area reports, and media reports. In assessing risks posed by contamination at the site, and in screening and developing alternatives for remediation, the most complete and current data sets should be utilized, including the Comprehensive Monitoring Program Reports.

Response: The RISR does acknowledge that it constitutes only a summary of more detailed information that has previously been compiled in various CARs, SARs, and media reports. For example, see Executive Summary, p. xxxv, and Section 1.0, pp. 1-1 and 1-3. Results of the CMP are not summarized in the RISR because they are not part of the RI. However, all relevant data sets will be considered in assessing risks and developing final remedial alternatives.

Comment 3: Many of the conclusions expressed in the RISR are contradicted by data subsequently gathered as part of the various Comprehensive Monitoring Programs (CMPs). See e.g. State Specific Comment 29 regarding biota. Therefore, conclusions contained in the RISR must be confirmed by CMP data; where such data clearly indicate that RISR conclusions are erroneous, appropriate modifications should be made.

Response: The Army has responded to all specific comments raised by the State. The Army disagrees with the State's contention that many conclusions expressed in the RISR are contradicted by data subsequently gathered as a part of the CMP. The CMP was designed to expand and enhance data developed in the RI program. However, the CMP is not a subject of the RISR. Please see the responses to the State's General Comment 2 and Appendix A Specific Comment 29, and the EPA's Cover Letter Comment 7.

Structures

Comment 4: The additional sampling information for six buildings in the North and South Plants, sampled for mustard and sarin, should be included or referenced in the Final RISR. The results are summarized in Sampling and Monitoring Operations for Mustard (HD) and Sarin (GB) [sic] (Tennessee Valley Authority, undated, approximately 1990).

Response: The additional sampling referred to by the State was conducted by the Tennessee Valley Authority (TVA) in the Fall of 1989 to monitor and sample for the chemical agents mustard and GB in selected buildings in the North Plants and South Plants. That program was not part of the RI. Samples were collected from within closed process vessels and piping systems. All sampling points were sealed after samples were obtained. The results of that investigation are presented in Sampling and Monitoring Operations for Mustard (HD) and Sarin (GB) at Rocky Mountain Arsenal (TVA,1990/ RIC 91064R01). The RI has always considered the structures associated with chemical warfare agents to be agent contaminated. The supplemental information collected by TVA is being considered in the FS.

Comment 5: The Army made the following recommendations for further study of structures on p. 42 of its Proposed Final Volume I, Summary of Results Structures Survey (Ebasco, September, 1988):

> "In the course of this survey, many tanks, pieces of process equipment, and pipe runs that may have contained contaminated liquids or residues were observed and documented. Prior to any decontamination planning or program, these vessels should be sampled."

The Army also states on p. 32 of Volume I of the Structures Survey that 54 structures were found to contain process equipment. Of these, process equipment in six buildings in the North and South Plants have been sampled for mustard and sarin, as reported in Sampling and Monitoring Operations for Mustard (HD) and Sarin (GB) at Rocky Mountain Arsenal (Tennessee Valley

Authority, undated, approximately 1990). However, the RISR does not indicate that any additional sampling of process equipment has been carried out in Arsenal structures. Such sampling is necessary to determine the nature and extent of contamination in those buildings and to develop and screen potential remedial alternatives.

Response: Please see the response to the State's General Comment 4 above regarding the six buildings referred to. The RI has always considered as a worst-case approach that all buildings containing process equipment are contaminated. Limited sampling in the RI verified this approach (see Appendix A3.3). The FS is using this worst-case approach and also evaluating additional sampling of buildings as appropriate to refine this approach. The Structures Sampling and Analysis Programs are being developed to support subsequent remediation.

Biota

Comment 6: Reliance on the data for the seven major contaminants of concern to describe the total nature and extent of RMA biota contamination is grossly inadequate. As can be seen from Tables 4.1-2 through 4.1-6 in the Biota Remedial Investigation Final Report (May 1989), at least 12 other compounds with known toxic properties have been identified in RMA biota at elevated levels. Presence of these compounds was not evaluated as part of the RI, and the extent of their influence is unknown.

Response: Data on the seven major contaminants of concern (COCs) provided only a portion of the data used to describe the nature and extent of contamination in biota on RMA. Thirty-two additional COCs to biota were identified and addressed in the Biota RI. Chemicals not analyzed in biological tissues included those that (1) would not be expected to occur in biological tissues at predictable concentrations due to depuration or metabolism, (2) chemicals for which there was no information relating concentrations in tissues to adverse effects, or (3) chemicals which had extremely limited known areal extent on RMA. These chemicals and others that met the criteria provided in the Biota RI for being COCs for biota were addressed by means of toxicity assessments. These assessments included information on the types of contaminant-related effects and other pertinent information used to characterize the nature of each contaminant.

All contaminants listed in Tables 4.1-2 through 4.1-6 of the Biota RI Report were evaluated in the Biota RI with respect to their toxicity, environmental persistence, and areal extent in abiotic media. The extent of influence of the chemicals that were considered COCs for biota was based on the spatial extent of the contaminant in the abiotic source media to which biota were potentially exposed.

Comment 7: The Draft RISR contains many generalizations and interpretations regarding contaminant transport behavior without supporting such conclusions with adequate Remedial Investigation data. For example, Table RISR A3.5-1 contains the category heading "detritivores" when making inter-trophic level comparisons. One genus of detritivore was sampled at two different locations--an insufficient survey on which to base categorical conclusions. Such generalizations should be deleted from the text or explained with qualifying language regarding the sparsity of data.

Response: The conclusions presented in section A3.5 are based on the findings of the RI program - they are not represented as "categorical." The text in section A3.5.1 noted that "the numbers of detections were variable and sample sizes were small." The text on page A3-148 of the proposed final has been modified to clarify these points.

Comment 8: Section 3.5 [sic] of the Remedial Investigation Report [sic] makes several references to the Army's inability to make more than general correlations between biota contamination and soil, water, and sediment concentrations (e.g. second paragraph on page A3-145). The Army is correct not to assume greater certainty regarding these relationships; however, it is equally inappropriate to use these same data as a basis for calibration and validation of the Ecological Risk Characterization models. The fact that Biota RI data are not appropriate for more than general correlation between animals and soil/sediment should be conveyed to the members of the Endangerment Assessment Subcommittee.

Response: This comment appears to refer to section A3.5 of the Remedial Investigation Summary Report. The Army appreciates the State's concurrence with its approach of not assuming greater certainty than is justified by the data. The text on page A3-145 has been modified to note that the correlations referred to by the State were based on data available at the time the Biota RI report was prepared. Section A3.5 refers to information from the Biota RI which identifies the sources of uncertainty associated with correlating concentrations of contaminants in biota and soils. These sources include mobility of organisms, inability to sample biota at the exact location where soil sampling was conducted (e.g., areas without appropriate habitat), and the fact that soil sampling composited samples over depth levels greater than those to which biota were reasonably exposed. These data constitute only a portion of the data that are being used for calibration and validation of the pathways model. Additional sources of data include the Phase II soil surveys, surficial soils studies, and collocated samples (shallow soils and sedentary biota) collected as part of the CMP which should substantially reduce the uncertainty in correlating soil and biota concentrations. The remaining uncertainty is being addressed by using parameter distributions and appropriate accepted statistical procedures, to the extent feasible. The recognition of uncertainty in the Biota RI led to some of the additional investigations that has reduced uncertainty, and has already been discussed in meetings of the EA Subcommittee. All relevant information will be considered by the EA.

Air

Comment 9: Since completion of the Air Remedial Investigation Final Report (August, 1988) (Air Final Report) several years of Comprehensive Monitoring Program (CMP) air quality data have been collected. The report does not mention this fact except in the case of PM10 monitoring. Since the RI PM10 data recovery was inadequate, the report states that CMP data will be used to supplement it. In fact, a similar problem exists for meteorological data. The RI only presents three months of on-site data. As a result, the Air Final Report [sic] relies primarily on Stapleton Airport data. On-site data are, however, preferable. The CMP and the Basin F IRA monitoring provide several years of on-site data, at various Arsenal locations. These local data should be used for future CERCLA products such as feasibility studies and risk assessments.

Response: We believe that Stapleton Airport meteorological data are adequate to support the FS. On-site data will be used in the future as available and appropriate. The RISR is a summary of the RI findings, hence CMP results are not generally summarized in this report. However, all relevant data will be incorporated into FS evaluations.

Comment 10: The State also has concerns about the Air RI Final Report "high event" sampling. The number of sampling events were limited, and the air monitoring instruments were frequently located upwind of the pollutant sources due to an inability to predict wind directions. The CMP continued the same data collection strategy. Although the CMP monitoring frequency for Volatile Organic Compounds (VOC's) and Semi-Volatile Organic Compounds (SVOC's) is not sufficient, these additional data are valuable, and should be referenced here. Furthermore, the State recommends increased frequency in monitoring at set stations to increase our understanding of high wind events.

Response: Wind directions are obviously variable, and it is impossible to always locate sampling locations downwind of future events. However, given this variability, the Army believes the data collected in the RI and CMP are sufficient to support the FS. Supplemental information was collected in addition to the CMP. The Basin F Interim Response Action (IRA-F) Air Monitoring programs included a 6-day sampling schedule for VOCs and SVOCs around Basin F, and a 12-day sampling schedule for total suspended particulates (TSP), respirable particulates (PM-10), metals, arsenic, and mercury. The CMP was revised in 1991 to include a 6-day VOC and SVOC sampling around Basin F and three sites at the RMA boundary, and conformed to the same sampling schedules. The Army will consider all available data when developing remedial alternatives.

Comment 11: There are other documents that summarize the CMP and Basin F IRA Air Monitoring data. This information need not be reproduced in total for the RISR; however, when evaluating remedial actions and risk assessments for various Arsenal areas, the Army should take into consideration **all** data previously collected in each respective area.

Response: As previously noted, the RISR is a summary of RI results. CMP investigations are not summarized in the RISR. All available and appropriate data are considered by both the EA and the FS.

Comment 12: Since the Air RI Final Report was completed, the configuration of Basin F has changed. Emission rates from the waste storage units (the waste pile, ponds, and tanks), have not been established. This information is necessary because the "baseline" situation has now altered. The assessment of future remedial actions will be based on the present status of Basin F, rather than the structures of several years ago.

Response: Emission rates from the Basin F Waste Pile vents were estimated under the IRA-F program in 1990. Results of the IRA F programs will be presented in the IRA-F Air Quality Monitoring Program Final Report (forthcoming). The baseline ambient air situation is being monitored under the current CMP.

Comment 13: The Army has not adequately characterized air emissions from the Basin F Interim Response Action structures. Concurrent canister samples and flowrate measurements must be taken from each hazardous waste management unit once per month, and HNU and OVA readings must be performed regularly to identify vent emissions. Flux box monitoring for volatile and semivolatile organic compounds in the waste pile and restored basin must be performed once per quarter.

Response: The monitoring done by the Army adequately characterizes air emissions from the former Basin F area. Under IRA-F the real-time flame ionization and photoionization detector (HNu PI-101 and OVA 128-GC) readings were collected monthly at the waste pile, tanks, and Pond A vents through September 1990 and quarterly thereafter. Three separate canister sampling events were conducted at the waste pile vents during 1990. Three separate flux-box sampling events were conducted in 1990 including both the waste pile cap and the restored Basin F floor. Data collected under IRA-F will be presented in the IRA-F Air Quality Monitoring Program Final Report (forthcoming).

Comment 14: The RISR does not include an air emissions inventory for the Arsenal. Prior to the initiation of remedial actions, the present air emissions of the areas to be remediated need to be established. These emissions are important for conducting a baseline risk assessment for the required "no action" alternative, and to determine combined air impacts of the various Arsenal emissions. The inventory should include waste storage structures, and fugitive emissions from contaminated soils. The inventory should also include emissions from interim response action sources.

Response: Conducting an air emissions inventory at RMA prior to the initiation of remedial activities would not be a cost effective use of resources. An ambient air monitoring and sampling effort was conducted to determine the integrated impacts of all structures. This program provides the exact data needed to address background conditions, whereas an emissions inventory, which requires emissions characterization, emissions estimates, modeling, and impact integration would be fraught with uncertainties and would be of less use than ambient air quality data in terms of existing conditions. Air quality impacts from each IRA will be addressed as that action is considered and evaluated.

Specific Comments

Comment 1: Page xxxiii -- This page states that "RI data show RMA air quality to be superior to that of nearby urban areas." While this statement may be accurate for criteria (NAAQs) [sic] pollutants, a comparison between on-post and off-post levels of toxic pollutants has not been conducted. In addition, some of the compounds which could impact air quality and are found in Arsenal soils and water are unique to RMA. Please modify accordingly.

Response: A qualifying statement has been added to the sentence to indicate that it refers to criteria National Ambient Air Quality Standard (NAAQS) pollutants.

Comment 2: Page 1-43, Table RISR 1.4-1, List of Technical Plans for RMA On-Post Operable Unit -- Basin F IRA and post-IRA reports should be added to this list of air RI documents.

Response: The Basin F IRA and subsequent reports were not part of the remedial investigation and are not included in Table 1.4-1 which lists technical plans for remedial investigation tasks. A complete list of Basin F IRA and post-IRA air reports is presented in Appendix C, Table RISR C.1-4.

Comment 3: Pages 2-4 through 2-9, Table RISR 2.1-1, Estimated Volumes of Contaminated Soils by Site -- These contaminated soils can affect air quality when they are transported by wind. Air should therefore be listed under the "potentially affected media" column, or the table should be divided into primary and secondary effects.

Response: Table RISR 2.1-1 has been revised to indicate that the air media can be affected by virtually any site for short durations given the proper meteorological conditions and/or a physical disturbance at the site.

Comment 4: Page 2-16, 2.1.3, Buildings, Equipment, and Storage Sites -- The Army states:

> Although hydrazine-related compounds were not detected in soils in the HBSF area of South Plants,...

This statement is misleading, and should be removed from the text or rewritten. The Hydrazine Blending and Storage Facility (HBSF) Phase I investigation was designed as a reconnaissance sampling program for all analytes within the HBSF area; Phase I borings were not located based on hydrazine fuels usage or documented spills. In fact, historical information on hydrazine storage, handling, and leaks became available only after implementation of the Phase I program. The historical data indicated numerous and major hydrazine fuel leaks resulting in widely distributed areas with hydrazine-contaminated soils.

To assess potential hydrazine-contaminated soils in heavy usage areas and at potential spill sites, twenty of the Phase II soil borings were placed based on the historical data. However, a USATHAMA GC certification method for hydrazine was not established prior to implementation of the Phase II investigation. Soils analysis for hydrazine in the HBSF, therefore, has never been conducted (see the State of Colorado May 21, 1990 letter to the Office of the Program Manager regarding State's Proposal to Improve the Remedial Investigation for the South Plants Area, Comment 8).

Response: The statement indicating that hydrazine was not detected in the HBSF area has been removed, and a statement indicating that hydrazine was not analyzed for due to lack of a certified method has been added. The HBSF is the subject of both an IRA and of additional FS investigations planned as part of the Phase II FS Field Data Collection Program.

Comment 5: Page 2-20, 2.1.6, Spill Sites -- The Army states:

> Exceptions [spill sites that have resulted in laterally or vertically extensive contamination] are in the Western Study Area, where a dibromochloropropane spill in the railyard and a trichloroethylene spill in the motor pool area have generated well-defined groundwater plumes in the alluvial aquifer.

Please modify this sentence to include the South Plants area where numerous significant spills have resulted in highly contaminated soils and groundwater including the South Tank Farm benzene plume in Section 2. Also, a newly discovered hydrazine-related groundwater plume beneath the HBSF is probably the result of spills in that area.

Response: Spills associated with the South Plants area are discussed in Section 2.1.3. Effects of these spills on groundwater also are identified in that section. The Army recognizes that numerous spills occurred in the South Plants area; however, spills occurring in the manufacturing areas have generally been included in the buildings, equipment, and storage site type, including those related to the South Tank Farm in South Plants. The text of both Sections 2.1.3 and 2.1.6 have been modified for clarity. Reference in the text to the trichloroethylene spill has been revised to indicate it is a possible spill; no direct documentation or other direct evidence of a source for the elevated trichloroethylene concentrations in groundwater or soil gas has been detected. The Army notes this as one area where contaminant detections may, in part, be a manifestation of conditions at upgradient off-post sources.

Comment 6: Page 2-21, 2.1.8, Windblown Contamination -- The last paragraph states:

> [t]he off-post impact of blowing dust is difficult to assess in the absence of off-post surficial soil data....

The Army has in the past year collected off-post surficial soil data which, when examined in connection with the on-post data, indicate that RMA is a source of wind-borne organochlorine pesticide contamination. Further investigations are currently being undertaken, and State comments on that program have been submitted to the off-post RI subcommittee (see State Proposed Surficial Soil Sampling Program North and Northwest of the RMA, April 9, 1990, and State comments on PMO-RMA Letter Work Plan for 17 Additional Surficial Soil Samples Off post [sic] RMA, May 13, 1991.) Since the above-referenced statement is not accurate it should be stricken from the text.

Response: The referenced passage has been removed from the text.

Comment 7: Page 2-22, 2.1.9, Off-Post Sources -- The Army includes this section to discuss the "relative importance [of off-post sources] in contributing to on-post contamination conditions in the water medium." However, in paragraph 2, the Army discusses a potential off-post source of groundwater contamination to the west of RMA. While additional sources exist in this area, this groundwater is generally downgradient and cross-gradient of the

RMA. Please provide references for these assertions or delete them from the text.

Response: The text has been revised. References to off-post sources of groundwater contamination located west of RMA have been removed from the text.

Comment 8: Page 2-23, 2.1.11, Balance of Areas Investigated -- The Army states:

> Rare, low-level detections of organics such as benzene in groundwater may reflect the petroleum-rich nature of the Denver Basin and lignite-bearing horizons of the Denver Formation. Such detections are typically found in the Denver Formation, and are spatially unrelated to contaminant plumes or other sources of contaminants.

This statement is misleading. Although benzene detections in the Denver Formation may in part be naturally occurring, the Army, in its document *North Boundary System Component Response Action Assessment Final Report, Volume I*, February 1989 states (page 8-21),"There are no data from upgradient areas with which to substantiate this hypothesis." A discussion of benzene and chlorobenzene distributions are also presented in that document, and are discussed in the current groundwater Comprehensive Monitoring Program (CMP) document. Because the above statement is unsubstantiated and not consistent with prior Army documents, please delete it from the text.

Response: The statement has been deleted from the text in Section 2.1.11. A more general statement regarding the potential for naturally occurring concentrations of organic compounds in the Denver Formation has been added to the text of Section 2.3.3.

Comment 9: Page 2-23, 2.1.11, Balance of Areas Investigated -- The text states that "[a]nomalous methylene chloride detections at low concentrations have been attributed to laboratory contamination." After reviewing the analytical results from selected contamination assessment reports, the State cannot concur with this conclusion. For example, at Site 4-5 detections as high as 800 ug/g were not sufficiently explained, and at many sites detections were dismissed as lab contamination although the lab blanks were clean. For additional discussion, please refer to State Comments on the Draft Final Task Plan, Volume 1, Feasibility Study Data Collection, January 22, 1989, and General Comment No. 4 on the Draft Final Phase I CARs For All Suspected Contaminated Areas of RMA, June 14, 1988. As discussed in these comments, many of these sites should be re-sampled to confirm whether methylene chloride actually exists in the soils.

Response: This portion of the text is specific to anomalous methylene chloride detections in the Balance of Areas Investigated. These areas are not associated with source areas or contaminant migration pathways. The example cited by the State (former site 4-5) was designated as sites WSA-5a, 5b, 5c, and 5d in the Western SAR. These sites are in the Solid Waste Burial Sites site type and are not part of the Balance of Areas Investigated. In previous reports methylene chloride was generally attributed to laboratory contamination when it was detected in laboratory blanks or was detected at low concentrations which were spatially inconsistent with adjacent sample results or site histories and contaminant migration scenarios. However, previous professional judgement regarding the origin of methylene chloride in soil samples is not an issue in this report because all methylene chloride detections have been incorporated into the appropriate data presentations. In addition, all methylene chloride detections will be addressed by the FS.

Comment 10: Page 2-23, 2.2, Potential for Occurrence of Chemical Warfare Agents and Unexploded Ordnance -- The text states:

> Agents generally have short half-lives when exposed to the natural elements and, with the exception of mustard that may have been trapped in voids beneath buildings, are not persistent. Agents are therefore not considered to be significant contaminants at RMA.

The State does not concur with this conclusion. See EPA correspondence dated May 20, 1991, in which EPA recommends that all agent detections be incorporated in the site-by-site risk characterization. Many of the agent detections pointed out by EPA for Sarin, Mustard, and Lewisite are higher than their respective PPLVs. This statement, therefore, should be deleted from the report, and agent detections should be summarized in the RISR.

Response: Please see the responses to the EPA's Cover Letter Comment 3, and Specific Comments 16, 21, 22, and A12 in Appendix F1. The statement referred to by the State has been revised, and a distinction drawn between soils and structures. The last sentence quoted by the State has been deleted. Agents may represent significant contaminants within structures. Any agent occurrences within the areas shown in Figure RISR 2.2-1 will be considered in the evaluation of remedial alternatives.

Comment 11: Page 2-28, 2.3.1, Unsaturated Zone -- Please make the following modification to the third sentence: "The unsaturated zone at RMA is relatively thin beneath Basin A, the lime settling basins, the Section 36 disposal trenches, and the central section of South Plants."

Response: The text has been revised to include the north-central portion of South Plants in the area where unsaturated thickness is five feet or less.

Comment 12: <u>Page 2-31, 2.3.4, Eolian Transport</u> -- This section states that air contamination "does not appear to be a current problem at RMA;" yet, page 5-6 of the Air Final Report states that: "The sources of toxic airborne contamination at RMA appear to be from known fugitive sources emitting dust and vapors, such as basins and surface impoundments.... The significance of these findings will be determined in the ongoing EA." Since a risk assessment has not yet been conducted, the statement that air contamination is not a problem should be deleted.

Response: The statement has been deleted from the text.

Comment 13: <u>Page 2-31, 2.3.5, Surface Water Transport</u> -- The Army states:

> The two most highly contaminated surface water bodies are small isolated holding ponds in Section 36.

Please give a detailed location of these ponds; provide chemical data (or a source for the data); and summarize the current status of the ponds.

Response: The sentence has been modified to refer to the Basin A sampling station and the South Plants sedimentation pond. Detections in samples from these stations are described in Section A3.2.1.

Comment 14: <u>Page 2-32, 2.4, Receptors</u> -- The Army states:

> Arsenic levels in the terrestrial plant species sampled near Basin A (morning glory, common sunflower) were within the range that could produce phytotoxic effects; however, no such effects were noted.

Please provide details of the study from which this conclusion was drawn. Note also that phytotoxic effects may be especially pronounced in younger plants; thus, the presence of arsenic in isolated soil areas may have prevented the establishment of any plants sensitive to arsenic.

Response: Details of the study from which this conclusion was drawn are presented in the Biota RI Report (Section 3.2.2, Methods; Section 4.3.2, Contaminants in Terrestrial Ecosystems, and Section 5.3, Contaminant Effects). Section 5.3.2.1, Effects of Contaminant Levels in Terrestrial Plants of the Biota RI reports that signs of obvious phytotoxicity were not observed and acknowledges that arsenic may have contributed to the low diversity of species in Basin A. The high level of disturbance and soil compaction, factors that could also affect plant species diversity, made this hypothesis difficult to evaluate.

Comment 15: Page 2-32, 2.4, Receptors -- The Army states:

> Invertebrate populations did not appear reduced as an effect of RMA contamination.

and

> Black-tailed prairie dog populations were not reduced as a result of RMA contamination.

Both conclusions are not adequately supported by the data. Because of RMA contamination a variety of ecological factors may have been altered such as species composition, reproduction rates, and primary productivity. The ecology of an uncontaminated, non-stressed RMA can only be speculated upon. This statement should therefore be deleted.

Response: Statement regarding adverse population effects were based on comparisons of invertebrate and prairie dog population densities in sites of known contamination with on-post and off-post reference areas. This methodology is consistent with EPA recommended methodology and with accepted scientific practice. Additional detail is provided in Section 5.3 Contaminant Effects of the Final Biota RI Report.

Comment 16: Page 2-33, 2.4, Receptors -- The Army states:

> Given the omnivorous behavior of coyotes, and the potentially large areal extent of their range, it cannot be concluded that RMA sources were solely responsible for the dieldrin level detected.

Bioconcentration of lethal levels of dieldrin is more likely to have occurred at RMA than anywhere else, given that dieldrin levels in the on-post environment are considerably higher than in nearby off-post areas. The text should therefore be modified to reflect this fact.

Response: Comment noted. The text adequately indicates that RMA is a likely local source of dieldrin detected in the coyote's tissues.

Appendix A Environmental Setting, RI Approach, Nature and Extent of Contamination

Comment 1: Page A1-4, A1.4, Geology -- The Army states:

> The eastern flank of the basin dips very gently, while the western flank of the basin dips steeply, exposing virtually the entire

> sedimentary section of the basin in outcrop along the Colorado Front Range. Because RMA is situated near the structural axis of the basin, strata at RMA dip gently to the southeast at less than one degree.

The only Denver Basin strata that dip steeply are those that occur between the Golden Fault Zone and the Basin Margin Fault. This zone is not technically part of the Denver Basin. The RMA sediments are on the western flank of the basin and dip gently to the southeast, toward the center of the basin. While the RMA is in fact situated near the structural axis of the basin, that has no direct bearing on the amount of regional dip associated with the aquifer formations. Please modify accordingly.

Response: The purpose of this paragraph is to describe the general geologic setting for the Denver Basin in which RMA is located. The description is consistent with a general description by Tweto (1980). The original and revised paragraphs are essentially identical in content to that presented in the North Central SAR (EBASCO, 1989h/RIC 89166R07; p.1-56). None of the parties, including the State, made a comment on that passage at that time. In addition, the Basin Margin Fault is postulated on the basis of interpretation of geophysical data. Other wells and geophysical data do not support this interpretation. Finally, given the very gentle nature of folding in upsection sediments along the structural axis of the basin, and the subvertical orientation of the axial surface, the location of RMA near the structural axis does imply that strata comprising the important near-surface aquifers have very low dips. The trace of the structural axis of the Denver Basin has been variously mapped to the east, west, and at RMA. Nevertheless, the paragraph has been revised for clarity.

Reference: Tweto, O. 1980. Summary of Laramide Orogeny in Colorado in Kent, H.C., and Porter, K.W., eds. Colorado Geology: 1980 Symposium, Rocky Mountain Association of Geologists. p. 129-134.

Comment 2: Page A1-6, A1.4.3, Alluvium-Bedrock Contact -- The Army states:

> The bedrock surface is weathered in places at the contact and varies from friable and heavily altered to more lithified, compacted material that is fractured and jointed over a depth interval of less than 5 ft.

In many parts of the RMA the thickness of the unconfined Denver has been investigated and found to be much greater than 5 feet. At a 4/8/91 Subsurface Drain Treatability Study meeting, for example, the Army stated that friable Denver Formation material was found to depths of approximately 45 ft and 65 ft below bedrock contact in the South Plants area. Also, in the *Draft Final Decision Document Other Contamination Sources Interim*

Response Action South Tank Farm Plume, January 1991, Shell states, "The uppermost portion of the Denver Formation is weathered and averages 4 to 6 feet thick, but may extend to approximately 20 feet at some locations." (page 5). Finally, in the *Northwest Boundary System Long-Term Improvements Interim Response Action B(ii) Draft Final Assessment Document*, January 1991, the Army states, "Based on the available drilling logs, ... the thickness of the weathered Denver is on the average of 15 feet at bedrock highs and approximately 5 feet at bedrock lows." Please modify the text accordingly.

Response: The text has been revised to indicate that the weathered portion of the bedrock surface may locally extend to depths of 45 to 65 ft below the alluvium-bedrock contact, and weathered bedrock is typically thicker on bedrock topographic highs than at bedrock lows.

Comment 3: Page A1-7, A1.4.4, Denver Formation -- The Army states:

> The unit (Denver) ranges in thickness from approximately 200 ft to 500 ft in thickness and is separated from the underlying Arapahoe Formation by a 30 to 50 ft thick relatively impermeable claystone interval known to geohydrologists working in the Denver Basin as the "buffer zone".

Certain geologic literature describes the transition between the Denver and Arapahoe formations as gradational and indistinct (Weimer, 1973) and based primarily on color change which is indicative of the introduction of early Tertiary volcanics. The K/T boundary, and thus the base of the Denver, has to date been described by this transition. Only the basal conglomerate of the Arapahoe formation is laterally continuous and distinctive enough in nature to identify consistently. Such geologic interpretations would appear to contradict suppositions that a true "buffer zone" exists in this area. Please provide references which evidence the existence of this "buffer zone" or, in the alternative, delete the statement from the text.

Response: The text has been revised to qualify the reference to the "buffer zone." Not all hydrogeologists familiar with the Denver and Arapahoe aquifers agree on the nomenclature for the zone of relatively less permeable sediments comprising an aquitard at the Denver/Arapahoe contact. Romero (1976) referred to the claystone interval separating the Denver and Arapahoe aquifer systems as the buffer zone.

Reference: Romero, John C. 1976. Groundwater Resources of the Bedrock Aquifers of the Denver Basin, Colorado: Report prepared by Division of Water Resources, Dept. of Natural Resources. p. 21, 22 and 38.

Comment 4: Page A1-11, A1.5.2, Unsaturated Zone -- Please make the following modification to the fourth sentence: "Thickness ranges from less than 5 ft in the area of the lakes, Basin A, First Creek, and the central area of South Plants to...".

Response: The text has been revised to include the north-central portion of South Plants in the area where the thickness of the unsaturated zone is 5 ft or less.

Comment 5: Page A1-12, A1.5.3, Unconfined Flow System -- Please provide the reference for the aquifer tests conducted in the unconfined Denver Formation, and list the well numbers in which the tests were conducted.

Response: The reference containing the results of the aquifer tests is listed in the text as EBASCO, 1989d. Section A4 of Appendix A References describes this reference as the Final Water Remedial Investigation Report. These results are contained in the Water RI Report in Appendix B, Hydrologic Data, Section B.4, Alluvial And Denver FM Aquifer Test Data. The wells completed in the Denver Formation portion of the UFS in which the tests were conducted include 01008, 01014, 02003, 23226, 24135, 24191, 26063, 26071.

Comment 6: Page A2-5, Boring Density -- Please explain how the boring density curve used in determining borehole spacing was generated.

Response: In order to maintain a consistent approach to the investigation of the multiple potential contamination sites on RMA, a method of selecting an appropriate number of bore locations within an individual site to assess the nature and extent of soil contamination was required. Although some guidelines for determining sample densities had been published in the available literature (and more have been published since the Army faced this problem), they were too generic to be of substantial value, and no standard or universally accepted methods were found, nor do they exist today. As a result, the Army convened a panel of technical experts from among its consulting teams to develop a standardized (for RMA) approach. The panel covered the disciplines of geology, geohydrology, engineering, statistics, chemistry, risk assessment, and environmental project management.

The panel was faced with the difficult challenge of balancing the desire to collect the maximum possible amount of site and contaminant information with the constraints imposed by a large but nevertheless limited availability of time, labor, analytical capabilities, and funds. The past experiences of the panel members were used to hypothesize what information would be necessary to assess the nature and extent of contamination at a variety of different site types and sizes. This information was then synthesized into a bore spacing curve in which even very small sites would have multiple sample locations given the fact that contaminant distribution at small sites could very well be sporadic, while larger sites would have wider bore spacings given the likelihood that larger sites resulted from activities that would create widely dispersed contamination patterns. Next, using the preliminary information that had already been amassed by the Army for suspected RMA contamination sites, the preliminary bore spacing curve was applied to a variety of actual sites, and the results were assessed in terms of the constraints described above. Upon review of these results, the bore spacing curve was refined as shown in Figure RISR A2.1-1. The text of Section A2.1.1.1, Boring Density has been revised slightly for clarity.

Comment 7: Page A2-84, A2.5.1, Phase I -- The text inaccurately states that "specific biological effects of contamination" were included in the Phase I biota database. The State has never seen such data, nor are we aware that such work has ever been conducted.

The biota RI was limited to generic population studies of invertebrates; juvenile/adult ratios studies on prairie dogs; reproductive success rates of avian species; and limited acetylcholinesterase inhibition studies on dead animals and selected species. "Specific biological effects," on the other hand, should include animal necropsy and specific histological studies neither of which were performed to our knowledge. Reference literature for the above-mentioned generic studies were not provided for State review. Such references must be added to the document.

Response: The statement that "specific biological effects of contamination" were included in the Phase I database is correct. This information was included in Section 2.0, Evaluation of Existing Information of the Final Technical Plan for Phases I and II of the Biota Assessment (ESE, 1988/RIC 88243R05). Subsection 2.3.2, Contaminant Effects in Biota, specifically addresses death, behavioral abnormalities, physiological malfunctions, and physical deformations as biological effects related to contaminants. All pertinent source documents were referenced in the appropriate sections and fully described in Section 8.0, References of that technical plan. The State had opportunity to review the Draft Final version of that document. The text includes a reference to this work plan.

The comment that necropsies were not performed is incorrect. Page 4-37 of the Final Biota RI Report states that "... raptors were necropsied and analyzed." Page 5-332 of the Final Biota RI Report presents the results of these necropsies in relation to contaminant concentrations found in tissues.

Comment 8: Page A3-2, A3, Nature and Extent of Contamination -- The Army states that the adjusted geometric mean (AGM) was calculated to determine mean values for data sets with less than 100 percent detections. However, it should also be explained in the text that sampling for specific contaminants in areas where those contaminants historically were not known to be stored, handled, or spilled would result in a biased, low estimate of the AGM. As an example, 38 of 41 groundwater samples analyzed for hydrazine-related contaminants as part of the South Plants Phase II sampling program were collected outside and upgradient of the Hydrazine Blending and Storage Facility (HBSF), the only area on the Arsenal known to store and handle the compounds (see the State of Colorado May 21, 1990 letter to the Office of the Program Manager regarding State's Proposal to Improve the Remedial Investigation for the South Plants Area, Comment 8). Calculation of the AGM for the Phase II study would result in a biased, low estimate of the mean concentration of hydrazine-related contaminants in groundwater. In actuality, recently collected RMA groundwater data within and downgradient of the HBSF indicated a wide distribution of hydrazine-related compounds. The State, therefore, cautions the Army not to rely on its AGM methodology in designing studies, assessing risks, or developing alternatives.

Response: The Army appreciates the State's cautionary remarks. Statements have been added to the text of page A3-2, and in Sections A3.2.1 and A3.2.3, as caveats regarding the purposes and use of the statistical information presented.

Comment 9: Page A3-2, A3, Nature and Extent of Contamination -- The Army states:

> While it is recognized that the AGM generally does not compute a representative mean value for sample populations with less than about 25 percent detections, summed total AGMs better reflect the actual sampled conditions in the water medium than do other methods, which either artificially assign values to samples with no detections, or overweight the significance of sporadic or anomalous detections. For soil, water, and biota it should be noted that as the percentage of analyses below the CRL increases, the AGM becomes a less reliable measure of a mean concentration for the data set.

The Army's assertion that summed total AGMs are more representative of sampled conditions than other methods is not substantiated. If the sampling methodology is not valid for sample populations with less than about 25 percent detections, an AGM should not be calculated for that population. Please modify the text and affected tables accordingly. Additionally, please cite the source for the information presented on AGMs.

Response: AGMs were presented for all sample populations with 4 or more detections in order to allow the readers to make their own comparisons between data sets. Nowhere in the text is it stated or implied that the validity of the sampling methodology is affected by calculations of AGMs. The reference (Romberg et al., 1984) was provided in the text.

Comment 10: Page A3-6, A3.1.1, Contaminant Distribution by Site Type -- The text should state that all tables in Section A3.1.1 summarize both Phase I and Phase II data, without distinguishing between the two. Examination of Table RISR A2.1-4 indicates that the certified reporting limits (CRLs) for some analytes decreased by as much as one-to-two orders of magnitude from the Phase I to the Phase II sampling programs (Table RISR A2.1-4); therefore, the ratio of Phase I to Phase II samples may have more to do with the frequency of detections than does the actual distribution of contaminants.

Additionally, there are several figures in Section A3.1.1 that include contaminants which were not sampled in soils during the RI, but which have a corresponding 0.0% detection frequency specified. For example, neither the ONCs on Figure A3.1-11 nor the PAHs on Figure A3.1-12 were sampled during the RI, but both have a 0.0% frequency detection. Specification of a frequency detection in this instance is not correct; for contaminants not sampled in soils as part of the RI, please replace the 0.0% value specified with a NOT SAMPLED (NS) indicator.

Response: The text has been revised to indicate that Phase I and II data are incorporated into the data tables. The figures referred to have been revised as suggested.

Comment 11: Page A3-6, A3.1.1, Contaminant Distribution by Site Type -- The Army states:

> Because of the limitations inherent in graphically summarizing results of over 260,000 analyses, detections representing a very small percentage of the normalized data are not depicted at this scale on the histograms. These data typically account for less than 0.04 percent for all analyte groups, and less than 1.0 percent of normalized data for concentration ranges within a depth interval for any group.

While we realize that there may be limitations in graphically summarizing results of such a large data set, detections cannot be arbitrarily removed from the histograms without: 1. summarizing, in tabular or graphic form, the data that are excluded; and 2. presenting the rationale used in excluding these data. Summarizing the percent of the detections represented by these data does not indicate the relative importance of the data in characterizing groundwater contamination. Please modify accordingly.

Response: No detections have been arbitrarily removed from the histograms or data tables. The Army recognizes that all data are important. The passage in question is merely intended to emphasize the limits of visual resolution associated with the histograms. These limitations exist because the color-coded segment corresponding to concentration ranges into which each depth interval on each bar is divided are demarcated by a black line of finite width. Measuring directly from the histograms, these black lines are approximately 0.01 inches wide. In those cases where plotting a detection or detections within a certain depth interval or concentration range results in a color-coded segment that is narrower than 0.01 inches, the segment will not be visible on the histogram.

Comment 12: Page A3-8, A3.1.1.1, Basins and Lagoons -- Page A3-8 attributes most metals in soils to "natural occurrences." However, this conclusion is contradicted by the fact that the highest percentage of detections were in ditches, lakes and ponds (p. A3-14), and the fact that metal concentrations at building sites decrease with depth (p. A3-31). This statement, therefore, should be removed from the document.

Response: This comment apparently refers to the first sentence of the last paragraph of Section A3.1.1.1, which states "Although the percentage of ICP metal detections is high, the majority of these detections are within the indicator range and are, therefore, generally attributed to natural occurrences." This statement refers to the data presented in Figure RISR A3.1-3, the analyte group detection frequency histogram for Basins and Lagoons, which shows that in Basins and Lagoons, 53.49 percent of detections were ICP metals, and only 3.78 percent of detections were ICP metals above the indicator range. Thus, 92.9 percent of ICP metal detections in Basins and Lagoons were within the indicator range. Detections within the indicator range are attributable to natural occurrences (see Section RISR A2.1.2.1 for a discussion of indicator ranges). ICP metal detections in other site types such as Ditches, Lakes, and Ponds are irrelevant to the observation in this section of the report.

Comment 13: Page A3-9, Table RISR A3.1-1, Summary of Analytical Results for Soils in Basins and Lagoons -- Examination of Table RISR A3.1-1 indicates that the upper CRL values for several contaminants are much greater than the Phase I and II CRLs listed in Table RISR A2.1-4. For example, the actual achieved CRL range represented in Table A.3.1-1 for 1,1-dichloroethane is 0.13-170, while the projected maximum Phase I and II CRLs were 0.9 ug/l and 0.074 ug/l, respectively; the CRL range listed in Table RISR A3.1-1 for chlorobenzene is 0.18-150 ug/l, while the maximum Phase I and II CRLs listed in Table A2.1-4 are 1 ug/l and 0.2 ug/l, respectively. Explanations for these high CRLs should be included, and the impacts of the higher CRLs on contaminant distribution assumptions should be discussed in the text.

Response: As the footnote on Table RISR A3.1-1 indicates, both the lower and upper CRL range values may reflect sample dilution prior to analysis. To analyze certain samples it is necessary to perform sample dilution to minimize interferences in sample matrices or to reduce the concentration of some analytes so they can be measured within the appropriate method certification range. During evaluation of the RI data and the designation of sites, when an elevated CRL was found in the database several factors were considered to evaluate whether there was potential for contamination at the sample site. The interpreter would consider factors such as the results from spatially adjacent samples, temporal data, contaminant properties and transport mechanism, and relative distance from a known source before judging whether a sample site should be considered to be part of a contaminated area.

Comment 14: Page A3-11, Table RISR A3.1-1, Summary of Analytical Results for Soils in Basins and Lagoons -- The frequency of detections for n-Nitrosodimethylamine is due to the inadequate design of the sampling program, and does not represent the true distribution of contaminants in the soils (see Jeff Edson May 21, 1990 letter to Don Campbell regarding State's Proposal to Improve the Remedial Investigation for the South Plants Area, Comment 8). This fact should be reflected in the text.

Response: A total of 85 analyses for n-nitrosodimethylamine were performed on samples from Basins and Lagoons during the RI. There were no detections in any of these samples, or in any soil samples collected from any site type at RMA. The State makes reference to their recommendations to complete additional sampling and analysis for n-nitrosodimethylamine in the HBSF, (Site SPSA-6, included in the buildings, equipment and storage sites). No detections of the analyte were reported in 198 analyses during the RI for this site type. The Army has agreed in its response to the State's recommendation (see Appendix F5.6) to install additional soil borings in the HBSF if a USATHAMA-certified analytical method for hydrazines in soil can be obtained. The State's recommendations and the Army's responses are included as Appendix F5 of this report.

Comment 15: Page A3-14, A3.1.1.3, Ordnance Testing and Disposal Areas -- The Army states:

> Some of the ordnance testing and disposal areas may contain unexploded ordnance that may pose a physical hazard if disturbed.

And on page A3-152:

> ...various types of unexploded ordnance have been collected during recent site surveys in Section 36 and the eastern portion of RMA.

The State was not informed that unexploded ordnance had recently been discovered on the RMA. Please include a summary section and map in the RI that presents the locations of all unexploded ordnance found on the Arsenal, and please notify the State upon finding unexploded ordnance in the future. Also, please describe how such ordnance is being managed. Additionally, if the ordnance is localized in specific areas, an investigation may be necessary

> to determine the extent and distribution of potential remaining unexploded ordnance.

Response: The passage on page A3-14 is correct. Some of the ordnance testing and disposal areas may contain unexploded ordnance that may pose a physical hazard if disturbed. This statement is based on the nature of the activities conducted in the areas, historical records, personnel interviews, and the results of previous surveys and investigations.

The passage on page A3-152 has been revised. Unexploded ordnance were located and properly disposed following Army procedures during previous surveys at RMA, but no unexploded ordnance have been found in investigations or surveys conducted since the RI commenced in 1984. However, during the RI a wide variety of demilitarized and decommissioned ordnance debris was identified and catalogued at several sites at RMA. There also were a number of other items identified during exploratory digging in burial trenches which may pose physical hazards if disturbed by future invasive investigative or remedial procedures. However, none of these other items was unexploded ordnance.

Regarding the various requests by the State:

- The potential for unexploded ordnance has been adequately addressed in various RI Products, including this report, the CARs and SARs. A map showing the locations with the greatest likelihood for encountering unexploded ordnance is provided in Figure RISR 2.2.-2.

- The Army maintains and routinely follows standard operating procedures which govern handling and management of unexploded ordnance at this U.S. Army facility.

- The sites where unexploded ordnance are potentially present are localized in specific areas as was stated in various RI products and other documents. No additional investigations are warranted because potential for the presence of unexploded ordnance at various sites was adequately addressed in the RI.

Comment 16:

Page A3-20, A3.1.1.4, Solid Waste Burial Sites -- The Army states:

> Three chemical waste burial sites, each including multiple trenches, are located within Section 36, and one burial site is within the South Plants area.

Please specify that the three chemical waste burial sites referenced by the Army are CSA-1a (Shell Complex Disposal Trenches), CSA-1b, and CSA-1c (Army Complex Disposal Trenches) identified in The *Proposed Final Remedial Investigation Report Central Study Area*, June 1989 (CSAR), page

> 3-14. Although it is stated in the CSAR that ,"...early joint Army/Hyman disposal practices took place in northern CSA-1b," the Army, to our knowledge, has never investigated the site nor characterized contaminant distribution associated with the Army/Hyman waste disposal practices (see State Proposal for Rectification of Remedial Investigation Data Gaps in the Central Study Area, March 2, 1990, Comment 1.B); therefore, we were not aware that "multiple waste burial trenches" had been identified in CSA-1b. Please provide the information supporting this conclusion.
>
> Additionally, please identify the site name and location, and reference the document which summarizes site characterization of the chemical waste burial site in the South Plants area.

Response: The text has been modified and the passage clarified to specify the designated sites. The Army employed various investigative techniques in the RI of the area in Section 36 now designated as the CSA-1b site. Based on RI soil contamination data and other information it was concluded that early joint Army/Hyman disposal took place in an area that straddles the CSA-1b/CSA-1c mutual boundary, as the two sites have been configured. The criteria used to draw the mutual CSA-1b/CSA-1c boundary were based on many things. In order to classify sites in an organized manner, an effort was made to include all burial trenches in the CSA-1c vicinity within its boundary so that CSA-1c contained predominantly burial sites and so that CSA-1b contained soil contamination attributable to nonburial activities. However, because of the complex setting and disposal history of the area, part of the early joint Army/Hyman disposal site falls within the northern portion of CSA-1b as it was drawn. During Phase II of the RI, exploratory trenches were excavated through burial trenches in the southern part of CSA-1c and the burial trenches were characterized. After the completion of the RI, the Army recognized that additional groundwater data were needed for the FS regarding any potential trenches in the CSA-1b/CSA-1c boundary area, and an IRA investigation (the Remediation of Other Contamination Sources Interim Response Actions ("Hot Spots")) is being conducted to collect these data (see Appendix C, Section C.13). The FS will address additional data collection needs in this area following review of the "Hot Spots" IRA results.

The Solid Waste Burial Site referenced in the South Plants area is the Hex Pit, Site SPSA-1f (former site 1-13), characterized in the Phase I CAR, Sites 1-13 and 2-18, (EBASCO, 1988/RIC 88286R07; p. 19; Figure SPSS-5b), and the SAR (EBASCO, 1989/RIC 89166R04; p. 3-20).

Comment 17: Page A3-20, A3.1.1.4, Solid Waste Burial Sites -- The Army states:

> Sanitary landfills were used for the disposal of trash, construction debris, and other material related to RMA activities, with the exclusion of chemical waste.

This statement is misleading. Although the level of contamination present in general rubbish disposal site CSA-1d was less than that found in the contaminated waste disposal sites, the Army states (CSAR, page 3-14), "CSA-1d contains low levels of contaminants. This fact refutes the assertion that it was used as a disposal site for "uncontaminated solid wastes"... The levels of contamination in CSA-1d appear to be attributable to incidental contamination of general rubbish materials and burning of refuse with fuels in some trenches. Please modify the text accordingly.

Response: The text of the passage in question has been clarified to indicate that sporadic, low concentrations of contaminants have been detected in some samples of landfill debris.

Comment 18: Page A3-21, Table RISR A3.1-3, Summary of Analytical Results for Soils in Ordnance Testing and Disposal Areas -- Table RISR A3.1-3 states that 158 borings were sampled in the Ordnance Testing and Disposal areas. However, it appears from an examination of Figure RISR A3.1-2 that only approximately 90 borings were actually located within the testing and disposal areas, and that the remaining 68 borings are located outside of those boundaries. Inclusion of outside borings is not appropriate since they will affect (bias towards a low value) the frequency of detections, concentration ranges, and statistical values. Please list bore numbers for all borings included within the testing and disposal area site boundaries, and modify Table RISR A3.1-3 based only on data from these borings.

Response: The State is correct that not all bores plot within the boundaries of the sites comprising this site type. The site boundaries are approximate; absolute boundaries will not be fixed until remedial alternatives are finalized. The following 158 borings are included in the data summaries for the Ordnance Testing and Disposal Areas site type. Approximately 40 of these are outside or adjacent to the site boundaries as depicted on the RISR graphics, but all are considered to be indicative of contaminant conditions in this site type. Bores within mapped boundaries include:

1419015285
1420015294
1429015304
1429015305
1532000004
1532000020
1532050001
1532050002
1532050003
1532050004
1532050005
1532050006
1532050007
1532050008
1532050009
1532050010
1532060001
1532060003
1532060004
1532060005
1532060006
1532060008
1532060009
1532060010
2232050012
2232050013
2232060011
2232060012
2232060014
2232060015
2232060016
2232060017
3118
3305
3486
3487
3488
3715
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3717
5282
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5481
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5543
5544
5545
5546
5547
5548
5549
5550
5551
5552
5553
5557
5558
5565
5582
5583
5586
5593
NRS30103
NRS30104
NRS30106

Bores outside mapped boundaries:

1532000013
1532050011
1532060002
1532060007
2232060013
3117
3119
3120
3121
3301
3302
3303
3304
3306
3309
3310
3311
3388
3489
3490
3702
3710
5269
5292
5296
5299
5301
5302
5374
5378
5482
5524
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Comment 19: <u>Page A3-55, A3.1.1.10, Balance of Areas Investigated</u> -- It appears that SHO references included in this paragraph should be replaced with VHCs; please modify the text if necessary.

Response: The text has been corrected.

Comment 20: Page A3-70, A3.1.2.3, Five- to 20-ft Depth Interval -- The Army states:

> Inorganics are elevated along a shallow bedrock feature which trends northwest/southeast across Section 36. This occurrence, like other elevated inorganics in bedrock samples, probably reflects the natural bedrock geochemistry.

The Army Complex Disposal Trenches located in Section 36 were completed in soils above the northwest-trending bedrock high, and soil and grab samples from the trenches indicated high levels of metals contamination. Therefore, the elevated metals concentrations in the 5-to-20 ft depth interval in this area may be related to operation of the disposal trenches. Examination of Figure A3.1-23 and A3.1-24 seem to support this hypothesis. The metals distribution does not appear to be random, but in most instances is associated with soils and groundwater organic contamination. Please modify the text accordingly.

Response: While the Army has shown that inorganics are elevated in and immediately below burial trenches in CSA-1c and CSA-1d, there are many samples from the 5- to 20-ft interval between trenches and elsewhere in other portions of Section 36 far from trenches which consistently show elevated inorganics concentrations. Typically, those samples were taken from bedrock materials or from soils derived from in situ weathering of bedrock materials. The shallow bedrock feature discussed in the text happens to be comprised of a characteristic volcaniclastic unit which would be expected to have elevated inorganics concentrations. The consistently elevated inorganics concentrations reported for samples of volcaniclastic bedrock materials confirm this expectation. A statement has been added to the text to clarify that there are both high naturally occurring inorganics in Section 36 5- to 20-ft soils as well as elevated inorganics in burial trenches in Section 36.

Comment 21: Page A3-72, A3.1.3, Sewers and Process Water Systems -- Page A3-72 states that no sediment samples were collected from chemical sewers. Are such analyses planned for the future?

Response: No. The chemical sewers are considered contaminated.

Comment 22: Page A3-85, A3.2.3, Unconfined Flow System -- Please make the following modification to the second sentence, "As discussed in Section A1.5.3 of Appendix A, the UFS comprises saturated alluvial and eolian deposits, and the upper portion of the Denver Formation in hydraulic connection with those deposits." Contrary to statements in the text, the UFS is not limited to alluvial, eolian deposits, and subcropping Denver sands.

Response: The text has been revised to clarify the description of the UFS.

Comment 23: Page A3-129, A3.3.1, Building Classification -- The text states:

> [h]istorical records of each structure were reviewed during the RI. Structures were classified on the basis of suspected contamination in conjunction with the limited sampling data available.

This classification approach is unreliable because it emphasizes historical information. Instead, each structure must be evaluated on a case-by-case basis, and sampled in a manner sufficient to determine the nature and extent of contamination present prior to demolition or future use (see State's Approach for Confirmation Sampling of RMA Structures, November 17, 1989). In addition to toxicity characteristic leaching procedure (TCLP) sampling, the Army should also perform sampling for any listed wastes that are likely to be present. The existence of aldrin and dieldrin in the non-source area surficial soils presents such a likelihood. 6 CCR 1007-3, Sec. 262.11 requires a generator of a solid waste to determine whether the solid waste is listed as a hazardous waste or whether the waste exhibits any of the characteristics of hazardous wastes. The analysis of building materials for listed and characteristic wastes, when there is potential that they exist, will ensure that the final disposal of building debris will be in compliance with RCRA/CHWMA, including the land disposal restrictions (LDRs).

Response: The use of historical records is an accepted means of evaluating contamination conditions in structures at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites. Sample collection is not required when there is no basis for believing a structure to be contaminated. Limited structures sampling during the RI was conducted, and results tended to confirm classifications based on historical documentation. There is no accepted protocol for structures sampling at present. The Army has convened an expert panel to evaluate structures sampling within the context of FS requirements.

Comment 24: Page A3-129, A3.3.1, Building Classifications -- The Army states that there are 763 existing structures. However, on p. 24 of Volume I of the Structures Survey, it is stated that there are 982 existing structures. The discrepancy is apparently due to the exclusion of the 219 electrical substations from the Final RI. The RI should be revised to indicate the existence of the electrical substations in the total number of structures and it should reference the information available on PCB contamination at each substation as summarized in the final pages of Table 24.1-2 of the Final Structures Survey. We expect to receive additional information regarding the extent of PCB contamination at the Arsenal in the coming months.

Response: The text has been revised to include the 219 substations, which when combined with the 763 structures, gives a total of 982. The ongoing polychlorinated biphenyls (PCB) inventory at RMA is being completed by the Army in compliance with 40 CFR763. This PCB inventory is being conducted in addition to and is not part of RI activities at RMA.

Comment 25: Page A3-141, A3.4.6, Metals -- The State lead standard is incorrectly cited as a 3-month average concentration. It is actually based upon a 1-month average concentration.

Response: The text has been changed to indicate that the State lead standard is based on a 1-month average.

Comment 26: Page A3-145, A3.5, Biota -- The Army states:

> Terrestrial producers (plants), and to some degree carnivores, show elevated levels of OCPs in tissue samples that can be broadly associated with OCP concentrations in RMA soils. This relationship also tends to hold for mercury in carnivores. Similar associations could not be made for OCPs, arsenic, or mercury in other trophic levels.

[sic]

Response: No comment noted.

Comment 27: Page A3-145, A3.5.1, Terrestrial Ecosystems -- The Army states:

> The following discussion groups species investigated by trophic levels in order to discuss the nature and extent of biota contamination at RMA. These groupings and representative species are listed below.
>
> Primary Producers Morning glory, sunflower
> ... [sic]
> Carnivores American kestrel, red-tailed hawk, ferruginous hawk, golden eagle, great horned owl, coyote, badger.

Given that the two forbs, morning glory and sunflower, do not represent the predominate RMA groundcover, inclusion of at least one grass would more appropriately characterize contaminant distribution at this trophic level.

Inclusion of coyote, owl, and badger in this list gives the erroneous impression that these species were studied in depth as part of the Remedial Investigation. In fact, these animals are represented only as isolated samples of opportunity in the Biota RI. Please modify the text accordingly.

Response: The text has been revised to indicate that these animals were samples of opportunity in the Biota RI.

Comment 28: Pages A3-146 and A3-148, A3.5.1, Terrestrial Ecosystems -- The Army states:

> Table RISR A3.5-1 allows comparisons between data contained in previously published RMA studies.

The Army's reference to previous biota contamination studies is appropriate, but the Army makes no apparent use of the information which these studies contain. Section 4.1.3 for example, of the Biota RI (Historical Contamination Levels in Wildlife) indicates that (among other things) mercury has been detected in producers (pg. 4-16) and that DDT can be found in a variety of trophic levels (pg. 4-12); however, this information is not reflected in the RISR.

Response: The purpose of the RI was to identify the current nature and extent of contamination. These conditions may vary through time. Data from past studies served as a basis for scoping the RI studies that identified the current nature and extent of contamination. The text has been modified to clarify that Table RISR A3.5-1 presents RI data. Presentations of various mean values used in previous studies are included to allow comparison of RI data with other studies.

Comment 29: Pages A3-148 and A3-149, A3.5.1, Terrestrial Ecosystems -- The Biota portion of the RISR includes only a few samples from various trophic levels. As a result, conclusions and observations presented on pages A3-148 and A3-149 are inaccurate, as is demonstrated by comparison of Tables RISR A3.5-1 and RISR A3.5-2 with results of the 1988 and 1989 Comprehensive Monitoring Program (CMP). These inconsistencies include:

A. pg. A3-148: (terrestrial trophic levels)
   1. 1988 and 1989 CMP results indicated aldrin detections in detritivores, omnivores, and primary producers; the RISR indicates aldrin only in herbivores.
   2. 1988 and 1989 CMP results indicated DDE in detritivores, herbivores, and primary producers; the RISR indicates DDE only in omnivores and carnivores.
   3. 1989 CMP results indicate DDT in all trophic levels but carnivores; the RISR indicates no DDT detections in any trophic levels.

B. pg. A3-149: (aquatic trophic levels)
   1. 1988 and 1989 CMP results indicate DDT detections in primary and top carnivores; the biota RI showed no DDT detections.

> Therefore, the use of all CMP data to verify RI observations and/or conclusions regarding the presence of contamination in the food chain is essential.
>
> CMP data also contradicts RISR observations regarding the areal extent of contamination in terrestrial biota (see Figure RISR A3.5-2). CMP data indicate biota contamination in several areas of RMA which the A3.5-2 [sic] map depicts as non-detect areas for various trophic levels.

Response: The CMP program built on information developed from Biota RI studies. Food webs, species, and sites were added to the CMP, based in part on information provided in the Biota RI. The fact that additional trophic levels were found to be contaminated in the CMP attests to the usefulness of this continued effort. The additional information on both areal extent and distribution within food webs provided in the CMP does not indicate any inconsistency. Increasing the number of species and locations should provide more detections. The CMP data provide additional useful information that will be incorporated into the biota portion of the EA process, and, together with calibration and validation of the pathways model, will provide a more complete understanding of contaminant distribution and transfer within biological systems at RMA. However, it is clearly stated that the RISR summarizes data from the Biota RI and not data from subsequent biota programs. The text on page A3-145 has been modified to further emphasize this point.

Comment 30: Page A3-149, A3.5.2, Aquatic Ecosystems -- The Army states:

> > In addition to these data for the RMA lakes, Rosenlund et al. (1986/RIC 86041R02) reported dieldrin, aldrin, and mercury in aquatic plants; dieldrin, endrin, DDE, and mercury in omnivores; dieldrin, aldrin, and mercury in primary carnivores; and dieldrin, aldrin, endrin, DDE, and mercury in top carnivores.
>
> The Army makes no attempt to account for the apparent greater success enjoyed by Rosenlund in detecting RMA contaminants; yet clearly the contamination is either no longer present or the RI program was inadequate to detect it. Either of these conclusions have great relevance to the RMA Remedial Investigation.

Response: There are other possible explanations of why more detections were reported by Rosenlund et al. than were obtained in Biota RI studies. Rosenlund's detection limits were in most cases lower than the CRLs used in the Biota RI, and the level of certainty regarding his results was also lower. Sedimentation in the lakes may have made some of the contamination less available to biota between the time that the Rosenlund data were collected and the time of the RI studies. Rosenlund's data were evaluated as relevant information for the Biota RI and provided a basis for continuing investigation and analysis during the CMP and EA phases. These points are included in the revised text.

Comment 31: Page A3-151. The Army states:

> The detection ratios between on-post and off-post samples were tested for significance using the method suggested by Sokal and Rohlf (1981). The percentage of dieldrin detections for terrestrial species was significantly greater on-post than off-post at the 95 percent confidence level with a 95 percent certainty. On-post versus off-post detection ratios for the other analytes were not significantly different.

The information presented in Figure A3.5-6 [sic] does not appear consistent with the claim of no statistical difference in frequency for most contaminant detections. According to the figure, aldrin and endrin had on-post detection frequencies of 3% and 4% respectively while none was measured off-post; mercury was detected in 20% of on-post samples and in only 8% of off-post samples. Please provide the specific statistical test which was used to arrive at your conclusions (the 1981 citation contains many different statistical tests and procedures), and details of the data which were used so that the parties can reproduce the Army's results. The meaning of "95 percent confidence level with a 95 percent certainty" is also unclear and should be explained. In addition, were on-post samples taken from less contaminated areas pooled with samples from more heavily contaminated on-post areas when this statistical comparison was made?

Response: All on-post sample results were pooled and compared to all pooled off-post data. The test used for comparison of collective on-post and off-post percentages of detection was the true difference between percentages test on page 765 of the referenced document (Sokal and Rohlf, 1980). This and other points have been clarified in the text in Section A.3.5.3. Note that statistical tests take into account sample size and the numerical value of detections, not just their frequency when calculating statistical significance of differences. In standard statistical usage, confidence is a measure of the reliability of the results of a statistical test, while certainty is a measure of the probability of the results being valid and not based on chance.

Comment 32: Page A3-151, A3.5.3, Comparison of Off-Post and On-Post Biota Sampling Results -- The Army states:

> ...only three samples in northern off-post control areas and one control sample from south of RMA are suspected to have moved off of RMA.

Please provide the basis for this suspicion.

Response: The text on page A3-151 has been revised.

Comment 33: Figures RISR A3.5-2 and RISR A3.5-3 -- Concentration ranges are expressed as ug/l in the legend. Did the Army intend to express this information in ug/g?

Response: The figures have been corrected; µg/g are the correct units for these concentration ranges.

Appendix B Vertical Extent of Groundwater Contamination in the Denver Aquifer

The Army has appeared to follow most of the decisions and suggestions presented by the OAS at the Vertical Extent of Contamination (VEC) technical subcommittee meetings. However, there are several topics that the State believes were discussed at the meetings but which have not been addressed in Appendix B. It is probable that the subjects were not included in the text and/or maps due to differences in understanding between the parties regarding the final status of the topics. Those subjects that we believe are still necessary to address are again presented in the following general and specific comments.

Comment 1: The only map of well locations included by the Army in Appendix B is a map showing the location of wells evaluated for inclusion in the Vertical Extent of Contamination (VEC) data base (Plate RISR B.2-1). While it is important to identify all wells considered for the program, it is equally important to include a map of only those wells actually selected for inclusion. Without such a map, it is difficult to verify that data base wells most representative of the vertical extent of contamination have been included on the corresponding cross-sections. Additionally, in those areas for which data are insufficient to determine the vertical extent of contamination, comparison of the two maps will indicate areas in which ABC data base wells are available for sampling, and those areas where additional wells would have to be constructed to determine vertical extent of contamination.

In addition to the map of VEC wells, please provide four maps that present well locations for the 0-50, 50-100, 100-150, and >150 foot depth intervals. The distribution of wells by depth definitely influences interpretation of vertical extent of contamination. The majority of wells in the data base are probably completed in the 0-50 foot depth interval, while the fewest number of wells will be completed in the >150 foot interval; therefore, without the requested maps, it is impossible to determine whether distribution of contaminants in the deeper intervals is representative of actual contamination with depth, or an incomplete presentation due to inadequate distribution of wells at these deeper intervals.

Please include a sixth cross-sectional figure (with estimated vertical extent of contamination) oriented east-west running from Section 33 to Section 32. The five cross-sectional figures currently included in the report do not contain data regarding the vertical extent of contamination beneath Basin A in Section 36. Since this area includes one of the most extensive alluvial plumes and some of the highest contaminant detections on the RMA, an understanding of the vertical extent of contamination beneath the basin is necessary. Additionally, due to an absence of wells completed deeper than 50 ft below bedrock contact, the vertical extent of contamination beneath Basin A and immediately to the west of the basin has not been defined. This should be represented on the cross-sections (see Appendix B Specific Comment 26E).

Response: The data evaluated for the VEC database are highly variable. Not all wells were sampled for all analytes; in addition, detection limits and CRLs vary considerably for different analytes and different analytical methods, and between different laboratories, as well as over the time period represented by the data evaluated in this investigation. The contaminant distribution maps are summaries of detections within various depth intervals beneath the bedrock/alluvium contact for various analyte groupings that satisfied the criteria et forth in Section B.2.3 of Appendix B. While the maps for DIMP, fluoride, and chloride present information for single analytes only, the maps for total organics and for arsenic, mercury, and ICP metals show summed concentrations for multiple analytes. The fact that a well is not plotted on an individual map for a given analyte or analyte group in a given depth interval is indicative only of the fact that the data, if any, for that well did not satisfy the criteria for inclusion in the VEC database as outlined in the text of Appendix B. It does not indicate that an analyte was not detected, nor that it was not sampled for, nor that no data were collected. The data selected for inclusion in the VEC database represent the contaminant conditions known on the basis of positive analytical evidence and considered to reliably reflect contaminant conditions at those sampled locations. If no detections were selected as representative of conditions at the well, the well was not included in the VEC database. The maps in Figures RISR B.3-1 through RISR B.3-18 and RISR B.5-1 through RISR B.5-5 show wells actually selected for inclusion in the VEC database. Therefore, only wells with one or more detections were included in the VEC database. The wells without detections, as well as the wells with detections and the wells not satisfying the criteria set forth in Section B.2.3 are shown on Plate RISR B.2-1.

It is the Army's understanding that one map showing the locations of all wells considered would be sufficient for the organizations and State. The databases of all wells that were considered and all wells that were included in the vertical extent evaluation was provided to the organizations and State as an attachment to the Draft Final Appendix B of the RISR.

However, an additional map of the wells included in the VEC database has been created as Plate RISR B.2-2 for the Proposed Final RISR. The file ALLDEN.DBF provided with the report is a listing of all sampled wells that are completed in the Denver Formation, and the file VEC.DBF is the VEC database of all wells included in this evaluation of the vertical extent of contamination. In addition, at the request of the State all wells in the ALLDEN file have been sorted by completion depth interval below the bedrock contact and plotted on four new figures, RISR B.2-1, RISR B.2-2, RISR B.2-3, and RISR B.2-4, for the Proposed Final version of the RISR. The reader is cautioned to bear in mind the limitations that apply to these maps and the caveats that these maps do not show areas of data collection for all analytes and are not directly comparable to sampling densities based on hydrostratigraphic water-bearing zones. Wells completed in the same hydrogeological units may not plot on the same depth maps due to variations in the bedrock surface across RMA, and discontinuities and variations in the stratigraphic units.

Additional wells in the Basin A area have been added to existing cross-sections N-N' and F-F'. These wells indicate the vertical extent of contamination in this area has not been defined. The State's comment indicated that the absence of wells on cross-sections in this area was the reason for requesting an additional cross-section; therefore, the Army believes these additional wells satisfy the State's comment, and an additional cross-section figure is not necessary.

Comment 2: The Army summary of the VEC data indicates that contaminants are migrating off-post in Denver Formation sands beneath the North Boundary Containment System (NBCS), the Northwest Boundary Containment System (NWBCS), and Section 22, and that the areal and vertical extent of contamination in these areas have not been defined. A study is therefore necessary to characterize extent of contamination migrating off-post between the two boundary systems.

Response: As an ongoing part of the Feasibility Study the most recent data are continually reevaluated to characterize contaminant migration that may have occurred or been detected since completion of the RI. The NBCS, NWBCS, and areas between these systems will be included in this ongoing process. Wells 22027, 22028, and 23184 have been part of the well network for the CMP. The FS will evaluate sample results as they become available.

Comment 3: If a well has been sampled for all contaminant groups and is found to have values below detection limits or background levels, it is appropriate to use that well to delineate vertical extent of contamination. However, if the well has not been sampled for all of the contaminant groups, it should not be used to define vertical extent, since it cannot be assumed that concentrations in the contaminant groups that were not sampled are below detection limits or background values. If any such well was included in the VEC data base, it should be identified and replaced with an appropriate well.

Response: The Army recognized the possibility described in the State comment when constructing the VEC database and cross sections of this report. The wells most recently sampled have the most complete sampling suite of analytes. The sample dates associated with each detection are included in the database so that the older data can be identified. Recently sampled wells were used as much as possible in representing the vertical extent of contamination on the cross sections. Where possible deep wells with more complete sampling suites were used to define vertical extent of contamination. Where not possible, the extent of contamination is qualified accordingly. If no recent samples were collected, and the well was in a location where the vertical extent of contamination was not defined, the well was identified as having an inconclusive sampling chronology (Table RISR B.5-1).

Comment 4: Page B-7, B.2.2, Selection of Water Quality Data and Page B-33, B.6, Summary -- The Army states:

> In cases where existing data could not be used to clearly identify reliable values of concentration, conservative values were selected. The resulting VEC database tends to overestimate the extent of contamination in areas where data were not conclusive.

Please clarify this comment. It is not clear: 1. whether existing data were used, reliable or not; 2. what qualifications were used in determining that data were not reliable; and 3. the source of the "conservative values" referenced by the Army. Additionally, it is not clear how selection of "conservative values" has resulted in the possible overestimation of the extent of contamination.

Response: The text has been revised to indicate that in cases where consistent values of concentration could not be identified, recent elevated detections were selected for inclusion in the VEC database. In using the higher concentrations, this approach is considered conservative because the extent of contamination may be overestimated.

Comment 5: Page B-8, B.2.4, Background Water Quality -- The Army states:

> In general, background concentrations of many organics found at RMA are near CRLs.

We are not aware that background concentrations for on-post RMA organic contaminants have been determined; therefore, please clarify the above statement.

Response: Background concentrations of on-post organic contaminants have not been determined. The Army can only speculate on the origin of these organic analyte concentrations, including both natural sources such as hydrocarbon deposits in various geological units, and potential upgradient off-post, man-made sources such as manufacturing, industrial, transportation, sewage treatment, or energy-related facilities, and other activities. The statement in the text has been clarified to indicate that concentrations of many organics in areas that are hydraulically upgradient of plumes are detected near CRLs.

Comment 6: Page B-8, B.2.4, Background Water Quality -- The Army states that Denver Formation wells completed in Sections 5, 6, 7, 8, 11, 12, 19, 20, 29, and 30 are hydraulically upgradient of known RMA source areas, and are therefore representative of background groundwater concentrations. This list should also include areas within Section 32, and possibly Section 31.

Additionally, please list all wells used in the determination of background inorganic and metals concentrations. All historical data included in the RMA Environmental data base [sic] for these wells should have been used in the calculation; please verify that this was done, or indicate which data were used for the calculation and explain the rationale for the approach.

Response: The list of Denver Formation wells considered representative of background concentrations has been revised to include all Denver Formation wells in Sections 5, 6, 7, 8, 11, 12, 19, 20, 29, 30, 31, and 32 except Wells 31006, 31007, and 31008. These three wells comprise a well cluster in an area potentially downgradient of some sources in Section 36. Table RISR B.2-1 has been revised accordingly. All historical data were considered in developing the VEC database. However, for purposes of this report, values presented in Table RISR B.2-1 are based on data included in the VEC database.

Comment 7: Page B-10, B.2.4, Background Water Quality -- The Army states:

> The wide range of detected concentrations and high standard deviations of detections shown in Table B.2-1 [sic] show that background concentrations vary substantially from location to location. This extreme variability may be attributable either to naturally high spatial or temporal variation, or to the presence of more than one population subset.

It is possible that the variation in concentrations is attributable to inclusion of wells screened in different Denver Formation sand units in the background calculations. If background concentrations were determined by sand unit, it is probable the variability would decrease.

Response: While it is possible that the suggested approach would reduce variability within individual hydrostratigraphic intervals, because of the difficulty in correlating hydrostratigraphic units across RMA, the overall range in background concentrations in the Denver Formation are better characterized by the approach used.

Comment 8: Page B-11, B.3, Areal Distribution of Contaminants -- The Army states that wells in which contaminants were not detected are not included on the contaminant distribution maps. However, Denver Formation wells with no organic detections, and with metals and inorganic detections at or below background values, should be included on the maps and plates. Inclusion of these wells would help to delineate, spatially and vertically, contaminated areas, as well as delineating those areas in which the vertical and areal extent of contamination has not been determined.

Response: As explained in the text, the wells with no detections are not shown on the maps because of the following reasons that could result in an inaccurate portrayal of concentration distributions:

- CRLs for most contaminants have varied. As a result, a well that was sampled when CRLs were higher could be mapped as uncontaminated. Nearby wells sampled when CRLs were lower could indicate the presence of contaminants.

- Analytical suites have varied. The State described this problem in their Appendix B Comment 3. A limited number of analytes may have been analyzed, and a potential contaminant that was not included in the analytical suite may not have been detected. This could result in a depicted below CRL location where contaminants were actually present.

Comment 9: Page B-11, B.3.1, Total Organic Analytes -- Please replace the sentence, "Most elevated levels of total organic analytes (greater than 10,000 ug/l)..." with "Most detections of total organic analytes exceeding 10,000 ug/l...". Any level of organics above background should be considered elevated.

Response: The sentence has been modified as requested.

Comment 10: Page B-12, Table RISR B.2-1, Background Concentrations of Inorganic Analytes in the Denver Aquifer -- Please include the well numbers, number of samples analyzed per analyte or analyte group for each well number, and corresponding number of detections per analyte or analyte group in the table.

Response: Please refer to the response to the State's Appendix B Comment 6 for a description of the methods used to construct Table RISR B.2-1. In light of the method used, it is appropriate to include only the number of detections in the table. These values are included.

Comment 11: Page B-17, B.3.1.2, Relation to Alluvial Contamination -- Please replace the final sentence in the first paragraph of Section B.3.1.2 with, "Areas of dissimilar distribution between the unconfined flow system and the Denver aquifer include the northeast area of South Plants, Section 22, and North Plants."

Response: The paragraph as written recognizes that there is a dissimilar distribution beneath North Plants. Therefore, a reference to the North Plants has not been added to this sentence.

Comment 12: Page B-18, B.3.2.1, Areal Distribution -- The Army states:

> Below Basin C, DIMP was detected at a maximum concentration of 25,600 ug/l in Well 26053, at a depth of 16 ft below the alluvium-bedrock contact. This concentration was reported in 1979; no samples were collected after this date.

Because of the high DIMP detection and the uncertainty with which the Army views pre-1984 data, Well 26053 should be resampled. If high DIMP detections are again found in the well, completion of deeper wells in the vicinity of Well 26053 will be necessary to define the vertical extent of contamination beneath Basin C.

Response: Well 26053 is not included in any proposed sampling at this time. From the FS perspective, additional sampling data are not required at this location in order to evaluate remedial alternatives. Final decisions regarding additional investigations in the Denver aquifer will be reached following discussions with the organizations and State in the appropriate RMA Committee and Subcommittee meetings formats.

Comment 13: Page B-19, B.3.3, Sum of Arsenic, Mercury, and ICP Metals -- Please replace the sentence in Section B.3.3 beginning with, "This range corresponds...", with, "This range corresponds to the upper limit of the range of background concentrations detected in upgradient wells..."

Response: The requested modification would incorrectly relate a range of values (10 to 100 µg/l) to a single value (99.3 µg/l), the upper limit of the range of background concentrations.

Comment 14: Page B-21, B.3.4, Fluoride -- Please add to the first sentence of this page that the secondary drinking water standard for fluoride is 2,000 ug/l.

Response: The secondary drinking water standard for fluoride has been added to the text.

Comment 15: Page B-22, B.3.4.2, Relation to Alluvial Contamination -- In the second paragraph of Section B.3.4.2, please include Sections 3 and 33 as having elevated Denver Formation fluoride concentrations with respect to unconfined flow system values.

Response: According to Mr. G. Mohrman, PMRMA, interference effects from chloride may potentially produce artificially high fluoride values (oral communication with Mr. J. Bush, EBASCO, October 28, 1991). Nevertheless, the text has been modified to include Sections 3 and 33, and to note the potential for these interference effects.

Comment 16: Page B-22, B.3.5, Chloride -- Please replace the first sentence of Section B.3.5 with, "Most chloride concentrations greater than or equal to 5,000,000 ug/l...". Any chloride level above background should be considered elevated not only those in exceedance of 5,000,000 ug/l.

Response: The sentence has been reworded as requested.

Comment 17: Page B-23, B.3.5.1, Areal Distribution -- The Army states:

> Chloride was not detected in this area below 194 ft.

Please clarify whether chloride was not sampled at depths greater than 194 ft, or was sampled and not found at levels above CRLs.

Response: A sentence indicating chloride was not sampled below this depth has been added to the text.

Comment 18: Page B-24, B.4, Vertical Extent of Contamination -- The Army states:

> Although the shallow bedrock of the Denver Formation appears to be effective in partly containing contamination within the unconfined flow system, it is not a completely effective barrier to migration.

Due to the number and range of contaminant detections in the Denver Formation, it is obvious that the Denver is not a barrier to contaminant migration. Because much more study is needed to understand not only the transport of contaminants in the Denver, but also the nature and extent of interaquifer communication between the Denver and the Arapahoe, it is inaccurate to imply that the bedrock acts as a barrier to vertical contaminant migration. The State, therefore, recommends omitting the sentence.

Response: The Army recognizes that the Denver Formation does not serve as a complete barrier to contaminant migration, as is expressly recognized in the referenced sentence. However, in many areas concentrations of contaminants are substantially less in the Denver Formation from those detected in the overlying UFS. Therefore, the Denver Formation clearly serves as a partial barrier to migration. The sentence has not been deleted. However, the Army recognizes that the need to evaluate the effectiveness of the Denver Formation as a barrier to migration on an area by area basis will be addressed by the FS.

Comment 19: Page B-24, B.4, Vertical Extent of Contamination -- The Army states:

> In the Denver aquifer beneath this area [the vicinity of Basin A], the concentration is typically less than 700 ug/l.

However, examination of Figure B.3-1 [sic] indicates that the majority of detections of total organic analytes (TOA) in the 0-50 ft depth interval beneath Basin A and immediately to the north of the basin, fall within the concentration ranges of >1000-10,000 ug/l, and >10,000 ug/l. The text should reflect this fact, and further indicate that these detections are located beneath the area of greatest alluvial contamination in the vicinity of Basin A, and are consistent with the major flow path in the overlying alluvium; therefore, the higher concentrations are representative of Denver contamination in this area.

Response: The sentence has been corrected to state that the concentration is typically less than 7,000 µg/l in the Denver aquifer beneath the vicinity of Basin A. Eighty-five percent of the detections in this area were less than 7,000 µg/l. Some of the concentrations above 1,000 µg/l that are shown in the figure are in the UFS. Four of the five detections above 10,000 µg/l were reported in 1977 through 1979; these concentrations may not be comparable to concentrations reported in more recently sampled wells.

Comment 20: Page B-26, B.4.2, Diisopropylmethylphosphonate (DIMP) -- The Army states:

> Other elevated concentrations of DIMP were detected in the 0- to 100-ft depth range between the NBCS and NWBCS in Section 23. In two of the deepest wells in this area, DIMP was detected at concentrations of 21.0 and 33.0 ug/l between 102 and 106 ft below the alluvium-bedrock contact...

It appears from the maps that the referenced wells are located in Section 22; please modify the text if necessary.

Response: The deepest wells (>100 ft) with detections are in Section 22; however, the elevated DIMP concentrations in the 0 to 100 ft depth range are in adjacent Section 23. The section reference has been removed from the text to alleviate any confusion.

Comment 21: Page B-28, B.5.1, South Plants Area -- The Army states:

> Although present in virtually all wells of the South Plants area, the concentration of VHOs and VAOs in deeper wells is relatively low. Consequently, the vertical extent of contamination has been determined with reasonable confidence.

Examination of the figures and plates in this document indicate that, in several areas within South Plants with very high detections of TOA in the 0-50 ft interval below bedrock contact, it appears that no or few wells are screened at depths >50 ft (see Specific Comment 28A, B, and C). Therefore, the vertical extent of contamination has not been determined; and this statement must be deleted from the text.

Response: Please refer to responses to the State's Appendix B Comments 28A, B, C, and D which provide additional discussion concerning the extent of contamination beneath South Plants. Based on these discussions the Army concludes that the extent of contamination beneath South Plants is approximately defined and is sufficient to support the FS. The statement has been modified to reflect this conclusion.

Comment 22: Page B-32, B.5.7, Miscellaneous Areas -- The Army indicates that Denver Formation well 22002, completed to 107 feet below bedrock contact and having a 1981 DIMP detection of 21 ug/l, is not being resampled as part of the CMP. Because the Army also states that the limited sampling history may have resulted in an inaccurate assessment of contaminant distribution in this area, we request that Well 22002 be resampled as part of the VEC program. The sampling will allow determination of the vertical extent and range of concentrations migrating off-post in Section 22.

Response: The text of Section B.3.1.2 has been revised to indicate that the construction of Well 22002 was of questionable quality, and this well was recently abandoned. No samples were collected from Well 22002 after 1983. As stated in the response to the State's Appendix B Comment 2, the CMP has monitored other wells in Section 2.2.

Comment 23: Page B-34, B.6, Summary -- Please add the following RMA areas to the list at the bottom of page B-34 representing areas needing additional investigation to characterize the vertical extent of contamination (see also Specific Comment 28):

- southeast corner of Section 35;
- Hydrazine Blending and Storage Facility, and downgradient of the facility (South Plants);

- on the southern boundary, and immediately south of South Plants on the western boundary of Section 1;
- immediately south of South Plants on the eastern boundary of Section 2;
- North Plants area;
- Basin A Neck flowpath on the southern boundary of Basin C;
- Basin C area;
- Basin F area;
- Basin E area, and connection between Basins D and E.

Response: The text has been revised to include most of the areas listed in the State's comment, and to indicate that these are areas where the absolute vertical extent of contamination has not been defined. Some sampling, well installation, and testing are planned in several areas of the Denver Formation in support of the FS. Final decisions regarding investigations will be made after appropriate consultations with the organizations and State and representatives of the FS.

The HBSF has not been added to the list of areas needing additional investigation to characterize the vertical extent of contamination because detections in the VEC in this area primarily are suspect concentrations of hydrazines and a nitrosamine reported in 1986 samples and associated blanks. Subsequent sampling in 1988 and preliminary results from sampling in August 1990 and March and August 1991 indicated no hydrazines are present in the wells in this area; however, nitrosodimethylamine was detected in an UFS well (01055) in August 1990 (uncertified method) and in March and August 1991. Nitrosodimethylamine was detected in Wells 01701 and 01051, both in the UFS in August 1991 only. Based on these results, the vertical extent of contamination in this area is approximately defined. Investigations designed to evaluate if hydrazines and nitrosamines are present in groundwater will continue to be conducted in this area.

Comment 24: Figure RISR B.4-1, Vertical Extent of Contamination in the Denver Formation Along Cross-Section A1-A1' -- In cluster well 01022 and 01023, the vertical extent of contamination as defined by the Army is located between the two wells. While this is correct given the current data, it should be noted that the Certified Reporting Limits (CRLs) for DIMP in the latest sample (and duplicate) for Well 01023 (1986) are 5.7 ug/l and 10.5 ug/l, both of which are greater than the TOA detection in Well 01022. Therefore, it is possible that contamination in this area extends deeper than Well 01022, but was not detected because of the high CRLS.

Response: Comment noted.

Comment 25: Figure RISR B.4-2, Vertical Extent of Contamination in the Denver Formation Along Cross-Section B1-B1' -- This figure indicates that the depth of contamination at wells 02030 and 02031 is defined by the alluvial-bedrock contact. However, groundwater flow in this vicinity occurs in the unconfined Denver Formation, not in the alluvium (see the South Tank Farm Interim Response Action documents), and high levels of organic contaminants along this flow path are well documented. Therefore, the depth of contamination should be changed to the base of the top sand unit.

Response: The Army infers that the State is actually referring to Wells 02032 and 02033, not Wells 02030 and 02031. The Army agrees that the base of contamination should be changed to the base of the volcaniclastic unit in Wells 02032 and 02033. Cross-section B1-B1' has been revised accordingly.

Comment 26: Figure RISR B.4-2, Vertical Extent of Contamination in the Denver Formation Along Cross-Section B1-B1' -- Well 23190 had two low detections of DIMP, one in 1988 and one in 1989. The sporadic detections of DIMP are indicative of vertical extent of contamination in this area; therefore, base of contamination should be changed to Well 23190.

Response: The values in the VEC database were selected to depict current contaminant concentrations at wells. These selected values were used to depict contaminant distributions as point plots and indicate the vertical extent of contamination by the use of cross-sections. It would be inconsistent to utilize data that are in the database of excluded detections, as the State suggests.

Comment 27: Figure RISR B.4-4, Vertical Extent of Contamination in the Denver Formation Along Cross-Section D1-D1' -- Please explain why the base of contamination was placed at Well 25009 and not at Well 25010 which had higher detections of most contaminants than did the shallower well.

Response: The figure indicates that one analyte, a volatile halogenated organic (VHO) compound, was detected in samples from Well 25010. However, no organics are reported in this well in the VEC database; therefore, the organic concentration of Well 25010 has been removed from the figure. The base of contamination is placed at Well 25009 and not 25010 because of the absence of organics detections that met the criteria of this investigation for inclusion in the VEC database.

Comment 28: Figures RISR B.4-1 through RISR B.4-5 and Plates RISR B.4-1 through RISR B.4-7 -- The following are general comments regarding modifications to cross-sections A1-A1' through E1-E1', and cross-sections A-A' through Q-Q':

A. In the extreme northeastern section of South Plants and immediately downgradient of the area known as the Hydrazine Blending and Storage Facility (HBSF), eight detections of TOA in the >100-1000 ug/l range and at depths of 0-50 ft below bedrock contact were measured. See

Figure B.3-1 [sic]. An examination of figures B.3-2 [sic] through B.3-4 [sic] indicates that wells completed at depths greater than 50 ft below bedrock contact do not exist in this area (this could be verified by examination of the well location maps with depth requested in Appendix B General Comment #1[)]; therefore, the vertical extent of contamination has not been defined in the vicinity of the HBSF. This observation should be reflected on the cross-sections; however, none of the wells with detections in the >100-1000 ug/l range are included on any of the cross-sections. To indicate that the vertical extent of contamination in the northeastern section of South Plants, and the area downgradient of this section, has not been determined, please include representative well(s) from this area on cross-sections A1-A1', E1-E1', G-G', and O-O'.

Response: The detections of total organic analytes (TOAs) in the >100 to 1,000µg/l range that the State refers to are the detections of hydrazines and a nitrosamine that were reported in 1986. These detections were suspect and resampling indicated that no hydrazines or nitrosamines were present in these wells. Concentrations of the other organics were typically less than 10 µg/l. For example, Well 01036, located on cross-section G-G' shows a concentration of 112 µg/l; however, hydrazines were reported at a concentration of 103 µg/l. The only concentration detected in this area that was higher than 100 µg/l (minus the hydrazines and nitrosamines) was 145 µg/l, detected in Well 01055, which is screened in the UFS (nitrosodimethylamine has been detected in this well, at less than 10 µg/l, in 1990 [uncertified method] and 1991). Deep wells to the north and south of this location are shown on cross-sections F-F' (Well 36104) and E1-E1' (Wells 01042 and 01043). Adding additional wells to the cross-sections, as the State has requested, would not change the interpretation of the vertical extent of contamination in this area (as approximately located on cross-section A1-A1').

B. On the western side of Section 1, along the southern boundary of South Plants, Figure B.3-1 [sic] indicates that approximately 20 TOA detections in the range >10,000 ug/l and 9 detections in the range >1000-10,000 ug/l have been measured in the 0-50 ft depth range below bedrock contact; these detections include hits of $1.11*10^6$ [sic] ug/l TOA measured in wells 01555 and 01565. See pages B-11 and B-16. However, with the exception of one well on the southern boundary of South Plants located on the extreme northwestern corner of these detections, it does not appear that any wells are completed at depths greater than 50 ft below bedrock contact in this vicinity. This uncertainty should be reflected in the cross-sections. Only one well, Well 01542 with TOA = 100,300 ug/l, is included on cross-section H-H', and none of the wells are included on the cross-sections with estimated vertical extent of contamination (A1-A1' through E1-E1'). The only other wells in Section 1 included on the cross-sections are not in the vicinity of the high TOA detections, and have TOA concentrations 4-to-6 orders of magnitude lower then the high TOA wells. To indicate that the vertical extent of contamination in this area has not been defined, please include several of the high TOA wells (including 01555 or 01565) on cross-sections A1-A1' and E1-E1', and additional wells on cross-sections H-H' and N-N'.

Response: Three wells in the 50 to 100 ft depth interval are located within the area of >100,000 µg/l concentrations, Wells 01015, 01081, and 01082. Well 01082 is located adjacent to Well 01542 and has been added to cross-sections H-H'. The VEC database indicates no organics were detected in this well or in Well 01015. Well 01015 is clustered with Well 01014, which has a total organic concentration of 214,102 µg/l. Well 01081 is located where total organic concentrations approaching 1,000,000 µg/l are present in the UFS; total organics were detected in Well 01081 at a concentration of 20.90 µg/l. The base of contamination in this area is approximately defined.

C. On the eastern boundary of Section 2 immediately south of South Plants, eight detections in the >100-1000 ug/l range, three detections in the >1000-10,000 ug/l range, and one detection in the >10,000 ug/l range have been measured; all wells are screened in the 0-50 ft interval below bedrock contact. With the exception of wells 02032/33 [sic], located at the downgradient extent of the identified area, it does not appear that wells completed to depths >50 ft below bedrock contact are present. The vertical extent of contamination has therefore not been determined in this area. To indicate this, please include several of the high TOA wells (including the well with TOA in the range >10,000 ug/l) on cross-sections B1-B1', H-H', and M-M'.

Response: Total organic concentrations in UFS wells located within 100 ft of Wells 02032 and 02033 were approximately 33,000 µg/l in Well 02502 and approximately 13,000 µg/l in Well 02503. These concentrations are in the highest range of concentrations detected in this area; therefore, it is not appropriate to discount the depth of contamination as defined by Wells 02032 and 02033. The well that the State specifically request to be added to the cross-sections (Well 02584) is screened in the UFS and has a total organic concentration of 12,802 µg/l in the VEC database. Because the primary purpose of the cross-sections is to show the vertical extent of contamination, additional UFS well have not been added to the cross-sections.

D. Include the well in the eastern part of Section 36 with a DIMP detection >1000 ug/l and TOA in the range >10,000 ug/l on cross-section A1-A1' and O-O' (well identification may be 36184, but we cannot tell without maps requested in General Comment 8). Data from this well are more representative of Denver Formation contamination downgradient of Anomaly C than are data from Well 36154 which was not located immediately downgradient of the anomaly. See Army responses to State Specific Comments 36 and 38, and EPA Specific Comments 68 and 70 on Central Study Area Report; Final Implementation Document for the Interim Response Action at the Army Complex Disposal Trenches, Summer, 1990.

Response: The State is correctly referring to Well 36184. This well is completed in the UFS and occurs in a cluster with Well 36153, which is screened to a depth of 110 ft below the alluvium-bedrock contact. Total organics in Well 36153 are reported in the VEC database at 5 µg/l. Cross-section A1-A1' currently shown Well 36154, which is screened to a depth of 128.8 ft below the alluvium-bedrock contact, with a total organic concentration of 28.8 µg/l. Because the Army is utilizing a conservative approach to showing the vertical extent of contamination, it is appropriate to use the well with the highest concentration in the deepest screened depth interval. In this case, Well 36154 meets this criteria.

E. None of the cross-sections include data from the 0-50 ft depth wells located within Basin A (two detections in the range >100-1000 ug/l, five detections in the range >1000-10,000 ug/l, and four detections in the range >10,000 ug/l), or data from the western perimeter of the basin with high TOA detections. The cross-sections should reflect not only positive detections, but also the lack of data at depth. Therefore, please include data from two Basin A wells, one well in the north and one well in the south of the basin, with detections in the range >10,000 ug/l in the 0-50 ft depth range on cross-section N-N', and the cross-section requested in General Comment 8. Additionally, the well located on the western boundary of Basin A with TOA in the range >100-1000 ug/l at the 50-100 ft and 100-150 ft depth intervals should also be included on these two cross-sections.

Response: Wells 36178 and 36179, screened to depths of 53.7 and 117.7 ft, respectively, below the alluvium-bedrock contact and located in the northwestern area of Basin A, have been added to cross-section N-N'. Wells 36170 and 36171, screened to depths of 85.1 and 146.6 ft, respectively, below the alluvium-bedrock contact and located in the southwestern area of Basin A, have been added to cross-section F-F'. Well 36171 is the well specifically requested by the State. No shallow wells (wells completed in the UFS) have been added in this area because the primary purpose of the cross-sections is to illustrate the depth of contamination, and the distribution of shallow detections is shown on the contaminant distribution maps.

F. It does not appear that wells completed >50 ft below bedrock contact are present beneath the North Plants facility in Section 25, and that therefore the vertical extent of contamination has not been defined in this area. Because this is not evident from reviewing the cross-sections, please include the well with TOA in the range >1000-10,000 ug/l on cross-sections D1-D1' and C-C1'.

Response: It is correct that there are no wells completed in the >50 ft depth interval beneath North Plants, and the vertical extent of contamination in this area have not been defined. However, no wells have been added to the cross-sections, as the interpretation of the inferred depth of contamination in this area, as shown on cross-section D1-D1' between cluster Wells 25008, 25009, and 25010 and cluster Wells 25012, 25013, and 25015 is dashed approximately 115 ft below the alluvium-bedrock contact.

G. The vertical extent of contamination has not been defined, and is currently not represented on cross-sections for the following areas in Section 26 below the designated depths:

- beneath Basin C at depths >50 - below bedrock contact: include Well 26053 (>10,000 ug/l TOA in the 0-50 ft depth interval) on cross-section B1-B1' or D1-D1', and D-D' or L-L'.
- beneath Basin F: no data at any depth interval are available; therefore, well(s) to the north and south (Wells 26128/129 [sic]) of the basin should be included on cross-section B1-B1' and the area beneath Basin F should be represented by a dashed and question-marked line.
- eastern perimeter of Basin F in the 0-50 feet interval: at depths >50 ft below bedrock contact there were eight TOA detections in the range >100-1000 ug/l, and one TOA detection in the range >1000-10,000 ug/l. The five wells selected to represent contamination in this area and presented on Figure B1-B1' [sic] have either no detections of organic contaminants (Wells 26138/139 [sic]) or low detections of organic contaminants (Wells 26140/141/142 [sic]) and therefore are not representative of the high level of TOA measured on the eastern boundary of the basin, and may not properly define the vertical extent of contamination. Please replace wells 26138/139 [sic] with representative 0-50 ft wells with TOA in the range of >100-1000 ug/l.
- beneath Basin E at depths >50 ft below bedrock contact: replace Well 26077 on cross-section D-D' with Well 26061 (TOA in the range of >100-1000 ug/l). And,
- beneath the connection between Basins D and E at depths >100 ft below bedrock contact: please include Well 26069 (TOA in the range >1000-10,000 ug/l) in the 50-100-interval on cross-section L-L'.

Response: The Army agrees that the vertical extent of contamination is poorly defined in areas of Section 26. This was noted in the Draft Final RISR, Appendix B (Page B-34, paragraph 3, line 7) and is shown on cross-sections B1-B1' and D1-D1' by a dashed, question-marked line. In addition, one of the wells the State has requested be added was specifically mentioned in the text (Page B-18, Section B.3.2.1, paragraph 2) and identified on Table RISR B.5-1 as a well with an inconclusive sampling chronology.

It is not evident that any of the changes the State requested to these cross-sections would alter the interpretation that the total depth of contamination cannot be inferred in areas of Section 26. Wells included on the cross-sections are the deepest wells in the area. All of the wells the State requested be added are screened in shallower depth intervals and do not provide additional information on the inferred depth of contamination.

Comment 29: ABC Data Base - The State's review of Category B and C wells in the ABC Data Base [sic] indicate that the following Category B wells should be included in the VEC Data Base [sic] for the respective analytes:

Data from Category B Exclusion that should be retained in the VEC Database.

Well	Data [sic]	Analyte	Result µg/l
01516	90002	CPMSO2	3.84
01517	89361	DLDRN	0.44
02005	88040	DBCP	1.3
02544	79191	DIMP	24.0
02545	89011	DIMP	0.65
02573	83111	DIMP	59.8
26074	79003	DIMP	6.52
	79037	DIMP	13.7
26130	80178	CPMSO	457
26136	79155	DIMP	3.4
26137	79107	DIMP	52.2
	79155	DIMP	2.6
26138	79227	DBCP	0.34
26139	79227	DBCP	0.32
26146	89216	DIMP	12.1
26148	88229	12DCLE	920
26150	89045	DIMP	0.445
	89124	DIMP	0.57

Data from Category B Exclusion that should be retained in the VEC Database.

26155	88078	AS	4.16
	88327	AS	2.41
26157	88209	12DCLE	620
	89044	12DCLE	930
*03003	87121	MG	8120
*22031	84339	ALDRN	1.49

* These data are in both the Category B exclusion and VEC database.

Based on our interpretation of Category B criteria, and our evaluation of the temporal and areal distribution of the detections in question, the wells/analytes should not have been excluded from the VEC data base [sic]. Please make the requested modifications, and any resultant modifications necessary to the cross-sections.

Response: Based upon the Army's review of the data the State requested be added to the VEC database, the Army has added the data for Wells 02005 (sample date 88011), 02545, 26074 (13.7 µg/l), 26138 (0.32 µg/l), 26139 (0.34 µg/l), and 26155 (2.41 µg/l), with the corrections identified in parentheses. Duplicate entries in the Category B exclusion and VEC database for Wells 03003 and 22031 have been removed from the VEC database and are retained in the HITSABC file because the concentrations were anomalous when compared to adjacent wells and to the chronological sequence. The figures have been revised accordingly. Data identified by the State for Wells 01516 and 01517 were not available when the VEC was established and, therefore, have not been added to the VEC database. The Army concludes that the data for the remaining wells should be excluded from the VEC database, based on the Army's interpretation of the criteria for exclusion, as outlined in Section B.2.3, Data Evaluation Criteria.

Appendix C Interim Response Actions

Comment 1: Page C-2, Table RISR C.1-1, Interim Response Actions at the Rocky Mountain Arsenal -- Please make the following modification to Objective 1, "Eliminate much of the potential for any future exposure from contaminated alluvial groundwater...".

Response: The requested modification has been made.

Comment 2: Page C-26, C.2.1, Description -- Please make the following modification to the first sentence, "The final alternative selected for the IRA will incorporate groundwater extraction and treatment, and..."

Response: The requested modification has been made.

Comment 3: Page C-26, C.2.1, Description -- Please make the following modification to the final sentence of the first paragraph, "The treated water will be returned to the alluvium by using recharge wells and trenches...".

Response: The requested modification has been made.

Comment 4: Page C-26, C.2.2, Impact -- Please make the following modification to the first sentence, "Implementation of this IRA will affect alluvial groundwater north of RMA and upgradient of the canals."

Response: The requested modification has been made.

Comment 5: Page C-27, C.3.1, Description -- Please make the following modification to the final sentence, "These recharge trenches increase the system's ability to reinject treated water and result in a reverse hydraulic gradient along portions of the slurry wall."

An evaluation of the impact of the recharge trenches on the downgradient potentiometric surface in the alluvial aquifer is included in The *Comprehensive Monitoring Program Annual Ground Water Report for 1990, Draft Report*, February 1991, which states:

> The potentiometric head was higher south of the barrier than north of the barrier along approximately two-thirds of the NBCS [North Boundary Containment System] ... In the summer of 1990, a reverse hydraulic gradient existed along most of the western half of the NBCS [but not the eastern half] as indicated by the shaded area on Figure 5.1-2 [emphasis added]. (page 64).

Response: The requested modification has been made.

Comment 6: Page C-37, C.9.1, (Closure of the Hydrazine Facility) Description -- The description of this IRA is incorrect. It reflects the previously selected alternative and timetable, both of which have been overtaken by events. Although the Army has not finalized its Proposed Amendment to the Decision Document for the Hydrazine Blending and Storage Facility, it has proposed to treat the wastewater in the Basin F Submerged Quench Incinerator. The Status paragraph must also be re-written to accord with the facts.

Response: The description of this IRA has been revised and updated.

Comment 7: Page C-38, C.10.3, Status (of Fugitive Dust Control) -- The text states that the "[a]ssessment of future (dust suppressant) applications will be on a case-by-case basis until the final Record of Decision." It is unclear what constitutes a case-by-case basis. As presented in the Implementation Document for this IRA, the language used to describe the Army's intentions for conducting future dust suppressant applications is vague and fails to demonstrate a commitment by the Army to adequately inspect and evaluate the area to determine the need for additional applications. In State comments previously submitted to the Army, the State addressed this issue (see State Comments on the Implementation Document for the Application of Dust Suppressant at Basin A (Section 36) of the Rocky Mountain Arsenal, May 10, 1991).

Response: Comment noted. Additional information regarding this and other IRAs may be obtained at the JARDF.

Comment 8: Page C-42, C.13.1, Description -- Please make the following modification to the final sentence, "The preferred IRA alternative is *in situ* vitrification (ISV), installation of a temporary subsurface barrier wall...".

Response: The requested modification has been made.

Appendix D Other Special Investigations

SURFICIAL SOILS INVESTIGATION

Comment 1: Page D1-8, D1.4.1, Organic Analytes -- The Army states that 270 surficial soil samples were analyzed for OCPs; however, only 266 sample locations are shown on Figure RISR D1.4-1. Please correct this discrepancy.

Response: Two hundred and sixty-seven sample locations were shown on Figure RISR D1.4-1 of the Draft Final RISR. The figure has been revised to show 270 sample locations.

Comment 2: Page D1-9, Figure RISR D1.4-1, Distribution of Total Organics in Surficial Soils (0-2 in.) -- The placement and orientation of the contours indicate that organic surficial soil contaminants have been transported off-post.

Response: Comment noted.

Comment 3: Page D1-13, D1.5, Interpretations and Conclusions -- Average wind speed of 9 mph at RMA should be clarified to read average annual wind speed of 9 mph. The last sentence should be changed to read "could account for most eolian transport of contaminated sediments."

Response: The requested modifications have been made.

Comment 4: Page D1-17 to D1-31, Table RISR D1.4-1b Army Analytical Results for the Surficial Soils Investigation at RMA -- Given the numerous NA (not analyzed) entries on this table, additional notation should be provided for NA entries to explain the reasons why no analysis was conducted.

Response: Confirmation GC/MS sampling was performed on a subset of the samples collected (shown under the label "Semivolatile Organics" on the tables referenced) in order to verify analyte identifications. Not all samples were subject to the confirmation GC/MS analyses.

Comment 5: Page D1-33 to D1-41, Table RISR D1.4-2 Shell Analytical Results for the Surficial Soils Investigation at RMA -- Given the numerous NA (not analyzed) entries on this table, additional notation should be provided for NA entries to explain the reasons why no analysis was conducted.

Response: Please see response to the State's Appendix D Comment 4 above.

GROUND DISTURBANCE INVESTIGATION

Comment 6: The 63 sites not included in the requested ground disturbance sampling program were excluded based on the following: 1) They had been previously investigated; 2) They were no longer discernible in the field; 3) They are located in an area that corresponded to a site as shown on the June 1989 preliminary map "Area of Known or Inferred Occurrence of Analytes Above Background Levels at the Rocky Mountain Arsenal"; or 4) They were found to be the result of non-RMA activities such as farming, containment system construction, or natural drainage depressions. Please provide greater detail regarding non-RMA containment system construction.

Response: There has been no non-RMA containment system construction. The sentence has been clarified.

Comment 7: In addition to the map and chemical analyses already provided in Appendix D, the State requests the following:

a) A map showing the approximate location of pre-existing non-source area borings. These borings could be included on the current Appendix D disturbance area map, but must be clearly designated as pre-existing non-source area borings;

b) A summary of the chemical data for all pre-existing borings referred to in the text (in addition to the data included from the 37 sampled ground disturbance areas);

c) Documentation of known or speculated source or cause of each of the 100 ground disturbances originally investigated.

Note that the State has yet to receive an Army response to these items previously requested in a March 14, 1990 letter from Jeff Edson to Donald Campbell.

Response: **a)** The locations of all nonsource area borings are plotted in Figure RISR A3.1-13. In addition, the Final Ground Disturbance Investigation Data Summary (EBASCO, 1990/RIC 90247R01) contains a map showing nonsource area borings that are located within ground disturbance areas identified by the State in its original proposal for a ground disturbance investigation.

b) Chemical data for all nonsource area borings are readily available to the State and other parties in the CARs, SARs, and in the RMA database. In addition, nonsource area borings are included in analyte distribution maps in Appendix A3 of the RISR.

c) An assessment of each of the original 100 proposed locations was included in the Final Ground Disturbance Investigation Data Summary (EBASCO, 1990/RIC 90247R01). In cases where the origins of ground disturbances were known, these origins have been noted. In cases where the origins of ground disturbances are unknown, it is inappropriate to speculate. In general, if historic information suggesting the possibility of contamination were available about disturbed areas, they would have been designated as such in the original Rocky Mountain Arsenal Contamination Control Program Management Team (RMACCPMT) "Tricolor Map" and investigated as potential sites. Such historical information does not exist, and therefore these areas were investigated as nonsource areas, and in most cases, sampling supported this designation. Speculation about the origins of ground disturbances whose origins are unknown and which have been shown to be uncontaminated serves no apparent purpose. By reference, the State's letter of March 14, 1990, from Jeff Edson to Don Campbell is responded to herewith.

Comment 8: The selection criteria used in locating the borings within the 37 disturbance areas are not provided; additionally, the location of several of the borings seems inappropriate. The majority of borings were completed in close proximity to the disturbance area centers. However, contrary to this trend, boring GD19026 is located in the SW corner of a disturbance area. In addition, the number of borings taken within a disturbance area seems to be independent of disturbance area size and shape. As an example, boring GD25019 is located near the top of a narrow disturbance area which extends over the entire length of section 25. Sampling near the top of this disturbance area may not give an accurate indication of contamination in the lower portion of the disturbance area almost a mile away. More borings are required to adequately characterize the area. Borings GD04007/GD04008 [sic], GD04006 and GD19026 also do not adequately characterize the disturbance areas in which they are located; therefore, further sampling is requested. It is possible that RI borings combined with GD borings adequately characterize the areas; if so, data from the previous RI borings should be summarized and incorporated into Appendix D.

Response: The Army believes the locations of all borings are appropriate. Boring GD 19026 is indeed located in the southwest corner of the disturbance area as it is shown in Figure RISR D2.1-1. However, in its original proposal for a ground disturbance investigation, the State identified this ground disturbance as "smaller bermed area SW of firing range" (November 28, 1988 letter from Jeff Edson to Don Campbell). Although the disturbance area is depicted on the map as including all of the firing range and areas to the north and east, boring GD 19026 is located southwest of the firing range in the area originally identified by the State as the ground disturbance to be investigated. The ground disturbance investigated by Bore GD25019 appeared to be a road along a telephone line. The area was included in the borrow area used during the Basin F IRA; GD25019 was located near the Sand Creek Lateral in a part of the ground disturbance not affected by the borrow operations. Likewise, Bores GD04007 and 04008 were placed to investigate a former parking lot or graded surface feature and were located in unvegetated areas, and 04006 was placed to investigate a ditch feature in the lowest point possible. Field personnel located bores at each disturbance so as to maximize detections of potential contaminants.

Comment 9: The majority of the 63 excluded sites were eliminated from the sampling program based on the assumption that previously completed borings had properly characterized the respective disturbance areas. It does appear that these borings fall within the specified disturbance areas. However, because the borings were completed as part of a grid and not specifically to investigate ground disturbances, it is unlikely that the number and locations of such borings are ideally suited to investigate potential contamination in these areas. If upon review of the data requested in Appendix B [sic] 7.a and 7.b, the State finds that a ground disturbance has not been properly characterized, additional sampling for that ground disturbance area(s) will be requested.

Response: According to RISR Section A2.1.1.1, Geotechnical Strategy: "The nonsource area sampling grid was adjusted based on field inspection to ensure that samples were collected from areas most likely to contain or concentrate contaminants (e.g. depressions, scarred areas, and similar features)." It is not clear why the State considers a boring within a ground disturbance area that happens to be part of such a sampling grid to be less valid than a similar boring that is similarly located within a ground disturbance area that happens to be part of such a sampling program requested by the State. The Final Ground Disturbance Investigation Data Summary (EBASCO, 1990/RIC 90247R01) contains a map showing the 63 excluded ground disturbances and the RI borings located within those ground disturbances, as well as the ground disturbances that were included in the investigation and the borings located within them. A review of this map indicates that there is at least one, and in some cases numerous borings located within most of the 63 excluded areas. Other excluded areas were determined to be SAR sites or to be related to containment system construction. Analytical data from nonsource area borings within the excluded areas typically did not show elevated concentrations of metals or organic analytes. Additional sampling is therefore unwarranted.

Comment 10: ICP metal detections above the IR (indicator range, the natural or background occurrence) were reported in 10 of the ground disturbance samples not rejected by QA/QC. For the 10 detections found (9 of which are shown) additional information from nearby soils/sewer RI borings and from Contamination Assessment Reports (CARs) and Study Area Reports (SARs) are provided. However, the exact location of these borings in relation to the GD borings is not shown on the maps provided. This makes it difficult to determine their relevance. It is also noted that GD25019 (mentioned earlier as a lone boring which was inadequate to characterize the mile-long disturbance area) is among the 10 detections above the IR. This again suggests the need for more sampling locations within this disturbance area.

Response: Please see the responses to the State's Appendix D Comments 7 and 8 above. Locations and chemical data for all nonsource area borings are readily available to the State and other parties in the CARs, SARs and in the IRDMIS database for RMA. In addition, these data are summarized and locations are plotted on numerous maps in Appendix A3.

Appendix E Contaminant Fate and Transport

Comment 1: Page E-77, E.3.2.9, Organonitrogen Compounds -- The Army States:

> Although the RISR [sic] sampling program conducted analyses for the hydrazines and nitrosamines in the vicinity of the hydrazine blending facility in the South Plants Study Area, they were not detected.

This statement is misleading. Please see Specific Comment #4 and modify the text accordingly.

Response: The text has been modified to more accurately reflect the RI program within the HBSF. Additional assessment work at the HBSF is being conducted under the Closure of the Hydrazine Facility IRA, and additional soil sampling for hydrazines or nitrosamines will be conducted under the Feasibility Study if a USATHAMA-certified analytical method is available.

Comment 2: Page E-108, E.4.3, Saturated Zone Processes -- The Army states:

> ...the confined groundwater system in the Denver Formation shows little or no evidence of lateral contaminant transport.

and

> The potential for lateral contaminant migration in confined water-bearing zones of the Denver Formation is considered minimal.

To our knowledge, the Army has never conducted an investigation of Denver Formation contamination with the purpose of evaluating lateral transport within the formation. Although the sand layers within the Denver Formation may be discontinuous across the Arsenal, they are laterally continuous in local areas and interfinger with other sand lenses. This interconnection of sands and the hydraulic gradient present in the Denver Formation may result in lateral migration of contaminants within the aquifer. Please delete these statements from the text.

Response: The Army has conducted hydraulic measurements of Denver Formation confined water bearing zones. Consideration of these data, in conjunction with the hydraulic gradient present, indicate that ground water flow rates are significantly less than in the UFS alluvium. The rate of lateral migration within the CFS is also substantially less than in the UFS. As a result, the potential for lateral contaminant migration in the confined Denver Formation is considered substantially less than in the alluvium of the UFS. Both passages have been modified to clarify this understanding.

Comment 3: Page E-111, R.5.1, [Sic] Volatile Halogenated Organics -- The Army states:

> In addition to on-post sources, a major influx of trichloroethylene enters the unconfined aquifer from the off-post sources south of RMA.

Please clarify in the text that the off-post trichloroethylene source is immediately up-gradient of Section 9 only. Because Section 9 is located in the extreme southwestern corner of the Arsenal, the source does not impact the majority of groundwater entering the Arsenal from the south.

Response: The Army believes that off-post sources located to the south result in water quality impacts to groundwater upgradient of RMA. These impacts are reflected in VHO contaminants found in the Western Study Area and a reference to this study area has been added to the sentence.

Comment 4: Page E-128, E.5.9, Organonitrogen Compounds -- The Army States [sic]:

> None of the ONCs on the target analyte list were detected in soil, water, or air at the RMA during the RI program.

This statement is misleading. Please see Specific Comment 4, and modify the text accordingly.

Response: The text has been modified to reflect the limited analysis of hydrazines during the RI program.

Appendix F3

Responses to Shell Oil Company's Comments on the Draft Final Remedial Investigation Summary Report, Version 2.3

Remedial Investigation Summary Report

Shell Oil Company

c/o Holme Roberts & Owen
Suite 4100
1700 Lincoln
Denver, CO 80203

July 1, 1991

Mr. Kevin T. Blose
Office of the Program Manager
Rocky Mountain Arsenal, Building 111
ATTN: AMXRM-E
Commerce City, CO 80022-2180

Re: Draft Final Remedial Investigation Summary Report

Dear Kevin:

Enclosed please find our comments on the Draft Final Remedial Investigation Summary Report.

If you have any questions, please contact Roberta Widdicombe with MK-Environmental Services at (303) 860-8621.

Sincerely,

George Roe
Manager, Technical
Denver Site Project

GR/jy

Enc.

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SHELL'S COMMENTS ON THE DRAFT FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
JULY 1991

General Comments:

Comment 1: This report provides a reasonable summary of a tremendously large volume of hydrogeologic and water quality data. However, because of its generality, inaccurate statistical calculations, and non-site specific information on fate and transport, it may prove to be of limited value to FS or risk managers. As such, the report should emphasize that FS and EA evaluations and decisions should be based on specific data sets, not on values contained within this summary report.

Response: While potentially useful to the FS and EA, the RISR is not intended to be the final source of information on the RI for these other programs, and the FS and EA evaluations and decisions will not be based on the data summaries as presented in the RISR. The RISR is specifically identified as a summary presentation of the information developed during the RI program.

Comment 2: Although Appendix E is titled "Contaminant Fate and Transport," there is essentially no discussion of the fate of contaminants. If there is to be such an Appendix at all, it needs to be (a) less academic, and focused on RMA-specific data, and (b) more appropriately balanced to include contaminant fate data. The latter is particularly important for RMA, where several years will pass before final remediation decisions are made.

Response: Appendix E is included in the RISR to provide a discussion of contaminant fate and transport which may be utilized as a reference for the RISR, as well as for the individual SARs, media reports, and FS documents. Rather than summarize the media- or study area-specific fate and transport information available in the earlier RI documents, this appendix includes sections containing detailed information concerning physical and chemical properties, individual contaminant behavior, environmental fate and transport processes, and contaminant migration pathways. Discussions in each of these sections concentrate on data specific to RMA. Furthermore, it is well-recognized that the properties and processes discussed in the initial section of the appendix, and used throughout the remainder of the appendix, are essential to understanding and determining both the fate and transport of contaminants in the environment.

Comment 3: Since a significant amount of additional air quality data have been collected under the CMP, it would be beneficial to include these data in this summary report. Information regarding OTSP and temporal changes in air quality between 1988 and 1990 would be particularly useful. Additionally, we recommend stating in the report that high-frequency (i.e., every six days) sampling of VOC was conducted for the 1991 CMP and will enhance the knowledge of organic compounds in air on the RMA, for future decision-making.

Response: As noted in responses to other organization comments, the CMP is not a subject of the RISR. Additional references have been added to the text (for example, p. A2-82) to aprise the reader of the CMP activities. All pertinent data will be considered in future decision making.

Comment 4: The discussions of biota in this draft final summary report contain a number of misleading statements regarding the ecological behavior and toxicological significance of RMA contaminants of concern. Since the function of the RI is to document the nature and extent of contamination only, these conclusions are inappropriate and should be deleted.

Additionally, many of the statements regarding negative effects on higher trophic levels are inconsistent with data collected under the Biota CMP, which generally show higher trophic levels to be free of observable effects.

Response: No specific examples are presented in this comment. Ecological and toxicological considerations were factors in the identification and selection of COCs for the Biota RI. The discussions of biota included in the RISR are an accurate summary of the findings of the Biota RI. As previously noted, the CMP is not a subject of the RISR. The text will not be revised.

Specific Comments

Comment 1: Page 1-18 through 1-33, Section 1.3. Throughout this section there are incorrect statements about the date when Shell Chemical Company became a lessee at RMA. Shell Chemical Company acquired the stock of Julius Hyman & Company in 1952, and Hyman continued in existence as the lessor until 1954, when it was merged into Shell Chemical Company. The first lease document executed by Shell instead of Hyman was Supplemental Agreement No. 13, dated effective July 6, 1955.

Response: References to the date when Shell became a lessee of facilities at RMA have been corrected throughout this section.

Comment 2: Page 1-1, first paragraph, second sentence. Agricultural chemicals were also produced at RMA.

Response: The sentence has been modified to state that agricultural chemicals were produced at RMA.

Comment 3: Pages 1-20 through 1-31. The document should indicate that the Army purchased and applied a variety of pesticides, including DDT. Also, it should indicate that wastes from the painting of munitions, the motor pool, munitions testing, and laundry were discharged to surface soils.

Response: Additional passages have been added to the text (Sections 1.3.1 and 1.3.3) regarding Army pesticide use and waste disposal.

Comment 4: Page 1-26, second paragraph, third sentence. This sentence could be misinterpreted to mean that all the listed chemicals were detected in the early 1950s. Because of the importance of the exact chronology of who knew what when about South Lakes contamination, we suggest either deleting the sentence or providing sufficient details to avoid confusion about this issue.

Response: The sentence has been modified to clarify who knew what when.

Comment 5: Page 1-27, second paragraph. This paragraph should be incorporated into the third paragraph on page 1-29. Its inclusion in Section 1.3.2 incorrectly implies that the off-post crop damage was a result of Hyman's operations.

Response: The paragraph has been moved to Section 1.3.3.

Comment 6: Page 1-28. The aqueous wastes were also neutralized with calcium hydroxide (lime) and calcium hypochlorite.

Response: The sentence has been revised to indicate that wastes were also neutralized with calcium hydroxide and calcium hypochlorite.

Comment 7: Page 1-28, third paragraph, second sentence. The Section 36 Trenches were used between 1952 and 1965, as cited in Appendix C, Page C-43, not ". . . 1952 through 1955."

Response: The typographical error has been corrected.

Comment 8: Page 1-30, third paragraph, fifth sentence. This sentence is incorrect. What in fact happened is that, at the Army's direction, Hyman and Shell delivered liquid wastes to the Army at the boundary of the leased premises and the Army conducted those wastes in the Army's chemical sewer to the basins.

Response: The text has been modified to indicate that Shell discharged its aqueous chemical wastes into the chemical sewers system connecting to Basin F.

Comment 9: Page 1-32, second paragraph. To reflect the actual language of the Cease and Desist Orders, change "the Army and Shell" to "the Army and/or Shell" in the first line; and change "Shell and RMA" to "Shell and/or RMA" in the third line.

Response: The requested modifications to the text have been made.

Comment 10: Page 2-11, first paragraph, first sentence. The distribution of contaminants in soils is typically irregular because of the heterogeneous nature of the soil matrix. Volume estimates based on the assumption of uniform contaminant distribution (i.e., simply calculating the volume of an arbitrarily defined cube at each site) has little reliability and should be qualified in the text.

Response: A statement emphasizing the heterogenous nature of the soil matrix and its effect on volume estimates has been added to the text.

Comment 11: Page 2-14, third paragraph. Please include in the discussion that waste pharmaceuticals from Fitzsimmons Army Hospital were buried at RMA.

Response: The text in Section 1.3.3, Waste Disposal Operations, has been revised to note that medical materials from off-post and overseas may have been disposed at RMA. A more detailed description of these activities is presented in the Final Phase I CAR, Site 36-17: Complex Disposal Activity, Version 3.2, January 1988, in Appendix 37-17D, pp. 25-26 ESE, 1988/RIC 88013R05. The information presented there cannot be substantiated.

Comment 12: Page 2-19, last paragraph. The chemical sewers are also significant because of the potential for increased rates of contaminant migration in the backfill along the lines. This mode of transport is illustrated by symmetrical concentrations of contaminants adjacent to the sewer lines between the South Plants and Basin A and to the east of Basins C and F.

Response: The possibility of enhanced groundwater flow along sewer trenches and backfilled trenches has been added to the text.

Comment 13: Page 2-29, first paragraph, fifth sentence. Other factors that affect transport include biodegradability, the composition of the aquifer, complexation (for metals and organics), flow velocity, and the chemistry of the compound (i.e., dissociation constants, etc).

Response: Biodegradability, aquifer composition, complexation, flow velocity, and analyte chemistry have been added to the list of factors that affect analyte transport.

Comment 14: Page 2-29, first paragraph, last sentence. "Some aquifer sediments may act as continuing, slow release sources." This interpretation was not discussed in the SARs and is at odds with typically very low TOC. Please provide supporting data.

Response: This sentence has been deleted.

Comment 15: Page 2-29, second paragraph. Basin F should be included in this listing of sources that have had "greatest contaminant releases to the unconfined flow system".

Response: Reference to former Basin F has been included in the text.

Comment 16: Page 2-32, first paragraph, last sentence. Tissue concentrations of chemicals, even lipophilic ones, do not always increase along food chains (e.g., Moriarty and Walker, 1987). Tissue concentrations of chemicals depend upon both the nature of the chemicals and the physiology and biochemistry of the species concerned. Please modify the statement to reflect this fact.

Response: The text has been modified to clarify that OCPs, which are known to bioaccumulate and biomagnify, are given as an example of the type of contaminants that are of concern in food webs.

Comment 17: Page 2-32, second paragraph, first sentence. Plants were not cleaned prior to analysis. Therefore, measured contaminant levels cannot be attributed entirely to contaminants present in plant tissues, where phytotoxic effects would be exerted. The unknown effect of contaminants adhering to plants on the analytical results complicates any discussion of phytotoxicity or bioaccumulation.

Response: The sentence is correct as stated. It does not imply that arsenic levels did or should have resulted in phytotoxic effects.

Comment 18: Page 2-32, second paragraph. Arsenic does not tend to bioaccumulate. Moreover, the statement that OCPs "are known to bioaccumulate and produce effects higher in food chains" is overly simplistic.

Response: As stated in Section 5.2.2.1 and 5.2.2.7 of the Biota RI report, arsenic does bioaccumulate, although only to a limited degree. The text on page 2-32 of the RISR has been modified to emphasize OCP bioaccumulation.

Comment 19: Page 2-32, third paragraph, second sentence. The basis and significance of the statement, "organochlorine pesticides at levels that could prove hazardous to higher-trophic-level species were detected in invertebrates sampled at contamination sites," are difficult to evaluate. If invertebrate tissue concentrations are being compared with criteria for "higher-trophic-level species," the statement is inappropriate and invalid. If the inference is that ecological processes make tissue concentrations measured in invertebrates a threat to higher trophic levels, this statement should not be included since RMA biota data appear to indicate that no threat exists to higher trophic levels.

Response: The sentence is correct as stated. In the context of the pathways analysis, elevated levels of contaminants in this trophic level could prove hazardous to higher trophic level species. No assertion was made that this was shown to be the case at RMA, but insufficient data were available at the time the Biota RI was prepared to rule out this possibility.

Comment 20: Page 2-32, third paragraph, fourth sentence. What is the significance of the statement "mercury concentrations exceeding certified reporting limits were also detected in earthworms collected in South Plants"? Certified reporting limits are simply the quantitation limits associated with the selected analytical method; the quoted language simply means that mercury was also detected in earthworms collected in the South Plants. Simple detections are irrelevant to toxicological considerations.

Response: The text has been revised to indicate that mercury was also detected in earthworms collected in South Plants.

Comment 21: Page 2-32, fourth paragraph, first sentence. The basis and significance of the statement, "Black-tailed prairie dog populations were not reduced as a result of RMA contamination, but organochlorine pesticides were detected in some prairie dog samples . . . at levels that could be hazardous to . . . predators," are difficult to evaluate. Achievement of levels of contaminants that "could be hazardous to . . . predators" depends on complex interactions among ecological parameters such as dietary fraction, consumption rates, seasonality and physiological status. RMA predator data indicate that no hazard is present for predators. Thus, the statement is not only speculative but at odds with the data.

Response: The statement is neither speculative nor is it at odds with the data. The context of this statement was the RMA food web leading to bald eagles in which most of the diet of wintering eagles was shown to be prairie dogs (Section 5.2 of the Biota RI). If the prey of an individual eagle came from an area in which prairie dogs were contaminated at the highest levels detected in the sampling program, these prairie dogs could be hazardous to the eagle predators. Available data on the foraging ranges of individual bald eagles at RMA could not rule out this possibility. The only chemical analyses performed on bald eagles at RMA were of blood, and these results could not confirm that individual eagles were not exposed to contaminants via the prairie dog pathway at RMA. The Army is aware that complex interactions among ecological parameters are involved.

Comment 22: Page 2-33, second paragraph, first sentence. This is an incomplete, misleading, and erroneous evaluation of existing information. Neither 1986 nor 1988 data revealed statistically detectable reproductive differences among kestrel populations on- and off-post [sic]. The fact that the average number of fledglings per nest was below maintenance levels suggests a regional rather than RMA-induced tendency.

Response: The words "American kestrel and" have been deleted from this sentence.

Comment 23: Page 2-34, first paragraph, first sentence. The proposed "correlation" discussed here cannot be supported without considerable documentation. Is there correlation between soil and tissue levels or just between soil levels and detectibility in tissues? What correlation analyses were used? Curiously, of all possible correlations between abiotic media and biota, the only one of significance was between soil and terrestrial carnivores. By their size and range, these animals would be least expected to show detailed spatial relationships to soil concentrations. This "correlation" might well prove to be spurious if rigorously examined.

Response: The text has been modified to clarify the meaning of these statements.

Appendix A Specific Comments

Comment 24: Page A1-2, Climate. Please include a frequency distribution of the number of "high-event" days per year for volatile and semivolatile organic compounds and potential windblown dust events.

Response: A total of six high event days for VOCs and SVOCs were selected based on threshold criteria. A total of twelve high event days for metals and particulates were selected for analysis. The frequency and thresholds were based on a judgement of on-site conditions.

Comment 25: Page A1-4, first paragraph. Modifications to all three boundary systems have recently been or are currently being made under the IRA program and should be mentioned here.

The ICS was completed in December of 1981, not 1982. Also, the NBCS includes injection or recharge trenches in addition to injection wells.

Response: Recent or pending IRA activities include installation of recharge trenches at the NBCS; extension of the slurry wall and installation of extraction, injection, and monitoring wells at the Northwest Boundary Containment System (NWBCS); and, at the Irondale Containment (ICS), installation of extraction, injection, and monitoring wells and improvements to the treatment facilities to allow for increased flow to the ICS. A discussion of these activities has been added to the paragraph. In addition, the ICS completion data has been changed to December 1981, and the presence of recharge trenches at the NBCS has been incorporated in the text.

Comment 26: Page A1-7, first paragraph, last sentence. The role of paleochannels in contaminant migration is over-emphasized. The paleochannels influence groundwater flow and contaminant migration but do not necessarily control it. For example, the DBCP plume from the railyard crosscuts the deepest paleochannel on the RMA.

Response: The text has been modified to state that paleochannels influence contaminant migration.

Comment 27: Page A1-8, last paragraph. Flow in part of Sand Creek Lateral is not necessarily infrequent. Frequent, possibly continuous discharge from the RMA steam plant enters Sand Creek Lateral in the South Plants area. This flow does not reach First Creek because of infiltration.

Response: The text has been revised to include infiltration as a reason that flow in Sand Creek Lateral does not usually reach First Creek. Discharge from the steam plant also typically infiltrates before it reaches Sand Creek Lateral.

Comment 28: Page A1-10, last paragraph. Continued urban development of areas south of RMA would not necessarily increase flooding potential. New developments are required to construct detention facilities which maintain peak flows at historic levels, preventing increased flows from occurring downstream.

Response: The text has been revised to state that the flooding potential would increase if properly sized detention facilities were not constructed.

Comment 29: Page A1-12, second paragraph. The wells that cause an approximately 11 ft drop in the water table during the summer are correctly described as part of the South Adams County Water and Sanitation District (SACWSD) public water supply system and are connected to the Klein water treatment plant.

Response: The text has been modified to correctly describe these wells.

Comment 30: Page A1-13, last paragraph, first sentence. Please clarify this sentence. By definition the potentiometric surface of a confined aquifer is above the bottom of an upper confining layer; therefore, if the potentiometric surface is below the confining layer, the aquifer is unconfined.

Response: The sentence has been corrected to state that where the potentiometric surface is below the water table of the UFS, recharge of the CFS may occur by leakage from the overlying UFS.

Comment 31: Page A1-14, first sentence. Although discharge from the CFS to the Arapahoe aquifer via leakage is possible, it is not probable because of the presence of the buffer zone overlying the Arapahoe Formation.

Response: The comment appears to refer to the first sentence of the second paragraph on p. A1-14. The sentence has been modified to indicate that discharge from the CFS may occur by leakage to the Arapahoe aquifer. Although the buffer zone may act as a confining unit separating the CFS from deeper aquifers, the buffer zone has not been determined to be a completely impermeable barrier to groundwater migration.

Comment 32: Page A1-14, second paragraph, last sentence. "Currently, production wells obtain water from the CFS on RMA."

Does this refer to the three wells in Section 4 that were installed in the mid-1950s and are used for fire protection and maintenance of water levels in the South Lakes? If so, Shell would like a copy of the logs of these wells, since our current understanding is that these wells are screened in the alluvium (i.e., UFS). If not, please identify which wells produce water from the CFS on the RMA.

Response: The word "no" was inadvertently omitted from this sentence. The sentence has been revised to indicate that no production wells obtain water from the CFS on RMA.

Comment 33: Page A1-18, first paragraph, first sentence. Please define "high Federal concern."

Response: The term "high Federal concern" is based on the designation of the bald eagle as a federally listed endangered species, and the ferruginous hawk (also a raptor) as a candidate for federal listing as a threatened species.

Comment 34: Page A1-18, last paragraph. "Counts" are not the same as "densities." Without information on the unit areas in which animals were counted, no valid claim of population enhancement, higher densities, or greater relative or absolute abundance of deer on RMA versus off-post can be made.

Response: The term "densities" in the text has been changed to "counts."

Comment 35: Page A2-8, second paragraph. Shell has commented on the soil sampling intervals selected by the Army in numerous documents. The 1-4 ft interval in the soil profile is important from a contaminant distribution standpoint and should have been represented in the sampling. Lithologic and chemical changes that influence sorption of contaminants occur in this interval.

Figure A2.1-4 [sic] shows that Phase II sampling was conducted in the 2-3 ft interval; however, this was probably an exception. Most Phase II samples were collected in the 0-1 and 4-5 ft intervals.

Response: Comment noted. Most Phase II samples were collected in the 0-1 and 4-5 ft intervals.

Comment 36: Page A2-84, third paragraph. This paragraph leads the reader to the erroneous conclusion that relationships between contaminant concentrations in environmental media and RMA biota and adverse effects on the biota have been thoroughly studied and documented, and are well understood. Information provided to date is insufficient to thoroughly document exposure, uptake, and toxicological effects of any contaminants on either individuals or populations. The existing information in fact indicates minimal or no toxicological effect.

Response: The Army disagrees with the first and last sentences in this comment. The Army believes that information developed for biota by the RI is adequate to initiate and support the FS. The paragraph in question is descriptive of the biota RI, and does not lead to any conclusions.

Comment 37: Page A2-89, first paragraph. The phrase "all OCPs" in the fifth sentence is not accurate. Arsenic and mercury are contaminants of concern, but not OCPs.

Response: The sentence has been corrected.

Unnumbered Comment: Page A3-2 second paragraph. The calculation of a probability weighted mean assumes that the samples were collected randomly. If the sampling was not collected randomly, the probability distribution would not accurately reflect the distribution of concentrations in the population. Instead, the distribution may reflect sample densities, and the sample median, geometric mean, and AGM would be biased toward concentrations of soils in areas with highest sampling density.

Response: Comment noted. The sampling was designed to help identify the nature and extent of contamination sites on RMA; an RI designed to randomly sample soils across the entire breadth of RMA would be an ill-conceived and uneconomical endeavor. The data summaries presented in Section A3 of Appendix A have been subdivided by site types to better focus the findings.

Comment 38: Page A3-6, Section A3.1.1. The relative frequency of various contaminant groups to each other is misleading. The frequency of detection of different groups can only be compared if the CRLs of the groups are similar. The CRLs for OCPs are one to two orders of magnitude below the remaining target analytes. Therefore, the frequency of OCPs may be an artifact of the low CRL for OCPs, rather than a true indication of extent of contamination.

Response: The relative frequency of various contaminant groups to each other is merely a way of presenting the data that were collected during the RI. The relative importance of detections of various contaminant groups is not necessarily related to the frequency of detection whether the CRLs are similar or not, but will be determined by the EA and risk assessment.

Comment 39: Page A3-9, Tables A3.1.1 - A3.1-10. What values were assumed for the nondetects for the calculation of sample standard deviation? Why was a geometric mean calculated, but not a geometric standard deviation. If the data are lognormally distributed, the standard deviation is either a geometric standard deviation or arithmetic standard deviation calculated for lognormally transformed data.

It should be noted in the text and on the data summary tables that the data included in the summary represent a composite of multiple sampling events that varied in sampling objective, density, and location. Therefore, the calculations of central tendency in these tables may be biased toward concentrations in densely sampled areas.

Response: The text has been revised to indicate that both the Phase I and Phase II data are summarized. The data summary tables for both soils and groundwater have been revised to include arithmetic means and standard deviations, and geometric means and geometric (log transformed, base e) standard deviations. No nondetect values were assumed in these calculations; as shown on the data tables, the statistical calculations were performed for the detections only. The adjusted geometric mean (AGM) value is the geometric mean value of the detections adjusted (multiplied) by the ratio of detections to nondetections. Cautionary statements have been added to the text in Section A3.1 and A3.2 regarding the purposes and use of the statistical information presented.

Comment 40: Page A3-66, last paragraph. This paragraph should include a qualifying statement that reiterates that actual samples were typically collected from 0-1, 4-5, and 9-10 ft, not from the full 0-2, 2-5, and 5-20 ft depicted on the referenced maps.

Response: A qualifying statement has been added to the text.

Comment 41: Page A3-72, last paragraph. Detections of DBCP in sanitary sewer sediments are problematic. It is Shell's understanding that there were laboratory problems with these DBCP analyses raising questions about the validity of the data. Further qualification of this paragraph is needed to convey the understanding that additional sampling is necessary prior to consideration of remedial actions.

Response: There were no laboratory problems associated with DBCP detections in samples collected from the sanitary sewers. DBCP was not detected by GC/MS semivolatile analysis which had a detection limit of 0.3 µg/g, but was detected at a concentration of 0.015 µg/g via gas chromatography/electron capture detector (GCECD) techniques which had a detection limit of 0.005 µg/g. No additional sampling is currently planned for this site. Final remediation decisions regarding the sanitary sewers have not been made.

Comment 42: Page A3-113, second paragraph. In addition to the DBCP plume that originates in the Rail Classification Yard, the TCE plume originating in the Motor Pool and migrating toward the ICS should be mentioned.

Response: A sentence mentioning the plume of trichloroethene that extends from the motor pool to the ICS has been added to the paragraph.

Comment 43: Page A3-119, Section A3.2.4 Confined Flow System. Artificial conduits caused by pre-RMA farm wells and deteriorating or improperly constructed wells may also have contributed to the irregular pattern of contamination in the Denver Formation.

Response: The text has been modified to include this hypothesis.

Comment 44: Page A3-125, second paragraph. The water quality information in the vertical extent database does not represent recent concentrations in all cases. For example, if a well had a detectable concentration from the early 1980s, but was not subsequently sampled, that early concentration was included in the database without verification. Older data do not necessarily represent current concentrations in those locations.

Response: The reference to present-day contamination has been replaced with a reference to the most recent representative contaminant concentration from available data. The Army recognizes that the approach used in constructing the VEC database was conservative in that it likely overestimated contaminant conditions.

Comment 45: Page A3-126, first paragraph. In the central portion of RMA, part or all of the upper 20 feet of bedrock may be located within the UFS and reflect alluvial aquifer contaminant distribution, not that of the CFS.

Response: While the elevated concentrations in the upper 20 feet of the Denver Formation in Section 1 typically are representative of UFS contamination, in Section 36 many of the elevated concentrations in the upper 20 feet of the Denver Formation are in the CFS. The previous section in Appendix A, Section A3.2.3, indicated that in some areas, groundwater in the uppermost subcropping stratum of the Denver Formation is under unconfined flow conditions. This section (Section A3.2.4) describes contaminants in the CFS; therefore, no changes have been made to the text.

Comment 46: Page A3-126, second paragraph. As noted above, OCPs are more likely to occur in higher frequencies and wider distributions because their CRLs are at least an order of magnitude less than other contaminants. Therefore, the frequency of detection may be irrelevant.

Response: Comment noted. Please see response to Shell Specific Comment 38.

Comment 47: Page A3-146, third paragraph. This finding is unsupported in the text, and the technical implications are not clear. Can it be said with statistical certainty that dieldrin detection frequencies are greater than those for arsenic and mercury?

Response: This sentence is "in general" true as stated. The statement makes no reference to statistical testing or results.

Comment 48: Page A3-151, first paragraph, last sentence. On what basis are the four samples "suspected" to have moved off RMA onto putative "control" sites? How dependent are the conclusions upon this suspicion?

Response: The text has been revised to clarify off-post control site sample results. Reference to the four samples has been removed.

Comment 49: Page A3-151, Section A3.5.3, Comparison of Off-Post and On-Post Biota Sampling Result. This comparison is critical to the scientific credibility of the analysis. It needs to be explored in greater detail, beginning with a thorough evaluation of the validity of the comparative data. If the data are acceptable, statistical comparison should be made of key parameters, accounting for alternate sources and temporal and spatial exposure processes. The analysis presented here cannot support so important an aspect of the evaluation.

Response: This section is a summary of the Biota RI document. It presents the results, at the stated levels of significance and certainty, of statistical comparison of composite on-post and off-post percentages of detections. Additional discussion of the data and reference to the statistical test used (the true difference between percentages test) have been added to the text.

Appendix B Specific Comments

Comment 50: Page B-4, third paragraph. Although in general we agree that the ". . . rates of migration in the Denver aquifer are generally slow compared to rates of migration in the unconfined flow system," we do not agree that this probably indicates that the data in the vertical extent of contamination (VEC) database, which covers a "broad time period," are representative of the present-day extent of contamination. The older data included in the VEC database are probably not representative of the current concentrations of contaminants because of a number of environmental fates that result in attenuation.

Response: The text states that the VEC database is considered generally representative of the present-day extent of contamination. The Army recognizes that many entries in the VEC database were from samples collected more than 5 years ago. In several areas where the older data are critical to understanding vertical extent, additional sampling as part of CMP or other programs has been planned.

Comment 51: Page B-7, first paragraph, last sentence. Although the stated purpose of Appendix B concerns the confined Denver aquifer, at least one alluvial well (e.g., Well 27085 on Figures RISR B.3-1, B.3-8, B.3-11, and B.3-15) and numerous wells screened in the weathered/unconfined portion of the Denver Formation are included in the evaluation. Therefore, water quality for the 0-50 ft interval may be more representative of the unconfined flow system than of the Denver aquifer.

Response: The stated purpose in the Introduction (Section B.1) incorrectly implied that only CFS wells were included in the VEC database. The screening process for the VEC database was conducted based on the location of the bottom of the screen relative to the bedrock depth.

If the base of the screen was below the alluvium/bedrock contact, the well was selected for inclusion in the VEC database. This resulted in the inclusion of some wells completed in the UFS. However, the focus of this investigation and report was on the vertical extent of contamination, and, therefore, focused on the CFS. The introductory paragraph has been revised to clarify this point.

Comment 52: Page B-9, second paragraph. Please see previous comments on the use of the AGM. Additionally, the correct measure of dispersion about the mean for lognormally distributed data is the geometric standard deviation.

Response: Please see previous responses to comments on the use of the AGM. The geometric standard deviations (natural log values) have been added to Table RISR B.2-1.

Comment 53: Page B-10, first paragraph. The standard deviations would have been even larger if the nondetects were included in the calculations by assuming the same zero concentration for nondetects as is assumed by the AGM.

Response: Please see the response to Shell's Specific Comment 39. As previously explained, zero concentrations are not assumed for nondetections in calculations of AGMs.

Comment 54: Page B-11, second paragraph. Non-detections are valid data points that help in the understanding of contaminant distribution. Since CRLs have decreased over time and the present-day contaminant distribution is being depicted, wells that have recently been below CRL would add to the assessment of distribution and variability of contamination in the confined Denver aquifer and should be included on the contaminant maps.

Response: Plate RISR B.2-1, Location of Groundwater Wells Considered for the Vertical Extent of Contamination (VEC) Database, shows all wells that are screened to a depth below the alluvium/bedrock contact and have been sampled one or more times. Plate RISR B2.-2, Location of Groundwater Wells Included in the Vertical Extent of Contamination (VEC) Database, was prepared for the Proposed Final RISR and shows all the wells included in the evaluation of the vertical extent of contamination. These maps can be used in conjunction with the contaminant distribution maps and the database of all analytical data that was provided to the organizations and State by examining the sample date(s), analytical suite, and depth below the alluvium/bedrock contact to ascertain where no contaminants have been detected. For the reasons discussed in the text, it could be misleading to display locations where no contaminants were detected. The FS will consider all relevant data available in the evaluation of remedial alternatives.

Comment 55: Page B-16, section [sic] paragraph. The deepest detection of organic analytes was in Well 01046, located approximately 2,000 feet to the east of either Well 01555 or 01565. These wells are screened within the weathered Denver

Formation of the unconfined flow system, not the confined Denver aquifer. Detections in these wells do not reflect conditions within the confined Denver aquifer, and are not consistent with the stated purpose of this study. Also, there is no mention of the fact that the alluvium is unsaturated and thin in much of the South Plants area; therefore, relatively high concentrations in the Denver Formation are not unexpected.

Response: This paragraph has been modified to indicate that many of the concentrations in the 0- to 50-foot depth interval in the South Plants are representative conditions in the UFS. In addition, please see response to Specific Comment 51.

Comment 56: Page B-28, Section B.5.1 SOUTH PLANTS AREA. Most of the contamination in the South Plants Area is located within the unconfined flow system.

Response: Please see response to Specific Comment 55. As indicated in the response, in Section B.3.1.1, the text has been modified, and the presence of contamination in the upper portion of the Denver aquifer is described as typically present in the UFS.

Comment 57: Pages B-33 through B-35, SUMMARY. Some of the contamination attributed to the upper Denver aquifer may actually represent contamination in the unconfined flow system.

Response: Please see response to Shell's Specific Comment 51.

Appendix C Specific Comments

Comment 58: Page C-42, third paragraph, last sentence. The "bench-scale" soil vapor extraction system that will be utilized is more accurately described as "pilot-scale."

Response: The term "pilot-scale" has been substituted into this sentence to replace the term "bench-scale."

Comment 59: Page C-43, first paragraph, third sentence. There is no "motor pool area groundwater extraction/treatment system." Groundwater to be extracted from the motor pool and railyard areas will be piped to the ICS for treatment.

Response: The text has been clarified to indicate that water extracted in the railyard and motor pool areas will be treated at the ICS.

Comment 60: Page C-44, second paragraph, last sentence. No construction activities for the South Tank Farm Plume IRA are scheduled for November 1991 or for any other time. Groundwater monitoring is the alternative selected for this IRA and has already been initiated.

Response: The text has been revised to indicate that groundwater monitoring was the alternative selected for this IRA. Although no construction of slurry walls or groundwater treatment systems are scheduled, monitoring wells and piezometers were installed and the groundwater monitoring has been initiated.

Appendix D Specific Comments

Comment 61: Page D1-2, Figure RISR D1.1-1 and Figures RISR D1.4-1 and RISR D1.4-2. Sample ID numbers should be added to sample locations on these maps since this information has not been published in any other document.

Response: This information was published in April 1991, in the Final Surficial Soil Program Data Summary Report, Version 3.1 (EBASCO, 1991/RIC 91121R01). Sample ID numbers have been added to Figure RISR D1.1-1.

Comment 62: Page D1-5, second paragraph, first sentence. Shell's contract laboratory used analytical methods certified by USATHAMA; therefore, the first sentence in this paragraph should read "the Army's and Shell's contracting laboratories used analytical methods certified by U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and/or the Program Manager for RMA."

Response: The requested modification has been made.

Comment 63: Page D1-5, second paragraph, fifth sentence. This sentence should read "specific protocols for all analytical methods used by all contracting laboratories may be obtained from PMRMA."

Response: The requested modification has been made.

Comment 64: Pages D1-16 through D1-41, Tables RISR D1.4-1a, D1.4-lb, RISR D1.4-2a, and D14-2b. It would be helpful to have surficial soil data listed numerically by sample ID rather than by section number. Moreover, Army and Shell data should be combined.

Response: The referenced data tables are presented in identical format to Tables 5-1a, 5-1b, 5-2a, and 5-2b, respectively, of the Final Surficial Soil Program Summary Report, Version 3.1, and will not be changed.

Appendix E Specific Comments

Comment 65: Page E-1, first bullet. Comparison of theoretical contaminant behavior to contaminant distribution hardly "confirm(s)" source areas or "verifies" the nature and extent of contamination. It simply provides a level of confidence in interpretations of contaminant transport based on theoretical behavior.

Response: The text has been revised and the terms "verification" and "confirmation" have been deleted.

Comment 66: Page E-2, Section E.2, Physical and Chemical Properties that Influence Contaminant Mobility. It would be helpful to include a discussion of diffusivity in air in the section on physical and chemical properties that influence contaminant mobility.

Response: Section E.2 has been modified to include a discussion on atmospheric diffusion as subsection E2.5. All subsequent subsections of Section E2 are renumbered.

Comment 67: Page E-6, Table E.2-1. The row of data provided for DBCP is shifted one column to the left. Also, the solubility value for DBCP of "11,000 mg/l" is incorrect. On Page E-18, Table E.2-3 gives more accurate solubility values of "1,000 and 1,230 mg/l" for DBCP.

Response: These typographical errors have been corrected.

Comment 68: Page E-43, fourth paragraph. The effects of adsorption and degradation in impeding the downward movement of DNAPLs is probably small in comparison to decreases in permeability and the degree of saturation of DNAPL in soil pores.

Response: The text has been modified accordingly.

Comment 69: Page E-45, first sentence. The heterogeneity of many aquifers precludes such gross generalizations as "higher concentrations will be encountered near the base of the aquifer where pure-phase contaminants denser than water have settled."

Response: Although the complexities of many aquifers preclude generalization, this illustration is useful in conceptualizing pure-phase contaminant behavior within a permeable unit. The text has been revised to read "...higher concentrations are generally encountered...".

Comment 70: Page E-45, second paragraph, second sentence. The concentrations actually measured in the aqueous phase do not need to exceed the aqueous solubility of the compound for NAPLs to be present. Measured dissolved concentrations may be quite a bit lower than the aqueous solubility.

Response: Agreed. The text states, however, that if concentrations exceed aqueous solubility, then separate phases will exist. The stated situation is the reverse of the comment.

Comment 71: Page E-45, second paragraph, third sentence. Attainment of equilibrium is not precluded by "all the compound entering solution" or vice versa.

Response: The reference to equilibrium has been removed from the text and has been replaced with a reference to the solubility limit.

Comment 72: Page E-45, second paragraph, last sentence.

1) Salinity only changes the solubility of ionic organic compounds.

2) Increases in salinity decrease the solubility of all ionic organic compounds. This decrease occurs because activity coefficients of organic compounds increase above one for all concentrations of increasing salinity, thus decreasing the solubility of the compound. The effect is quantified by the Setchenow Equation.

Response: 1) The presence of electrolytes in solution can decrease the solubility of nonpolar solutes, a process known as salting out. The presence of the electrolyte interferes with the organization of the solvent about the solute molecules, thereby making the nonpolar solutes less soluble. Further, increasing salinity has a greater effect on ionic inorganic solutes.

References:

Hurne, R.A. 1969. Marine Chemistry - The Structure of Water and Chemistry of the Hydrosphere. Wiley-Interscience, New York, NY. pp. 81-85.

Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper & Co. San Francisco, CA. pp. 67-70.

2) In dilute solutions, solubility of ionic compounds is enhanced in the presence of inert electrolytes. Activity coefficients of ionic species in these dilute solutions are less than one. In more concentrated solutions, activity coefficients may become greater than one, and in very

concentrated electrolytes the solubility of an ionic salt may become smaller again. The use of a single equation to describe these complex electrolyte effects often results in error when applied over a wide range of ionic strengths, such as occur at RMA.

Reference:
Stumm, Werner and J.J. Morgan. 1981. Aquatic Chemistry - An Introduction Emphasizing Chemical Equilibria in Natural Waters. Wiley-Interscience, New York, NY. pp. 299-300.

Comment 73: Page E-46, first paragraph, last sentence. The solubility of all cations varies as solution chemistry (i.e., ionic strength) varies, not just some. The effects can be predicted using appropriate models for activity coefficients (e.g. Debye-Huckel, Davies, or Pitzer models) and are similar for ions of similar charge. Solubility of metals also depends on complexation of the metal.

Response: The sentence has been revised slightly for clarity. The solubility of species in solution is dependent on many effects, including electrolyte concentration, complexation, and also solid-solution equilibria. However, the solubility of some species is far more sensitive to solution composition than the solubility of other species. For instance, the Debye-Huckel equation defines the activity coefficient as a function of the square of the ionic charge. As a result, the activity coefficient of a trivalent cation varies much more than that of a monovalent cation for the same change in solution ionic strength.

Reference:
Garrels, R.M. and C.L. Christ. 1965. Solutions, Minerals, and Equilibria. Freeman, Cooper & Co. San Francisco, CA. pp. 58-64.

Comment 74: Page E-48, third paragraph. K_{ow} is a measure of partitioning between organic and aqueous phases and is only used to predict adsorption to soil organic carbon. It is not considered valid for adsorption to mineral surfaces (e.g., clays).

Response: The text has been modified accordingly.

Comment 75: Page E-48, last paragraph, last sentence. Adsorption of organic compounds to organic carbon correlates well with K_{ow}. Adsorption of organic compounds to inorganic sediment particles does not correlate well with K_{ow}. This distinction is important on the Arsenal where aquifer sediments have been found to contain little or no detectable organic carbon (Shell 1990; WCC 1911 [sic]).

Response: The text has been modified accordingly.

Comment 76: Page E-50, second paragraph. Is the F_{oc} value of 0.01% a typographical error? Most writers cite 0.1% as the critical level of organic matter below which inorganic sorption becomes significant.

TOC data collected by Shell near Basin C and north of Basin F and by Woodward-Clyde near the NWBS indicate that, [sic] the amount of organic carbon in unconfined aquifer sediments is very low. Shell aquifer samples contained less than 0.05% TOC (detection limit) and the Woodward-Clyde samples contained from 0.001% to 0.014% TOC. Therefore, it may not be appropriate to use the K_{oc}-K_d relationship to calculate retardation.

Response: The critical level of soil organic carbon varies with the methods used to calculate K_{oc}. For some methods, the lower level of applicability is 0.01 percent f_{oc}. Limitations in the K_{oc}-K_d relationship are described in the paragraph cited, as well as the preceding paragraph. Emphasis on the use of K_{oc} and f_{oc} values to estimate adsorption does not imply that organic chemicals will not adsorb on mineral surfaces in the absence of organic matter. Some adsorption will always occur, and may be of particular significance in clays with vary high surface area and where chemisorption is a factor. Methods for estimating adsorption effects in the absence of organic matter are currently unavailable.

References:
Dragun, James. 1968. The Soil Chemistry of Hazardous Materials. Hazardous Materials Control Research Institute. Silver Springs, MD. pp. 243-250.

Lyman, W.J., W.F. Rechl, and D.H. Rosenblatt. 1982. Handbook of Chemical Property Estimation Methods - Environmental Behavior of Organic Compounds. McGraw-Hill, New York, NY. p. 4-5.

Comment 77: Page E-50, Section E.2.7. The organic carbon content of unconfined aquifer sediments measured in Section 36 may not be representative of the entire RMA. The range measured in Section 36 was 0.07% to 0.68% f_{oc}, which is significantly higher than that measured by Shell and Woodward-Clyde as discussed in the above comment. Since the f_{oc} may be over-estimated, the range of retardation factors calculated for the unconfined aquifer may be too high.

For example, the retardation factor for trichloroethylene calculated from laboratory studies for the Chemical Sales Superfund site just west of RMA ranges from 1.2 to 1.6 as compared to 3.8 to 28 calculated in this summary report. Retardation derived for dieldrin based on RMA field data are also lower than the range of 47 to 440 estimated in Table RISR E.2-5.

Response: The section summarizes a single investigation, and also states that heterogeneity of natural occurring soils, sediments, and waters may account for variability in transport behavior observed in different areas of RMA. Organic carbon contents are known to vary in different types of soils, aquatic sediments and sub-soils. As Shell has previously pointed out, sorption to inorganic phases may also be a significant retardation mechanism. As such, if the K_{oc}-K_d relationship is inappropriate, it is difficult to predict whether actual sorption to inorganic substrates will be greater or less than the sorption predicted for low organic carbon soils on the basis of this relationship. Page E-52 also states that given the high potential for variability in K_{oc} and F_{oc} values, these retardation factors should be used only in a relative sense, and that there may be large differences in mobility for a given compound in different environments.

Comment 78: Page E-52, second paragraph. The bulk density value given for aquifer sediments seems to be incorrect. A value of 2.7 g/cm^3 corresponds to grain density with virtually no porosity. Bulk density of coarse-grained, quartzose aquifer sediments is usually assumed to be 1.6 to 1.8 g/cm^3.

Field data may also be used to calculate retardation factors on the RMA and to compare theoretical rates with observed rates.

Response: The bulk density used in Table RISR E.2-5 was inappropriate, and has been modified. Field data have been used to calculate retardation factors, as described in Section E.2.7. Other methods, such as tracer studies (ESE, 1988d) have also been attempted. These field-based methods have been only partially successful.

Comment 79: Pages E-57 through E-59, Table RISR E.2-5. Shell found no detectable concentrations of TOC (i.e., <0.05%) in aquifer sediments underlying Basin C and north of Basin F (Shell 1990); therefore, it should be noted that the retardation factors are probably lower than those listed in this table.

Response: Despite the fact that no detectable concentrations of organic carbon were found underlying Basin C and north of Basin F, there is no evidence that retardation factors may be lower than calculated in Table RISR E.2-5. The K_{oc}-K_d relationship has been applied at its lower limit, where sorption to inorganic soil phases may become significant. There is no evidence that these inorganic sorption effects, particularly in fine-grained sediments, will be any less than the organic carbon sorption effects calculated at the lower limit of the K_{oc}-K_d relationship. In addition, Page E-52 already states that given the potential for high variability in K_{oc} and f_{oc} values, these retardation factors should be used only in a relative sense.

Comment 80: Page E-60, first paragraph. "...contaminants may be... systematically concentrated or biomagnified in successively higher trophic level species." Given that the model essentially assumes a homogeneous abiotic environment (i.e., temporal and spatial variability is not directly accounted for), the BMFs should be adjusted to take in to account these factors as they relate to exposure. In this case, it should be stated there that, in the context of the model, exposure-weighted BMFs may be less than 1.0, particularly for metals, i.e., contaminants may <u>not</u> be systematically concentrated in some cases.

Response: The statement is correct as expressed. Systematic concentration does not imply either high rates or homogeneity of concentration. The concerns regarding the fact that, at RMA, an assumption of uniform exposure for some species is unlikely will be addressed in detail in the EA.

Comment 81: <u>Page E-60, second paragraph, second sentence</u>. "The BCF for a particular contaminant at a given trophic level in an aquatic system is merely the ratio between the contaminant concentration in organisms a that trophic level and the contaminant concentration in the ambient water." This statement is incorrect and misleading. BCF is entirely independent of trophic level and is a meaningful quantity only when water is the sole source of a contaminant (i.e., laboratory experiments). BAF, in the context of the RMA model, is the ratio of contaminant concentration in organisms at a trophic level to contaminant concentration in the preceding trophic level. What is actually being described here, therefore, is the BMF since trophic level transfer is implicit in the definition given and the denominator is the abiotic medium.

Response: The text has been modified to clarify these definitions.

Comment 82: <u>Page E-60, second paragraph, third sentence</u>. "Bioassay techniques"--in which responses of a living organism are used to gauge the toxicity of a sample--have nothing to do with bioconcentration factors. The phrase "bioassay techniques" should be replaced with "quantitative analytical techniques."

"BCF values may be measured using bioassay techniques or may be estimated from empirical relationships based on solubility, K_{ow} and K_{oc}." This statement should include the caveat that bioconcentration can be greatly affected by other factors (e.g., lipid content of the target organism, the molecular size and shape of the contaminant, physiological control of uptake, biotransformation, bioavailibility, intra- and interspecies variations and environmental conditions.

Response: The text has been modified as suggested. As this is a summary document, it is not appropriate to include all caveats here. The other factors influencing bioconcentration factors (BCF) will be addressed appropriately in the forthcoming EA.

Comment 83: <u>Page E-60, second paragraph, fourth sentence</u>. "At the lowest trophic level organisms are assumed to be autotrophs, and any contaminant accumulation in them is attributed solely to direct uptake from water." This statement is probably adequate to describe concentrations of contaminants in phytoplankton. The model however (as we currently understand it), combines phytoplankton and zooplankton (which may feed on phytoplankton), such that the "true" value for "plankton" as a multi-trophic group may fall between the BCF and BAF. In addition, this statement appears to assume no uptake of contaminant from sediment via macrophyte roots which is known to be incorrect and is not consistent with the diagrammatic representation of the model which has been provided at the on-post meetings. The statement also appears to assume that aquatic invertebrates do not feed at all (acquire contaminant only from water). Such assumptions would be in error.

Response: The statement assumes that BCF is the primary mode of uptake for all plankton and aquatic invertebrates, although some will also be ingesting contaminants as well, as has been clarified in the text. This assumption is documented in the literature referenced in the Biota RI report for this trophic level. The uptake of contaminants from sediment through macrophyte roots would pass through a water interface and not be at variance with the general statement made in the text.

Comment 84: Page E-60, second paragraph, sixth sentence. A statement regarding the methodology used to calculate BMFs should be included.

Response: A statement regarding methodology for calculating biomagnification factors (BMF) is presented in the last sentence of this paragraph. Additional detail is provided in Section 5.0 of the Biota RI report, which this document summarizes.

Comment 85: Page E-60, second paragraph, ninth sentence. "The BMF. . . is calculated by summing BAFs over each pathway. . ." The factor calculated here is not the BMF since it does not relate to the abiotic medium, it is actually a feeding fraction "normalized" trophic level BAF. BMFs are calculated by multiplying trophic level specific BAFs.

Response: The definition presented here is consistent with the general definition and use of the term BMF. Additional information is provided in Section 5.0 of the Biota RI report, which this document summarizes.

Comment 86: Page E-60, third paragraph. The "back-calculation" procedure as described here ignores temporal and spatial variability and the resultant value for the abiotic medium should not be applied as a clean-up criterion. The probable product of this back-calculation procedure is an extensive, arsenal-wide, clean-up effort, when all that may be really necessary is intensive remediation of a few selected areas. Temporal and spatial variability must be considered when devising alternative clean-up programs.

Response: The back-calculation approach summarized here was based on general assumptions and does not address the temporal and spatial variability of contaminant distribution in abiotic media. The goal of the back-calculation is to derive a single cleanup biota criterion for each of the abiotic media. This criterion will then be divided into the medium concentration at a specific site to calculate a site-specific exposure index (EI). The EI will identify areas having contamination greater than the biota criterion. This process is being implemented in the ongoing EA process at RMA.

Comment 87: Page E-63, first paragraph, second sentence. The central importance of the MATC parameter requires that it be rigorously defined. For what species will MATCs be developed? What criteria will be used to develop MATCs? Since MATC is defined as a LOAEL, are the adverse effects expected at that tissue concentration considered harmless? On what basis? Will the same adverse effect be applied to all species? If so, how will equivalent toxicological significance in different species be demonstrated? If not, how will differences be reconciled?

Response: A more detailed discussion of the use of maximum allowable tissue concentrations (MATCs) is provided in the Biota RI report, which this document summarizes. Additional evaluation of the MATC approach is under development as part of the forthcoming EA. Adverse affects will be defined for species as appropriate.

Comment 88: Page E-66, Section E.3.1 COMPARTMENT MODEL. The calculations and conclusions in this section are based on the assumptions that the aquifer contains more than the minimum threshold fraction of organic carbon of 0.1% required to use K_{ow} to predict K_d. This is not realistic in many areas. For example, Shell found no detectable amounts of TOC (i.e., <0.05%) in unsaturated and saturated sediments beneath Basin C and north of Basin F (Shell 1990).

Response: Sediments at RMA have been observed with organic carbon contents at levels equal to or greater than the 0.1 percent value used to prepare this figure. In addition, the compartment model is used to illustrate the relative behavior of contaminants in generalized solid-liquid-gas systems, rather than to predict their migration potential in a specific environment.

Comment 89: Page E-81, third paragraph. Desorption of OCPs from soils and sediments is believed to display hysteresis. Is there any direct evidence at the RMA that the OCPs in aquifer sediments are secondary sources of groundwater contamination, in view of both hysteresis and low TOC?

Response: As discussed by Mackay and Cherry (1989), kinetic limitations to desorption have been observed in both field and laboratory studies. The practical effect of these kinetic limitations is to slow the removal of contaminants from the aquifer, thereby increasing both the time required to achieve cleanup and the volume of water that must be extracted to flush the contaminated zone. In addition, the partition coefficients study has demonstrated the presence of contaminants within saturated zone aquifer sediments. Slow desorption of these contaminants should be anticipated in developing remediation strategies.

Comment 90: Page E-82, second paragraph. It should be stated that arsenate and arsenite exist as anions since the behavior of anions is important in determining the geochemical behavior of arsenic.

Response: The text has been modified accordingly.

Comment 91: Page E-83, second paragraph. With regard to wind transport of fine particles containing arsenic, iron oxide often serves as cement to clay-sized particles and thus [sic], would form larger aggregates which would be less available for wind transport. The statement about the resolubilization of arsenic as the more toxic arsenite species is unclear. Redox reactions of metals in solid phases are very slow and the likely situation for reduction of arsenate to arsenite would be for the arsenic to remain in the solid phase since the mobility of arsenate and arsenite are similar.

Response: Windblown transport of contaminants is suspected to be an important migration mechanism at RMA. Solid phase reduction is presumed to occur in association with the aqueous phase, as in lacustrine sediments. Please refer to the cited references in Section E.3.2.14, particularly in the fourth paragraph for further explanation.

Comment 92: E-86, second paragraph. Cadmium, copper, lead, and zinc behave similarly because they exist as cations. In addition to hydroxide aqueous complexes, halides also form complexes with these metals.

Response: The text already states that these metals occur as divalent cations or as complex species. Chloride has been added as a potential ligand.

Comment 93: E-86, fourth paragraph. What is the relevance of Table RISR E.3-1 in illustrating the order of increasing affinity for the solid phase? The ranges shown in the table are too broad to draw conclusions about the behavior of the various elements.

Response: The text has been revised for clarity. A wide range of natural conditions may lead to a wide variety of sorptive behavior. Change in these conditions may result in changes in mobility.

Comment 94: Page E-108, fourth paragraph. Please clarify the first sentence.

> The data from the vertical extent report do not support the contention that contaminants are transported extensively in the vertical direction.

Response: The first sentence of this paragraph indicates that lateral and vertical migration are more efficient within the UFS than in the underlying CFS. The vertical extent report deals principally with the presence of contaminants in the CFS portion of the Denver Formation aquifer, not the overlying UFS. Contaminants within the UFS appear to be transported both laterally and vertically to a greater degree than in the confined waterbearing zones of the Denver Formation.

Comment 95: Page E-127, third paragraph. A tailing effect for DBCP in groundwater by release from fine-grained sediments has not been demonstrated. In fact, data downgradient of the ICS indicate that no tailing effect occurs in the aquifer.

Response: The text refers to the source of the DBCP plume in the railyard, not downgradient of the ICS. Initial concentrations in the railyard are likely to have been much greater than those experienced by aquifer sediments off post, making any tailing effects more evident near the source.

Comment 96: Page E-132, third paragraph. See comment for page E-81, third paragraph.

Response: Please see the response to Shell Specific Comment 89.

Comment 97: Page E-135, Section E.5.14 ARSENIC. The description of the fate and transport of arsenic described in the first three paragraphs is inconsistent. Either a consistent model should be formulated or a statement should be added to indicate that no complete model to explain the data has been determined.

Response: The text has been modified to enhance consistency among these paragraphs.

Tables

Comment 98: Table RISR A3.5-1. Demonstration of "clear biomagnification tendency" may be complicated by artifacts of data selection and presentation. For example, the coyote is in fact omnivorous, while the carnivores listed here feed at a number of trophic levels. Body burdens from the individual animals included in the data (whether those burdens were acquired on- or off-post [sic], or from multiple sources) can skew the presentation. For example, it is highly unlikely that golden eagles acquire their full body burden on RMA.

Therefore, mechanistic linkage to RMA, or risk management on the basis of measured body burdens, must account for alternate sources.

While valid and defensible correlation of tissue concentration with trophic level may be possible, it must be done with care. This is more clearly demonstrated in the aquatic food web demonstration, where inappropriate specification of "plankton" as primary consumers (zooplankton, presumably meant here, actually feed at a number of trophic levels), inclusion of the very broad-feeding bluegill as a separate trophic level, and equation of bass and pike (which feed at various levels) have masked any possible pattern in tissue burdens. Similar processes pertain to the terrestrial food chain analysis, where the allegedly "clear" pattern is a result of somewhat unclear grouping of species.

Response: The "clear biomagnification tendency" can be complicated by the factors stated, but the statement in the first bullet on page A3-148 is correct as expressed. While the selection of species for which data are available to examine trophic levels is limited and not ideal, the pattern alluded to in the text is evident from the data. Risk management implications will be addressed as part of the EA process that has not yet been completed.

Comment 99: Tables RISR E.2-1 and RISR E.2-3. The information provided in these tables is, depending upon a given compound, either inconsistent with or could be supplemented with the information which EBASCO has prepared for the Army for the On-Post RC/IEA. A discussion of the QA/QC of this data, which has presumably been performed, would add to the reader's confidence in considering the data. The converse of this argument is: What data was [sic] rejected or not considered?

Response: Please see response to EPA's General Comment 2 on Appendix E. The information and data presented in Appendix E2 are representative values obtained from various sources as indicated on the tables. This information is generally consistent with that prepared for other programs, but due to the range of reported values in the literature for various parameters, is not necessarily identical to the data packets that Shell refers to.

Unnumbered Comment: Tables E.2-4 through E.2-6 [sic] Reported log K_{oc} values have been compared with readily available literature values and important discrepancies have been listed below. Although we understand that reported values frequently differ markedly for a given compound (Kadeg et. al. 1986), we note that some of these values differ by as much as two orders of magnitude. Therefore, the values reported in these tables should be verified.

Compound	Log K_{oc} Reported in Biota IR [sic]	Log K_{oc} Value Obtained From Literature	Literature Reference
Benzene	1.62	2.50	[2]
DDT	4.58	5.48	[3]
DDT	4.58	5.39	[4]
Fluoranthene	4.58	5.32	[3]
Hexachlorobenzene	6.08	5.22	[1]
Parathion	3.40	4.03	[4]
Phenanthrene	3.85	4.22	[3]
Pyrene	3.42	5.13	[3]
Trichloroethylene	2.64	2.02	[1]

[1] SRC 1991
[2] EBASCO 1990
[3] Kadeg et al. 1986
[4] Rao and Davidson 1980

Response: It is agreed K_{oc} values differ, sometimes by two orders of magnitude, depending upon the method of calculation. The potential for high variability in K_{oc} values is pointed out in Section E.2.8. Table RISR E.2-3 provides a list of various K_{oc} values and the references for each of them. It is the Army's intent to use appropriate methods for determining K_{oc} values, which are discussed and reviewed in the RMA Exposure Assessment.

Comment 100: Table RISR E.2-6 and Page E-60, second paragraph, fifth sentence, and Page E-63, second paragraph, last sentence. This information is impossible to evaluate. What are the "lowest trophic level" organisms referred to? Where are the tissue and water analyte concentrations from which the listed BCFs were derived? Were they calculated using regression equations? There is no "Table RISR A.2-1" listed in the Table of Contents. What was the basis for selecting the mallard, blue gill [sic], pike and eagle for BMF calculations? Estimates of BMF for the species considered should be listed individually; lumping them into a range yields little insight into the "relative degrees of concentration and magnification in biotic systems." Also, it should be made clear that these numbers calculated in the Biota RI reflect limited "field data."

Response: The text in Section E.2.10 has been revised to clarify the discussions of bioconcentration and biomagnification. Information presented in Table RISR E.2-6 for bioconcentrations was calculated using regression equations. Ranges in BMFs are presented for the species at RMA for which sufficient data were available from the Biota RI to calculate BMFs.

The ranges in BMFs by specific analyte for all the species noted in footnote c in Table RISR E.2-6 were used as a summary tool to compare relative degrees of biomagnification by analyte. The revised text notes that BMFs may vary greatly by species due to differences in susceptibility, feeding habits, the environment, and assessment methodologies.

Reference to Table RISR A.2-1 in footnote b in Table RISR E.2-6 is a typographical error and has been corrected; the correct reference is to Table RISR E.2-3.

Figures

Comment 101: Figure A2.1-2 [sic]. Figure A2.1-2 [sic] shows that samples were collected at 5-ft intervals to 30 ft and then at 10-ft intervals thereafter. This should be 20 ft, rather than 30 ft.

Response: Figure RISR A2.1-2 has been corrected to show that from 20-ft depth on, samples were typically collected at 10-ft intervals.

Comment 102: Figures RISR A3.1-3 through RISR A3.1-12. These figures are graphically sophisticated, but misleading for the following reasons. The data include multiple sampling rounds of variable sampling density, none of which were collected randomly. Therefore, the probability distributions likely reflect density and frequency of sampling as much as the true distribution of analyte concentration. Fewer samples were collected at deeper depths; therefore, the "percent detection" at these depths are likely biased by the particular criteria used to select total depth.

The depth intervals are not accurate. Typically, samples were taken between 0-1, 4-5, 9-10, and >20 ft; therefore, the representation of 0-2, 2-5, and 5-20 ft is misleading in that it suggests that most samples were collected over wider intervals. This representation places emphasis on the anomalies rather than the norm.

The comparison of percent detections between analyte groups is misleading in that it reflects those analytes that have lower CRLs, rather than those that are truly more common. For example, the OCPs are the most commonly detected analyte group on all but two of the figures. This may reflect the lower CRL for the OCPs, rather than a higher frequency of occurrence.

Response: Given the volume of data collected by the RI, and the complexities introduced by the vast scope of the investigations, including the need to analyze thousands of samples for multiple analytes at different laboratories utilizing certified methods with different CRLs, and the design of the program which appropriately concentrated more sampling at shallower depths and in areas with a greater likelihood of contamination than a purely random approach, any summary data presentation format will have some limitations. Nevertheless, the referenced figures represent an efficient and informative method of conveying both the nature and extent of the contamination in the various site types at RMA. Samples were collected between 14- to 15-ft and 19- to 20-ft depths as well as 9- to 10-ft within the 5- to 20-ft interval. Therefore, the 0- to 2-ft interval is represented by one sample, as is the 2- to 5-ft interval, and the 5- to 20-ft interval is represented by three samples. The higher frequency of detections for OCPs may, in part, be a result of the low CRLs used for these analytes; OCPs are more likely to pose risks at low concentrations than many other analytes, however.

Comment 103: Figure RISR A3.2-14. This figure will not be informative to the risk manager because it provides no information regarding the natural occurrence of the "total ICP metals" against any contaminant levels, nor the form of these metals. Chromium, for example, could be present naturally in an insoluble silicate matrix, or it may be present as a soluble salt, but is unlikely to be present in its elemental form.

Response: This figure is not intended to serve the risk manager with specific information, but rather to provide a summary presentation of ICP metals concentrations detected during the RI. Evaluation of risks posed by ICP metals is a subject of the EA.

Comment 104: Figures RISR A3.2-15 through A3.2-19. Please see comment on Figures RISR A3.1-3 through A3.1-12.

Response: Please see response to Shell Specific Comment 102.

Comment 105: Figure RISR E.4-8. The South Tank Farm Plume is not migrating into the South Lakes as depicted in this map.

Response: The arrow in Figure RISR E.4-8 showing the contaminant migration pathway towards the South Lakes has been shortened to show that the South Tank Farm Plume has not migrated to the lakes.

REFERENCES

EBASCO. 1990. Final preliminary ecological risk assessment, Harbor Island Site, Seattle, Washington. EPA Contract No. 68-01-7250.

Kadeg, R.D., S.P. Pavlou, and A.S. Duxbury. 1986. Elaboration of sediment normalization theory for nonpolar organic contaminants. United States EPA, Office of Water Regulations and Standards, Criteria and Standards Division. SCD #4. Washington, D.C.

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Rao, P.S.C. and J.M. Davidson. 1980. Estimation of pesticide retention and transformation parameters required in nonpoint source pollution models. IN: Environmental Impact of Nonpoint Source Pollution. M.R. Overcash and J.M. Davison (eds.). Ann Arbor Science, pp. 23-67.

Shell. 1990. Laboratory Study on Dieldrin Transport in Soils and Groundwater: Sorption of Dieldrin on RMA Soils-RMA Project Status Reports 2-90, 3-90, 4-90, and 5-90.

SRC. 1991. Syracuse Research Corporation Chemfate database.

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Appendix F4

Responses to the United States Fish and Wildlife Service's Comments on the Draft Final Remedial Investigation Summary Report, Version 2.3

Remedial Investigation Summary Report

United States Department of the Interior

FISH AND WILDLIFE SERVICE
FISH AND WILDLIFE ENHANCEMENT
ROCKY MOUNTAIN ARSENAL FIELD OFFICE
BUILDING 111
COMMERCE CITY, COLORADO 80022-2180

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

July 3, 1991

Office of the Program Manager
for Rocky Mountain Arsenal
ATTN: AMXRM-E (Mr. Kevin Blose)
Building 111
Commerce City, CO 80022-2180

Dear Mr. Blose:

The U.S. Fish and Wildlife Service (Service) has reviewed the Draft Final Remedial Investigation Summary Report. The Service notes that the subject document is a summary of the Remedial Investigation, however, sometimes more current information is provided on specific subjects (e.g. IRA's, surficial soils and ground disturbance investigations). We assume that the portion on wildlife is a summary of species distribution and abundance at the time of the RI, however if it is intended to be current, additional information is needed. Please notify the Service regarding the reported time period of this summary report to clarify the factuality of the information presented.

If you have any questions or comments, please contact Patty Stevens at 289-0232.

Sincerely,

Donald R. Gober
Coordinator

enclosure

U.S. FISH AND WILDLIFE SERVICE
ROCKY MOUNTAIN ARSENAL FIELD OFFICE
COMMENTS ON DRAFT FINAL
REMEDIAL INVESTIGATION SUMMARY REPORT
JULY 1991

Volume I [sic] [Sections 1.0, 2.0, and 3.0]

Comment 1: Page 1-24, paragraph 3, line 7. This should read "between 1946 and 1982, at which time all manufacturing operations in the South Plants ceased."

Response: The sentence has been corrected as requested.

Comment 2: Page 1-24, paragraph 3, line 10. Is Shell Chemical Company really still a lessee of facilities in the South Plants?

Response: No. Shell's lease expired in 1987. The text has been corrected.

Comment 3: Page 1-25, paragraph 1, line 3-4. It is unclear whether Shell acquired the South Plants or Julius Hyman and Company. Please revise for clarity.

Response: The sentence has been clarified.

Comment 4: Page 1-30, paragraph 2, line 6. "Wsates" is misspelled, it should read wastes.

Response: This spelling error has been corrected.

Comment 5: Page 2-17, paragraph 4, line 5. This should read "Aldrin/dieldrin ratios range from less than 1 in some shallow areas of the lake to over 100 in deep areas of the lake".

Response: The sentence has been corrected as requested.

Comment 6: Page 2-18, paragraph 1. While the potential for groundwater migration of organochlorine pesticides (OCPs) from lake sediments is reduced due to the strong adsorption of OCPs to lake sediments, the potential does exist for migration of OCPs up the food chain (bioaccumulation) through the direct ingestion of contaminated sediments by bottom feeding organisms.

Response: A statement has been added to emphasize this point.

Comment 7: Page 2-19, paragraph 1, line 3. It is stated that contaminant contribution from chemical sewers is difficult to assess due to the influence of other contaminant sources. What is the primary source of contamination?

Response: Both sewers and other sites are or were primary sources to soil and, in some cases, water contamination. In areas such as Section 36, where sewers overlap with other types of sources, the interpretation of how much contamination is associated with each source is somewhat arbitrary. In Table RISR 2.1-1, the volume of contaminated soil associated with sewers is less than that associated with basins and lagoons; ditches, lakes, and ponds; and solid waste burial sites.

Comment 8: Page 2-20, paragraph 1. The benzene, toluene, and xylene plume in the South Tank Farm area is well defined and has supposedly resulted from a benzene spill in the tank farm area. this plume is the subject of the South Tank Farm Plume IRA.

Response: While numerous spills and leaks occurred in the South Plants area, this section of the text addresses contamination sites that are the results of spills in areas not included in other site-type discussions. The South Plants area is included in the buildings, equipment, and storage site-type, and is discussed in Section 2.1.3 of the text.

Comment 9: Page 2-21, paragraph 4, line 4. Only one IRA (ongoing) has been implemented to control fugitive dust.

Response: The sentence has been corrected.

Comment 10: Page 2-24, paragraph 1, line 6-10. This sentence should read "... though still considered contaminants ...". Additionally, the potential still exists for accidental releases of chemical warfare agent during remedial investigations and activities.

Response: The sentence has been corrected as requested. The potential for accidental releases of chemical warfare agent during remedial investigations and activities is, given the design of these programs, extremely remote and unlikely.

Comment 11: Page 2-27, paragraph 3, line 2. This is the first time that "eolian" is defined, although it is used prior to this. It should be defined the first time it is used.

Response: The first use of the term eolian, on page 2-21 of the Draft Final RISR, has been eliminated. The term is therefore now defined the first time it is used.

Volume II [sic] [Appendix A]

Comment 1: Page A1-1, paragraph 1. The southern boundary of the Arsenal is also adjacent to industrial and commercial activities.

Response: The sentence has been changed to reflect the presence of industrial and commercial activities in the area of Montbello on the southern boundary of RMA.

Comment 2: Page A1-15. Wildlife. The service assumes that the wildlife portion of this report is representative of the wildlife at the time of the Biota RI only as this is a summary report. If the intent is to document current wildlife diversity and abundance, please contact the service for additional information.

Response: The USFWS is correct in its assumption. However, all available data will be used in the EA and FS.

Comment 3: Page A3-2, paragraph 1, sentence 2. This is not a complete sentence.

Response: The sentence has been corrected.

Comment 4: Page A3-88, paragraph 2, sentence 1. This sentence is missing a parenthesis.

Response: The missing parenthesis has been added.

Volume III [sic] [Appendix A Figures and Plates]

Comment 1: Figure RISR A1.6.1. [sic] Vegetation Map. Visual observation of Section 36 indicated more vegetation is present than appears on this map.

Response: Figure RISR A1.6-1 is based on an earlier report by MKE, as indicated by the reference in the figure (MKE, 1988). Vegetation will not be remapped for the RISR.

Comment 2: Figure RISR A3.2-24. Total ICP Metals. The color code does not match the colors used to define sampling locations.

Response: The color code in Figure RISR A3.2-24 has been corrected.

Comment 3: Figures RISR A3.5-1 through A3.5-3. The use of animal symbols for defining biota sampling locations and trophic levels is a unique way of the presenting the material. The service appreciates it.

Response: The Army appreciates the comment.

Volume IV [sic] [Appendix B]

Comment 1: Page B-9, paragraph 3, line 1. Table RISR B.1-2 should read Table RISR B.2-1.

Response: The reference to Table RISR B.2-1 has been corrected.

Comment 2: Page B-32, paragraph 2, line 8. The word "including" should be changed to "included".

Response: The sentence has been corrected.

Volume V [sic] [Appendix C, Appendix D, and Appendix E]

Comment 1: Page C-37, paragraph 1. The hydrazine wastewater will now be transported to Pond A for storage until incineration can occur.

Response: The paragraph has been modified to reflect this.

Comment 2: Page C-44, paragraph 2. "Buttons" should read "bottoms" in line 4. What construction is expected to begin in November 1991? The service was not aware of any additional construction, only of continued periodic monitoring of existing wells for contaminant distribution and water table levels.

Response: The spelling of "bottoms" has been corrected, and the description has been updated to indicate that groundwater monitoring is the selected alternative.

Comment 3: Page D1-4, paragraph 2. Plastic/rubber gloves may contaminate soil through the coating that is applied to the gloves. Was this taken into consideration during the analytical process?

Response: The surficial soil samples were being analyzed quantitatively for OCPs, arsenic, and mercury. The semiquantitative SVOC screen that was conducted on most samples did not reveal the presence of phthalates or other compounds that may be associated with the use of gloves. All pesticide hits are confirmed by second column analysis.

Comment 4: Page E-130, paragraph 2, line 6. This should read "significant migration from their source areas".

Response: The sentence has been corrected as requested.

Appendix F5

Responses to the Colorado Department of Health's Proposals for Data Gap Rectification or to Improve the Remedial Investigation

Remedial Investigation Summary Report

INTRODUCTION

Appendix F5 of the RISR presents the Army's responses to the State's proposals for data gap rectification or the improvement of the RI for six of the seven study areas, as listed in the State's letter of July 26, 1989 (attached). The Army notes that proposals regarding the Eastern, Western, Southern, North Central, Central, and South Plants study areas are pertinent to, and were received in time to be responded to in the Proposed Final version of the RISR. Of the other items listed in the State's letter, the Army notes that:

- Recommendations for a Structures Sampling Program have been received and are considered within the framework of the Structures Sampling and Analysis Programs being developed by the Army

- The Off-Post Northwest Proposed Ground Water Monitoring Well Locations have been received but are not germane to the RISR and are not responded to herein

- The State submitted its response to the Army's proposal for the Phase I Vertical Extent of Contamination Investigation, Rocky Mountain Arsenal as scheduled in the attached letter. Appendix B of the RISR presents the results of that investigation, and should be construed as the Army's action with respect to the State's submittal.

To the best of the Army's knowledge, the remaining items have not been received.

31 JUL 1989 pd

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

1876

Roy Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

July 26, 1989

Mr. Donald Campbell
Office of the Program Manager
Rocky Mountain Arsenal
Attn: AMXRM-PM, Building III
Commerce City, CO 80022

Subject: Schedule for Submittal of State Proposals for Data Gap Rectification, Rocky Mountain Arsenal

Dear Mr. Campbell:

As promised during the July 5-7 Study Area Reports meetings, enclosed is the anticipated schedule for submittal of a series of State proposals for data gap rectification regarding the RMA remedial investigation. The schedule was developed based on perceived Army priority, level of work required by the State to develop particular plans and our availability of resources. If, upon review of this schedule, there are topics on which your staff would need input sooner, we can consider reprioritization of the schedule. As we have discussed previously, this schedule contains target submittal dates only, provided as a courtesy to aid the Army in its future activities. The State may actually transmit these documents before or after the proposed milestones. The State is looking forward to working with the Army to resolve these important issues.

If you have any questions regarding this schedule, please call.

Sincerely,

Jeff Edson
RMA Project Coordinator

cc: Michael Hope
David Anderson
Chris Hahn
Edward McGrath
Connaly Mears
Mike Gaydosh
Lt. Col. Scott Isaacson
Tony Truschel

RMA 89-1071 1/2

State of Colorado RI Data Gap Identification Program,
Rocky Mountain Arsenal

	Topic	Document to Army
1.	Vertical extent of contamination proposal • State's well inventory • review of proposal	Aug 1
2.	Unknown/TIC Identification • State's List of Prevalent Unknowns	Aug 4
3.	Eastern, Western, and Southern Study Areas Areas requiring additional characterization	Aug 11
4.	Offpost Northwest Proposed Ground Water Monitoring Well Locations (as promised to Mr. Charles Scharmann)	Aug 11
5.	North Central/Central Study Area Data Gaps and Proposed Data Collection Activities	Aug 25
6.	State's Analysis of Volatiles in Shallow Soils and Recommendations	Aug 28
7.	North Plants Study Area Data Gaps and Proposed Data Collection Activities	Sept 8
8.	South Plants Study Area Data Gaps and Proposed Data Collection Activities	Sept 15
9.	Structure Sampling Program Recommendations	Sept 22
10.	Analysis of Army's Data Quality Assessment and Recommendations for additional work or documentation	Sept 29

Appendix F5.1

Eastern Study Area

Remedial Investigation Summary Report

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

1876

Rov Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

August 2, 1989

Mr. Donald Campbell
Deputy Program Manager
Rocky Mountain Arsenal
AMXRM-PM, Bldg. 111
Commerce City, Colorado 80022-2180

Re: Eastern Study Area; Clarification of State Concerns Regarding Site Inadequacies and Rectification

Dear Mr. Campbell:

The State is responding to the minutes for the RMA Eastern SAR Subcommittee meeting which was held on June 6, 1989. Since these minutes were incorporated into the Final Eastern Study Report without the State's knowledge and without the opportunity for the State to confirm or refute the Army's characterization of discussions, this letter should also be included in the Administrative Record.

Concern 1: Adequacy of RI Data for Sites ESA 3a, 3b, 3c

The State's concerns regarding perceived data gaps for sites ESA 3a, 3b, and 3c were addressed by the Army's commitment to perform additional characterization work as explained in its Meeting Summary. We anticipate that this work will be set forth in a task plan which the State will comment upon as appropriate.

Concern 2: Surface Water Ditch Samples

As a result of some apparent miscommunication, the State's concern number 2 has not been adequately addressed. The State noted in comment number 11 on the Eastern SAR that the sporadic detections of contaminants in First Creek and its tributaries merited additional sampling to confirm whether they constitute pathways of contamination. The Army suggested that the nine Comprehensive Monitoring Plan sampling stations along First Creek should satisfy this concern; however, as explained in comment no. 7 on the proposed surface water CMP, it is the State's perception that sampling proposed in that plan will not close this data gap. Therefore, the State again requests that the First Creek and tributary ditches in Section 31 and 6 be re-sampled to provide a sufficient data base to evaluate this potential contaminant pathway. I apologize for any misunderstanding that may have resulted from the State's communications on this matter and would welcome an opportunity to clear up any remaining confusion on this subject at future Feasibility Study working meetings.

RMA 89-1105

Concern 3: Structures Survey

The State agrees with the Meeting Summary concerning this issue and intends to submit recommendations on a sampling program for structures.

Concern 4: Re-Sampling Monitoring Well 20001

The minutes reflect the Army's commitment to re-sample well 20001 which historically has shown detections of Arsenal contaminants; however, the parties acknowledged at the meeting that this well may not be of sufficiently sound construction to enable the Army to obtain a reliable sample. It was therefore agreed that in such an event the well would be replaced or a new well drilled as nearby as possible and with the same monitoring interval as the old well. The Army subsequently informed the State at the July 6, 1989, RMA Committee Meeting that Well 20001 has been destroyed and cannot be re-sampled. Therefore, the State expects the Army to install a new well as agreed on June 6. Initially, the State recommends two sampling episodes to verify detections of RMA contaminants.

Additional Concern: Composited Phase I Soil Borings Conducted in the RMA Non-Source Areas

The State reiterated its position that due to the grid-based boring placement and the compositing of 0-1 foot and 4-5 foot intervals, the non-source area boring program is of little use in characterizing the nature and extent of contamination in the RMA non-source areas. The State insisted that data collected from this program be used sparingly, and specifically maintained that results from this program could not be relied upon to assert that those areas are uncontaminated. The parties acknowledged that the State has proposed two programs, the ground disturbance investigation and the surficial soil sampling program to provide a level of Remedial Investigation data to enable the Army to enter into the Endangerment Assessment/Feasibility Study phases of the investigation. The State's programs will not establish conclusively that the "non-source areas" are "uncontaminated"; nor do they necessarily preclude the need for additional sampling during Feasibility Study and site remediation activities.

At the meeting, and in response to the State's General Comment 8, representatives of the Army informed the State that detections during Phase I of the soil boring program were resampled during Phase II, and that these samples were not composited. However, upon reviewing the data, the State has identified numerous instances where detections were not confirmed by further sampling. We anticipate forwarding to you a list of the more troubling instances of unconfirmed detections with a proposal to re-sample and further characterize as necessary. This list will not be limited to the Eastern Study Area. The parties did agree that the issue would be revisited once the E.A. has been completed.

Additional Matters:

The final statement in the Summary is incorrect. It was agreed at the meeting that the Army would send a letter to the State memorializing the parties' agreements, and that the State would have an opportunity to respond as appropriate. Instead, this Summary was prepared and inserted into the SAR without the State's knowledge or consent.

I hope that this letter clarifies the State's positions regarding these matters and wish again to express the State's appreciation for the Army's willingness to attend the meeting and attempt to resolve the State's concerns. We look forward to resolving these issues.

Sincerely,

Jeff Edson
RMA Project Coordinator
Hazardous Materials and
Waste Management Division

JE:jmb
D:\WS2000\RMA\CAMPBEL3.LTR

Attachments

cc: Michael Hope, Esq.
John Moscato, Esq.
Chris Hahn, Shell
Edward J. McGrath, Esq.
Connally Mears, EPA
Bill Clemmons, EPA
Lt. Col. Scott Isaacson
Tony Truschel, GeoTrans

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S EASTERN STUDY AREA; CLARIFICATION OF STATE CONCERNS REGARDING SITE INADEQUACIES AND RECTIFICATION
AUGUST 1989

Concern 1: Adequacy of RI Data for sites ESA 3a, 3b, 3c

The State's concerns regarding perceived data gaps for sites ESA 3a, 3b, and 3c were addressed by the Army's commitment to perform additional characterization work as explained in its Meeting Summary. We anticipate that this work will be set forth in a task plan which the State will comment upon as appropriate.

Response: This work was set forth in the Draft Final Phase I FS Field Data Collection Task Plan, which the State reviewed and returned written comments on under cover of a letter addressed to Mr. Don Campbell - PMRMA from Mr. Jeff Edson - CDH, dated January 22, 1989. We believe this letter was misdated and should have been dated January 22, 1990. In addition, the Army plans to resample Well 05004 as part of the Phase II FS Field Data Collection Program. The State had previously requested that this well, which was installed and sampled as part of the RI Phase II program, be resampled.

Concern 2: Surface Water Ditch Samples

As a result of some apparent miscommunication, the State's concern number 2 has not been adequately addressed. The State noted in comment number 11 on the Eastern SAR that the sporadic detections of contaminants in First Creek and its tributaries merited additional sampling to confirm whether they constitute pathways of contamination. The Army suggested that the nine Comprehensive Monitoring Plan sampling stations along First Creek would satisfy this concern; however, as explained in comment number 7 on the proposed surface water CMP, it is the State's perception that sampling proposed in that plan will not close this data gap. Therefore, the State again requests that the First Creek and tributary ditches in Section 31 and 6 be resampled to provide a sufficient database to evaluate this potential contaminant pathway. I apologize for any misunderstanding that may have resulted from the State's communications on this matter and would welcome and opportunity to clear up any remaining confusion on this subject at future Feasibility Study working meetings.

Response: In their comments on the Draft Final Phase I FS Field Data Collection Task Plan, the State concurred with the Army plan to further investigate the Open Storage Yards (ESA-3), the Section 31 Storage Yard, the Section 5 Storage Yard, and the Section 6 Storage

Yard (Comment Hj of State's Comments on the Draft Final Task Plan (Volume 1) Feasibility Study Data Collection - December 1989), and noted that "[o]f particular interest to the State is the sediment samples to be collected from tributary ditches in Section 31." The State specifically indicated that "[t]his concern was conveyed to Don Campbell in an August 2, 1989 letter from Jeff Edson regarding ESA data gaps."

Concern 3: Structures Survey

The State agrees with the Meeting Summary concerning this issue and intends to submit recommendations on a sampling program for structures.

Response: Concern noted.

Concern 4: Re-Sampling Monitoring Well 20001

The minutes reflect the Army's commitment to resample well 20001 which historically has shown detections of Arsenal contaminants; however, the parties acknowledged at the meeting that this well may not be of sufficiently sound construction to enable the Army to obtain a reliable sample. It was therefore agreed that in such an event the well would be replaced or a new well drilled as nearby as possible and with the same monitoring interval as the old well. The Army subsequently informed the State at the July 6, 1989, RMA Committee Meeting that Well 20001 has been destroyed and cannot be resampled. Therefore, the State expects the Army to install a new well as agreed on June 6. Initially, the State recommends two sampling episodes to verify detections of RMA contaminants.

Response: Well 20002 was installed and sampled in the Phase I FS Field Data Collection Program. A second sample will be collected as part of the Phase II FS Field Data Collection Program, and results of both samplings will be made available to the State.

Additional Concern:
Composited Phase I Soil Borings Conducted in the RMA Non-Source Areas

The State reiterated its position that due to the grid-based boring placement and the compositing of 0-1 and 4-5 ft intervals, the non-source area boring program is of little use in characterizing the nature and extent of contamination in the RMA non-source areas. The State insisted that data collected from this program be used sparingly, and specifically maintained that results from this program could not be relied upon to assert that those areas are uncontaminated. The parties acknowledged that the State has proposed two programs, the ground disturbance investigation and the surficial soil sampling program to provide a level of Remedial Investigation data to enable the Army to enter into the

Endangerment Assessment/Feasibility Study phases of the investigation. The State's programs will not establish conclusively that the "non-source areas" are "uncontaminated", nor do they necessarily preclude the need for additional sampling during Feasibility Study and site remediation activities.

At the meeting, and in response to the State's General Comment 8, representatives of the Army informed the State that detections during Phase I of the soil boring program were resampled during Phase II, and that these samples were not composited. However, upon reviewing the data, the State has identified numerous instances where detections were not confirmed by further sampling. We anticipate forwarding to you a list of the more troubling instances of unconfirmed detections with a proposal to resample and further characterize as necessary. This list will not be limited to the Eastern Study Area. The parties did agree that the issue would be revisited once the E.A. [sic] has been completed.

Response: Concern noted. Both the ground disturbance and surficial soil investigations were carried out, and are summarized in Appendix D of the RISR. Results of both programs were released in the Final Ground Disturbance Investigation Data Summary Report (EBASCO, 1990/RIC 90247R01) and the Final Surficial Soil Investigation Data Summary Report (EBASCO, 1991/RIC 91121R01).

Additional Matters:

The final statement in the summary is incorrect. It was agreed at the meeting that the Army would send a letter to the State memorializing the parties' agreements, and that the State would have an opportunity to respond as appropriate. Instead, this summary was prepared and inserted into the SAR without the State's knowledge or consent.

Response: The State's comment is noted.

Appendix F5.2

Southern Study Area

Remedial Investigation Summary Report

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH

4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

Roy Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

November 10, 1989

Mr. Donald Campbell
Office of the Program Manager
Rocky Mountain Arsenal
AMXRM-PM, Building 111
Commerce City, CO 80022-2180

Re: State's Proposal to Improve the Remedial Investigation for the Southern Study Area

Dear Mr. Campbell:

Enclosed is the State's proposal to improve the Remedial Investigation for the Rocky Mountain Arsenal Southern Study Area (SSA). As State personnel have previously informed you, the significant data gaps that remain, based upon the RI conducted to date, must be rectified to ensure that the nature and extent of contamination in the SSA is fully defined. Unless the data gaps are filled, the Feasibility Study could result in the selection of an inadequate remedy based upon insufficient data.

This document was prepared based upon the State's review of the Southern Study Area Report (SSAR), Army responses to State comments on the SSAR and the SSA component of the Onpost Exposure Assessment.

This proposal prescribes a "limited" data collection program to address "significant data gaps" identified to date in the remedial investigation. This proposal does not specify all the data which will need to be collected to ensure a comprehensive Feasibility Study (FS) for the SSA.

Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Non-Source Area Investigation;
- the Structures Survey;
- the Methylene Chloride detections found during the remedial investigation;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance/Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

RMA 89-1679 1/2

As always, the State is willing to meet and work with the Army to rectify the significant RI data gaps for the SSA. If you have any questions, please call me.

Sincerely,

Jeff Edson

Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

JE/cf

cc: Michael Hope
Chris Hahn
Edward McGrath
Tony Truschel
LTC Scott Isaacson
Bruce Ray
John Moscato, Esq.
Connally Mears

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S PROPOSAL TO IMPROVE THE REMEDIAL INVESTIGATION FOR THE SOUTHERN STUDY AREA

NOVEMBER 1989

Comment 1: SSA Nonsource Area Characterization

The State has prescribed two programs to provide a minimum data base to enter the Endangerment Assessment and Feasibility Study phases of the RI/FS program: the surficial soil sampling program and the ground disturbance program. The State provided a list of ground disturbances to be investigated in a November 28, 1988 letter to Mr. Donald Campbell. The State understands that the surficial soils program is complete although data from that program have not yet been received. The State was also informed at the November 2, 1989 RMA Committee Meeting that the Army has also completed its field work for the ground scar program. The State had hoped and expected to have substantial participation in the screening of those sites proposed for investigation. Unfortunately, we were not given the opportunity. However, we are looking forward to receiving a detailed report explaining the investigation undertaken by the Army and setting forth the Army's rationale for dismissing a substantial number of proposed sites from that investigation. Mr. Kevin Blose assured the State at the Committee Meeting that such a report would be prepared and conveyed to the State.

In addition to these programs, the State requests that all significant contaminant detections found in the Phase I boring program be verified, and further investigated, as appropriate. As indicated in the cover letter to this document, the State's analysis of nonsource area detections indicative of the need for further investigation will be presented under separate cover.

Response: As noted in previous responses to State comments regarding additional investigations in Nonsource areas, Phase II programs were undertaken where Phase I analytical data or previously unidentified historical information or field observations indicated some potential for contamination. The surficial soil sampling and ground disturbance programs were intended to assess the degree and types of potential soil contamination at selected nonsource area locations, and support the development and assessment of feasible remedial actions. These sampling programs are considered supplemental to previous nonsource area studies but are still basically independent of past sampling efforts.

The Army believed that the organizations and State did reach consensus on all major points regarding field activities and that the State was fully apprised of any changes to the ground disturbance program. Results of that program were released in the Final Ground Disturbance

Investigation Data Summary Report, Version 3.1 in April 1990 (EBASCO, 1990/RIC90247R01).

Comment 2: South Tank Farm Plume

In the Southern Study Area Report (SSAR), State General Comment 3 (Appendices), the State indicated that the potential Volatile Halogenated Organics (VHOs), primarily chloroform and chlorobenzene, and Volatile Aromatic Organics (VAOs), primarily benzene, groundwater plumes are migrating towards and may be impacting Lake Ladora. Since presenting this comment, additional data incorporated from the South Plants Study Area Report (SPSAR) indicates that VAO and VHO plumes are not completely or properly characterized. Specifically, the following significant data gaps have been identified:

a. The extent of VHO contamination in WBZ 2 and 3 has not been fully investigated. Based on the following observations:

   i) the lateral extent and magnitude of the VHO plume in Water Bearing Zone 1 (WBZ 1);
   ii) the downward vertical gradients in SPSA-1 (Central Subarea) and the South Tank Farm SPSA-2 (Southern Subarea), probable sources for the VHO and VAO plumes, respectively; and
   iii) the fact that the only sampling point in Section 2 south of the SPSA-SSA boundary and immediately north of Lake Ladora had a VHO detection in the range of 10-100µg/l.

   It is probable that a VHO plume is migrating within WBZ 2 (and possibly WBZ 3, though no wells were sampled in Section 2 within this zone) southward from SPSA towards Lake Ladora. The extent of contamination in this zone must be characterized.

b. Figure SPSA 3.3-3 (SPSAR) indicates that a second VHO plume originates in the vicinity of the center of SPSA-2b. The plume is migrating towards the southeast, and has concentrations equivalent to those of the southwest-trending plume at the SPSA-SSA boundary. The Army has not discussed the potential for VHO plume migration to the southeast, and the resultant possible impact on Lower Derby Lake. No wells in Section 1, downgradient of the SPSA VHO plume, were sampled for VHOs in WBZ 1 or 2 (the two wells sampled in WBZ 1A-1, Figure SSA 2.3-1 in the SSAR, appear to be crossgradient from the plume as it is presented in Figure SSA 3.5-3). The presentation of a single VHO plume in Figure SPSA 3.5-1 contradicts both the 2-lobed VHO plume presented in Figure

SPSA 3.3-3, and the potentiometric contour maps in Figures SPSA 1.5-5 and 1.5-7.

c. Figure SPSA 3.3-8 indicates that a second VAO plume originates in approximately the same location as the northwest-trending VHO plume, in the vicinity of SPSA-2b. The VAO plume is migrating towards the southeast, and plume concentrations are equivalent to those of the south-west-trending plume in the SPSA-SSA boundary. Very high benzene concentrations, greater than 10,000 µg/l, were consistently detected at the SPSA-SSA boundary in WBZ 1 (Figure SSA 2.3-6), yet no wells were placed immediately downgradient of the detections or upgradient of Lower Derby Lake (again, the two wells sampled in WBZ 1A-1, Figure SSA 2.3-5, appear to be cross-gradient from the plume as it is presented in Figure SPSA 3.3-8). The presentation of a single VAO plume in Figure SSA 3.5-1 contradicts both the 2-lobed VAO plume presented in Figure SPSA 1.5-5 and 1.5-7. The Army stated in the SPSAR (page 2-37) that "absolute concentrations [of VAOs] generally increased by one order of magnitude between 1979 and 1988." Therefore, the potential impact of this plume on Lower Derby Lake must be characterized.

It appears that the Army has completely mischaracterized the southeast-trending VHO and VAO plumes migrating from SPSA-2b, across the SPSA-SSA boundary and towards Lower Derby Lake. Plume definition in all three water-bearing zones, but especially WBZ 1, is necessary. Additionally, the extent of VHO and VAO contamination in WBZs 1 and 2 in the vicinity of Lake Ladora downgradient of SPSA must be investigated. This can be done by sampling properly-screened and completed wells currently in place, or by installation and sampling of new wells sited specifically for VHO and VAO plume definition in Sections 1 and 2. The State has received the Shell Letter Technical Plan for the Remediation of Other Contaminant Sources IRA, South Tank Farm Plume (11/3/89), and will be providing comments on the field plan based on the goal of VAO and VHO plume characterization. The State again requests that sources of the VHO and VAO plumes be characterized in the South Tank Farms Hot Spot IRA. This is especially significant given the order of magnitude increase of VAO concentrations in groundwater between 1979 and 1988, and the resultant potential impacts on the Lower Derby and Ladora Lakes.

Response: (a) The need for additional investigations in this area will be addressed by the FS.

(b) In analyzing a "second VHO plume," it would be more appropriate to compare data from the same time period. The figure referenced in this comment (Figure SPSA 3.3-3) uses 1979 and 1983 data to show the two lobes of a VHO plume, whereas Figure SSA 3.5-1 uses data from 1987 and 1988. Figure SPSA 3.3-4 uses 1988/1989 data to show a more recent configuration of the VHO plume. This configuration correlates well with the one shown in Figure SSA 3.5-1; moreover, Figure SPSA 3.3-4 only shows an inferred southeastern trending lobe at 10 µg/l of the VHO plume.

In response to the comment that "no wells in Section 1 were sampled for VHOs in WBZ 1 or 2", please see Figure SSA 1.5-1, SSA 2.3-1, and SSA 2.3-2. Ten wells in Section 1 of the SSA were sampled in WBZ 1A-1 (see Figure SSA 2.3-1) and are <u>downgradient</u>, not cross-gradient from SPSA VHO plume (see Figure SSA 1.5-5 for a depiction of the groundwater flow). Two wells in Section 1 were sampled in WBZ 2 (see Figure SSA 2.3-2) and are also downgradient of the VHO plume. When comparing the most recent and contemporaneous data from the two study areas, a "second VHO plume" would not be inferred.

(c) A second southeast trending VAO plume does not exist; however, there is a small lobe of the VAO plume that trends to the southeast which is contained entirely within the SPSA. The outer border of this lobe contains VAOs at a concentration of 100 µg/l, and is still contained within the SPSA. Five wells (01582, 01028, 01047, 01030, and 01031) in Section 1 of the SSA in WBZ 1A-1 are located directly downgradient of this lobe (see Figure SSA 1.5-3 for well locations and again, see Figure SSA 1.5-5 for a description of the groundwater flow). The potentiometric contour maps referenced in this comment only show trends for the SPSA; it is preferable to reference SSA potentiometric and groundwater contour maps that show trends in the SSA.

The "absolute concentrations" of the VAO plume have changed between 1989 and 1988; likewise it appears that the configuration of this plume has changed somewhat in this time period. However, at the time of the RI investigation of this plume, no VAOs were detected in wells downgradient of the plume.

The FS is planning to sample Wells 01582, 01049, 01578, 01579, 01580, 01581, and 01588 as part of the Phase II FS Field Data Collection effort. In addition, a new monitoring well will be installed 500 feet east of Tank 464B.

Comment 3: Better Characterization of Site 11-1 (Buried lake sludge)

Site 11-1 was used as a disposal site for OCP- and mercury-containing sludges from Lake Ladora, and possibly Upper and Lower Derby Lakes. the following are inconsistencies and inaccuracies presented in the Army's responses to comments for the SSAR:

a. Only three of the trenches in 11-1 (figure 11-1-2, pg 3, 11-1 CAR) had borings located adjacent to them in the Phase I investigations, no borings were completed in any of the three trenches;

b. Because OCPs were not detected <u>outside</u> of the trenches in the Phase I programs, OCPs were not sampled for in Phase II, despite the fact that lake sludges were known to have been contaminated with pesticides;

c. Borings 3 and 4, <u>not</u> located in any trench, had mercury detections in the 0-1' and 7-8' intervals respectively;

d. A Geraghty and Miller boring in the northeastern section of the site had a dieldrin detection;

e. Monitoring well 02011 is generally downgradient of Site 11-1; (see Army response to State specific comment 22, SSAR, pg. 12/16), but is <u>not</u> along the same flowpath. Therefore, despite the Army assertion, contamination from Site 11-1 is not likely to be detected in Monitoring well 02011.

Therefore, despite the Army's contention that "the nature and extent of contamination (has been) adequately defined" (see Army response to State Comment 22, SSAR), the site has not been sufficiently characterized. Based upon this insufficient data the Onpost Exposure Assessment has recommended this site for the no-action alternative. To obtain adequate information for the Exposure Assessment and the Feasibility Study, the following deficiencies must be corrected:

a. Because dieldrin and mercury were detected in the northern section of Site 11-1, it appears that Lake Ladora sludges have been disposed of by land application as well as in the trenches; therefore, the areal and vertical extent of the sludge contamination must be determined;

b. Despite the Army's contention in Site 11-1 (pg 9, final paragraph), the Dames and Moore study <u>did</u> detect aldrin, dieldrin, and endrin, and tentatively identified chlordane, DDD, DDE, phathalates and diethylbiphene in Site 11-1 soils (Rocky Mountain Arsenal Southern Tier Contamination Survey, 1985, pg. 4-7); therefore, a resampling program for OCPs at this site is required;

c. The Dames and Moore study delineated three contamination zones (Rocky Mountain Arsenal Southern Tier Contamination Survey, 1985, pg. 4-11), all of which must be characterized by the Army;

d. Surface waters drain to both Lake Ladora and a local depression just south of the site (Site 11-1 CAR, pg.5). Sediment samples must be taken from the depression, and surface waters sampled in order to survey this area for possible contamination.

Response: The buried lake sludges were presumed contaminated with OCPs at the inception of the RI investigations; consequently, Phase I samples were collected from areas peripheral to the buried sludges. OCPs were not detected in these samples. However, on the basis of mercury contamination identified at the site during the RI and its areal and vertical extent towards the site's outer boundaries and lowest anticipated depths of emplacement, and inference was made that any volume of soils bearing potential contamination by OCPs was already accounted for by the incident mercury contamination. On that basis the Army concluded, and continues to maintain, that the RI at this site is complete. Additional soil sampling within the buried lake sediment sites will be addressed by the FS in the Soil Subcommittee meeting format. If specific action levels and remediation technologies for soils developed during the FS are markedly different for OCPs and mercury reassessment of this area may be appropriate.

Several inaccuracies and inconsistencies were identified in the State's comments, notably:

Comment 3a: Three Phase II borings were located in trenches where buried sludges were presumed to be disposed. Results of the analyses found mercury at depths ranging from 4 ft to 10 ft, and at concentrations ranging from 0.055 to 0.71 µg/g. Mercury was detected above indicator level (0.1 µg/g) at several Phase II locations.

Comment 3b: OCPs were not analyzed during the Phase II investigation on the basis of (1) no Phase I detections of OCPs and (2) inconclusive evidence from the Dames and Moore study regarding OCP contaminant occurrence. Standard procedure for Phase II investigations was to evaluate the site on the basis of Phase I analyses or additional historical data that came to light following the Phase I investigation. As noted earlier, OCPs were presumed to be present at this site, but at concentrations below the Phase I CRLs.

Comment 3c and 3d: Comments are noted, but it is unclear why the State considers these facts inconsistent with conclusions presented in the SSAR (see preceding responses).

Comment 3e: Well 02011 is not only downgradient of "Site 11-1", it is also along the same flow path for groundwater in this area (see Figure SSA 1.5-5 for general groundwater flowpaths). Samples from this well, and others within one-half mile downgradient of the site, did not contain OCPs. In addition, Well 11006 will be sampled in phase II of the FS Field Data Collection Program.

Finally, in response to States final four comments:

(a) The State's conclusion that "land application" of "Lake Ladora sludges" occurred is purely speculative. In fact, very little is known about the engineering methods used to dispose of the buried sediments. The Army maintains that, for the purposes of the RI, the areal and vertical extent of contamination has been verified.

(b) The State is clearly mistaken in saying that Dames and Moore verified the presence of OCPs at Site 11-1. The paragraph in the Dames and Moore report referred to by the State was general in nature and in fact referred to contaminants found not just at Site 11-1 but two others investigated (12-1, Buried Lake Sediments, and 12-2, Rod and Gun Club Pond). Review of the chemical results at Site 11-1 (Dames and Moore, 1985/RIC85218R01, Appendix D.4) did not reveal the presence of any OCPs. Mercury was the only target analyte detected by Dames and Moore at this site, and was consistent with the results of the Phase I and II analyses for the RI. Groundwater samples from Wells 12006, 12007, and 12008 in the Rod and Gun Club pond vicinity will be collected during Phase II of the FS Field Data Collection Program.

(c) The three zones Dames and Moore identified are within or adjacent to site SSA-3a. The RI borings sampled in Phase I and Phase II were located in each of the three zones delineated by Dames and Moore. While the RI program may not have been as site intensive as Dames and Moore's for these three zones, they were investigated as part of the RI and were characterized, based on the RI results, in the SSAR.

(d) Surface water has not been observed in the depression located south of the Section 11 sediments. Four Phase I and II borings were drilled on the edge of this depression as part of the Section 11 Non-Source Area investigation. Phase II borings were triangulated around a Phase I boring where toluene had been detected in the nontarget fraction. Phase II results confirmed, by GC/MS methods, the presence of toluene in the 4 to 5 ft interval of one of the three borings. Neither OCPs nor mercury were detected in Phase I samples collected from this depression.

Comment 4: Uvalda Ditch DBCP Detections

In its response to State specific comment #28 on the SSAR, the Army has indicated that additional sampling will be conducted in this area to verify DBCP detections in Uvalda Ditch. The State assumes that this investigation will be done as proposed and will provide comments on the approach upon receipt of the technical plan.

Response: Uvalda Ditch was included in the Phase I FS Field Data Collection Program.

Comment 5: Ground Disturbance in Site 12-1 Trash Dump

The State requests that the Army investigate two features that may be indicative of RMA activities: a) two craters, one of which is located in the west-central and the other in southwest portion of the site, and b) a ground scar located along the northeastern half of the site. These disturbances could be appropriately addressed as part of the ground disturbance program and should be included, if not done so already.

Response: The intent of the ground disturbance program was to address potential contamination issues at previously uncharacterized locations. Therefore, the disturbances referred to by the State at Site 12-1 were not investigated as part of the ground disturbance program. Seventy-five soil samples were collected from 23 borings and several trenches excavated at this site during the RI. Contamination by OCPs, semivolatile halogenated organics (SHOs), and heavy metals was found to be widespread throughout the site, and encompassed all of the three disturbances noted by the State. Additional sampling at this site would not serve to further characterized this site, and is not warranted.

Comment 6: Upper Derby Lake, Havana Pond, Rod and Gun Club Pond Water Quality

In its response to EPA specific comment #9 on the SSAR, the Army indicates that water quality in lakes other than Lower Derby, Lake Ladora, and Lake Mary were not addressed because Upper Derby Lake, Havana Pond, and Rod and Gun Club Pond are not permanent bodies of water on RMA and are not as important from and ecological and recreational standpoint.

The State insists that this is a significant data gap. Documenting and assessing water quality in these less prominent lakes is important to determine an overall picture of contaminant presence and migration in the RMA lake system. Furthermore, lakes with intermittent presence of water still have ecological significance. The State, therefore, requests that water quality be determined for Upper Derby Lake, Havana Pond, and Gun Club Pond.

Response: All available surface water quality data was incorporated into the SSAR. The source of the data was Morrison-Knudsen (MKE), Holmes, Roberts and Owens' consultant on Shell's behalf. MKE felt that from an ecological standpoint, these intermittent water bodies had diminished value compared to other aquatic systems on RMA. The Army believes that, despite the intermittent nature of these water bodies, their ecological importance still must be considered. Currently, the CMP includes annual water quality investigations, usually during spring runoff, at all of these sites. This information can be used to supplement data needs identified in the water RI. Chemical analyses include all RMA target analytes as well as pH, conductivity, alkalinity, nitrates, and metals. The water levels in these water bodies are also monitored on a weekly basis.

Comment 7: Sporadic or Isolated Detections in the Denver Formation

It is the State's understanding that the Vertical Extent of Contamination (VEC) investigation will evaluate all Southern Study Area (SSA), Denver Formation sporadic or isolated contaminant detections. This study should examine historical records, well construction history, sampling and detection frequencies for each analyte, and temporal concentration fluctuations when analyzing detections. This investigation should also compare potential migration pathways across study areas (eg: VAO and VHO detections in the SPSA and SSA). If the evaluation of current data is inconclusive with respect to inclusion or exclusion of a given well and analyte in the VEC study, the well may need to be resampled for that analyte(s). The State anticipates that the study will include, but not be limited to, Denver Well 02038, in which an isolated DBCP hit was detected (see Army Response to EPA Specific Comment 68, SSAR Appendices).

Response: Historical records, sampling and detection frequencies for each analyte, and temporal concentration fluctuations were all addressed in the SSAR. All of the above were incorporated as part of the data presentations in Section 2 or discussed in the text of Section 2 of the SSAR. Well construction history was discussed in the Task 4 and 44 reports, which were also referenced in Section 2 of the SSAR.

As discussed in the response to EPA Comment 68, SSAR Appendices, the DBCP hit in Denver Well 02038 is "likely the result of inadvertent laboratory/field contamination or analysis error and do(es) not indicate actual groundwater contamination." The response to Comment 68 explains that because "DBCP was only detected at very low levels in only 1 of 4 samples from each well; these wells are not located near surface sources of DBCP contamination; and that analysis of samples from the shallower wells in these clusters did not detect DBCP; it is highly unlikely that this contamination was caused by downhole contamination during drilling or [is] due to faulty well completion."

Denver Formation groundwater data from the SSA were reviewed as part of the investigation of the extent of contamination in the Denver Formation. Results of that investigation are reported in Appendix B of the RISR.

Comment 8: Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Nonsource Area Investigation;
- the Structure Survey;
- the Methylene Chloride detections found during the remedial investigations;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance/Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

Response: Comment noted.

Appendix F5.3

North Central Study Area

Remedial Investigation Summary Report

15 Nov 89
12:30

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

Roy Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

November 10, 1989

Mr. Donald Campbell
Office of the Program Manager
Rocky Mountain Arsenal
AMXRM-PM, Building 111
Commerce City, CO 80022-2180

Re: State's Proposal to Improve the Remedial Investigation for the North Central Study Area

Dear Mr. Campbell:

Enclosed is the State's proposal to improve the Remedial Investigation for the Rocky Mountain Arsenal North Central Study Area (NCSA). As State personnel have previously informed you, the significant data gaps that remain, based upon the RI conducted to date, must be rectified to ensure that the nature and extent of contamination in the NCSA is fully defined. Unless the data gaps are filled, the Feasibility Study could result in the selection of an inadequate remedy based upon insufficient data.

This document was prepared based upon the State's review of the North Central Study Area Report (NCSAR), Army responses to State comments on the NCSAR, the NCSA component of the Onpost Exposure Assessment.

This proposal prescribes a "limited" data collection program to address "significant data gaps" identified to date in the remedial investigation. This proposal does not specify all the data which will need to be collected to ensure a comprehensive Feasibility Study (FS) for the NCSA.

Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Non-Source Area Investigation;
- the Structures Survey;
- the Methylene Chloride detections found during the remedial investigation;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance/Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

RMA 89-1678 1/2

As always, the State is willing to meet and work with the Army to rectify the significant RI data gaps for the NCSA. If you have any questions, please call me.

Sincerely,

Jeff Edson

Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

JE/cf

cc: Michael Hope
Chris Hahn
Edward McGrath
Tony Truschel
LTC Scott Isaacson
Bruce Ray
John Moscato, Esq.
Connally Mears

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S PROPOSAL TO IMPROVE THE REMEDIAL INVESTIGATION FOR THE NORTH CENTRAL STUDY AREA
NOVEMBER 1989

Comment 1. NCSA Nonsource Area Characterization

The State has prescribed two programs to provide a minimum data base necessary to evaluate non-source areas in the Onpost Endangerment Assessment and the early stages of Feasibility Study. These programs are the surficial soil sampling and the ground disturbance program, proposed in November 15, 1988 and November 26, 1988 letters to Mr. Donald Campbell, respectively. The State understands that the surficial soils program is complete although data from that program have not yet been received. The State was also informed at the November 2, 1989 RMA Committee Meeting that the Army has also completed its field work for the ground scar program. The State had hoped and expected to have substantial participation in the screening of those sites proposed for investigation. Unfortunately, we were not given that opportunity. However, we are looking forward to receiving a detailed report explaining the investigation undertaken by the Army and setting forth the Army's rationale for dismissing a substantial number of proposed sites from that investigation. Mr. Kevin Blose assured the State at the Committee meeting that such a report would be prepared and conveyed to the State.

In review of the NCSAR, the following ground disturbances, indicative of potential RMA spill or disposal activities, were identified:

a. Ground disturbance within Site 35-5 (State Specific Comment #8, NCSAR);

b. Undocumented pits in Section 35 (State Specific Comment #9, NCSAR);

c. Four ground disturbances located west of Basin A. Two of the four historical ground disturbances were later found to be associated with Site 36-13 and characterized by the Army. However, the remaining two disturbances, located within subarea NCSA-1d appear not to have been investigated to date; and

d. Network of small ditches thought to have been drainage diversions from the Sand Creek Lateral (State Comment #24, NCSAR).

> These disturbances must be investigated to assess if these areas are sources of contamination. This could be done under the Ground Disturbance Program [sic].
>
> In addition to the surficial soil sampling and ground disturbance programs, the State requests that significant contaminant detections found in the non-source area contamination assessments be verified, and further investigated, as deemed appropriate by the organizations. As indicated in the cover letter of this document, the State's proposal for additional investigation of specific non-source area contaminant detections will be provided under separate cover.

Response: 1. a. The ground disturbance referred to by the State appears to be the one investigated by the ground disturbance program as boring GD35010.

b. Boring GD35013 was located in a manmade depression between Basin B and the old unused caustic waste basin on the aerial photo examination and field inspections (1989). We believe this boring is located in the area of the "pits" referred to in State Specific Comment 9 on the NCSAR.

c. The two disturbances the State refers to are located within Site NCSA-1d, an area including the old liquid storage pool for South Plants runoff. Because these disturbances are within a recognized SAR site, as shown on Plate RISR 2.0-1, Remedial Investigation Contaminated Soil Sites at Rocky Mountain Arsenal (the "Pink Map"), they were not included in the ground disturbance program. Inclusion on the Pink Map was one criteria for exclusion from the ground disturbance program.

d. The ground disturbance program evaluated the small ditches referred to by the State. Boring GD35012 is believed to be located at the extreme western terminus of the central of the three ditches. Review of the Phase II Data Addendum for Site 35-7 shows that two Phase II borings, 5591 and 5592, were located along the feeder ditch and the southern of the three small ditches, approximately 40 ft downstream of the headgate on the Sand Creek lateral, and on the feeder diversion ditch approximately 340 ft downstream of the headgate, respectively. Lead was detected in both borings in the 0-1 ft interval above indicator level. Chromium, copper and zinc were also detected, but within indicator levels. DDE was detected in the 0-1 ft interval of boring 5591 at 0.5 ppm, but was not detected further downstream in the drainage ditch network. The NCSAR classified the Sand Creek lateral as a Category 3 source (contributions to groundwater).

The State's final request and intent to provide additional proposals for nonsource areas under separate cover is noted.

Comment 2. Better Definition of Alluvial Ground Water Contamination in Sections 34 and 35 Apparently Emanating from the South Plants

The chloroform plume migrating northwest from the South Plants is not defined at this point in the remedial investigation representing a significant data gap.

The Army's response to State comments regarding this data is insufficient to adequately address this plume. The Army has proposed to use two cluster wells installed under Task 44, 35087-35089 and 34012-13 to aid in defining the source of the chloroform plume. However, monitoring wells 34012, 34013, and 35089 are completed in the Denver formation and therefore will not be useful in delineating the plume in the unconfined alluvial flow system where the plume is present (1988 CMP, Figure 4.3-4). Monitoring wells 35089 and 35088 were not analyzed for chloroform in the FY88 CMP. The wells, located in the southwestern part of Section 35 (1988 CMP, Figure 4.3-3) may help delineate the southern extent of the chloroform plume if they are sampled in future episodes of the CMP, but these wells do not appear to be located along or near the main axis of the plume.

Therefore, the State again proposes that unconfined flow system monitoring wells be installed in Section 34 and 35 to delineate the chloroform plume. Characterization of the plume and ground-water flow path will require the greatest density of well locations to be sited in the central and northwestern portions of Section 35 and the northeastern part of Section 34. Borings associated with the monitoring wells may also help to define the structure of the major paleochannel trending to the northwest through the two sections (see State Specific Comment #14, NCSAR). The State is available to work with the Army in locating these monitoring wells.

Response: The FS is planning to install two new clusters of wells in Section 35 to investigate the chloroform plume. These will be installed during the Phase II FS Field Data Collection Program and will be sampled at least twice.

Comment 3. Characterization of Chemical Sewer Line Feeding the Lime Settling Ponds

As documented in the Final CAR, Chemical Sewers - North Plants and South Plants (page 44 and Plate CS-SP-1), the original (30 inch?) chemical sewer line feeding the Lime Settling Ponds from South Plants is still in place; and despite the Army's claim to the contrary, soils surrounding the feed line were not characterized in either the Site 36-4 Phase I and II investigations, or in Task 10. In the 36-4 Phase I CAR, Boring 3185 was located just south of a manhole hypothesized to be associated with the abandoned feed line.

Therefore, because the location of the lines was not known to the Army at that time (4/87), and was not presented in the Phase II investigation or in the NCSAR, it is difficult for the State to understand how "soils surrounding this pipe were adequately characterized during the Site 36-4 Phase I and II investigations (Army Response to State Specific Comment #25, NCSAR). The line is still in place; the outlet, though plugged with brick and mortar, was observed to be leaking, and the soils have not been investigated. The contamination in and around the chemical sewer line remains a potential source of contamination to ground water. The surrounding soils must be characterized.

Response: The State's comment contains an error in reference; the 36-4 Phase I CAR does not show the location of, or data collected from Boring 3185; such information was presented in the 36-20 Phase I CAR (p. 9, Fig. 36-20-5). Soil samples were collected from soils in the vicinity of the feed line referred to by the State. Borings 3137 and 3133 (36-4 Phase I CAR), 3185 (36-20 Phase I CAR), and 3428 (36-4 Phase II CAR) were apparently located within approximately 50 feet of the feeder line, although its precise location is uncertain. The entire area is characterized as a Category 3 source on the basis of overall RI data results. Consequently, the feeder line and the surrounding soils are within areas which require remediation. The FS will address the feeder line as part of the evaluation of remedial alternatives for the South Plants chemical sewers. If removal of the lines is the selected alternative, sampling will be conducted at that time.

Comment 4. Effectiveness of the Northwest Boundary Containment System

The numerous relevant concerns about the Northwest Boundary Containment System (NWBCS) represent a significant data gap at this point in the RI/FS. The Army response to the State's General Comment #3 (NCSAR Appendices) was that a comprehensive evaluation of the NWBCS to the level that the State requests is beyond the scope of the NCSAR. The State did not expect such evaluation in the NCSAR; however, such an evaluation is necessary to determine the nature and extent of contamination in this area. Recent communications from the Army indicate that it intends to undertake such investigations, apparently in the context of a NWBCS Improvements IRA. The State will provide comment on this program upon receipt of the technical plan.

Response: Comment noted. The Draft Final Implementation Document for the NWBCS Short-Term Improvements IRA was released in May 1990 and reviewed by the State. Construction on the system extension is now completed. The Proposed Decision Document for the NWBCS was released in June 1991. The State has opportunity to comment on that document.

Comment 5. TX Disposal Wells in Sections 23 and 24

The State anticipates that all TX disposal wells will be investigated under the Task 37 Abandoned Well Program to determine whether they have been adequately abandoned. This specific task was agreed to by the Army (see Army response to State Specific Comment #6, NCSAR).

Response: The Abandoned Well IRA reviewed the TX disposal wells to determine if they had been adequately abandoned. Every well located was closed according to the procedures outline in the technical plan for the Abandoned Well IRA. Details of the TX well review and closure actions are included in the Final Rocky Mountain Arsenal Abandoned Well Closure IRA Report, Version 3.0 (Weston, 1990/RIC 90072R07) which was made available the the State.

Comment 6. Potentially Contaminated Water from the North Bog Sprayed on the Areas of Sections 26 and 23

At this point in the Remedial Investigation, the Army does not know the magnitude or the extent of contamination, if any, resulting from the spray disposal of water from the North Bog (see State Specific Comment #5, NCSAR). Therefore, these areas must undergo further investigation.

A surficial soil sampling program should be developed for these specific areas. The Phase II shallow soil sampling program around Basin F and the State's proposed surficial soil sampling program may be able to shed light on contamination in this area, but only if the samples are collected in areas of suspected spray disposal. If so, they may be used as an initial screening. Note that neither of these programs were designed to assess this particular contamination; instead the State's surficial soil program was designed to detect windblown contaminants emanating from the known source areas.

Response: Comment noted. The surficial soil sampling program results for Sections 23, 24, and 26 show OCP contamination in 0-2 inch soils in the area referred to by the State, where North Bog waters were apparently sprayed. Based on the development of applicable, or relevant and appropriate requirements (ARARs), Exposure Assessment results, and the remedial alternatives proposed by the FS, the Army may consider additional surficial soil data collection efforts.

Comment 7. Basin F, the waste pile, the tank farm, Pond A and Pond B, which are all located in Section 26 of the North Central Study Area (NCSA), are RCRA/CHWMA hazardous waste management units. CHWMA is independently applicable to all hazardous waste management units at the Rocky Mountain Arsenal.

The Basin F Interim Response Action is only an interim action. The cover system will only be effective for a short-term period. Significant amounts of contaminated soils are present in the Basin [sic], both within and outside of the wastepile. In order for the closure of Basin F to provide adequate protection of human health and the environment, additional investigations may be warranted. The State will supply the Army with specific comments, concerns, and requirements under separate cover.

Response: The Army notes that, as a result of the Basin F IRA, technically Basin F no longer exists, and reference should properly be made to the former basin. The Basin F IRA initiated in July 1986 and implemented between February 1988 and July 1989 is one in a series of IRAs which are being performed at Rocky Mountain Arsenal (Arsenal) as part of the remedial action process developed pursuant to the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), as amended, 42 U.S.C. 9601 et seq. and the National Contingency Plan (NCP), 40 CFR Part 300, for the purpose of mitigating or preventing the spread of contamination, reducing actual or potential risks to human health and the environment, and expediting the clean-up prior to the completion of the final, comprehensive remedial plan. The Basin F IRA was performed pursuant to CERCLA Section 104, 42 U.S.C. 9604, and is designed to be consistent, to the maximum extent practicable, with the final response actions selected for the Arsenal. The process for the remediation of contamination at the Arsenal is set forth in the Federal Facility Agreement prepared pursuant to CERCLA Section 120, 42 U.S.C. 9620, the Technical Program Plan adopted under the Federal Facility Agreement, and the Settlement Agreement prepared pursuant to CERCLA Section 122, 42 U.S.C. 9622, which became effective February 17, 1989. Prior to February 17, 1989, the remedial action process at the Arsenal was governed by the terms of the proposed Consent Decree of February 1, 1988, and the RI/FS Process Document.

Comment 8. Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Non-Source Area Investigation;
- the Structures Survey;
- the Methylene Chloride detections found during the remedial investigation;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance/Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

Response: Comment noted.

Appendix F5.4

Western Study Area

Remedial Investigation Summary Report

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

1876

Roy Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

November 10, 1989

Mr. Donald Campbell
Office of the Program Manager
Rocky Mountain Arsenal
AMXRM-PM, Building 111
Commerce City, CO 80022-2180

Re: State's Proposal to Improve the Remedial Investigation for the Western Study Area

Dear Mr. Campbell:

Enclosed is the State's proposal to improve the Remedial Investigation for the Rocky Mountain Arsenal Western Study Area (WSA). As State personnel have previously informed you, the significant data gaps that remain, based upon the RI conducted to date, must be rectified to ensure that the nature and extent of contamination in the WSA is fully defined. Unless the data gaps are filled, the Feasibility Study could result in the selection of an inadequate remedy based upon insufficient data.

This document was prepared based upon the State's review of the Western Study Area Report (WSAR), Army responses to State comments on the WSAR, the WSA component of the Onpost Exposure Assessment, and the State's review of the Motor Pool and Railyard Classification Yard IRA Alternative Assessment Reports.

This proposal prescribes a "limited" data collection program to address "significant data gaps" identified to date in the remedial investigation. This proposal does not specify all the data which will need to be collected to ensure a comprehensive Feasibility Study (FS) for the WSA.

Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Non-Source Area Investigation;
- the Structures Survey;
- the Methylene Chloride detections found during the remedial investigation;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance/Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

RMA 89-1680 1/2

As always, the State is willing to meet and work with the Army to rectify the significant RI data gaps for the WSA. If you have any questions, please call me.

Sincerely,

Jeff Edson

Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

JE/cf

cc: Michael Hope
Chris Hahn
Edward McGrath
Tony Truschel
LTC Scott Isaacson
Bruce Ray
John Moscato, Esq.
Connally Mears

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S PROPOSAL TO IMPROVE THE REMEDIAL INVESTIGATION FOR THE WESTERN STUDY AREA
NOVEMBER 1989

Comment 1. Non-Source Area Characterization

The State has prescribed two programs to provide a minimum data base to enter the Endangerment Assessment and Feasibility Study phases of the RI/FS program: the surficial soil sampling program and the ground disturbance program. The State provided a list of ground disturbances to be investigated in a November 28, 1988 letter to Mr. Donald Campbell. The State understands that the surficial soils program is complete although data from that program have not yet been received. The State was also informed at the November 2, 1989 RMA Committee Meeting that the Army has also completed its field work for the ground scar program. The State had hoped and expected to have substantial participation in the screening of those sites proposed for investigation. Unfortunately, we were not given that opportunity. However, we are looking forward to receiving a detailed report explaining the investigation undertaken by the Army and setting forth the Army's rationale for dismissing a substantial number of proposed sites from that investigation. Mr. Kevin Blose assured the State at the Committee Meeting that such a report would be prepared and conveyed to the State. Without having reviewed the report and without having much familiarity with the Army's program as carried out, the State specifically requests that particular attention be given to the following ground disturbances in the WSA (see also EPA Specific Comment #31, Western Study Area Report (WSAR) Appendices):

I. Section 3

A. Ground stain in the southeast section of the Rail Classification Yard immediately north of Sixth Avenue (visible in 1948 aerial photograph);

B. Large light-toned fan-shaped ground scar southwest of Buildings 171 through 176 (visible in 1955 aerial photograph);

C. Two ground stains in the central portion of Section 3 (visible in 1970 aerial photograph); and

D. Ground scar at the intersection of the new railroad tracks and a north-south road in the southeastern corner of Section 3 (visible in 1975 aerial photograph).

II. Section 4

A. Trench T1 (standing liquid observed in 1948 aerial photograph);

B. Trench T3 and two T2 trenches;

C. Open Storage Yards OS1, OS2, OS3, and OS5;

D. Each of the three areas identified as ground stains (GST) in Section 4 Non-Source Area CAR (immediately north of T1, and immediately west of buildings 626 and 627);

E. North-trending ditch immediately north of WSA-6 (Site 4-6), east of Phase I Boring 37, and adjacent to "B" Street;

F. Westerly-trending ditch and surface depression north of OS3 and WSA-3 (Site 4-3);

G. Continuation of major drainage ditch from just north of WSA-6 (Site 4-6) to the northeast between WSA-4 (Site 4-4) and WSA-5 (Site 4-5); and

H. Two ground scars in SW corner of Section 4 (visible in 1955 aerial photograph).

In addition to these programs, the State requests that all significant contaminant detections found in the non-source area contamination assessment be verified, and further investigated, as needed and deemed appropriate by the organizations. As indicted in the cover letter to this document, the State's analysis of significant non-source area detections indicative of the need for further investigation will be presented under separate cover.

Response: The Final Ground Disturbance Investigation Data Summary Report, Version 3.1, and the Final Surficial Soils Investigation Data Summary Report, Version 3.1, were released in August 1990 and April 1991, respectively. Results of both investigations are summarized in Appendix D of the RISR. With respect to the ground disturbances listed by the State, the following information is presented:

I. Section 3

A. Remedial Investigation (RI) Boring 1503000050 was drilled and sampled in the area of this ground stain. No analytes were detected above their indicator limits.

B. Remedial Investigation (RI) Phase I Borings 1503000025, 1503000046 and 1503000049 were drilled and sampled in the area of this ground stain. No analytes were found above their indicator limits.

C. RI Phase I Boring 1503000024 was drilled in this area. No analytes were found above their indicator limits.

D. RI Phase I Boring 1503000028 was drilled in this area. No analytes were found above their indicator limits.

II. Section 4

A. The ground stain north of trench T1 was sampled in October 1989 under the ground disturbance program (Boring GD04005) at the request of the State. Trench T1 was included in the Phase I FS Field Data Collection Program.

B. Trenches T2 and T3 were sampled in October 1989 under the ground disturbances program (Borings GD04004 and GD04002, respectively).

C. Open Storage Yards OS1 and OS2 were sampled in October 1989 under the ground disturbances program (Borings GD04007 and GD04008, and GD04003, respectively). OS 3 was sampled during the RI and reported in the UNC-4 Phase I and II CARs (Borings 1504000022, 2204000044, 2204000045, and 2204000046). 1,1,2,2-Trichloroethylene was detected in the 0-1 ft sample from 2204000046. No other analytes were detected above their indicator levels in these borings. RI Phase I Borings 1504000025 and 1504000034 were drilled in OS 5. No analytes were detected above their indicator levels in these borings.

D. The ground stain north of T1 was sampled in the Phase I FS Field Data Collection Program. The other two ground stains are scheduled to be sampled in the Phase II FS Field Data Collection Program. (See State's Comment 2 below).

E. This ditch was sampled under the Phase I FS Field Data Collection Program in 1990.

F. This ditch was sampled under the Phase I FS Field Data Collection Program in 1990.

G. This ditch was sampled under the Phase I FS Field Data Collection Program in 1990.

H. These ground scars were sampled in October 1989 under the ground disturbances program (Boring GD04001).

Comment 2. Additional Soil Borings - Motor Pool Area (WSA-6)

Several ground stains and ground disturbances identified in aerial photographs do not appear to have been sampled during the Phase I soil boring program. Additionally, potential sources of contamination to groundwater, and isolated and/or high contaminant detections must be reinvestigated. The State proposes soil investigations for the following areas identified in the Site 4-6 Contamination Assessment Report:

Location	Potential Products/Contaminants
• parallel to and just east of railroad tracks west of building 627 and (foundation) 626	trimethyl benzene, naphthalenes, trimethyl and nonyl phenols, butoxyl ethanol, tridecane, tetrachloroethylene
• pit east of Building 627	trimethyl benzene, naphthalenes, trimethyl and nonyl phenols, butoxyl ethanol, tridecane, tetrachloroethylene
• southeastern corner of Building 625	paints, solvents, acids, thinners
• west and south of Building 631	TCE, chloroform, tetrachloroethylene
• ditch east of Building 631	TCE, chloroform, tetrachloroethylene
• south of Building 621	
• southeast of Building 624	caustics (oakite, zurco), chlorinated organic solvents, HCs, TCE, tetrachloroethane
• underground gasoline lines from storage tanks to Building 629	non-target aromatic, cyclic, and chlorinated HCs, alkanes
• major drainage ditch west of Building 627 to northern boundary of WSA-6	

(of the 6 borings placed in the ditch adjacent to 627 during Phase I study, Boring 4 is too far upgradient of 627 to be affected by Motor Pool discharges. Only Borings 5 and 9 were completed to depths greater than 20 feet, and <u>both</u> of these borings - separated by over 300 feet - had tetrachloroethylene detections at 20 feet).

<u>Location</u>	<u>Potential Products/Contaminants</u>
• adjacent to railroad tracks by Phase I Boring 38	aldrin (49 to 50 ft, 62 to 63 ft)
• adjacent to railroad tracks north of Building 624	high metal concentrations (Cd, Cr, As, Hg)

Response: With respect to each location, the Army notes the following:

• Parallel to and just east of railroad tracks west of building 627 and (foundation) 626	This area will be sampled during the Phase II FS Field Data Collection Program. (See State's Comment 1, part II.D above).
• Pit east of Building 627	This area will be sampled during the Phase II FS Field Data Collection Program.
• Southeastern corner of Building 625	RI Boring 23 was drilled in a ditch in this area. Pyrene or fluoranthene was tentatively identified at 0.2 µg/g, and chromium, lead, and zinc were above their indicator ranges. These constituents were at elevated concentrations only in the surface interval of the boring. A soil gas sample was collected from the southeast corner of Building 625 and analyzed for the chlorinated hydrocarbons that would indicate solvents, paints, or thinners. Soil gas concentrations decreased away from a source area northwest of Building 624, and did not indicate an additional source at Building 625. Therefore, no additional samples are needed in this area.

• West and south of Building 631; east of Building 631; south of Building 621	In all of these locations, chlorinated ditch solvent constituents are the contaminants of concern of listed by the State. These compounds were analyzed in soil gas samples collected across the motor pool site, and only one source was indicated to the northwest of Building 624. Solvent concentrations uniformly decrease away from this source, and no other sources are indicated in the areas listed. The source identified by soil gas sampling near Building 624 was investigated with soil borings and confirmed by groundwater monitoring wells. No additional sampling is needed in these other areas.
• Southeast of Building 624	No ground staining or wetness has been observed in this area since a 1948 photograph, and the soil gas program indicated no chlorinated organic solvent sources there. Caustics and hydrocarbons have not been analyzed for in this area, but floor drains in this building lead to the ditches to the west, which already have been sampled and discussed in the Western SAR.
• Underground fuel lines from tanks to Building 629	The FS will address removal and storage remediation of the underground fuel lines, including confirmation sampling during remediation.
• Adjacent to railroad tracks by Phase I Boring 38	Borings 2, 10, 17, 24, 25, and 39 were all drilled within 100 ft of Boring 38, and no aldrin was detected in any soil samples from these or other Motor Pool area borings except at depths of 50 ft and greater in Boring 38. Wells in this area are being monitored to confirm whether aldrin is present in the soil and is migrating to the groundwater in this area. Therefore, no additional soil samples are needed.

• Adjacent to railroad tracks north of Building 624	Fourteen soil borings (Borings 3-10, 17,23-25, 38, and 39) have been drilled to characterize the elevated metals concentrations in shallow soils to the north of Building 624. The WSAR already has interpreted these metals levels to extend along the ditch throughout the site. Since the analytical results are consistent between borings, no additional samples are needed to confirm this characterization of the site. Additional sampling in the ditch to the north of the site is planned in the FS.

Comment 3. Better Definition of Groundwater Contamination Upgradient of WSA Source Areas

The Army continues to insist that off-post Alluvial [sic] sources of VHOs, VAOs and OCPs upgradient of the Motor Pool and Rail Classification Yard are potentially migrating on-post into these areas (CDH Specific Comment 9, EPA Specific Comments 55, 83, 95, 96, and 98, WSAR Appendices). Based upon historical and current data from the two Alluvial wells located upgradient of the sites, 03008 and 03011 (Plates WSA 1.5-4 and WSA 1.4-1, WSAR), these statements are unsubstantiated. The Army also references a "potential source of groundwater contaminants in an off-post area generally upgradient from RMA" as a site that "may be an example of the type of site that could contribute contaminants to WSA groundwater" (EPA Specific Comment 98, WSAR Appendices). These vague and unfounded statements cannot be substituted for complete characterization and mitigation of the contamination present at the Motor Pool and Rail Classification Yard. The State believes that alluvial contamination present beneath the two sites are directly related to RMA activities. If the Army continues to disagree with this conclusion, then additional data collection must be initiated to characterize groundwater migrating on-post upgradient of Sections 3, 4, and 9. The State proposes that 3 to 4 Alluvial aquifer wells be installed; one between "B" Street and Well 03011 along Sixth Avenue, a second bisecting the distance between Wells 03011 and 03008 along Sixth Avenue, and a third located just south of Sixth avenue along "B" Street.

Further characterization is also necessary for the TCE plume that appears to be entering RMA Section 9 from the south. The plume and flux across Section A-A' (Plate WSA 3.2-2) is based on data from three monitoring well clusters located along one inferred flow line (09008, 09009, 09011, 09012; and 09013, 09014). Rather than speculating on the width of this plume, the Army should implement a prudent monitoring well installation program for Section 9. The State proposes that monitoring wells be installed in the following locations:

A. Four (4) monitoring wells should be installed along the south boundary of Section 9. Two wells should be placed, one each, 150-200 feet on either side of monitoring well [sic] 09013 to better define the width of the TCE plume. Additionally, one monitoring well should be placed between the inferred edge of the plume and the east boundary of Section 9 and one well placed between the inferred edge of the plume and the boundary with the U.S. Post Office facility.

B. One monitoring well should be placed upgradient of the Motor Pool Area in Section 4 along the inferred groundwater flowline.

Response: The reference to a "potential source of groundwater contaminants in an off-post area generally upgradient of RMA" as a site that "may be an example of the type of site that could contribute contaminants to WSA groundwater," is in regard to a report the EPA released to the attendees at the April 13, 1989 Committee meeting at RMA. The report, prepared by Ecology and Environment for the EPA, indicated that a site at 49th and Havana Streets was an off-post source of trichloroethane contamination to groundwater (E&E, 1989, Preliminary Assessment for 49th and Havana Street, Denver, Colorado. TTD F08-8902-07. Prepared for the USEPA). This site is upgradient of and a potential contributor to on-post contamination at RMA.

The Army's position has been and remains that upgradient off-post sources may contribute to on-post contaminant detections. The data presented in the WSAR for Section 9 clearly indicate off-post sources of VHO contamination in the unconfined aquifer (see Plates WSA 2.4-1; WSA 3.2-2, and WSA 3.2-3).

The Army disagrees with the State's recommendation to install additional wells along Sixth Avenue and "B" Street upgradient of the Motor Pool area. Well 03011 should be regularly monitored, however. The Motor Pool area is recognized as a source to groundwater, and Well 03011 is situated upgradient along the flow path to Wells 04035, 04048, 04049, 04050, and 04051, where VHOs and VAOs were detected during the RI.

A. The Army disagrees with the State's recommendation that additional wells be installed along the southern border of Section 9 to define the width of the plume migrating on-post. Definition of the plume width at that location is not significant to determining remedial alternatives, if any, that the Army should instigate for this groundwater plume. The Army encourages the State and EPA to continue attempts to locate the source or sources of this VHO contamination which is entering RMA from the south. Monitoring of the unconfined aquifer wells in Section 9, and up- and downgradient of WSA-2 in Section 4, will continue to provide data to the FS for use in evaluating all options regarding remedial alternatives.

B. Both Well 03008 and Well 03011 were sampled in 1989. No OCPs or VOAs were detected in samples from these wells. Therefore, no additional investigations are needed in this area.

Comment 4. Sporadic Detections of Contaminants in Denver Formation Monitoring Wells

It is the State's understanding that the Vertical Extent of Contamination (VEC) investigation will evaluate all WSA Denver Formation detections of VHOs (chloroform, methylene chloride, 1,2-dichloroethane, and 1,1,2-trichloroethane; WSAR Section 3.0, page 3-39), VAOs (benzene, toluene, m-Xylene, o,p-Xylene and ethylbenzene; WSAR Section 3.0, page 3-50), benzothiazole (WSAR Section 3.0 page 3-56), OCPs (aldrin, dieldrin, isodrin, and endrin), and arsenic (WSAR Section 3.0, page 3-66). This study should examine historical records, well construction history, sampling and detection frequencies for each analyte, and temporal fluctuations of concentrations in analyzing isolated or questionable detections. The investigation should compare potential migration pathways across study areas (eg: OCP detections in the South Plants Study Area (SPSA) and the WSA). If the evaluation of current data is inconclusive with respect to inclusion or exclusion of a given well and analyte in the VEC study, the well may need to be resampled for that analyte(s).

Response: Denver Formation groundwater data from all study areas were reviewed as part of the investigation of the extent of contamination in the Denver Formation. Results of that investigation are reported in Appendix B of the RISR.

Comment 5. Under separate cover, the State will also provide the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- the Non-Source Area Investigation;
- the Structures Survey;
- the Methylene Chloride detections found during the remedial investigation;
- unknown and tentatively identified compounds;
- the Army's current Quality Assurance Quality Control (QA/QC) reporting program; and
- the Biota Remedial Investigation.

Response 5: Comment noted.

Appendix F5.5

Central Study Area

Remedial Investigation Summary Report

12:45

STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220
Phone (303) 320-8333

1876

Roy Romer
Governor

Thomas M. Vernon, M.D
Executive Director

March 2, 1990

Donald Campbell
Deputy Program Manager
Rocky Mountain Arsenal
AMXRM-PM Building 111
Commerce City, Colorado 80022-2180

Re: State Proposal for Rectification of Remedial Investigation Data Gaps in the Central Study Area

Dear Mr. Campbell:

Enclosed are the State's identified data gaps for the Central Study Area (CSA) of the Rocky Mountain Arsenal along with general proposals for improving the remedial investigation (RI) for this area. As these proposals are necessarily broad, we recommend that the parties meet to discuss these concerns, and that the Army address these data gaps in a workplan to be circulated for review and comment prior to commencement of additional field work. As we have previously stated for other data gap packages, these proposals for additional work represent the minimal field investigations necessary to define broadly the nature and extent of contamination in the various study areas. Further work may be necessitated based on the results of these investigations, or based on the requirements of the Feasibility Study.

The vast majority of data gaps identified in the enclosed comments pertain to the inadequate characterization of Section 36 trenches. The proposals for additional investigations are based upon the approach adopted by the Army in its Phase I and II investigations of this area. Thus, in completing the additional work suggested by the State, the Army will merely be satisfying the goals and protocols dictated by those programs consistently throughout the complex disposal area. Most likely, additional characterization would be necessary prior to a detailed Feasibility Study or selection of remedial alternative. Further identification of vertical and lateral extent of contamination may also be indicated based upon results of the State's proposed program.

The data gaps identified, and recommendations contained in this proposal supersede those previously provided as an appendix to the State's comments on the Army's Draft Alternative Assessment for the Complex Disposal Area. Under separate cover the State has provided analysis and proposals to address other RI concerns including:

RMA 90-0401 1/2

1. Structures

2. Methylene chloride detections possibly not attributable to laboratory contamination

3. Incomplete investigations of contaminant detections in "non-source" areas

4. Vertical extent of contamination in groundwater.

Matters discussed in those submittals may also pertain to the Central Study Area and should be addressed. In addition, the State may be submitting proposals for rectification of data gaps in the biota and air RIs. The State also anticipates proposing certain tentatively identified and unknown compounds for further analysis once it has received a response to its September 28, 1989, letter. Some of these compounds may be of issue in the Central Study Area.

The State would welcome the opportunity to discuss these matters with Army representatives at their earliest convenience. In the meantime, if you have any questions, please feel free to call.

Sincerely,

Neil Kolwey for

Jeff Edson
RMA Project Manager
Hazardous Materials and
  Waste Management Division

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Enclosures

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S PROPOSAL FOR RECTIFICATION OF REMEDIAL INVESTIGATION DATA GAPS IN THE CENTRAL STUDY AREA

MARCH 1990

Comment 1. Central Study Area Trenches

The Central Study Area (CSA) contains extensive, complex disposal areas. Much of the characterization presented in the Central Study Area Report (CSAR) is based on historical evaluation and aerial photography interpretation. The field investigations in the areas were limited and, in many cases, disposal areas were "characterized" by relying on the characterization of one trench to represent many disposal trenches.

The State believes that the CSA disposal areas remain a significant remedial investigation data gap. Based on review of information to date, the State has outlined each area where information is still lacking and a recommendation as to what needs to be done to complete an adequate RI characterization in accordance with the Army's Phases I and II programs. The State is available to work with the Army on these recommendations for additional work.

A. CSA - 1c Area

Trench and pit information collected prior to and during the Phase I CSA-1c (36-17N) program were based on extensive historical evaluation of aerial photographs, and field geophysical studies. The geophysical investigations used continuous magnetic and electromagnetic (EM) surveying to delineate possible patterns and trends indicative of trench-type disposal at the site. The Phase I geophysical study delineated seven areas, or anomalies, that represented probable trench disposal of wastes: A, B, C, E, F, G, and H. The Army acknowledged that only one Phase I borehole was completed in a trench (3086, Anomaly B), and that traditional Phase II methodologies were inadequate for the complex disposal site 36-17N (Site 36-17 Phase I CAR, page 62). Therefore, the Phase II program incorporated continuous trenching, grab samples (of excavated trench material), and borings (completed to 5 feet [ft] below bottom of trench). For purposes of this comment package, the State defines the term "pit/boring" to mean <u>trenching and subsequent boring</u> completed to 5 ft below the bottom of the waste trench.

Design of the Phase II program was based on the assumption that characterization of specific trenches in a given anomaly would adequately characterize all trenches in the anomalies. However, examination of

Table 36-17-II-1 (Phase II CAR 36-17), indicates that although contents of some trenches within an anomaly may be similar, any one trench is not representative of all trenches within that anomaly. This is particularly evident in the two anomalies with the highest trench excavation density (sampled by continuous trenching), C and H. Therefore, it is probable that material excavated in selected trenches in remaining anomalies may not be indicative of material buried in neighboring trenches. Additionally, locations of trenches excavated in Phase II did not always coincide with historical (aerial photographs) and Phase I geophysical data (e.g., Anomalies C and H). It is therefore apparent that this preliminary information cannot be relied upon to locate the boundaries of the trenches.

The 9 (and possibly 10, if pit/boring 3592 is included, see comment 1.A.v below) pit/borings which were completed in natural soils during the Phase II study cannot be used to characterize the trenches within the anomalies.

The following summarizes data gaps present in each anomaly within CSA-1c, and provides recommendations necessary to provide limited characterization of the trenches in the respective anomaly.

i. Anomaly A - The Site 36-17 Phase I CAR states (page 30) "Aerial photographs indicate more than 10 pits and trenches and two 200-ft long trenches oriented east-west (in Anomaly A). Geophysical results confirmed three trenches and indicate more potential disposal sites than previously noted" (emphasis added). Fourteen trenches and pits were identified in the Phase I geophysical study (Site 36-17 Phase I CAR, Figure 36-17-7).

The Phase II program consisted of only three pit/borings to investigate three of these trenches. However, only 1 pit/boring (3581) was completed in a trench; the remaining 2 pit/borings (3580 and 3582) were completed in natural soils (Site 36-17 Phase II CAR, Figure 36-17-II-1).

In the Spring 1989 field survey conducted by Woodward-Clyde Consultants, two exploratory trenches were excavated across the trench in which Phase II pit/boring 3581 was completed, further defining the boundaries of the trench located in the southeastern section of Anomaly A (Results of Field and Laboratory Investigations Conducted for the Remediation of Other Contamination Sources IRA, 11/89, Section 4.2.2.1).

Recommendation: The remaining thirteen trenches and pits in the anomaly must be characterized. This can be accomplished by pit/borings, grab samples of the waste materials, and documentation of all disposal trench contents encountered during excavation.

ii. Anomaly B - According to the Site 36-17 Phase I CAR (page 30), "Aerial photographs indicate ... at least four trenches (in Anomaly B) ... Geophysical results confirm the four trenches and indicate one or more additional trenches. All of the trenches, including a 7-ft deep open trench, appear to be about 200 ft long ...". Five trenches and two pits were identified in the Phase I geophysical study (Site 36-17 Phase I CAR, Figure 36-17-7). However, the Phase II program consisted of only two pit/borings to investigate this area.

Recommendation: The remaining three trenches and two pits must be characterized, utilizing pit/borings and grab samples of the waste materials. Disposal trench contents encountered during excavation should also be documented.

iii. Anomaly C - The Site 36-17 Phase I CAR states that (page 30) "At least five trenches ... were identified (in Anomaly C) in aerial photographs. Geophysical results confirmed the location of the trenches and suggested the presence of other trenches in adjacent areas" (emphasis added). Six trenches and three pits were identified in the Phase I geophysical investigation (Site 36-17 Phase I CAR, Figure 36-17-7). Four of the trenches were located in the northern section of the site and two in the south, with the trench axes oriented north-south (N-S).

The Phase II program consisted of a continuous trench crossing the northern section of Anomaly C, and actually identified six disposal trenches (Site 36-17 Phase II CAR, Figure 36-17-II-1) but possibly missed an easternmost trench (Site 36-17 Phase I CAR, Figure 36-17-7). One grab sample was taken from each of the six trenches. The program also included three pit/borings (3585, 3587, 3588), only two of which were completed in trenches (pit/boring 3588 was located in natural soils south of its original location 3586 due to a white phosphorus fire). The two southern trenches in Anomaly C were not investigated; the western trench due to the white phosphorus fire and the eastern trench due to the discovery of 55-gallon drums containing Lewisite (Site 36-17 Phase II CAR, Table 36-17-II-1).

Recommendation: To be consistent with the Army Phase II investigation, borings should be completed (to 5 ft below bottom of trenches) in the six northern trenches. Although pit/boring 3585 was completed in the same trench as grab sample 3606, that pit/boring was not located beneath the grab sample which contained significant concentrations of aldrin, dieldrin, isodrin, and arsenic and therefore cannot be used to determine the vertical extent of contamination beneath the grab sample. Accordingly, a boring should be completed to 5' [ft] below the bottom of the trench in the location from which grab sample 3606 was taken. Also, Table 36-17-II-4 chemical results, the location of pit/boring 3587 in Figure 36-17-II-1, and the uncertainty associated with depth to bottom of the easternmost trench shown in cross-section CC' (Site 36-17 Phase II CAR, Figure 36-17-II-1), indicate that pit/boring 3587 may not have been completed below the actual trench. This trench, therefore, should also be resampled. The continuous trench completed in the northern section of Anomaly C should be continued to the east to determine if an easternmost trench exists. The two large southern trenches must be characterized with pit/borings and grab samples of the waste materials. Additionally, disposal trench contents encountered during excavation should be documented.

iv. Anomaly E - Aerial photographs reviewed in the Phase I investigation indicated 4 to 7 pits in Anomaly E (Site 36-17 Phase I CAR, page 31), and the Phase I geophysical study identified 9 small, discrete pits (Figure 36-17-7). The Phase II program consisted of 3 pit/borings, all of which were completed in natural soils (Site 36-17 Phase II CAR, Figure 36-17-II-1 and Table 36-17-II-1).

Recommendation: It appears that none of the pits in Anomaly E have been characterized. This can be accomplished by completing two east-west trending continuous trenches, one across the northern half of Anomaly E (and the northern set of pits) and the second continuous trench across the southern half of the anomaly (and southern set of pits). Grab samples should be taken of the waste materials, borings completed below the bottom of the pits, and pit contents documented.

v. Anomaly F - The Phase I geophysical survey identified six small trenches and pits in Anomaly F (Site 36-17 Phase I CAR, Figure 36-17-7). The Phase II program consisted of three pit/borings to investigate this area (3590-3592). Pit/boring 3590 was completed in natural soils. According to Table 36-17-II-1, depth to trench bottom for pit/boring 3592 was 0.5 ft; also, no disposal contents were encountered during excavation, indicating that 3592 may also have been completed in natural soils (Site 36-17 Phase II CAR, Figure 36-17-II-1 and Table 36-17-II-1).

Recommendation: Five of the six trenches in Anomaly F have not yet been characterized. This can be accomplished by completing two east-west (E-W) trending continuous trenches, one across the northern two trenches and one through the southern three trenches shown in Figure 36-17-7 (Site 36-17 Phase I CAR). Borings should be completed below the bottom of the five trenches, grab samples collected of the waste fill material, and disposal contents documented.

vi. Anomaly G - The Phase I geophysical study identified four approximately 200-ft long N-S trending trenches in the central and eastern half of Anomaly G, and six small pits near the western edge of the site (Site 36-17 Phase I CAR, Figure 36-17-7). The area also appears to correlate to a site previously investigated by Moloney (1982; RIC # 85085 R01) which consisted of three N-S oriented trenches (Site 36-17 Phase I CAR, page 32). There is currently one open trench in Anomaly G, but it is unclear which of the four trenches identified in the Phase I geophysical study represents this trench.

The Phase II program consisted of two pit/borings (3602 and 3603). Pit/boring 3602 was completed in a surface burn, and pit/boring 3603 was completed in natural soils; no debris was encountered during excavation of the pits (Site 36-17 Phase II CAR, Table 36-17-II-1).

Recommendations: The open trench and 2-to-3 trenches identified in the Phase I geophysical study have not been investigated. Because of the uncertainty associated with location of the filled trenches with respect to the open trench, characterization of this area should include two E-W trending continuous trenches located on both sides of the open trench. If buried trenches are identified, grab samples should be taken of the waste materials, borings completed below the bottom of the trenches, and materials encountered during excavation documented. Additionally, a boring should be completed below the bottom of the open trench.

vii. Anomaly H - The Phase I geophysical investigation identified 10 trenches and 5 pits in Anomaly H (Site 36-17 Phase I CAR, Table 36-17-7). Eight of the 10 projected trenches, oriented E-W, were located on the western edge of the anomaly, ranging from the northern to southern boundaries of the site.

The Phase II program consisted of a N-S trending continuous trench completed in the western half of Anomaly H, which identified four (E-W trending) disposal trenches (Site 36-17 Phase II CAR, Table 36-17-II-1). Four borings were completed in the waste trenches (3596 to 3599), but boring 3599 was not analyzed due to probable mustard contamination. Pit/boring 3600 located a fifth trench in the eastern section of the anomaly. A possible sixth (E-W trending) trench located in the northeastern corner of Anomaly H (Site 36-17 Phase I CAR, Figure 36-17-7), was not investigated.

In the Spring 1989 investigation conducted by Woodward-Clyde Consultants, 17 exploratory trenches were completed in Anomaly H, and four exploratory trenches were completed just to the west of the anomaly (Results of Field and Laboratory Investigations Conducted for the Remediation of Other Contamination Sources IRA, 11/89, Section 4.2.2.3 and Figure 4-6). The investigation identified five E-W trending disposal trenches in the western section of Anomaly H, and one trench (previously unidentified) to the west of the anomaly.

Recommendation: Further characterization needs include: 1) placement of a boring in the southernmost trench to investigate contaminant distribution below the bottom of the trench (replacement boring for boring 3599 which was not analyzed in Phase II); and 2) a pit/boring in the northeastern corner of Anomaly H to locate the trench indicated by the Phase I geophysical survey. Additionally, in contrast to the five trenches identified in the Spring 1989 study, the continuous trench completed by the Army in the Phase II investigation identified only four disposal trenches; please explain this discrepancy.

B. CSA-1b Area

The Army and Hyman reportedly shared a joint trench disposal area north of Site 36-3 in Site 36-17S during the late 1940's and early 1950's. The site is probably "... adjacent to and north of site 36-3..." (Site 36-17 Phase I CAR, page 16) and may be evidenced by the ground disturbances apparent in aerial photographs taken from 1948 to 1965 (Site 36-17 Phase I CAR, page 17). Woodward-Clyde Consultants, in their review of six aerial photographs taken between 1948 and 1975, identified trenches in the northern portion of Site 36-17S (Final Task Plan, Volume I, Remediation of Other Contamination Sources, 6/89, page 5-4). Also, as summarized by the Army on page 3-20 of the CSAR: 1) the historical references to joint Army-Hyman contaminated waste disposal trenches; 2) the Phase I geophysical responses in the northern section of CSA-1b northern zone; and 3) the distribution of chlordane and DDE/DDT (Plates CSA 2.1-50 and 2.1-54, respectively), "confirm the field location for these trenches (CSA-1b northern zone, Figure CSA 3.2-1, CSAR). Additionally, the Army indicates in Figure CSA 3.2-1 (CSAR) that the entire northern zone of Site 36-17S may have been used as a trench-disposal area. However, no exploratory trenches or pit/borings were completed in this area during Phase I or II site investigations.

Recommendation: None of the trenches in the northern zone of Site 36-17S have been characterized. A geophysical investigation of all or part of this area was supposedly conducted during the Spring 1989 field study, but the area investigated was not depicted graphically and results of the study were not presented (Results of Field and Laboratory Investigations Conducted for the Remediation of Other Contamination Sources IRA, 11/89, Section 4.2.1.4). If the Spring 1989 geophysical survey incorporated the northern zone of Site 36-17S and data can be used to interpret trench locations, additional geophysical data are not necessary although any existing data should be transmitted to the parties without delay. If, however, geophysical data are not available for this area or available data are questionable, a second geophysical investigation will be necessary to delineate trench locations. Design of a pit/boring program, similar to that conducted in CSA-1c, should then be based on geophysical survey results, further examination of aerial photographs, and chlordane and DDE/DDT distributions. Depending on disposal trench orientation, the trenches can be investigated using continuous trenching, or transects across individual trenches, in addition to grab samples of waste fill material and borings. This program should also document disposal trench contents encountered during excavation.

NOTE:

The State has previously requested that the Army investigate pre-1952 joint Army-tenant disposal trenches located in the northern zone of CSA-1b (CSAR, Appendix CSA-F, State Comment 30). The Army stated in its response to State Comment 30 that "the ongoing hot spot IRA addressing the trenches in the CSA is currently investigating these (CSA-1b northern zone) trenches." In response to EPA Comment 37 (CSAR, Appendix CSA-F), the Army again states that "The characterization of probable burial trenches in this area in CSA-1b northern zone, is being addressed in the Hot Spot IRA presently being conducted by the Army." The State therefore assumes that characterization of these trenches is being addressed in the Complex Disposal Trenches IRA, and requests a summary of all data collected to date regarding trench locations, dimensions, chemical concentrations of the waste material and soils beneath the trenches, and trench contents.

C. CSA-1d Area

Excavated material from trenches in two geophysical anomalies within Subarea CSA-1d (Site 36-7) indicate that the site was used for the disposal and burial of rubbish (Site 36-17 Phase II CAR, Table 36-7-II-1). However, the presence of low to moderate levels of Organosulfur Compounds, Herbicide Related (OSCHs), fluoracetic acid, Polynucleated [sic] Aromatic Hydrocarbons (PAHs), and Organochlorine Pesticides (OCPs) in trench fill material and below the base of the trenches, in conjunction with the Army statement that "some trenches were reportedly used for the destruction and disposal of incendiary bombs, white phosphorus (WP) grenades, mustard-filled (distilled mustard (HD)) projectiles, agent ID Set vials, M125 (GB) bomblets..." (Site 36-7 Draft Phase I CAR, page 8), indicates that the trenches may also have been used for the disposal of agent related wastes.

The Phase I geophysical study delineated eight anomalies: A, B, E, F, G, N, Q, and the southwestern corner of Site 36-7. The anomalies are probably associated with disposal trenches and pits (Site 36-7 Phase I CAR, page 27-31). However, Phase II pit/borings were only completed in Anomalies A and B.

i. Anomaly A - Although only three trenches were identified in Anomaly A in the Phase II investigation (Site 36-7 Phase II CAR, Figure 36-7-II-1), the Phase I CAR indicated that visible ground scars noted in the field correlated with 12 trenches and 8-to-10 pits identified by Moloney in the Assessment of Historical Waste Disposal in Section 36 of RMA report, RIC 85085R01, 1982 (Site 36-7 Phase I CAR, page 27). This discrepancy needs to be addressed. The Phase I geophysical data also suggested that Anomaly A may extend beyond the northern and western Phase I geophysical survey boundaries (Site 36-7 Phase I CAR, page 27). No additional geophysical investigations were conducted to address this concern. Additionally, the strongest soil conductivity values mapped at Site 36-7 occurred in the northern part of Anomaly A and corresponded to the location of a large ground scar mapped in the field. Though Phase II pit/boring 3683 was completed in natural soils in this area, the presence of ground scars and Phase I geophysical results warrant a second pit/boring in this locale.

ii. Remaining Anomalies - As previously stated, no pit/borings or continuous trenches were completed in Anomalies E, F, and G (probable buried metal and waste materials), Anomalies N and Q (probable buried nonferrous metals and debris), and the southwestern corner of 36-7 (trench identified by Moloney in this location).

Recommendation: Characterization of CSA-1d trenches and pits should consist of pit/borings or continuous trenches, grab samples, and borings in Anomalies E, F, G, N, and Q, and the southwestern corner of 36-7. A second pit/boring is recommended for the northwestern section of Anomaly A.

D. CSA-1a Area

In response to State Comment 7F in the Final Alternatives Assessment Report, Other Contamination Sources IRA, Shell Section 36 Trenches (Alternatives Assessment Report), Shell disagreed with the State's assessment that Shell trench locations and structures were well documented. Shell instead asserted that exact locations, depths, and widths of the trenches are not known (Alternatives Assessment Report, page A-36). In light of Shell's assertion, the State believes a level of data collection should be undertaken to address these data gaps. The goals and approach are consistent with Army investigations (where completed) in the CSA-1c complex disposal trenches. The program should consist of:

i. Comparison of aerial photographs (Site 36-3 Phase I CAR, page 9) with Phase I geophysical data to determine trench locations and orientations, and total number of trenches;

ii. Continuous trenching oriented perpendicular to the long axes of the disposal trenches and completed to the base of the disposal trenches. This will determine trench locations, depths, and widths and elevation of the water table across the site. Transects will be selected based on the aerial photograph/geophysical evaluation in Part A;

iii. Sampling of waste material excavated from the trenches, and documentation of trench contents; and

iv. Borings completed to 5 feet below bottom of selected trenches and sampling from the 0-to-1 foot and 4-to-5 foot intervals to determine the vertical distribution of target analytes below the trenches.

Response: A general response was formulated to address the entirety of this comment. This response covers the general scope of the comment, but does not specifically address many of the individual aspects pertaining to certain anomalies and trench clusters. Individual points are discussed in the following sections. Several of these issues have been previously presented by the State and were discussed in response to earlier comments on the CSAR.

In response to the State's "Note", the Army notes that the Complex Disposal Trenches IRA does not include any soil sampling, but consists of groundwater monitoring in the Complex Disposal Area. Geophysical investigations in this area are planned as part of the Phase II FS Field Data Collection Program.

The State's general contentions in these comments are: A) the characterization of one trench cannot be used to represent many disposal trenches and B) each trench within the identified anomalies was not sampled strictly according to Phase I and Phase II procedures, and therefore, the RI is not adequate and this lack of consistency constitutes a significant RI data gap for the CSA.

The State also presents field sampling proposals that it feels would supplement the Phase I and II investigations and "satisfy" its perceived RI data gaps.

The following statement is particularly pertinent given the general tone and concept of the State's Comment 1.

> "...The objective of the RI/FS process is not the unobtainable goal of removing all uncertainty, but rather to gather information sufficient to support an informed risk management decision regarding which remedy appears to be most appropriate for a given site. The appropriate level of analysis to meet this objective can only be reached through constant strategic thinking and careful planning concerning the essential data needed to reach a remedy selection decision..."

The above quote is excerpted from Interim Final Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Section 1.1, Purpose of the RI/FS (USEPA, 1988). The fundamental goal of an RI is to collect sufficient high quality data to select an appropriate remedial approach from a number of potential remedial options. The over-collection of data is as much a problem as not collecting enough data. The over-collection of data implies that valuable resources, i.e., time and money, were wasted on unnecessary information collection, resources that should have been applied to properly selecting and implementing a remedial action. Enough confirmatory data are already available to assess the CSA trenches. As always, if the FS uncovers a specific data need, it has the flexibility and mechanisms to collect those data.

As to relying on the A. "...characterization of specific trenches in a given anomaly..." to "...characterize all trenches in the anomalies.":

Any investigation program for the CSA trenches using invasive methods must carefully weigh the risks to personnel safety and of potentially spreading buried contamination against acquiring more information. The scope of the Phase II trench characterization in the CSA was designed to balance data collection and historical confirmation with risks to personnel and the environment.

Contrary to the State's position, the characterization of selected trenches was appropriate and effective. The strategy used "pit/borings" to evaluate and confirm the accuracy of the historical, aerial photography, and geophysical data for applicability in characterizing the nature and extent of contamination within the Complex Disposal Area. The approach minimized the potential for worker exposure and contaminant transport from disposal areas known to be grossly contaminated.

The conclusive characterization of the location and contents of each trench would require a prohibitive number of samples/analyses. For this reason, a representative set of trenches from disposal areas defined by visual surveys, aerial photography, and geophysical data were used as appropriate for the investigative unit in the Complex Disposal Area.

For the design of the field investigations in the Complex Disposal Areas, historical disposal information was compiled, analyzed, and summarized. Historical documentation of disposal activities indicated that disposal areas were comprised of trenches which were generally constructed and filled chronologically with waste materials. Disposal of wastes in the trenches was generally nonrandom, meaning that similar wastes generated at specific time periods were disposed in trenches which were within close and predictable proximity to each other within a disposal area.

Sample locations within anomalies were selected to verify the location and contamination of trenches as documented by the historical disposal record, aerial photography, and geophysical data. The location and contents of a trench within an anomaly were verified against the historical record, aerial photography, and the geophysical data and important information was also acquired from samples collected in inter-trench areas. The information developed by this approach could be used, in conjunction with other environmental data, to evaluate the nature and extent of contamination within the anomalies and the entire Complex Disposal Area.

It is the Army's opinion that the nature and extent of contamination within the Complex Disposal Area has been adequately characterized for the RI, using the approach for the Phase I and II investigations which protected workers and minimized disruption of the sources of contamination identified in previous noninvasive studies. Additional field studies may be conducted by the FS to supplement RI data and address FS or post-FS issues, if required.

In response to B. "...the CSA disposal areas remain a significant remedial investigation data gap.":

Each anomaly area was characterized as a landfill or burn area comprised of trenches containing complex mixtures of wastes as verified by the samples analyzed and the historical record of disposal at the anomaly. Other soil and groundwater samples were used to evaluate the fate of contaminants that may have originated in the trenches of the identified anomalies.

It is not clear what benefit would be gained for the RI by carrying out the State's recommended field investigations. Historical disposal data were already generally confirmed by the field investigation. Further pit/borings could only verify the contents on a trench-by-trench basis, and this amounts to "overkill." The proposed additional sampling of each of the trenches does little to enhance the RI conclusions pertaining to the nature and extent of contamination associated with the anomalies within the Complex Disposal Areas of the CSA. Additional groundwater monitoring is planned as part of the Phase II FS Field Data Collection Program downgradient of the trenches.

The RI presents enough data to adequately evaluate remedial alternatives pertaining to the disposal sites within the Complex Disposal Area. Additional data may be required to further resolve trench dimensions and refine contaminated material volumes for the remedial design and remedial action phases. As stated many times previously and reiterated here once again, the FS is capable of acquiring additional data to refine estimates further.

Through analysis of the complete set of geophysical, historical, soil, and groundwater data, the nature and extent of contamination in the Complex Disposal Area was adequately characterized at an appropriate scale to meet the data requirements of the EA and initiate and continue with the EA and FS.

Comment 2. Discrepancies Between CSA and Adjacent Study Area Potentiometric Surface Maps

The Army states in its response to State General Comment 1 (CSAR, Appendix CSA-F) that the Denver Formation AM/AL potentiometric surface map presented in the CSAR (Plate CSA 1.5-5) is in close agreement with the revised regional Zone A potentiometric surface map shown in Figure 2.10 of the Final Water Remedial Investigation Report (WRIR). However, review of the two figures indicates that the Zone A potentiometric contours between the CSA and North Plants Study Area (Sections 36 and 25), CSA and the Eastern Study Area (Sections 36 and 31), and CSA and the North Central Study Area (Sections 36 and 35) as represented in these two figures do not coincide. Potentiometric contours projected across study areas should match exactly; lack of agreement between the areas indicates a corresponding lack of Denver Formation hydrologic data collected by the Army.

According to the Army, the Denver Zone A potentiometric data presented in the CSAR are more recent, site-specific, and accurate than those presented in the WRIR (see Army responses to State General Comment 1, Shell Specific Comment 37, and EPA Specific Comment 58, CSAR Appendix CSA-F). The

> interpretation of the CSAR Zone A potentiometric data represents a significant departure from that presented in the WRIR regarding migration pathways downgradient of CSA contaminant sources. In WRIR Figure 2.10, the gradient in Denver Zone A wells [sic] 36110, 36103, 36066, 36064, 36157, and 36160 is towards Section 25 in the north, whereas, in the CSAR, the gradient for the same six wells is to the northeast towards Section 31 (CSAR, Plate CSA 1.5-5). Because Zone AM/AL is projected to subcrop immediately northeast of the CSA (CSAR, pages 1-55 and 1-58), the northeastern component of flow in CSA Zone AM/AL presented in the CSAR indicates that Denver Zone A contaminants will discharge downgradient of the CSA to the First Creek alluvial aquifer flow system.
>
> This flow path is only evident in the interpretation of the Denver Zone A potentiometric data presented in the CSAR, <u>not</u> in the WRIR. Therefore, the regional Zone A potentiometric map presented by the Army in the WRIR appears to be in error when compared to the more recent and accurate data presented in the CSAR. The Army must reevaluate existing data, or <u>collect sufficient new data</u>, such that the contours projected across the CSA Section 36 boundaries agree with the North Central, North Plants, and Eastern Study Area Zone A potentiometric data. This evaluation should have been completed in the RI, and is necessary for the assessment of FS remedial alternatives. The State requests a copy of the Army's evaluation when completed.

Response: The Army disagrees with the State's contention that the perceived discrepancies between the Final WRIR Figure 2.10 potentiometric surface map of the Denver Zone A and the Plate CSAR 1.5-5 potentiometric surface map of the Denver Zone AM/AL constitute an RI "data gap." Furthermore, additional data are not required to adequately reanalyze and rectify their perceived discrepancies.

The potentiometric surface maps identified above were constructed at different scales, using a different network of control wells, and with data collected at different times. The WRIR Figure 2.10 is a regional scale presentation of Spring 1987 data which uses only five control wells within the CSA to characterize regional Denver Zone A conditions, whereas the Plate CSAR 1.5-5 is a CSA specific scale presentation of Spring 1988 data which uses ten control wells within the CSA (twice the number as used in the WRIR Figure 2.10) to characterize Denver Zone AM/AL Zone conditions. Furthermore, Denver Zone AM/AL is a subdivision of Zone A. Given the local geologic conditions in the CSA, the potentiometric surface may, in fact, be different for Zone AM/AL than for Zone A in general. The potentiometric surface presented in the Plate CSAR 1.5-5 was constructed to better evaluate the complexities of groundwater flow within the Denver Zone AM/AL that were not apparent in the regional presentation. Thus, the use of the Plate CSAR 1.5-5 allows better characterization of the potential pathways for contamination migration within the CSA.

Because of the differences in scale, time, and data used between these maps, potentiometric surface contours should not be expected to be exactly coincident. To the contrary, if the contours were made to be coincident, it could illustrate either a rare static groundwater system or a lack of technical understanding of temporally and spatially sampled data, and the dynamics of groundwater systems, among other circumstances.

When the differences in scale, dates, control points, and aquifer specifics between the two maps are evaluated, neither map is more nor less accurate than the other. These maps are depictions of interpretations of potentiometric surfaces. Potentiometric surface maps are representations of hydrogeologic conditions reflecting the conceptual model of groundwater flow in the area.

The differences in the two maps are not significant when relative volumes of potential groundwater flow and the ultimate fate of the potentially transported contaminants are considered. Four calculations of estimated contaminant flux are presented in the CSAR which illustrate the relative significance of groundwater flow paths and contaminant transport within the CSA. These estimates clearly illustrate that the flow of groundwater along the flow path from the western portions of the CSA toward the First Creek alluvial aquifer system are on the order of 1/10 to 1/50 that of flows toward the northwest. This supports the conclusion that contaminant transport through the Denver Formation volcaniclastic and AM zones toward the First Creek alluvial aquifer is not a major transport mechanism, although the possibility exists for contamination transport along this flow path.

Groundwater sampling during the RI at wells located downgradient of the Denver/First Creek alluvial aquifer contact indicate that contaminants from sources in the south and west have not yet reached the First Creek alluvial aquifer. These data supported the conclusion stated in the CSAR that the dense clay-rich lithology and configuration of the Denver Formation in the CSA was an effective barrier to flow, as well as attenuating contaminant transport from localized sources in the south and west.

Eventually, the First Creek alluvial aquifer could receive contaminants from groundwater discharged from the Denver Formation, but the nature and extent of contamination in this area, at present, has been adequately characterized in the RI. Because the potential for the ultimate contamination of the First Creek alluvial aquifer exists, the FS team's proposed well installation program as described in the response to the State's comment 6 (below) is appropriate. This proposed program will help resolve when contaminant discharge into the First Creek alluvial aquifer is likely to occur by evaluating localized vertical and horizontal gradients in the Denver Formation. Further discussion pertaining to this groundwater flow path and potential contaminant migration in this area is provided in response to the State's Comment 6 below.

Finally, the CMP continually refines hydrogeologic conceptual models at RMA. Future refinement by that program or the FS will take the conditions in the Denver Formation Zone A into account.

Comment 3. Verification of High Arsenic Concentrations in Monitoring Wells 36145 and 36146

Arsenic (As) was historically detected at 110 mg/l and 55 mg/l in alluvial and Denver wells 36145 and 36146, respectively, located immediately south of CSA-1d. The Army stated that results were based on total As, and that further review of historical records indicated that results from a subsequent resampling period were below detection limits for dissolved As in the two wells (see Army response to State Specific Comment 22, CSAR Appendix CSA-F). Information on the historical data referenced must be presented.

It is the State's understanding that monitoring Wells 36145 and 36146 have not yet been resampled in the Comprehensive Monitoring Program (CMP) for dissolved As (see Army response to State Specific Comment 22, CSAR Appendix CSA-F). Well 36145 must be sampled because it appears to be located along, "A well defined arsenic pathway ... in the unconfined aquifer leading northwest from the Basin A area to the Basin A Neck..." (NCSAR, page 3-169). Possible upgradient sources for the As plume include the M-1 Settling Basins in the SPSA (SPSA-1e), the Lime Settling Basins in the NCSA (NCSA-1b), and the Shell and Army complex disposal areas CSA-1a and CSA-1c-H in the CSA (CSAR, page 3-91). Additionally, Wells 36145 and 36146 must both be sampled for total As to substantiate or invalidate the historical data. Total As values in the range of 100 mg/l, if present, would necessitate a characterization of the extent of As contamination in the alluvial aquifer.

NOTE:
The Draft Final Task Plan Feasibility Study Field Data Collection Report, Volume 1, 12/89 (page 6) states that Well 36145 will be sampled for filtered (dissolved) and unfiltered (total) As. However, it is not clear from the Task Plan that Well 36146 will also be sampled for both total and dissolved As under the CMP; only dissolved arsenic data are provided for Well 36146 in the 1988 Annual Ground Water CMP Report (12/89). The State requests confirmation that Well 36146 will be sampled for both total and dissolved As in the CMP. Additionally, confined Denver Well 36146 is listed as an unconfined well in Table 3.2-2 and Figure 4.3-3 of the 1988 CMP Report (12/89), but is shown as being completed in Denver Formation Zone AM in Appendix C of the same report. Please clarify this discrepancy.

Response: Historical data for Wells 36145 and 36146 are presented below.

Summary of Well Sampling Results for Arsenic at Wells 36145 and 36146

Julian Date	Program	Analysis	Data Results Well 36145	Data Results Well 36146
83222	Regional	As (total)	110,000 µg/l	
83222	Regional	As (total)		55,000 µg/l
84178	RMA Containment	As (filtered)	LT detection limit	
88131	CMP	As (total)	Dry	LT 2.50 µg/l
89006	CMP	As (total)	Dry	4.82 µg/l
89164	CMP	As (filtered)	Dry	2.87 µg/l
90085	FS Phase I	As (total)	Dry	
	FS Phase I	As (filtered)	Dry	
90010	CMP	As (total)		
	CMP	As (filtered)		LT 2.35 µg/l

Well 36145 was found to be dry during the Phase I FS Data Collection Program and therefore was not sampled.

Well 36146 was sampled in January 1990 under the CMP. Filtered As samples were collected at that time and were below the certified reporting limit.

Well 36146 was completed in the Denver Zone AM and was originally interpreted to reflect confined conditions at the time of completion. It appears water levels have dropped and hydrogeologic conditions have changed since then. Currently, the CMP has interpreted the Denver Zone AM at the Well 36146 location to reflect unconfined conditions. Therefore, Table 3.2-2 and Figure 4.3-3 are correct.

Comment 4. Verification of Sporadic or Nonrepeating Detections of Contaminants in Deeper Denver Formation Units

Volatile Halogenated Organic Compounds (VHOs), Volatile Aromatic Organic Compounds (VAOs), OSCHs, Organophosphorus Compounds, GB-related (OPHGBs), Dibromochloropropane (DBCP), OCPs, and arsenic were detected in CSA Denver Formation wells during historical sampling and/or the RI sampling program (see State Specific Comment 23, CSAR Appendix CSA-F). Because this indicates that RMA contamination is impacting the Denver Formation, the State requested that all conclusions to the contrary presented in the CSAR be removed. In response to the request, the Army stated that, in all cases of Denver Formation contaminant detections, "the detection has not been confirmed by a repeat detection from a subsequent sampling event or the well is suspected or confirmed to be of inferior well construction" (see Army response to State Specific Comment 23, CSAR Appendix CSA-F); however, specific well numbers and construction and sampling histories were not referenced or provided. The State needs to examine and correlate the well number, sampling frequency, chemical data and well construction history for these Denver wells prior to agreeing or disagreeing with the Army's response to the State Specific Comment 23.

The Army states in Response to EPA Specific Comment 10 (CSAR, Appendix CSA-F) that "Repeated detections of contaminants in samples from wells screened in confined zones are only considered to be artifacts of poor well construction." Between this and the previously referenced comment, the Army has invalidated ALL detections of ALL analytes in ALL CSA Denver wells. The State strongly disagrees with this position. These Denver CSA wells must be evaluated as part of the Vertical Extent of Contamination study.

Response: In response to the first paragraph of Comment 4, we suggest that the State brings up a key point when it says that it needs to review data before agreeing or disagreeing with the conclusions that "detections have not been confirmed by a repeat detection...or the well is suspected or confirmed to be of inferior well construction." We anticipate that after the State has reviewed all the data, historical as well as RI, it too will arrive at the same conclusions we have drawn.

In response to the second paragraph of Comment 4, the key word here within the quotations is "Repeated". Where repeated detections were found, <u>all</u> were from wells of known or suspected inferior construction. Nonrepeated or nonverified detections did occur in both adequately constructed wells and inferior wells. Denver CSA wells were evaluated in the vertical extent study. Results of that study are presented in Appendix B of the RISR.

Comment 5. Additional Characterization Needed for CSA-2d - Incinerator NW3601 [sic]

The Army's statement that "additional site characterization may be necessary in the FS" for Site CSA-2d (Incinerator NN3601) is misleading since <u>no</u> field characterization of the site has been undertaken (see Army response to State Specific Comment 40, CSAR Appendix CSA-F). Additionally, the size of the incinerator (described by the Army as "small" in the response) does not eliminate the possibility that it has contaminated surrounding soils.

The Army has indicated that it will collect soil samples from the 0 to 1 foot and 4 to 5 foot intervals in two borings in the vicinity of Incinerator NN3601 during the FS data collection program (Draft Final Task Plan, Feasibility Study Data Collection Report, 12/89, page 6-8). The sampling plan is acceptable, however, a more extensive Phase II program will probably be necessary if contaminants are detected in either of the two borings. In addition, given the nature of the contamination which can be anticipated to surround an incinerator, a Surficial Soils Sampling Program (0 to 2 inches) should be undertaken. Although the State neglected to include this comment in its submittal on the above-referenced report, it is now requesting that such a program be implemented. We apologize for any inconvenience this oversight may have occasioned.

Response: As stated in response to State Specific Comment 40 (CSAR Appendix CSA-F), characterization of the CSA-2d incinerator site was accomplished during the RI using data from the historical record, field observations, and evaluation of environmental samples collected from soils and groundwater surrounding the site. Thus, use of the word "additional" was not misleading. Additional site characterization to supplement the existing site characterization was carried out during the FS as described in the Phase I Field Data Collection Task Plan. Bores 36BORE001 and 36BORE002 were sampled in the incinerator location. Dieldrin and DDT were detected in 36BORE001 from the 0-1 ft depth interval. There were no organic analyte detections in 36BORE002. In addition, surficial (0-2 inch) soil samples were collected in the vicinity of the incinerator. Results of the surficial soils investigation have been previously presented in the Final Surficial Soil Investigation Data Summary Report, Version 3.1 (EBASCO, 1991/RIC 91121R01) and are summarized in Appendix D1 of the RISR. The FS Phase I results are consistent with the findings of the surficial soil investigation.

Comment 6. Assessment of the Potential for Contaminant Migration to First Creek Alluvial Aquifer

The Army had formerly claimed that the vadose zone contamination in CSA-1c was not a probable source of contamination to groundwater because of low Denver Formation permeabilities and the potential for chemical attenuation (see reference sited [sic] in State Specific Comment 38, CSAR Appendix CSA-F). The Army further contends, in its response to State Specific Comment 38, that:

"The suite of contaminants detected in samples from these wells indicates little or no hydraulic communication between the alluvial aquifer to the east and the unconfined Denver Formation aquifer to the west. Thus, the data corroborate the stated conclusion regarding the effective groundwater barrier imposed by the low permeability of the Denver Formation volcaniclastic unit which here comprises the unconfined aquifer. These data do indicate the presence of localized sources of contaminants to the unconfined Denver Formation with subsequent flow in the system toward the northeast."

> The first two sentences of this quote are unsupported by the data. On the contrary, recent data from unconfined Denver Formation Wells 36158, 36184, and 36185 indicate that contaminants from trenches in CSA-1c anomalies <u>are</u> impacting the water table (see Army response to State Specific Comment 38, CSAR Appendix CSA-F) and subsequently flowing to the north-northeast. There may be reduced flow rates in the unconfined Denver, but the phrase "effective groundwater barrier" is both misleading and inaccurate. The Army's unsupported conclusion would mean that the potential for contaminant migration to the First Creek alluvial flow system does not exist. The only way to assess the potential impact of CSA-1c contamination on the First Creek flow system is to monitor contaminant movement in the unconfined aquifer. This necessitates completion of 2 to 4 wells downgradient of Wells 36158, 36184, and 36185, and upgradient of Wells 36501, 36502, 25038. The wells can be installed in a two-phased program. Two wells would initially be completed (in a line perpendicular to the hydraulic gradient) approximately one-third of the way between Wells 36158, 36184, 36185, and Wells 36501, 36502, 25038, closer to the upgradient wells. If RMA contaminants are encountered in the first-phase wells, two additional wells would be installed between the first phase wells and Wells 36501, 36502, 25038. This program will monitor contaminant migration towards the First Creek alluvial aquifer.

Response: The recent data from Wells 36158, 36184, and 36185 do support the conclusions presented in the CSAR and in response to State Specific Comment 38 (CSAR Appendix CSA-F). The suite of contaminants and relative concentrations of contaminants detected at these wells indicate little or no hydraulic communication between the Basin A alluvial aquifer to the west and the unconfined Denver Formation to the east. The lack of volatile hydrocarbon compounds (VHCs), organosulfur compounds, mustard related (OSCMs), OSCHs, and DBCP detections in Wells 36158, 36184, and 36185 illustrate the isolation of the unconfined Denver Formation from the Basin A alluvial aquifer. Likewise, the relatively high concentration detections of VHOs, OPHGBs, and methylene chloride in these three wells is compatible with sources overlying the unconfined Denver Formation. The sources of contamination at these wells are disposal trenches in the eastern portion of the CSA-1c site. Also, the migration of contaminants within the unconfined Denver Formation from these source trenches toward the First Creek alluvial aquifer is apparent. However, because no contamination of the First Creek alluvial aquifer has been detected in Wells 36501, 36502, or 31501, and only single, isolated, and nonrepeated detections of chlorophyenylmethyl sulfide and DIMP in Well 31005, the conclusion regarding the Denver Formation as an effective barrier to groundwater flow or as an attenuator of contaminant migration is supported by the data.

As a part of the Phase II FS Field Data Collection Program, the FS plans to install four new wells in the area indicated by the State. The four wells will be sampled twice, and two of them will be the sites of pumping tests designed to determine aquifer hydraulic properties to support the FS in alternatives analysis.

Comment 7. Characterization of DNAPL from Shell Section 36 Trenches

The lateral and vertical extent of a dense non-aqueous phase liquid (DNAPL) found in Well 36517 during the August 1989 Shell field sampling program has not been characterized. The volume, distribution, and migration pathway of the DNAPL in both the vadose and saturated zones must be investigated. The State recommends that characterization of the DNAPL include groundwater sampling for the presence of dissolved-fraction analytes listed in Table 3-3 of the Results of Field Investigations Conducted August and September 1989, Shell Section 36 Trenches, RMA report (Shell Section 36 Field Report). The groundwater sampling is also necessary to determine organochlorine pesticide (OCP) concentrations downgradient of the Shell Trenches. OCPs, which comprise 78 percent of the identified DNAPL (Shell Section 36 Field Report, Table 3-3), were not analyzed for in the 11 cone penetrometer groundwater samples collected during the August 1989 Shell field program. Additionally, OCP data from 16 wells sampled during April 1989 did not meet quality control criteria (Draft Final Alternatives Assessment for Other Contamination Sources IRA, Shell Section 36 Trenches, September 1989, page 4-9).

The State is willing to work with Shell and the Army in designing a field program to characterize the lateral and vertical extent of the DNAPL.

Response: The FS is evaluating various remedial alternatives for the Shell trenches area, as part of the Detailed Analysis of Alternatives. Additional characterization of the trenches, including DNAPLs, will be undertaken by the FS as necessary for the assessment of remedial alternatives.

Comment 8. Additional Investigation of Dieldrin in Surficial Soils in the Vicinity of CSA-2a

Three Phase II borings, 3724-3726, were triangulated around Phase I boring 3277 to investigate the extent of surficial dieldrin contamination detected in the Phase I program. Dieldrin was detected in all three borings, indicating that the extent of contamination has not been determined (see EPA Specific Comment 41, CSAR Appendix CSA-F). The Army's response to the comment stated that the distribution of dieldrin in the soils would be addressed either in the surficial soil sampling program, or during the FS if additional characterization is needed for remedial alternative assessment.

The surficial sampling program was not designed to characterize the extent of surficial contamination around specific sites that had Phases I and II detections.

Rather, the program's purpose was to detect areas of possible windblown contamination. Therefore, the extent of dieldrin contamination around Phase II borings 3724-3726 (Site CSA-2a, former Site 36-2) was not addressed in this program. Because Phases I and II borings failed to determine the extent of dieldrin (and other OCP) surficial contamination, additional sampling is necessary to characterize the site, independent of the remedial alternative selected in the FS.

Response: The surficial soil sampling program was designed to characterize areas of possible windblown contamination. The dieldrin contamination in surficial soils detected in Borings 3277 and 3724 to 3726 was considered to be of windblown origin. Therefore, findings of the surficial soil sampling program have been integrated with the RI data to assess contaminant dispersion to soils from the eolian pathway. As indicated in the RISR, surficial (0-2 inch) soils throughout RMA are recognized as being contaminated by OCPs. Consistent with the response to State Specific Comment 41 (Appendix CSAF), the FS program will address these findings in the evaluation of remedial alternatives.

Comment 9. Assessment of Mustard Contamination in Site 36-17S

In the Phase I soil investigation of Site 36-17S, the Rocky Mountain Arsenal Laboratory (RMAL) reported positive results for mustard analyses in samples composited from the 0-to-1 foot and 4-to-5 foot intervals of Borings 3090, 3092, 3093, and 3094 (Site 36-17 Phase I CAR, page 26). Because of the mustard detections in the four borings, the samples were not analyzed for any RMA contaminants. Supposedly, a subsequent Quality Assurance review performed by the RMAL found that the reported mustard values were below the certified detection limit of 2.1 ppm. However, as stated by the Army, "Sample holding times ... had expired and these samples were not re-collected" (Site 36-17 Phase I CAR, page 47).

Two Phase II borings were completed approximately 50 feet to the northeast and southeast of Phase I Boring 3094 and sampled for mustard-related organosulfur compounds. However, Phase II replicate borings were not completed for Borings 3090, 3092, and 3093. Additionally, the two closest Phase II borings to Boring 3093 (3667 and 3682), and the only Phase II boring completed in the vicinity of Boring 3092 (3666) were not analyzed for mustard or mustard-related organosulfur compounds (Site 36-17 Phase II CAR, Table 36-17-II-5). No Phase II borings were placed in the vicinity of Boring 3090 (Site 36-17 Phase II CAR, Figure 36-17-II-3). Therefore, the lateral and vertical extent of possible mustard contamination in the vicinity of the three borings has not been characterized. The State requests that borings be completed adjacent to Phase I Borings 3090, 3092, and 3093, and the 0-to-1 foot and 4-to-5 foot intervals be analyzed for mustard, dithiane, and oxathiane (samples should not be composited). Additionally, if mustard contamination is found, the Army is requested to provide the disposal history associated with its occurrence in this area.

Response: While it is correct to state that preliminary results of analyses by the RMA Laboratory of composited samples from the 0 to 1 ft and 4 to 5 ft intervals of Phase I soil Borings 3090, 3092, 3093, and 3094 indicated mustard was present, it is also correct to state that the QA review for those samples indicated mustard was not present at levels above the 2.1 ppm CRL. Additionally, according to standard procedure at the time, when a positive agent analysis was preliminarily reported from a composited sample, separate analyses of the individual 0 to 1 ft and 4 to 5 ft intervals of the aforementioned borings were also conducted in order to pinpoint the interval(s) producing the positive result in the composite samples and determine the concentration for the detection. The analytical results from the individual intervals from those borings also indicated mustard to be below the CRL. It is unfortunate that the eight samples detained for this more extensive clearance procedure were lost RI target analyte analyses due to elapsed holding times. In hindsight, it may now be appropriate to say that the eight samples, once being cleared for shipment off-post, should have been analyzed anyway even though they would have been a couple of days past their holding times for volatile analyses.

The tight time constraints to provide clearance for samples prior to sample shipment to meet tight holding time deadlines, as well as the hazardous nature of the agent potentially present, required analytical reporting procedures susceptible to false positive reports. The circumstances of detections and routine laboratory QA procedures in some situations resulted in discounting the preliminary detections.

There is no corroborative evidence that supports the contention that mustard was indeed present at the site of these four borings. Visual evidence of the soils encountered during boring logging indicated no trenching or disturbed materials indicative of disposal. Visual inspection of surficial materials at the sites also do not indicate disposal activities typical of mustard munitions demolition or mustard disposal. Geophysics completed in the vicinity of Borings 3092, 3093, and 3094 do not indicate trenches or disposal. There are no documented historical records that indicate mustard was in fact handled, disposed, or demilitarized at the specific locations of the borings. Field testing during drilling activities with the M8 alarm and M18A2 test kits did not indicate the presence of mustard at the four sites. Therefore, on the basis of all this investigative information, the preliminary reports for mustard were discounted as false positives. In addition, the location where mustard disposal activities did take place in 36-17N trenches have been corroborated by several pieces of information.

The area of Site 36-17S where the set of four borings were clustered, was investigated subsequently in Phase II. The density of borings completed in the area is comparable to other RMA sites with similar contaminants, disposal histories, and hydrogeology. Phases I and II borings in the vicinity of Borings 3090, 3092, 3093, and 3094 were all analyzed for organosulfur compounds by GC or GC/MS methods. The gas chromatography flame photometric detector (GC/FPD) method detects OSCM analytes that are related to or degradation products of mustard. Additionally, samples from several borings were also analyzed for the OSCM analyte thiodiglycol (TDG), by the high-pressure liquid chromatography (HPLC) method. The GC/MS method, in addition to detecting degradation OSCMs, also is capable of detecting mustard in its nontarget or tentatively identified compound capabilities. Furthermore, all Phase I and II borings were screened by the RMA Laboratory for mustard and other chemical agents as was standard procedure. Mustard was not detected in any samples from nearby borings. The following table lists borings completed in the immediate vicinity of the four previously listed borings and gives the analytical tests conducted on the samples from these borings capable of detecting OSCMs.

	Boring	Method
Phase I	3090	Mustard
	3091	SVOC, mustard
	3092	Mustard
	3093	Mustard
	3094	Mustard
	3095	SVOC, mustard
	3213	SVOC, mustard
	3214	SVOC, mustard
Phase II	3662	Mustard, SVOC
	3663	Mustard, OSCM, TDG
	3664	Mustard, OSCM
	3665	Mustard, OSCM
	3666	Mustard, SVOC, TDG
	3667	Mustard, SVOC
	3668	Mustard, OSCM, TDG
	3669	Mustard, SVOC, TDG
	3442	Mustard, OSCM, SVOC
	3443	Mustard, OSCM, TDG
	3430	Mustard, OSCM
	3431	Mustard, OSCM
	3432	Mustard, OSCM

Nevertheless, the locations of these Phase I bores with report mustard detections are included in the area shown in Figure RISR 2.2-1 of the RISR as having a potential for agent occurrences. The FS will address the areas shown in Figure RISR 2.2-1 as part of the evaluation of remedial alternatives.

Comment 10. CSA Nonsource Area Characterization

The State has prescribed two programs to provide a minimum data set necessary to evaluate non-source areas in the Onpost Endangerment Assessment and for the early stages of the Feasibility Study. These programs are the surficial soil sampling proposed in the November 15, 1988 letter to Mr. Donald Campbell, and the Ground Disturbance Program, proposed in the November 26, 1988 letter to Mr. Donald Campbell. The Surficial Soils Program is apparently complete although data from that program have not yet been received. The State was also informed at the November 2, 1989 RMA Committee Meeting that the Army had completed its field work for the ground scar program. Although, the State expected to have substantial participation in the screening of those sites proposed for investigation, it was not given that opportunity. However, we have received a preliminary report explaining the investigation undertaken by the Army and setting forth the Army's rationale for dismissing a substantial number of proposed sites from that investigation. The State will convey specific comments and problems concerning that report under separate cover.

In addition to these programs, the State has requested that significant contaminant detections found in the Phase I boring program be verified, and further investigated, as appropriate.

Response: The comments are noted. The Final Surficial Soil Investigation Data Summary Report, Version 3.1 was released in April 1991 (EBASCO, 1991/RIC 91121R01), and the Final Ground Disturbance Investigation Data Summary Report, Version 3.1 was released in August 1990 (EBASCO, 1990/RIC 90247R01). Both programs are summarized in Appendix D of the RISR.

In response to the last paragraph of this comment, significant Phase I contaminant detections were investigated by the Phase II sampling program as appropriate.

Appendix F5.6

South Plants Study Area

Remedial Investigation Summary Report

Rec'd 21 May 90
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STATE OF COLORADO

COLORADO DEPARTMENT OF HEALTH
4210 East 11th Avenue
Denver, Colorado 80220-3716
Phone (303) 320-8333

Telefax:
(303) 322-9076 (Main Building/Denver)
(303) 320-1529 (Ptarmigan Place/Denver)
(303) 248-7198 (Grand Junction Regional Office)

1876

Roy Romer
Governor

Thomas M. Vernon, M.D.
Executive Director

May 21, 1990

Mr. Donald Campbell
Office of the Program Manager
Rocky Mountain Arsenal
AMXRM-PM, Building 111
Commerce City, CO 80022-2180

Re: State's Proposal to Improve the Remedial Investigation for the South Plants Study Area

Dear Mr. Campbell:

Enclosed is the State's proposal to improve the Remedial Investigation (RI) for the Rocky Mountain Arsenal South Plants Study Area (SPSA). As State personnel have previously informed you, the significant data gaps that remain, based on the RI conducted to date, must be rectified to ensure that the nature and extent of contamination in the SPSA is fully defined. Unless the data gaps are filled, the Feasibility Study could result in the selection of an inadequate remedy based upon insufficient data.

With this report, the State has provided the Army with six data gap summaries and proposals for the seven Study Areas. The seventh and final State data gap summary will be provided upon review of the recently received North Plants Tennessee Valley Authority reports. As stated above, the Colorado Department of Health believes it is essential that these data gaps be investigated as soon as possible. To date we have not received any response from the Army on the five previously provided summaries.

This document was prepared based upon the State's review of the South Plants Study Area Report (SPSAR), along with responses to State comments on the SPSAR.

This proposal does not identify data gaps associated with the RI characterization of the South Plants chemical sewers. It is the State's position that the characterization of the extent of contamination in the underlying soils beneath and surrounding the South Plants chemical sewers can only be done once the sewer piping has been removed. The removal of these chemical sewers, along with contaminant identification in the soil, must be done prior to issuance of the on-post Record of Decision, unless characterization of the underlying soils associated with these sewers can be done without sewer removal (i.e., trenches adjacent to the piping). It is impracticable to attempt to select an adequate remedy without knowledge of the nature and extent of the soil contamination.

This proposal prescribes a "limited" data collection program to address "significant data gaps" identified to date in the remedial investigation. This proposal does not specify all the data which will need to be collected to ensure a comprehensive Feasibility Study (FS) for the SPSA.

Under separate cover, the State previously provided the Army with specific RMA-wide comments and proposals to help rectify the data gaps and problems with:

- Structures;
- Methylene chloride detections possibly not attributable to laboratory contamination:
- Incomplete investigations of contaminant detections in "non-source" areas:
- Vertical extent of contamination in ground water.

Matters discussed in those submittals may also pertain to the SPSA and should be addressed. In addition, the State may be submitting proposals for rectification of data gaps in the biota and air RIs. The State also anticipates proposing certain tentatively identified and unknown compounds for further analysis once it has received a response to its September 28, 1989 letter. Some of these compounds may be of issue in the SPSA.
As always, the State is willing to meet and work with the Army to rectify the significant RI data gaps for the SPSA, along with the five previously presented data gap summaries. If you have any questions, please call me.

Sincerely,

Jeff Edson

Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

JE/cf

cc: Jackie Berardini
Chris Hahn
Edward McGrath
Tony Truschel
Major Lawrence E. Rouse
William Clemmens
Bradley Bridgewater
Connally Mears

RESPONSES TO THE COLORADO DEPARTMENT OF HEALTH'S PROPOSAL TO IMPROVE THE REMEDIAL INVESTIGATION FOR THE SOUTH PLANTS STUDY AREA

MAY 1990

Comment 1. Characterization of the Northwest Chloroform Plume

As recognized by the Army in its North Central Study Area Report (NCSAR), a volatile halogenated organic (VHO) plume (specifically chloroform) has been detected in Water Bearing Zone 1 (WBZ-1) in sections [sic] 35 and 34 of the Rocky Mountain Arsenal (RMA). (See State's Proposal to Improve the Remedial Investigation for the North Central Study Area, November 10, 1989, Comment 2.) The sources of this plume must be identified as part of the Remedial Investigation (RI). As more fully explained below, the State's review of existing RI data indicates that these sources are probably located in the South Plants Study Area (SPSA). The contaminants then migrate west-northwest through section 2, into section 35, and from there northwestward into section 34.

Figures SPSA 3.3-3 and 3.3-4 depict a VHO plume emanating from section 1 and migrating southwest through the extreme southeast corner of section 2. However, review of the WBZ-1 potentiometric surface map indicates that ground water in this area also migrates to the northwest through the northern part of section 2 and into section 35 (Figure SPSA 1.5-5). Therefore, the source of this southwest migrating plume may also be the source of the VHO plume detected in the NCSA.

The Army's limited well data support the above-stated hypothesis. WBZ-1 Well 02594, the only well sampled for VHOs in this area, was sampled once in 1988, and had a detection in the range of 100- <1,000 µg/l. Contaminants in this well could have migrated from the sources described above, and would continue to migrate to the northwest into section 35. Downgradient WBZ-2 Wells 02045, 02043, and 02041, and WBZ-3 Well 02042, all of which are located in subareas SPSA-3 and SPSA-8, also showed detections of VHOs in 1983, the only time they were sampled for these contaminants (Figure SPSA 2.4-1; for locations of monitoring wells in the SPSA <u>see</u> Figure SPSA 1.5-3). In discussing ground water data from section 1, the Army stated that "{a}ll of the occurrences in WBZ 2 were below higher concentration plumes in WBZ 1 " (SPSAR, pp. 3-76). WBZ-1 well data corresponding to the deeper wells listed above are not available; however, based upon the Army's observations, it is logical to conjecture that the detections in WBZ-2 and 3 are indicative of higher concentrations in overlying WBZ-1.

Recommendation: To characterize the VHO plume, existing WBZ-1 Wells 02003, 02005, 02053, and 02594 located in the northwestern section of SPSA-3e, should be sampled. The annual FY88 sampling program included the former two wells, but did not include the latter, although as previously noted, well [sic] 02594 was sampled in 1988. Contemporaneous sampling is preferable. In addition, the screen in Well 02053 may be set at or above the water table; if so, it should not be included in the proposed sampling event.

If the chloroform plume boundaries cannot be delineated using data from existing wells, construction of new unconfined monitoring wells must be completed in this area. This monitoring well program should be consistent with the State's monitoring well program proposed for sections 35 and 34 (see State NCSA data gap letter, November 10, 1989, Comment 2). The State would welcome an opportunity to work with the Army in designing such a program.

Response: Several wells have been sampled to investigate chloroform contamination in Section 35 since the collection of RI data. These wells and the sample periods are:

- 02003 - CMP, winter 1987-1988, fall 1989
- 02005 - CMP, winter 1987-1988, fall 1988, spring 1989, fall 1989
- 35013 - CMP, winter 1987-1988, fall 1988, spring 1989, fall 1989
- 35052 - CMP, winter 1987-1988, fall 1988, fall 1989

Results from these sampling periods are presented in appropriate CMP Annual Groundwater Reports.

The analytical results from these wells show a distribution which is consistent with that shown in the SPSAR (1979, 1983, and 1988 data). The lowest contour interval in the FY89 CMP report (0.5 µg/l) is twenty times lower than that shown in the SPSAR (10 µg/l). The trace of the 0.5 µg/l contour line in that report suggests that the South Plants (specifically the western portion of Section 1) is a source of chloroform to Section 35. Additionally, several elevated chloroform concentrations were detected immediately downgradient of Sand Creek Lateral. These elevated concentrations suggest that Sand Creek Lateral is also a source of chloroform to Section 35.

Wells 02053 and 02594 will be sampled as part of the FS to address a potential chloroform source in the eastern portion of Section 2. In addition, the FS is planning to install two new well clusters in the SE 1/4 of Section 35 to investigate the chloroform plume. These will be installed during Phase II of the FS Field Data Collection Program.

Comment 2. Characterization of Northwest DCPD Plume

The Army has identified a dicyclopentadiene (DCPD) plume apparently originating in the southeastern section of subarea SPSA-3, and migrating toward the southwest (Figure SPSA 3.3-5). However, review of the WBZ-1 potentiometric surface map shown in Figure SPSA 1.5-5 indicates that ground water in this area potentially flows to the northwest into section [sic] 35. Therefore, the possibility of a northwestern migrating plume originating in this same area must be investigated.

In addition, the sources of the DCPD plume(s) have not been identified. It is probable that the plume(s) originate in the chlorine Plant/Steam Plant subarea, SPSA-3c, including Tanks 321A and 321E (see Figure SPSA 3.3-5). Soils sampled in the vicinity of Tank 321A had DCPD concentrations in the range of >10-100 µg/l [sic] at the 5-20 depth [sic] interval (Figure SPSA 2.1-11): soils underlying Tank 321E have not been analyzed. Data from Wells 02005 and 02594, located to the northwest of these tanks, had DCPD detections of 100 - <1,000 µg/l in 1979 and 1988 respectively (Figure SPSA 2.4-4), indicating possible contributions to ground water.

<u>Recommendation</u>: Wells 02005, 02594, and 02053, if screened below the water table, could be used to determine whether there exists a northwestward-migrating DCPD plume in WBZ-1 of subarea SPSA-3. If data from these wells are insufficient to define plume boundaries, however, additional monitoring wells will be necessary. If so, this program could be combined with that proposed in item 1 to characterize the northwest migrating chloroform plume.

In addition, since the well data that were used to define the southwest-trending DCPD plume appear to be over 10 years old (SPSAR, p. 3-84), Wells 02006, 02544, 02007, 02002, and 02546 should be re-sampled to better characterize this plume. Wells 02006 and 02007 were sampled in the annual FY88 Comprehensive Monitoring Program (CMP); however, contemporaneous sampling is preferable.

Response: The potentiometric surface of WBZ-1 (SPSAR, Figure SPSA 1.5-5) shows that, due to the South Plants groundwater mound, groundwater flow in the southeastern section of subarea SPSA-3 can be southwest, west, and/or northwest. RI and subsequent CMP sampling adequately characterize the southwest migration of DCPD from the southeastern section of SPSA-3. However, the west and northwest potential DCPD migration from this area has not been characterized due to limited coverage of sampled wells. This limited coverage has shown that DCPD existed at Well 02594 in 1988 at concentrations between >100-1,000 µg/l (SPSAR). Because the extent of DCPD migration west and northwest from SPSA-3 may effect the design of remedial actions in this area, several additional wells will be sampled. These wells are screened in WBZ-1 and include 02003 (sampled by the CMP) to determine the north extent, 02053 to determine the northwest extent, and 02594 to determine the west extent. The results from sampling these wells will also be used to help identify DCPD sources in SPSA-3. In addition, the FS is planning to install two well clusters in the SE 1/4 of Section 35 as part of the Phase II FS Field Data Collection Program. These will further aid in determining the extent of DCPD contamination to the north and northwest of SPSA-3.

Although DCPD data presented in the SPSAR are over ten years old, Wells 02005 and 02007, both located within the plume, have been sampled during subsequent fall 1988 and fall 1989 periods. Fall 1988 results are presented in the CMP Annual Groundwater Report for 1989 (Stollar, 1990); fall 1989 data are presented in the CMP Annual Groundwater Report for 1990. DCPD concentrations within the southwest migrating plume, as presented in the SPSAR, are confirmed by these subsequent CMP data. Wells 02023, 02034, and 02037, also sampled under the CMP during fall 1988 and fall 1989, monitor the downgradient extent of this plume. Additionally, quarterly CMP water level data collected from this area indicate that hydraulic conditions have not changed significantly since the collection of RI data. The confirmed plume concentrations, the monitoring of the downgradient extent, and the consistency of hydraulic conditions, combine to provide an adequate characterization of the southwest migrating DCPD plume.

Comment 3. Characterization of the Southeast Migrating Plumes Emanating from the South Plants Southern Subarea SPSA-2

Figures SPSA 3.3-3 through 3.3-8 indicate that two separate lobes of VHO, volatile aromatic organic (VAO), and volatile hydrocarbons (VHC) plumes appear to originate in the southern subarea SPSA-2. The western lobe of VHO, VAO, and VHC plumes migrating towards the southwest and Lake Ladora, are currently being investigated by Shell and the Army as part of the South Tank Farm Interim Response Action (IRA). (South Tank Farm composite plume Figure SPSA 3.3-1). However, the eastern lobe of the plumes, forming in the vicinity of Tanks 463G, 463H, and/or 464B have not been characterized.

Based on the WBZ-1 potentiometric surface map (Figure SPSA 1.5-5), these plumes migrate from the eastern half of subareas SPSA-2a and the Open Storage Area (SPSP-2b [sic]), southeast towards Lower Derby Lake. The Army has not investigated the potential impact of these plumes on the lake in either the SPSAR or the Southern Study Area Report (SSAR), and presents contradictory or incomplete interpretations of the VHO, VAO, and VHC plumes in the two reports. The discrepancies include:

a. VHO plume - in the SPSAR, a southeast-trending VHO plume originating in the vicinity of Tank 463G and/or Tank 464B is shown migrating towards

Lower Derby Lake (Figure SPSA 3.3-3); however, this plume is ignored in the SSAR VHO discussion and plume presentation (Figure SSA 3.5-1).

b. VAO plume - in the SPSAR, a southeast-trending VAO plume originating in the vicinity of Tank 464B is shown migrating towards Lower Derby Lake and possibly Upper Derby lake [sic] (Figure SPSA 3.3-8); however, this plume is ignored in the SSAR VAO discussion and plume presentation (Figure SSA 3.5-5).

c. VHC plume - in the SPSAR, a south-southeast flow component is represented in WBZ-1 in the vicinity of Tank 464B (Figure SPSA 1.5-5). That report also presents a southeast-trending VHC plume in Figure SPSA 3.3-6. These data are not included in the SSAR which presents a plume configuration that is inconsistent with that presented in the SPSAR.

The inconsistencies between the SSAR and SPSAR demonstrate that the Army has not characterized the southeast-trending VHO, VAO, and VHC plumes originating in subarea SPSA-2. This failure represents a significant data gap, especially since these plumes could impact Lower Derby Lake.

Recommendation: In its Letter Technical Plan for the Remediation of Other Contaminant Sources IRA, South Tank Farm Plume, October 11, 1989 (Shell Tech Plan), Shell proposed construction of four wells, 01578 through 01581 which were apparently completed during the fall of 1989. (Draft Final {sic} Alternatives Assessment of Other Contamination Sources IRA, South Tank Farm Plume, March 1990, p. 5). Although not designed for this purpose, these wells could be used to define the plumes described above; however, locations and data from these wells have not been made available to the State. Therefore, the State requests these data as soon as possible to determine if they can be used to evaluate contaminant distributions in the vicinity of Lower Derby Lake. In addition, existing Wells 01027, 01028, 01049, and 1588 [sic] should be sampled for the three analyte groups to aid in the delineation of the lateral extent of the plumes.

Response: The Army assumes Well 1588 referred to by the state is Well 01588. At the time the SSAR was prepared, there was no evidence of a southeast-trending plume of volatiles extending from the South Plants into the SSA, hence it was not addressed in the SSAR. Because this plume is located in an area where a southeast groundwater gradient from the South Plants groundwater mound intersects the northwest gradient from the regional system, groundwater flow in this area is difficult to predict. To more completely understand groundwater flow and VAO, VHO, and VHC migration in this area, Wells 01582, 01049, 01578, 01579, 01580, 01581, and 01588 will be sampled by the FS for these three analyte groups. The drilling and well completion logs for Wells 01578, 01579, 01580, and 01581 are attached for the State's review. Well 01027 has been abandoned and cannot be sampled; Well 01028 will not provide any further information to delineate lateral extent than Well 01582, and will not be sampled.

Comment 4. Data Gaps Identified in the State's Review of the South Tank Farm (STF) Interim Response Action Investigation

Although data have not been made available to the State or presented in the Draft Final {sic} Alternatives Assessment for the STF plume, Shell has reportedly completed fall 1989 field work originally proposed in the Shell Plan. In that plan, Shell appeared to be addressing:

a. the southeast-trending plumes originating in subarea SPSA-2; and

b. the light non-aqueous phase liquids (LNAPL) in the immediate vicinity of Tank 464A.

The State's November 30, 1989 comments on the Shell Plan enumerated potential data gaps in the study. These are summarized below:

a. investigation of potential VHC LNAPL plumes in the vicinity of Tank 463H in site SPSA-2a, and Tank 464B in site SPSA-2b;

b. additional characterization of the lateral extent of LNAPL contamination in the vicinity of Tank 464A;

c. investigation of the status of Tanks 464A, 464B, 463G, and 463H;

d. investigation of VHC/VAO vadose zone contamination; and

e. VAO/VHO source identification for the southwest-migrating STF plumes.

After a preliminary review of the Draft Final {sic} Alternatives Assessment of Other Contamination Sources IRA, South Tank Farm Plume (STFP Alternatives Assessment Document), it appears that some of the RI data gaps identified by the State regarding the LNAPL and the southeast-migrating plumes will now not be addressed as part of the STFP IRA. Because of the apparent modification in the scope of the IRA and concerns the State has with the document, additional State comments on the STFP data gaps have been presented in the State's comment package on the Alternatives Assessment document and in the State of Colorado Comments on Shell Letter Technical Plan, Fall 1989 South Tank Farm Plume Investigation. In addition, the State will continue to examine these issues and identify data gaps through the IRA process. Since investigation of the data gaps is not included in the IRA, they must be addressed in the RI/FS or as a separate IRA investigation.

Response: Potential data gaps identified by the State in comments on the Shell South Tank Farm IRA investigation (November 30, 1989) are being addressed as follows:

a. Potential VHC LNAPL plumes in the vicinity of Tank 463H and 464B will be addressed by the FS. NAPL sampling of suitable existing wells in South Plants is included in the FS Phase II Field Data Collection Program.

b. The lateral extent of LNAPL contamination in the vicinity of tank 464A was investigated and reported in the Report of the Investigation of the LNAPL Plume near 464A, Section 1, RMA (Shell, 1989/RIC89264R01).

c. The State has been previously informed that the tanks in the South Tank Farm (including tanks 464A, 464B, 463G, and 464H) are empty. Additional investigations of the "status" of these tanks is unnecessary.

d. A conservative approach was used to delineate vadose zone contamination in the South Tank Farm area in the SPSAR. Vadose zone contamination near the LNAPL will be further investigated as a part of the Treatability Study for the South Tank Farm LNAPL plume (Technical Work Plan, LNAPL Plume Soil Vapor Extraction [SVE] Process Field Demonstration Treatability Study, Shell. 1990/RIC 91002R01).

e. The additional characterization of both mobile and immobile LNAPL in the South Tank Farm Plume (STFP) should satisfy the State's request for further source identification for the southwest-migrating plume.

In addition to the above responses, we would like to note that:

1. The data referred to as not available to the State were transmitted to the Colorado Department of Health (CDH) in May 1990 in a report titled Hydrogeologic and Water Quality Conditions, South Tank Farm, RMA.

2. The Final Implementation Document, Other Contamination Sources IRA, South Tank Farm Plume (Shell, 1991/RIC 91298R01) presents the scope of work for this IRA. The FS Phase II Field Data Collection Program does include NAPL sampling in the South Tank Farm area, as noted above. Additional NAPL investigation proposals will be addressed through the FS Groundwater Subcommittee meeting format.

Comment 5. LNAPL Characterization Within the SPSA

A. Sources of VHC Ground Water Plumes

Except for the Shell investigation of light nonaqueous phase liquids (LNAPL) in the immediate vicinity of Tank 464A in subarea SPSA-2b (Report of the Investigation of the LNAPL Plume Near Tank 464A, Section 1, RMA - LNAPL IRA Report), the presence of light or dense NAPLs in the SPSA does not appear to have been adequately investigated. This represents a significant data gap for the SPSA. In its LNAPL IRA Report, Shell concludes that there appears to be a close correlation between the configuration of a 1989 separate-phase LNAPL plume (shown in Figure SPSA 3.3-9) and the 1988 dissolved VHC plumes, assumed to reference Figure SPSA 3.3-6 of the SPSAR (LNAPL IRA Report, p. 8). In Figure SPSA 3.3-9, however, two separate-phase plumes are mapped. One appears to originate in the vicinity of Tank 463H in subarea SPSA-2a to the north; and the other around Tank 464A in subarea SPSA-2b to the south (the eastern lobe of the STF plume). The plumes are composed primarily of VHCs, incorrectly labeled as VAO LNAPLs in the figure. Shell investigated the soils and ground water only within the latter plume (subarea SPSA-2b), and verified the presence of VHC-dominated LNAPLs in the vicinity of Tank 464A (LNAPL IRA Report).

In Responses to State of Colorado Comments on Shell Letter Technical Plan, Fall 1989 South Tank Farm Plume Investigation, Shell states on page 10:

> The LNAPL plume shown in the vicinity of Tank 463H in Figure SPSA 3.3-9 appears to be negligible relative to the plume near Tank 464A, based upon measurements in existing wells. The plume near Tank 463H was drawn based upon measured LNAPL thickness of 0.01 ft in Wells 01533 and 01550. Measurements made in these and other wells in the vicinity in late June 1989 showed no LNAPL to be present.

In the LNAPL field investigation, Shell installed seven new wells to monitor the LNAPL plume in the vicinity of Tank 464A (LNAPL Field Report). Well 01545 was located the greatest distance form Tank 464A at approximately 60 feet. Wells 01550 and 01533, used by Shell to monitor LNAPL in the vicinity of Tank 463H, are located 270 feet and 470 feet, respectively, from the tank. Additionally, based on the vadose zone map in Figure SPSA 1.5-2 and the D.P. Associates, Inc. Sections Plots and Well Summary, the water table in these two wells is above the top of screen by approximately 3 to 8 feet. Because of the distance from the tank and the location of the screen with respect to the water table, it would be surprising to find any LNAPL in the well; therefore, the presence of 0.01 [sic] LNAPL in the two wells should be investigated.

In addition, page 20 of the FTFP [sic] Alternatives Assessment Document acknowledges that additional monitoring is necessary to characterize the LNAPL plume nears Tanks 464A and B. Given the inadequate data and Shell's questionable interpretation of those data, the State concurs that additional characterization is necessary and should be indicated [sic] on an expedited basis. We would welcome the opportunity to work with Shell and the Army to design an appropriate field program.

Considering the correlation between dissolved VHC contaminants in the eastern lobe of the South Tank Farm plume and the VHC LNAPLs in the vicinity of Tank 464A, it is possible that the remaining VHC ground water plumes shown in Figure SPSA 3.3-5 and 3.3-6 may also be partially or completely derived from corresponding LNAPL plumes. The dissolved VHC ground water plumes that may also indicate corresponding LNAPL plumes include the north plume, the southeast-migrating plume originating in SPSA-1 (SPSA-1 southeast plume), the western lobe of the South Tank Farm plume, and the southeast-migrating plume referenced in Comment 3 above (SPSA-2b southeast plume).

<u>Recommendation</u>: The State requests that the possible presence of LNAPLs corresponding to the plumes described above be investigated. A phased approach would be reasonable: further work would be done if NAPL is detected in the first phase of investigation. The State further requests that the northern LNAPL plume originating in the vicinity of Tank 463H (Figure SPSA 3.3-9) be investigated and the resultant data distributed to the parties. A discussion of this plume was not presented in the SPSAR text. Characterization of separate-phase product may require installation of additional monitoring wells screened both above and below the top of the water table. The majority of existing wells initially monitored by Shell in the Tank 464A investigation were screened below the water table only; this may have distorted results on LNAPL thickness and distribution. For any existing well selected for the investigation, screened intervals with respect to the water table must be documented. The State is prepared to work with the Army in selecting and designing an appropriate monitoring network to accomplish this task.

In any areas where LNAPLs are found, it is probable that vadose zone contamination at or below residual saturation is also present. Therefore, the vertical and lateral extent of LNAPL contamination in the unsaturated zone must also be characterized.

The sources of the VHC plumes must be identified. If the Army determines that NAPLs are not the source of the VHC plumes, it must investigate other possible sources.

B. Possibility of NAPLs Indicated by Pumping Well APW-2

In the November 1983 Stearns-Roger South Plants Groundwater Treatment Pilot Plant Report (Stearns-Roger Report), a free-flowing black liquid was discovered in pumping well APW-2, located to the northwest of Building 537 in subarea SPSA-1. The zone of pumping was approximately 40 feet below land surface (Stearns-Roger Report, pp. 5-18), or 25 feet below the top of bedrock. Inexplicably, this information was not presented in the SPSAR. From the tentative list of contaminants identified in the liquid present at "significantly high levels" (Stearns-Roger Report, pp. 5-18), and the behavior of the liquid in the presence of water, it appears that both a dense and light fraction of NAPLs exist.

Recommendation: The lateral and vertical distribution of this fluid within the Denver Formation must be investigated and the source(s) identified.

Response: The two issues discussed by the State are being addressed as follows:

A. Additional investigation into the possibility of LNAPL occurring in other portions of the South Plants will be undertaken by the FS. The Phase II FS Field Data Collection Program includes sampling for NAPLs in the South Plants area. The South Tank Farm Plume LNAPL Treatability Study (to be proposed soon) will include field investigative techniques that, if successful near tank 464A, may be applied elsewhere if the need is defined by the FS.

As the State is aware from its review of the LNAPL report, Shell installed additional wells in 1989 in the South Tank Farm that are screened above the water table specifically to address the questions that the State raises. All the construction details were transmitted to CDH over a year ago.

B. Reference to the NAPL detected by Stearns-Rogers in 1983 in pumping well APW-2 was inadvertently omitted from the SPSAR. Additional investigations into the possible presence of LNAPLs in the South Plants will be addressed by the FS. Wells 01513 and 01507 in the vicinity of Well APW-2 are included for sampling in the Phase II FS Field Data Collection Program. Investigations into the possible presence of DNAPLs in the South Plants will be addressed as a later phase of the proposed Treatability Study of Subsurface Drains in the South Plants.

Comment 6. Characterization of Arsenic in SPSA Ground Water

A. Identification of Sources of Arsenic Contamination

The Army investigation of arsenic (As) in SPSA ground water failed to identify the M-1 pits (Site SPSA-1e) as a major source of As contamination to ground water. A spring [sic] 1989 sampling study, however, determined that "the high concentrations of As downgradient of the M-1 Settling Basins clearly indicate that this site is a direct source of arsenic contamination to the groundwater" (Final Alternatives Assessment of Interim Response Actions for Other Contamination Sources, M-1 Settling Basins, November 1989-M-1 [sic] Alternatives Assessment Report, p. 2-9).

The M-1 Basins were one of three principal contributors of As to SPSA soils. The others included the As storage silos (Building 523 and associated tanks), and a segment of the chemical sewer associated with an abandoned mustard and dichlor pit, located north of Building 434 (SPSAR, pp. 3-115). All three sites have high concentrations of As in the 5 to 20 foot soil intervals (Figure SPSA 1.5-2), and are in probable contact with the ground water (Figure SPSA 1.5-2). These remaining two sites may also be contributing significant levels of As to ground water and consequently should be characterized.

B. Discrepancies and Problems with Arsenic Data

Two sampling episodes conducted by the Army identified only sporadic detections of As in the SPSA ground water; however, problems associated with the two sampling programs include the following:

a. of the six WBZ-1 wells sampled for As in 1988, none were located downgradient or in the vicinity of the M-1 Basins, the storage silos, or the abandoned mustard pit; and

b. 37 of the 41 WBZ-1 wells sampled in 1979 had CRLs in the range of 10,000-100,000 µg/l, four to five orders of magnitude greater than dissolved arsenic concentrations measured in the four downgradient wells on the northern boundary of SPSA (SPSAR, Figure SPSA 2.4-22).

In addition to the inadequate sampling size and distribution of the 1988 program and the extremely high CRLs reported in 1979, a discrepancy exists between pre-1989 and 1989 arsenic data collected by the Army. Sampling conducted prior to 1989 supposedly indicated that the majority of arsenic found in the SPSA and Central Study Area (CSA) wells was suspended (absorbed to particles) in solution (M-1 Alternatives Assessment Report, pp. 2-9; Army Response to Colorado Department of Health Section 1 Specific Comment 22 , CSAR Appendix CSA-F). In the Spring 1989 sampling program, however, almost all of the arsenic was in the dissolved phase, indicating that arsenic is mobile in SPSA and CSA ground water (M-1 Alternatives Assessment Report, pp. 2-9).

The SPSAR references wells downgradient of the M-1 pits that had high levels of total arsenic (SPSAR, pp. 3-115). The Army does not provide well numbers, sampling dates or total arsenic concentrations for these wells; however, based on a review of historical records, it appears that two of the wells correspond to Wells 01503 and 01504. These wells have pre-1989 total arsenic concentrations up to 50,000 µg/l (M-1 Alternatives Assessment Report, p. 2-9). Though the two wells appear to have been sampled for total and dissolved arsenic in the SPSAR, the Army only presented dissolved arsenic concentrations in the report (maximum 1979 value of <1 µg/l, Figure SPSA 2.4-22). Total arsenic values should not have been arbitrarily excluded from the SPSAR, especially since these data confirm that the M-1 basins [sic] are sources of arsenic to SPSA and CSA groundwater [sic]. The State requests an explanation of this discrepancy in the presentation of the data.

Recommendation: To adequately assess the distribution of arsenic downgradient of the abandoned mustard pit and arsenic silos, the following WBZ-1 wells should be sampled for both total and dissolved arsenic:

a. abandoned mustard pit - Wells 02545, 02056, 02581, 02572, and 01522; and

b. arsenic silos - Wells 01524, 01078, 01515, and 01514.

Because flow directions are not definitely known immediately downgradient of the ground water mound in subarea SPSA-1, these wells have been selected to maximize the chances of intercepting flow paths downgradient of the two sites. This evaluation was based on the WBZ-1 potentiometric map presented in Figure SPSA 1.5-5. The Army is requested to inform the State of any updated and/or revised data that would modify well selection for the arsenic sampling program.

Total and dissolved arsenic is scheduled to be sampled on a quarterly basis in Wells 01083 and 01524 (upgradient of the M-1 Basins) [sic] and Wells 01503, 01504, and 36193 (downgradient of the M-1 Basins) as part of the Other Contamination Sources IRA, M-1, [sic] Settling Basins (M-1 Alternatives Assessment Report, p. 4-2).

Response: With respect to the items presented in the State's recommendation above:

A. Please see the SPSAR source area discussion for the Buried M-1 Pits (Section 3.2.1.5, pp. 3-19 and 3-20, SPSAR), wherein the M-1 pits are (1) classified as a category 3 source (contaminants in contact with groundwater); and (2) delineated as "potentially leaching (arsenic) into the groundwater..." Please also see Section 3.3.13.1, a discussion of the migration pathways for arsenic. In particular, note the third full paragraph of this discussion on page 3-115 which states "...total arsenic (dissolved and undissolved) was sampled from wells downgradient of the M-1 pits (SPSA-1e), and results indicate that high levels of arsenic are present in the non-aqueous phase."

As these discussions imply, the Army has, in fact, identified the M-1 pits as a source of arsenic contamination to groundwater.

B. The occurrence of arsenic in SPSA groundwater was presented in two ways: (1) dissolved arsenic was presented in text, tables, and on plume maps; (2) total arsenic was presented in text. Values for total arsenic were inadvertently omitted from tables.

Sampling for dissolved and total arsenic will be conducted at Wells 01522, to investigate groundwater downgradient of the mustard pit, and at Wells 01503, 01514, 01515, and 01524 to investigate groundwater in the vicinity of the arsenic trichloride storage silos, as part of the Phase II FS Field Data Collection Program.

Downgradient of the mustard pit Wells 02545 and 02056 were sampled under the CMP during fall 1988, spring 1989, and fall 1989. Another downgradient well, 02058, was sampled during fall 1988 and spring 1989. The analytical results indicate that arsenic has not migrated to these wells. Well 02572 is cross-gradient from the mustard pit and will not be sampled by the FS. Well 02581 is within 100 ft of sampled Well 02058. Because Well 02058 is located closer to the downgradient flow path from the mustard pit than 02581 and is not scheduled for the CMP sampling, Well 02058 will be sampled by the FS; Well 02581 will not. Well 01078 located downgradient of the arsenic trichloride storage silos was sampled under the CMP during June and December 1989.

Comment 7. Additional Characterization - Vapona Spill (SPSA-1)

The following two documented vapona spills occurred in subarea SPSA-1: (1) a 200-gallon spill south of Building 471; and (2) a 1980 spill consisting of 53,397 pounds of vapona [sic] in the vicinity of Tank Farm 0110, south of Building 472 (Shell Spill Sites Phase I CAR sites 1-13 and 3-18, pp. 11 and 13). No borings were placed to investigate these spills. Additionally, vapona was not analyzed for in SPSA soils during Phase I and Phase II soil boring investigations (SPSAR, Table SPSA 2.1-1).

Recommendation: Soil borings in the areas of the suspected spills, south of Building 471 and in the TF0110 area, must be sampled for vapona to characterize vapona distribution in the soils.

Response: A soil boring program consisting of four borings drilled to the water table will be conducted during the Phase II FS Field Data Collection Program to investigate the alleged Vapona spills and to further characterize the extent of organophosphorous compounds, pesticide-related (OPHP) soil contamination in these areas.

Comment 8. Characterization of Hydrazines and Nitrosamines in SPSA Soils and Ground Water

The Hydrazine Blending and Storage Facility ("HBSF") is a RCRA facility, subject to state hazardous waste laws and regulations. Consistent with this authority, the State requests that the Army submit a closure plan for this facility.

The occurrence and distribution of hydrazine in the soils, and hydrazines and nitrosamines in the groundwater beneath and downgradient of subarea SPSA-6 (Hydrazine Blending and Storage Facility, HBSF, Site 1-7) have not been characterized.

A. Problems with Existing Ground Water and Soils Data

An examination of the ground water and soils data presented in the SPSAR reveals major problems with the data, including the following:

1. In 1986, 12 monitoring wells located on the perimeter of and within the HBSF were sampled for hydrazines, and four wells were sampled for nitrosamines; however, results of the study were ambiguous and unreliable (Site 1-7 Phase I CAR, p. 11); consequently, they cannot be used to characterize ground water contamination in the area.

2. Forty-one wells in the SPSA were sampled in a second program in 1988. According to the Army, "no hydrazines or nitrosamines were detected by gas chromatography (GC) in any of the 1988 samples" (Site 1-7 Phase I CAR, p. 11). However, of the forty-one wells tested, only three are located along flow paths that could be impacted by operations at the facility (SPSAR, Figure SPSA 2.4-17). And, although no known sources of these chemicals were known to be present other than in the HBSF, 30 of 41 wells were located outside of that site in subareas SPSA-1, -2, -3, -5, and -9. With the exception of one sampling point in SPSA-5, the remaining 29 wells are located upgradient or cross-gradient of the HBSF. Non-detections of hydrazines and

nitrosamines in these ground water samples, therefore, cannot be used to determine effects of the HBSF on local ground water.

3. The two primary process liquids stored and handled in the HBSF included anhydrous hydrazine (hydrazine) and unsymmetrical dimethylhydrazine (UDMH) (Site 1-7, Phase 1 CAR, p. 20). However, though hydrazine and UDMH were blended in the west yard and stored in the west and east yards of the HBSF since the beginning of operations in 1960, comparison of the Certified Reporting Limits (CRL) presented in Table SPSA 2.4-2 and shown in Figure SPSA 2.4-17 indicates that neither of these two analytes were sampled in HBSF wells during the 1988 investigation. The only hydrazine fuel sampled in the 11 HBSF wells were [sic] monomethyl hydrazine (MMH). This compound had a relatively high CRL of 3,000 µg/l when compared to CRLs of 31 µg/l and 22 µg/l for hydrazine and UDMH, respectively.

4. Hydrazines and nitrosamines were not detected in the 15 soil borings completed during the Phase I investigation. However, the Phase I investigation was designed as a reconnaissance sampling program for all analytes within the HBSF area; Phase I borings were not located based on hydrazine fuels usage. Additionally, historical information on hydrazine storage, handling, and leaks became available only after implementation of the Phase I program (Site 1-7 Phase I CAR, p. 26).

Twenty of the Phase II soil borings were placed to assess potential hydrazine and nitrosamine soils contamination in heavy usage areas and at potential spill sites. Although both sets of compounds were supposed to be analyzed for in the Phase II program, a USATHAMA GC certification method for hydrazine was not established prior to implementation of the Phase II investigation (Site 1-7 Phase II CAR, p. 3). Soils analysis for hydrazine, therefore, never took place.

B. <u>Evidence of Leaks at Hydrazine Blending and Storage Facility</u>

Documents from 1962 to 1983 have reported numerous sources of hydrazine fuel leaks, including:

> {l}eaks on pipe flanges where meters were removed; leaking inspection plates on the storage tanks; leaking arm valves and pump shaft seals at load and unload stations; leaking pressure lines; leaking drum station valves and pump shaft seals; short fill-line hoses and cracked hoses; leaking valves in the blender; cracks in the concrete slab of the blender

> facility; leaking drums stacked on the concrete slab; and leaking flange fittings.

(Site 1-7 Phase 1 CAR, p. 22).

A 1978 site inspection of the HBSF also indicated that "almost every major fuel product line was leaking and at least three were frozen in the open position" (Site 1-7 Phase I CAR, p. 23). The apparent negligence in maintaining this facility has obviously resulted in hydrazine-contaminated soils in the HBSF area. This conclusion is indirectly supported by the results of a 1983 Army soil gas survey (Site 1-7 Phase I CAR, p. 23). It is possible the Army activities at this site have also resulted in hydrazine-contaminated ground water.

Recommendation: The incomplete characterization of the HBSF is a major data gap. The State makes several recommendations below regarding this problem; however, this list may not be exhaustive. Other problems may potentially exist and will need to be addressed. RI characterization should include:

1. sampling wells within the East and West Yards of the HBSF and immediately downgradient (not cross-gradient) of the facility for hydrazines and nitrosamines; and

2. completing additional soil borings for hydrazine, UDMH, and nitrosamines analyses. Borings should be placed in key locations, including the following:

    a. within the concrete dike surrounding Tank US-4 at depressions or runoff-collection areas in the soils (this will address the 1975 loss of 2,000 pounds of UDMH, and the 1976 spill; (Site 1-7 Phase I CAR, p. 21);

    b. within the concrete dikes surroundings tanks HAS-1, -2, -3, CS-1, and US-1, -2, and -3 in soil depressions or runoff-collection areas;

    c. in soils below joints in the chemical sewer lines connecting the East Yard with the inground concrete tank in the West Yard (Ebasco HBSF Report, Figure 3-2);

    d. in soils below the tributary chemical sewer lines from the West Yard Tanks and the Blender Facility;

e. below the inground concrete tank;

f. in the railroad tank car and truck downloading/uploading areas (north and south ends of Building 756);

g. in the Blender;

h. in the Drum-Filling Station (Building 761);

i. in the Drum-Storage Pad;

j. in the Drum-Cleaning Shed (Building 759);

k. in the Transfer Pump Pit in the East Yard of the HBSF; and

l. in soils immediately beneath joints in the overhead pipeline.

(Reference Ebasco Hydrazine Blending and Storage Facility Wastewater Treatment and Decommissioning Assessment, Version 3.1, 6/88 --Ebasco HBSF Report, Figure 1-4 and Table 1-2).

Borings specified in items f through l above should be completed in soils if present. If the sites are located on concrete foundations, the borings should be placed in soils below cracks in the concrete, or in soil depressions immediately surrounding the facilities.

The proposed boring will: (1) address the spills and leaks summarized in the Site 1-7 Phase I CAR; and (2) evaluate the integrity of the below-ground chemical sewer lines which have not been investigated by the Army. The sampling program for the chemical sewer and the inground concrete tank could be done in conjunction with the HBSF IRA demolition program; however, all borings must be sampled prior to regrading and backfilling of the site.

The State requests the opportunity to participate in the design of the soil boring and groundwater data collection programs.

Response: With respect to the State's contention that the Hydrazine Blending and Storage Facility (HBSF) is a RCRA facility, the Army notes that the HBSF is the object of an IRA, one of several in a series of IRAs which are being performed at Rocky Mountain Arsenal (RMA) as part of the remedial action process developed pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended, 42 USC Section 9601 et seq., and the National Contingency Plan (NCP), 40 CFR Part 300, for the purpose of mitigating or preventing the spread of contamination, reducing actual or potential risks to human health and the environment, and expediting the clean-up prior to the completion of the final, comprehensive remedial plan. The HBSF IRA is being performed pursuant to CERCLA Section 104, 42 USC Section 9604, and is designed to be consistent, to the maximum extent practicable, with the final response actions selected for RMA. The process for the remediation of contamination at RMA is set forth in the Federal Facility Agreement prepared pursuant to CERCLA Section 120, 42 USC Section 9620, the Technical Program Plan adopted under the Federal Facility Agreement, and the Settlement Agreement prepared pursuant to CERCLA Section 122, 42 USC Section 9622, which became effective February 17, 1989. Prior to February 17, 1989, the remedial action process at RMA was governed by the terms of the Proposed Consent Decree of February 1, 1988, and the RI/FS Process Document.

As part of IRA-H, the Army has sampled for hydrazines and nitrosamines in existing Well 01701, located downgradient of the Storage Shed, Change House, and Loading Dock; and Well 01702 located downgradient of Tanks US-3 and US-4. Additionally, Wells 01008, 01019, 01036, 01051, 01054, 01055, 31003, 36069, 36075, and 36080 have been sampled. Hydrazines have not been detected in these wells; however, n-nitrosodimethylamine was detected in Well 01055 in August 1990 (uncertified method), and in March and August 1991. n-Nitrosodimethylamine was also detected one time (August 1991) in Well 01701 and Well 01051. As part of the Phase II FS Field Data Collection Program, a new alluvial monitoring well will be installed approximately 100 ft northeast of soil boring 9 (Figure 1-7-II-1, Site 1-7 Phase II CAR). This location is downgradient of the Blender, Drum Storage Pads, Loading Dock, Drum-Filling Station, In-Ground Tank, and Storage Tanks HAS-1, -2, -3, CS-1, and US-1, and -2. This well will be sampled for hydrazines and nitrosamines.

Presently there is no USATHAMA-certified method for analysis of soil samples for the presence of hydrazines. Additional soil borings, located at the sites specified by the State, will be sampled if a USATHAMA-certified analytical method for hydrazines in soil can be obtained.

Comment 9. Buried Hex Pit (SPSA-1f) Characterization

Neither Shell nor the Army has adequately characterized the buried Hex Pit site in the northeastern section of the subarea SPSA-1. Historical information indicates that hexachlorocyclopentadiene wastes (Hex bottoms) were disposed of in an open pit (Hex Pit, Site SPSA-1f) from 1951 to 1952, and that the pit was subsequently backfilled (Investigation of the Hex Pit as a Possible Source of Groundwater Contamination at the RMA, August 1989 -- Shell Hex Pit Report, p. 2). During excavation of the foundation of Building 571B, a black tarry substance, consistent with the appearance of Hex bottoms, was encountered at 4 feet below land surface.

Prior to a Shell April 1989 field program, the extent of field investigations within the Hex Pit area consisted of a single soil boring completed to a depth of 1 foot (Shell Hex Pit Report, p. 3). The 1989 field investigation (summarized in the Shell Hex Pit Report) consisted of sampling three existing and five newly-constructed wells for four Hex bottom analytes (hexachlorocyclopentadiene, hexachlorobenzene, hexachlorobutadiene, and hexachloroethane). The following problems and omissions are evident:

a. Soil borings were not collected within the site; therefore, the chemical composition and distribution of the waste within the pits were not defined;

b. Hex Pit dimensions are assumed; actual areal and vertical extent of the disposal site is not known;

c. Because soil borings have not been completed to the bottom of the Hex Pit, the distance between the base of the pit and the top of the water table is not known. Despite the obvious lack of data, Shell concludes that "the Hex Pit has probably not been in contact with groundwater since {1984}" (Shell Hex Pit Report, p. 7);

d. Of the three existing wells sampled in the field investigation, none of the purported downgradient wells (01506, 01508) are actually downgradient of the Hex Pit based on the April 1989 water table map (Shell Hex Pit Report, Figure 5); therefore, data from these two wells do not define the contamination contribution from the Hex Pit.

e. It is questionable as to whether newly-constructed downgradient well 36153 [sic] is along a flow path influenced by the Hex Pit; and

f. Ground water quality results from the spring 1989 sampling episode are questionable. Hex data from the USATHAMA certified method MM8A were invalidated; laboratory recoveries for standard matrix spikes were unacceptably high for all but two of the analytes; and field-collected sample matrix spike recoveries were low which "may indicate that ... reported concentrations ... are artificially low" (Shell Hex Pit Report, p. 9).

The only definitive results from the study indicate that the Hex Pit is contributing hexachlorobenzene to ground water. Well 01572, immediately downgradient of the site, had a concentration of 11 µg/l, approximately one order of magnitude greater than upgradient concentrations. Additionally, cluster wells 36511/36512, 6,000 feet downgradient of Well 01572, also showed elevated levels of the analyte (4.9 µg/l and 11 µg.l [sic], respectively). Well 36512, screened over the lower part of the alluvial aquifer, had higher concentrations than Well 36511 (screened over the upper part of the aquifer), indicating potential sinking of the product along the flow path.

Recommendation: Areal and vertical extent of the Hex Pit must be determined, and Hex bottom composition and distribution characterized.

Hex Pit contribution to ground water contamination must be defined. Wells 01573, 01507, 01572, 36511, 36512, and 36513 should continue to be sampled for Hex bottom analytes. Data from Wells 01506 and 01508 should not be included in this program.

Response: With respect to the State's list of problems and omissions, as designated above:

a. A soil boring will be drilled as part of the Phase II FS Field Data Collection Program at the site to identify the depth of the Hex pit bottom, and to characterize the nature of contaminants present within the pit.

b. The Army is confident that the assumed dimensions of the Hex pit are accurate enough to support the FS. Given that most of the Hex pit is overlain by Building 571B, absolute pit dimensions cannot be determined until final remediation of this structure is initiated.

c. The soil boring proposed in a) above will yield the depth of the pit bottom. Water elevations will be obtained from nearby wells.

d. Wells 01506 and 01508 were used to identify the lateral extent of a potential plume moving away from the Hex pit. Well 01572 was installed to characterize contaminants immediately downgradient of the pit.

e. We assume that the State is referring to Well 36513. The Army is confident that Wells 36513, 36512, and 36511 adequately investigate the downgradient pathway.

f. Additional sampling will be conducted during the Phase II FS Field Data Collection Program at Wells 36511, 36512, 36513, 01572, and 01573 to confirm previous results. Well 01507 is both up- and cross-gradient of the Hex Pit, but will be sampled for NAPLs and the CMP suite of analytes in the Phase II FS Field Data Collection Program as part of the NAPL investigation requested by the State in Comment 5.b above.

The FS is evaluating various remedial alternatives downgradient of the Hex Pit in Section 36 as part of the Detailed Analyses of Alternatives. Source area remediation within South Plants is also being addressed by the FS.

Comment 10. Drainage Ditch Characterization, Subareas SPSA-5 and SPSA-9

According to the Army, the primary drainage ditches in section [sic] 1 have been used to carry surface water runoff and process water discharges since the 1940's (SPSAR, pp. 3-48). The drainage ditch originating in subarea SPSA-5a, has had surface water detections of organochlorine pesticides (OCPs), VHOs, DCPD, benzene, and dibromochloropropane (DPCP [sic]) at a sampling station in subarea SPSA-9 just southeast of the boundary with subarea SPSA-5 (Figures SPSA 2.2-1 through 2.2-3 and 2.2-9, and SPSAR, pp. 3-37, and 3-49). Although this ditch (SPSA-9a) "eventually merges with First Creek" (SPSAR, pp. 3-36), no surface water samples or soil borings have been taken at the point where the ditch exits SPSA-9 from section 1 into sections 6 and 31.

<u>Recommendation</u>: To determine the influence of surface water contaminants on downgradient soils and surface water drainages, we request that sediments and surface water be sampled for the above contaminants at the point the drainage ditch exits section 1.

Response: Sediments have been sampled at this location at 0-1 ft and 4-5 ft depths. Results are presented in both Sections 2 and 3 of the SPSAR. Surface water in this ditch is present only during rare storm events; therefore, no surface water samples were collected.

Borehole/Well No.: # 01578 **Project/Task No's.:** 8046 3706.0161

Date Started: 11/21/89 **Date Completed:** 11/22/89

Drilling Inspector: Craig Allen

Reviewed DMB 1-9-90

Drilling Company: Arrow Drilling

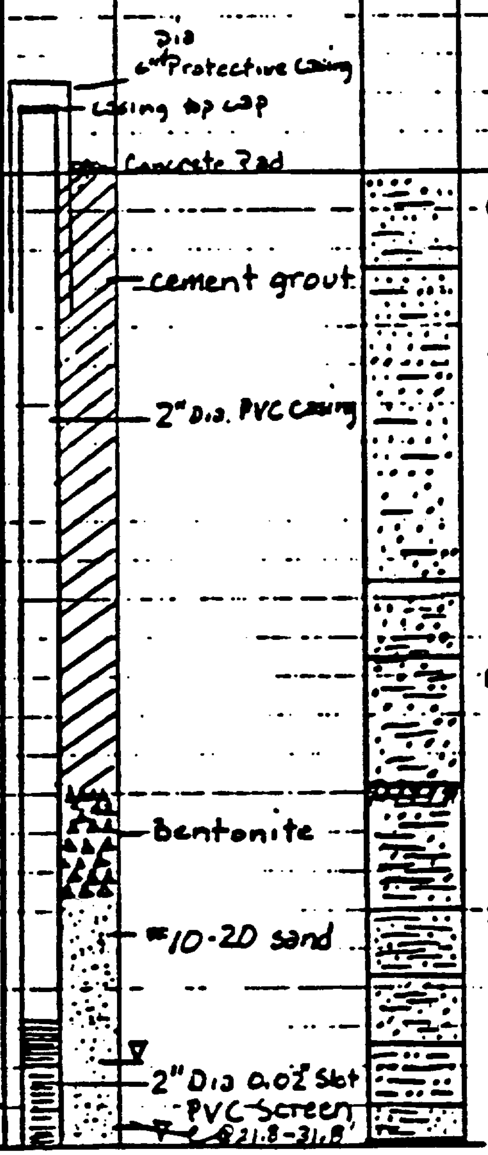
Surveyed Location: N 177707.523
E 2185066.886

Surveyed Elevation: GS 5267.86 ft.
TOC 5269.60 ft.

Total Depth Drilled: 31.8 ft. **Drilling Type:** Hollow Stem Auger

Static Water Level Depth: 24.62 ft.
below TOC, 11-27-89

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description
5 10 15 20 25	N/A	CONTINUOUS SAMPLING w/ 5' SAMPLE BARREL	100% 100% 100% 100% 100%				

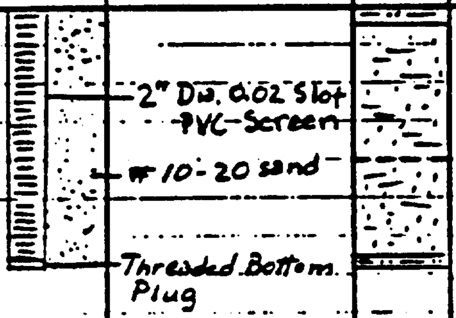


0-4	0-2.5	sand: clayey, v.f. to coarse grained; dk brown; dry
	2.5-4	sand: silty, v.f. to v. coarse grained; lt brown; dry
4-9		sand: silty, v.f. to v. coarse grained; lt brown; dry
9-14	9-10.5	sand: silty, v.f. to v. coarse grained; lt brown; dry
	10.5-12.5	sand: clayey, silty, v.f. to coarse grained; med brown; dry
	12.5-14	sand: clayey, v.f. to coarse grained; med brown; slightly moist; stiff
14-19	14-15.9	sand: clayey, v.f. to coarse grained; med brown; slightly moist; stiff
	15.9-19	claystone: sandy, v.f. to v. coarse grained; dk brown to gray; dry; moderately wthd; moderately fractured; friable
19-24	19-20.7	claystone: sandy, v.f. to med grained; dk brown to bluish gray; moist; highly fractured
	20.7-22.4	sandstone: clayey, v.f. to med grained; lt brown; slightly moist; cemented; hard
	22.4-24	siltstone: sandy, v.f.grained; moist; moderately fractured; friable

Borehole/Well No. : ⁴ 01578 **Project/Task No's.** : 8048/3766.01.01

Date Started : 11/21/89 **Date Completed** : 11/22/89

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description
25 30 31.8		Continuous Sampler w/5' Sample Barrel	100% 100%		2" Dia. 0.02 Slot PVC-Screen #10-20 sand Threaded Bottom Plug		24-29 24-24.9 sandstone: clayey, v.f. to med grained; lt brown; dry; poorly cemented; friable 24.9-25.3 siltstone: sandy, v.f. to med grained; med brown; saturated; moderately fractured; highly weathered 25.3-29 sandstone: clayey, v.f. to med grained; lt brown; dry to slightly moist; poorly cemented; friable 29-31.8 29-31.5 sandstone: clayey, v.f. to coarse grained; med brown to orange; moist to saturated; highly fractured; friable 31.5-31.8 siltstone: sandy, v.f. to med grained; med brown to orange; dry; slightly fractured; hard; grades to a claystone: sandy



Page No.: 2 of 2

Borehole/Well No.: #01579 **Project/Task No's.:** 8048/37060121

Date Started: 11/22/89 **Date Completed:** 11/27/89

Drilling Inspector: Craig Allen

Reviewed OMB 1-9-90

Drilling Company: Arrow Drilling

Surveyed Location: N 177569.576
E 2184639.589

Surveyed Elevation: GS 5268.00 ft.
TOC 5269.22 ft.

Total Depth Drilled: 28.60 ft.

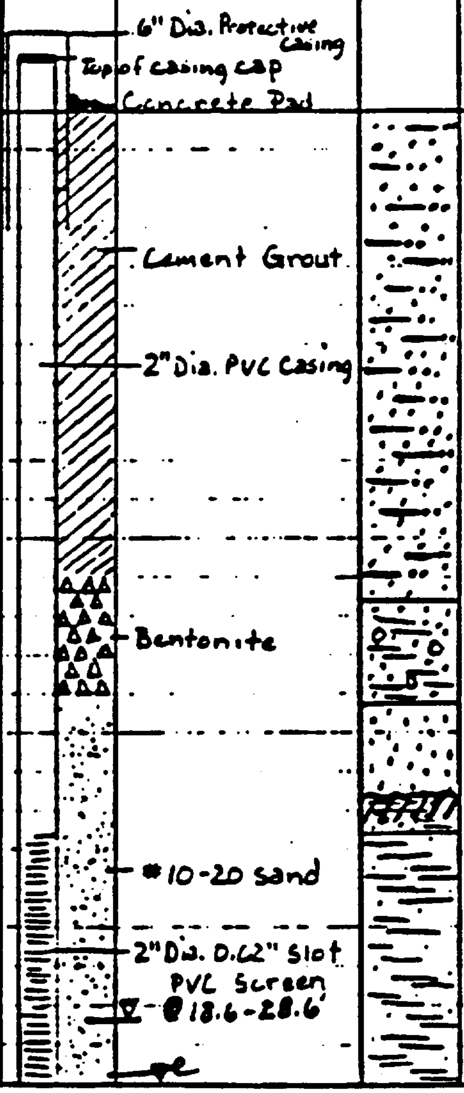
Drilling Type: Hollow Stem Auger

Static Water Level Depth: 24.80 ft.
Below TOC, 11-28-89

Sample Information

Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery
0–4	N/A	Continuous sampling w/ 5' sample barrel	100%
4–9			80% Compaction
9–14			80% Compaction
14–19			90% compaction of sand
19–24			100%

Well Construction



Subsurface Information

Borehole Schematic · Lithologic and Hydrologic Description

Ground Surface

0-4 sand: silty, v.f. to v. coarse grained; lt to med brown; dry; approx. one ft. topsoil

4-9 sand: silty; v.f. to v. coarse grained; lt brown; dry to slightly moist

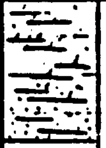
9-14
9-12.7 sand: silty; v.f. to v. coarse grained; lt brown; dry to slightly moist
12.7-14 sand: clayey, v.f. to v.coarse grained; med brown; slightly moist; stiff; 20% tan clayey sand nodules

14-19
14-15.2 sand: clayey; v.f. to v.coarse grained; med brown; slightly moist; stiff
15.2-17.3 sand: v.f. to v. coarse grained; med brown; slightly moist - compacted
17.3-18.6 sand: clayey; v.f. to med grained; med brown; slightly moist; stiff
18.6-19 claystone: sandy, v.f. to coarse grained; med brown; dry to moist; moderately fractured; slightly weathered; blocky structure

Page No.: 1 of 2

Borehole/Well No.: #C1579 **Project/Task No's.:** 3048/3706.0101

Date Started: 11/22/89 **Date Completed:** 11/27/89

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description
25 28.6	N/A	CONTINUOUS SAMPLING w/ 5' SAMPLE BARREL	100%		2" Dia 0.02" Slot PVC Screen #10-20 sand Threaded Bottom Plug		19-24 19-22 claystone; sandy, v.f. to med grained; med brown to green; dry to moist; highly fractured moderately wthd 22-24 claystone; sandy, v.f. to coarse grained; lt brown; dry; highly fractured; moderately wthd 24-~~29~~ 28.6' claystone; sandy, v.f. to coarse grained; med brown, tan to orange; slightly moist; highly fractured; minor wthd; slightly friable; distinct DCPD odor; few thin interbeds of sandstone; v.f. to v.coarse grained; lt brown approx 26-27'

Page No.: 2 of 2

Borehole/Well No.: #01590 **Project/Task No's.:** 8049/3706.C1.01

Date Started: 11/21/89 **Date Completed:** 11/21/89

Drilling Inspector: Craig Allen

Reviewed AMB 1-9-90

Drilling Company: Arrow Drilling

Surveyed Location:	N 177289.776 E 2185140.603	**Surveyed Elevation:**	GS 5260.82 ft. TOC 5262.80 ft.

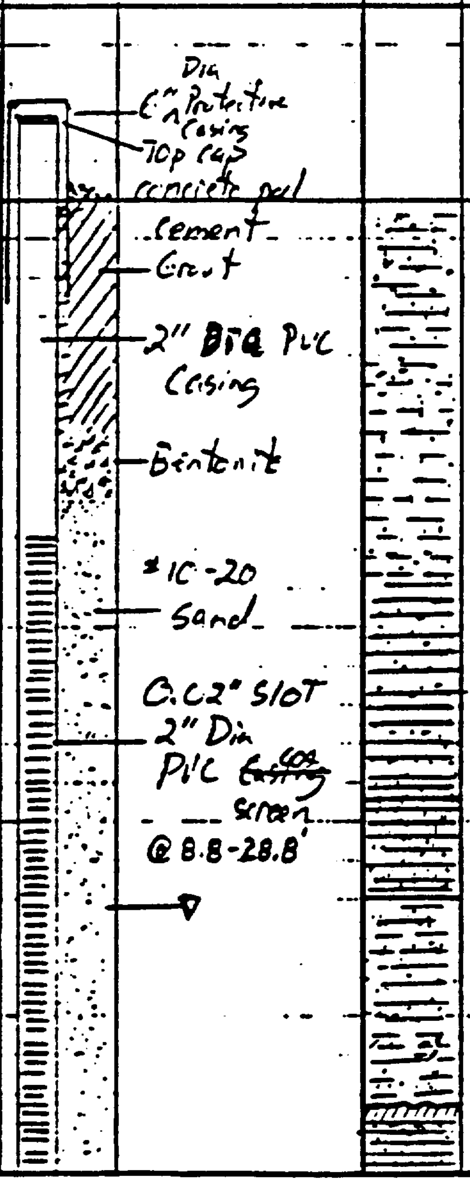
Total Depth Drilled: 28.8 ft. **Drilling Type:** Hollow Stem Auger

Static Water Level Depth: 20.2 ft.
Below TOC, 11-27-89

Sample Information

Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery
0–5	NA	CONTINUOUS SAMPLING W/ 5' SAMPLE BARREL	100%
5			80% Compaction
10			100%
15			100%
20			80%
25			

Well Construction



Subsurface Information

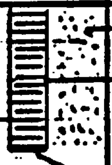
Lithologic and Hydrologic Description

Ground Surface

0-4	0-2.4	sand: silty, v.f. to med grained; dk brown; moist; top soil
	2.4-4	sand: silty, v.f. to v. coarse grained; light brown; dry
4-9		sand: silty, v.f. to v. coarse grained; light brown; slightly moist
9-14	9-9.8	sand: silty, v.f. to v. coarse grained; light brown; slightly moist
	9.8-14	sand: clayey, v.f. to v.coarse grained; reddish brown; moist; w/ minor tan clayey sand nodules
14-19	14-15.4	sand: clayey, v.f. to v.coarse grained; reddish brown; moist
	15.4-18	clay: sandy, v.f. to v.coarse grained; reddish brown; moist
	18-19	sand: clayey, v.f. to v.coarse grained; reddish brown; moist
19-24	19-23.2	sand: clayey, v.f. to v.coarse grained; reddish brown; moist to saturated
	23.2-24	claystone: sandy, v.f. to v.coarse grained; red brown; dry to moist; moderately wthd; friable

Borehole/~~Well~~ No.: 70158C **Project/Task No's.:** Exam 3206.0101

Date Started: 11/21/85 **Date Completed:** 11/21/89

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description
30	N/A	CONTINUOUS SAMPLING	100%		#10-20 Sand 0.02" Slot 2" Dia. PVC Screen Threaded bottom plug		24-28.1 24-27.3 claystone: sandy, v.f. to v. coarse grained; red brown; saturated 27.3-28.1 siltstone: sandy, v.f. to med grained; dk gray to blue; v. dry; v. friable; few thick bedding planes thru out

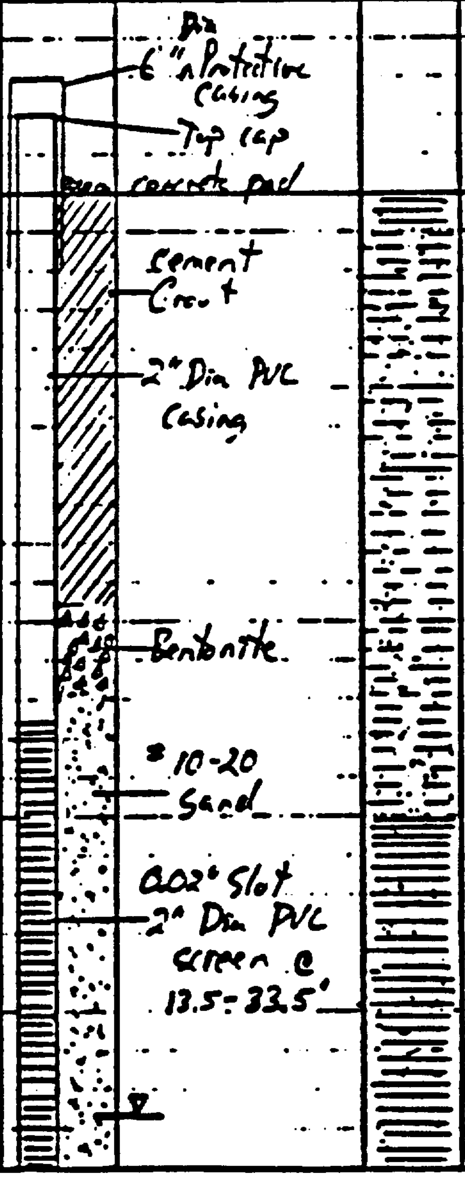
Borehole/Well No.: #01581
Project/Task No's.: 8048 7706.01.01
Date Started: 11/20/89
Date Completed: 11/20/89
Reviewed AMB 1-9-90
Drilling Inspector: Craig Allen
Drilling Company: Arrow Drilling

Surveyed Location: N 177262.445
E 2184871.680
Surveyed Elevation: GS 5266.66 ft.
TOC 5266.54 ft.

Total Depth Drilled: 33.5 ft.
Drilling Type: Hollow Stem Auger
Static Water Level Depth: 25.60 ft.
Below TOC, 11-28-89

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description

Depth Below Ground Surface (ft.)	Blow Count/ Feed Pressure	Sample Type	Sample Depth/% Recovery
0–5	N/A	CONTINUOUS SAMPLING w/ 5' SAMPLE BARREL	100%
5			75% COMPACTION
10			75% COMPACTION
15			100%
20			100%
25			



Ground Surface

0-4		sand: silty, v.f. to v.coarse grained; red brown; moist to 2 feet then dry
4-9		sand: silty, v.f. to v.coarse grained; lt brown; slightly moist
9-14		sand: silty, v.f. to v.coarse grained; lt brown; slightly moist
14-19	14-16	sand: silty, v.f. to v.coarse grained; lt brown; slightly moist to moist
	16-19	sand: clayey, v.f. to v.coarse grained; red brown; moist; w/ minor tan clayey sand nodules
19-24	19-21.5	sand: clayey, v.f. to v.coarse grained; red brown; moist
	21.5-24	sand: clayey, v.f. to v.coarse grained; red brown; moist; more clay than above interval; saturated at 24 feet

Page No.: 1 of 2

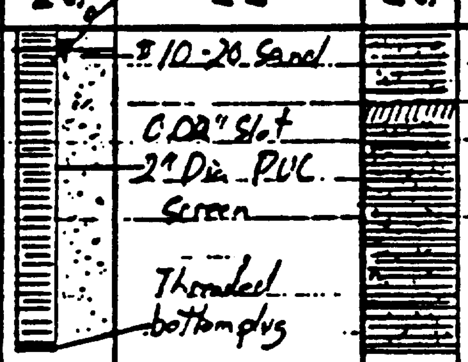
Borehole/~~Well No.~~: 301581 **Project/Task No's.:** ECHE 3700.01.01

Date Started: 11/20/86 **Date Completed:** 11/20/86

Sample Information				Well Construction		Subsurface Information	
Depth Below Ground Surface (ft.)	Blow Count/Feed Pressure	Sample Type	Sample Depth/% Recovery	Well Schematic	Material Description	Borehole Schematic	Lithologic and Hydrologic Description

Depth Below Ground Surface (ft.): 30, 40

Sample Depth/% Recovery: 80% Tube Broken; 100%



24-29	upper 2.5	sand: clayey, v.f. to v.coarse grained; mod brown; saturated
	lower 1.5	claystone: sandy, v.f. to v. coarse grained; mod brown to dk green; moist; highly wthd; friable; blocky structure Denver Fm. at 27 feet
29-33.5	29-32.5	claystone: sandy, v.f. to v. coarse grained; mod brown to dk green; moist to saturated; moderately wthd; moderately fractured; friable; hard
	32.5-33.5	claystone: sandy, v.f. to v. coarse grained; mod brown to grayish orange; moist to dry; moderately wthd; moderately fractured; friable; hard

Appendix F6

Additional Comments and Responses on Proposed Final Remedial Investigation Summary Report, Version 3.1

Remedial Investigation Summary Report

INTRODUCTION

The Remedial Investigation Summary Report (RISR) is designated in the Federal Facility Agreement as a formal RI Product for the On-Post Operable Unit at RMA. As such, the Draft Final version of the RISR is subject to review and comments by the organizations and State. In accordance with the Federal Facility Agreement, the organizations and State submitted comments on the Draft Final RISR. Responses to those comments were prepared and were, along with certain revisions and modifications requested in the comments or agreed to in the responses, incorporated into the Proposed Final version of the RISR, which was resubmitted to the organizations for their acceptance or dispute.

The Federal Facility Agreement does not provide an opportunity for comment on Proposed Final versions of formal RMA RI/FS Products, nor are formal responses to such comments required by the Agreement. Rather, the signatory parties to the Agreement typically review Proposed Final Products in order to determine whether or not to exercise their right to invoke the Dispute Resolution Process, or to formally accept the document as a Final Product.

The EPA, while expressing their intent not to dispute the RISR, submitted additional comments to the Army regarding the Proposed Final RISR. The State also submitted additional comments. To ensure that the concerns of both EPA and the State regarding the RISR are addressed, and to facilitate a cooperative atmosphere among all the parties, the Army has elected in this case to provide written responses to these additional comments as part of the Final RISR.

Appendix F6.1

Responses to Environmental Protection Agency Comments on the Proposed Final Remedial Investigation Summary Report, Version 3.1

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
999 18th STREET - SUITE 500
DENVER, COLORADO 80202-2405

Ref: 8HWM-FF

DEC 9 1991

Kevin Blose
ATTN: AMXRM-PM
Rocky Mountain Arsenal
Commerce City, Colorado 80022-2180

Re: Rocky Mountain Arsenal (RMA)
Proposed Final Remedial
Investigation Summary Report,
November 1991.

Dear Mr. Blose:

We have reviewed the above referenced document and have the enclosed comments. We are not invoking dispute resolution with the understanding that our remaining concerns will be addressed during FS studies. Please note our concern about the statement that there was no statistically significant difference between detection ratios for on and off post biota other than for dieldrin. We request that a caveat accompany this statement, such as to preclude it from being used out of context. Our contact on this matter is Linda Jacobson at (303) 294-1977.

Sincerely,

Connally Mears

Connally E. Mears
EPA Coordinator for RMA Cleanup

Enclosure

cc: Brian Anderson, RMA
Major John Fomous
Brad Bridgewater, DOJ
David Shelton, CDH
Jeff Edson, CDH
Vicky Peters, CAGO
Janet Yanowitz, Geotrans
Bill McKinney, Shell
George Roe, Shell

RMA 91-1602 1/2

ENVIRONMENTAL PROTECTION AGENCY'S COMMENTS ON THE PROPOSED FINAL REMEDIAL INVESTIGATION SUMMARY REPORT, NOVEMBER 1991

General Comments:

For the most part, the Army's responses to EPA's comments on the draft [sic] RISR are satisfactory. The EPA has comments and questions, however, on the following responses.

Response: Comment noted. EPA previously commented on the Draft Final RISR.

Specific Comments:

Comment 1. Army's Response to EPA Appendix A General Comments, Comment 2: The Army states "Additional side-specific investigations in limited areas will be considered in the FS." EPA believes that such investigations are necessary, and we have actively participated in FS subcommittee meetings to define the limited areas requiring further definition. Please note our concerns in the following areas:

1) The influence that flow in the Denver Formation may be having on contaminant migration, particularly in the South Plants area. EPA asked for better definition of the Denver Formation, per our letter of November 22, 1991.

2) An investigation of NAPLs per discussion at FS Data Needs meeting on October 17, 1991.

3) The nature and extent of vertical contamination specifically in Sections 25 (North Plants area) and 26 (Basins C, D, E, and F). The Army states on pages F2-46 and F2-47 that the vertical extent of contamination in these areas has "...not been defined."

4) The reason(s) why "...concentrations of organic analytes vary with depth in an irregular manner..." (Appendix B, page B-26) in the North Boundary Containment System area.

5) The implications of data needs of a possibly lower DIMP standard.

6) The necessity of additional IMPA and NDMA testing for FS evaluations.

7) Verification and source definition of anomalous hits.

8) Validation of surety detections, currently thought to be questionable, including reliable quantification of the concentration levels and the volume of soils impacted.

9) Phase II investigation for better definition of surficial soils for FS data needs.

Another issue which needs to be addressed is the correlation of on-post remedial goals with off-post criteria.

Response: With respect to the EPA's concerns as noted above:

1) The FS is in the process of collecting additional groundwater data in the South Plants area as part of the Phase II FS Field Data Collection program for groundwater. These additional data will be used in conjunction with other available data to refine the understanding of Denver Formation properties and contaminant migration as they pertain to achieving the goals of the FS.

2) As the EPA is aware, further investigation of NAPLs is included in the Phase II FS Field Data Collection program for groundwater in the South Plants area. In addition, the NAPLs investigation proposed by the State in the October 17, 1991 meeting referred to by the EPA is being evaluated by the Army within the context of FS goals.

3) and 4) The FS is evaluating the results of the investigation of the vertical extent of groundwater contamination in the Denver aquifer, as presented in Appendix B of this report. Based on this evaluation, and the additional data developed by the Phase II FS Field Data Collection program, the FS will determine to what extent, if any, further information is required in these areas in order to evaluate remedial alternatives.

5) The FS will evaluate its data needs with respect to developing or revising remedial alternatives in the event DIMP standards are lowered.

6) The necessity of additional isopropylmethyl phosphonic acid (IMPA) and n-nitrosodimethylamine (NDMA) sampling will be evaluated by the FS as part of the overall evaluation of remedial alternatives.

7) The EPA's concern is noted. In general, additional verification and source definition of anomalous hits beyond that undertaken as part of the RI in Phase I and Phase II, and in the FS Field Data Collection program, is unwarranted and unnecessary.

8) Areas with a potential for agent occurrences will be included in the evaluation of remedial alternatives conducted by the FS.

9) Surficial soils investigations to address specific exposure assessment and FS needs are planned as part of FS. The organizations and State will be kept informed of these activities and the results of the investigations. In addition, the need to address the correlation of on-post remedial goals with off-post criteria was identified in the Subcommittee meeting on remedial action objectives (RAOs), held December 11, 1991 at RMA.

Comment 2. Army's Response to EPA Cover Letter Comments, Comment 10: The Army states that the text has been modified to include the fact that information presented in Appendix B will be considered in the FS. Where is this mentioned in the text?

Response: The reader's attention is directed to the first and second paragraphs of Section B.1.1, particularly the second sentence of the second paragraph, which states that the results of the Phase I investigation of the vertical extent of groundwater contamination are presented in Appendix B. That the FS will consider the information developed during Phase I is stated in the final paragraphs of Section B.1.1, Purpose and Scope, on page B-2 of Appendix B of the RISR, and again in Section B.6, Summary, in the second complete sentence on page B-35.

Comment 3. Page A3-140, paragraph 1: The data, included in this report, are not conclusive enough to "show...that RMA is not a significant source of airborne particulates." The data collected for the Comprehensive Monitoring Program for Air, which supports this conclusion, should be referenced.

Response: The Comprehensive Monitoring Program (CMP) was not a subject of the Remedial Investigation Summary Report (RISR), hence it was not included in the discussion presented in Section A3.4 of Appendix A. However, findings of the CMP for air support the conclusion that RMA is not a significant source of airborne particulates. While RMA may be a local, short-term source of total suspended particulates (TSPs) during periods of invasive remedial activities coupled with high-wind events, the CMP concluded that these impacts were localized and fell off rapidly with distance from the location of the activity. (CMP Air Quality Data Assessment, Fiscal Year 1990 Final Report, Version 3.1; Section 4.2.6, Summary; RLSA, 1991/RIC 91311R01). Air quality for TSPs is consistently superior on post at RMA than in the off-post Denver urban area.

Comment 4. Page A3-153: The Army states that "using the 'true difference between percentages' method suggested by Sokal and Rohlf (1981), only the percentage of dieldrin detections for terrestrial species at the 80 percent confidence level was significantly greater on post than off post with a 95 percent certainty. On post versus off post detection ratios for the other analytes were not significantly different."

> We are concerned that this statement presents a misleading oversimplification, and should be accompanied by a caveat. Although we do not intend to invoke dispute on this item, we do not agree with it and must insist that it be flagged such as not to be taken out of context. We suggest that the statement be accompanied by a caution indicating its limitations, in that it pertains only to pooled populations and does not take into account differences in age groups.
>
> First, please note that the above-quoted is a statistical statement that does not take into account the ecological significance of contamination findings. For example, with regard to mallards, the Biota RI states that "for mercury, significant differences were found between juveniles from control and contaminated sites, as well as differences among age groups when contaminated and control sites were pooled." (Biota RI, Volume I, p. 4-44). Second, use of a different statistical method yields different results. Please note that the difference between percentages of detects is statistically significant for mercury ($p<0.001$) and marginally significant for arsenic and aldrin ($p=0.10$) when the analysis was performed with a one-sided Fisher's exact test. We believe that the test indicated by the Army (Sokal and Rohlf) may have been used inappropriately, as we have not been able to duplicate the results for mercury. The approach described by Sokal is used to determine the sample sizes required in an experimental setting to detect a given "true" difference between two percentages. The prespecified difference should be the minimum difference that the investigator feels is ecologically important. As indicated in the mercury example above, we believe that ecologically significant indicators (juvenile and age-groups) were ignored. Finally, the statement about 80 percent confidence with 95 percent certainty is a statement about statistical power which does not make sense unless the difference worth detecting is given.

Response: EPA is correct that the "true difference between percentages" method suggested by Sokal and Rohlf was inappropriately cited in the text as a test of significance between on-post and off-post detections ratios. The text has been revised to clarify that the "true difference between percentages" test was used to determine whether sample populations were large enough to evaluate the significance of the percentage difference between on- and off-post detections ratios. Chi-square tests and the one-sided Fisher's exact test were performed on the data for the seven contaminants of concern, and according to these tests arsenic, mercury, and dieldrin detections appeared to differ significantly between on- and off-post samples. However, when the "true difference between percentages" test suggested by Sokal and Rohlf was applied, only the percentage difference between on- and off-post dieldrin detections was great enough that the number of samples collected could be shown to be adequate to establish that the difference was significant at the 80 percent confidence level with a 95 percent certainty.

Comment 5. Response to State of Colorado Comment 2(a) on the Proposal to Improve the Remedial Investigation for the Southern Study Area: The response needs to be expanded to discuss specifics of how the State concern for the degree of investigation of the extent of VHO contamination in Water Bearing Zone (WBZ) 2 and 3 will be addressed in the FS.

Response: The FS is considering the need for additional investigations in this area. The specifics have not been established, and further discussion of factors affecting the area are appropriate. For example, while local flow conditions in WBZ-1 are towards Lake Ladora, and contaminant conditions within WBZ-1 are well established, it is not clear whether flow conditions within WBZ-2 and -3 are towards the lake, or reflect regional groundwater flow conditions to the north and northwest. In addition, given the shallow nature of Lake Ladora, the local hydraulic gradient imposed by the presence of the surface water in the lake, and the depth of WBZ-2 and -3, it is also not established that, even if contaminants were migrating to the southwest in WBZ-2 and -3 in this region, they could affect surface water in Lake Ladora. It may be appropriate to include the area between South Plants and Lake Ladora in further FS investigations as part of the evaluation of proposed remedial alternatives; these concerns can be addressed as part of the FS data needs process.

Comment 6. Response to State of Colorado Comment 9 on the Proposal to Improve the Central Study Area Remedial Investigation: The text states that "The tight time constraints to provide clearance for samples... required analytical reporting procedures susceptible to false positive reports." Is resampling to verify the presence of mustard at these suspect locations planned during the FS? Have analytical methods or handling procedures (including clearance time for samples) been improved to prevent recurrence of this in the future?

Response: Agent compound screening of samples collected in areas where the potential for agent occurrence exists will be a component of FS sampling throughout the evaluation and implementation of remedial alternatives. Sample handling and analytical protocols are designed to ensure that valid analytical data is collected. While it is impossible to predict every contingent condition which may affect the generation of false positive reports, every effort to assure data validity has been and will continue to be exercised throughout the RMA environmental programs.

Appendix F6.2

Responses to Colorado Department of Health Comments on the Proposed Final Remedial Investigation Summary Report, Version 3.1

Remedial Investigation Summary Report

COLORADO
DEPARTMENT
OF HEALTH

4210 East 11th Avenue
Denver, Colorado 80220-3716
Phone (303) 320-8333

Telefax Numbers:
Main Building/Denver
(303) 322-9076
Ptarmigan Place/Denver
(303) 320-1529
First National Bank Building/Denver
(303) 355-6559
Grand Junction Office
(303) 248-7198
Pueblo Office
(719) 543-8441

ROY ROMER
Governor

JOEL KOHN
Interim Executive Director

December 9, 1991

Office of the Program Manager
Rocky Mountain Arsenal
ATTN: AMXRM-E (Mr. Kevin Blose)
Building 111
Commerce City, CO 80022-0166

Re: State Comments on the Proposed Final RI Summary Report

Dear Mr. Blose:

Enclosed are the State's comments on the above-referenced report. Of concern to the State are major and still unresolved data gaps, such as lack of adequate characterization of chemical agent contamination, and the inexact understanding of the contaminants in disposal trenches, understanding of the contaminants in disposal trenches, underground piping, and structures.

The State urges the Army to discuss these data gaps in upcoming FS meetings in an attempt to rectify the existing holes before the RI Report is finalized. If you have any questions or comments, please don't hesitate to call.

Sincerely,

Jeff Edson
RMA Project Manager
Hazardous Materials and
Waste Management Division

JE/cf

RMA 91-1603 1/2

cc: Vicky Peters, AGO
George Roe
John Fomous
Edward McGrath
Bradley Bridgewater
Connally Mears
John Barth
Ira Starr, GeoTrans

COLORADO DEPARTMENT OF HEALTH'S COMMENTS ON THE PROPOSED FINAL REMEDIAL INVESTIGATION SUMMARY REPORT
DECEMBER, 1991

General Comments:

Comment 1. The nature and extent of chemical warfare agent contamination has not been adequately characterized. Figure RISR 2.2-1 summarizes the information made available to the Parties. It is a map showing Areas with Potential for Agency [sic] Occurrences, and is, according to p. 2-23, "drawn conservatively as a 'worst-case' scenario." This limited information is not sufficient for inclusion in the quantitative assessment of risk performed in the EA, nor is it adequate to conduct a Feasibility Study to remove these contaminants. Thus, a sampling program to determine the extent of agent contamination must be undertaken throughout all areas of potential agent contamination. The Army must provide justification for the areal extent of the sampling program. During the October 25, 1991, FS data needs meeting Kevin Blose stated that the database is not inclusive of all known agent contamination, explaining that there were certain areas on the Arsenal which the Army knew were contaminated with agent. Because the Army felt that exact contaminant levels were not necessary, these sites were not sampled for agent as part of the RI. This information, promised in the FS data needs meetings, must be provided to the Parties to be used in our review of an agent sampling program.

Response: Figure RISR 2.2-1, Areas with Potential for Agent Occurrences at Rocky Mountain Arsenal, represents the worst-case scenario for chemical warfare agent occurrence at RMA. Throughout the FS process and the Record of Decision (ROD) these areas will be treated as if contaminated by agents. That is, the scope of all remedial actions designed in the FS for the areas shown on Figure RISR 2.2-1 and evaluated for eventual selection in the final remedy will include treatments capable of handling chemical warfare agents.

It is not the Army's intent to dismiss the potential for agent contamination within designated areas on Figure RISR 2.2-1 from consideration within the context of the FS. Analytical screening for agent is a standard procedure on all soil samples collected from potential agent occurrence areas as part of the FS Field Data Collection program, and will continue to be employed for confirmation samples taken from these areas during the implementation of any remedial actions. The purpose and intent of this sampling is, and will continue to be, to focus the actual remediation efforts in order to achieve the most effective and efficient remedy possible. The State, as well as the organizations that are party to the Federal Facility Agreement, will be kept fully apprised of the information developed by these sampling programs.

Comment 2. In several Army responses to comments on the RISR, and during the FS data needs meetings, the Army has stated that a "worst-case" would be assumed rather than undertaking additional data collection. For example, regarding the nature of contamination in disposal trenches and the depth of contamination in those trenches (Army Complex Disposal Area), the contamination surrounding underground piping and sewers, the contamination of structures, and the presences of chemical agents. In these areas the nature and extent of contamination has not been adequately determined; in addition, it will not be acceptable to limit the choice of remedial actions based upon a lack of data. For example, the choice of capping as the remedial alternative for disposal trenches will not be acceptable if justified only because there may be agent or unexploded ordnance, or the trench may extend to depths to which excavation is difficult. If limited characterization of any RMA site prevents the Army from fully screening and developing remedial options, then the RI has obviously not been adequate, and additional sampling must be carried out.

Response: The State is correct in noting that the Army has taken a worst-case approach towards contaminant conditions at certain sites, rather than initiate additional data collection efforts at this time. However, the State incorrectly implies that this worst-case approach will be used to "limit" the choice of remedial actions. On the contrary, the worst-case approach is intended to ensure that these sites will be the object of remedial actions designed to remedy precisely the 'worst-case.' Confirmation sampling conducted during the implementation of remedial actions will be utilized to confirm the efficacy of the selected remedial alternatives and to fine tune the remedy as appropriate.

Comment 3. In several RISR responses to comments, and in the FS data needs meetings, the Army has responded to specific data gathering requests of the parties by explaining that these would be addressed by interim response actions (IRAs) or in the Surface Water CMP. Two of the referenced IRAs were the Lake Sediments and Chemical Sewers IRAs. Although a discussion was held a couple of years ago regarding prevention of contaminant loading to the lakes from ditches and overland flow around South Plants, the State is not aware of any concrete plans to establish an IRA to deal with this issue; nor were we aware that such an IRA would encompass characterization or remediation of the lake sediments themselves. A Chemical Sewers IRA, on the other hand, has never even been discussed. We request updates on the status of such efforts. In addition, since these IRAs have not even been established, it would appear that data could be gathered more rapidly under the F.S. Data Gap [sic] program which is currently ongoing. No reason to delay such investigations has been provided.

The State has not received the Surface Water CMPs [sic] for 1989 or 1990, nor are we aware of any results from the South Tank Farm LNAPL Treatability Study. This information should be provided as soon as possible. Additional data needs may be identified upon review of those documents.

Response: The State presents no specifics regarding where such references to the "Lake Sediments" and/or "Chemical Sewers IRAs" were made in either the responses to comments included in the Proposed Final RISR or in any FS data needs meetings. No such references are included in any RISR responses to comments; in addition, while the proceeding of any meetings having to do with FS data needs are not a subject of the RISR, the Army disputes the allegation that such IRAs were referenced in those meetings. The State is kept apprised of the status of IRAs through the RMA Committee and Subcommittee meetings in accordance with procedures outlined in the Federal Facility Agreement. The potential for an action to prevent sediment-bearing runoff from entering the lakes is currently being considered and will be the focus of an upcoming Committee meeting.

The CMP report on surface water for 1989, titled "Comprehensive Monitoring Program, Final Surface Water Data Assessment Report for 1989, Version 2.0" (RLSA, 1990/RIC 91343RO1), was released to the parties on December 4, 1991. The draft 1990 CMP surface water data assessment report is presently under review and will be forthcoming. The Draft Technical Evaluation, LNAPL Plume Soil Vapor Extraction (SVE) Process Field Demonstration Treatability Study is also under review and will be released to the parties when completed.

Comment 4. Adequate characterization of the Central Study Area disposal trenches remain [sic] a significant data need. The Army has promised to review its decision regarding additional characterization of the Army-Hyman trenches and Army trenches to the east of the bedrock divide (36-17N). The results of its review should be presented to the parties as soon as they are available.

Response: Comment noted.

Specific Comments:

Comment 1. F2-28, Comment 26. The State's comment, though somehow lost in transmission, was as follows:

Page A3-145, A3.5, Biota--The Army states:

> "Terrestrial producers (plants), and to some degree carnivores, show elevated levels of OCPs in tissue samples that can be broadly associated with OCP concentrations in RMA soils. This relationship also tends to hold for mercury in carnivores. Similar associations could not be made for OCPs, arsenic, or mercury in other trophic levels."

> The meaning of the term "broadly associated" is unspecific and should be clarified. The Army apparently intends this passage to describe attempts to correlate tissue concentrations to soil samples. It is not clear how plants and carnivores could be correlated with specific soil concentrations, while intermediary trophic levels cannot. This is especially true given the tendency for the foraging behavior of higher trophic levels to result in larger home ranges. Thus, this lack of correlation for intermediary trophic levels brings into question any correlation claimed between soil levels and carnivores. We would appreciate a clarification of this statement.

Response: The State's comment, as received by the Army, was accurately reproduced in its entirety on page F2-28 of Appendix F of the RISR. That comment consisted only of a quotation of a passage from Appendix A of the RISR. As is evident, no comment regarding the quoted passage was originally made, and that fact was noted in the Army's response. In response to the comment which the State now makes with respect to the quoted passage, the Army notes that the "broadly associated" relationship between OCP levels in plants, and to some degree carnivore tissue samples, and OCP levels in RMA soils is a statement of fact regarding the data collected during the RI. No "correlation" was claimed between soil levels and carnivores. Use of the term "broadly associated" rather than "correlated" was deliberate in order to avoid precisely the sort of inappropriate conclusion which the State imputes was the Army's intent.

Comment 2. P. F2-38, Comment 13. This comment was apparently misunderstood by the Army. The State intended to point out that the Army was claiming that background concentrations of metals were in the range of 10 to 100 ug/l range [sic] when in fact the geometric mean concentration of background was only 5.95 ug/l according to Table RISR B.2-1 (the arithmetic average was 12.6 ug/l). Although no range of values was given in these tables [sic], background concentrations must be below 10 ug/l in a significant portion of all background samples to have resulted in these values.

Response: Table RISR B.2-1 reports adjusted geometric mean concentrations, not geometric mean concentrations. In the Army's opinion the text change for section B3.3 recommended by the State in Comment 13 (p. F2-38) lacks clarity. However, the idea presented by the State has been included by replacing the sentence "This range corresponds to the range of background concentrations . . ." on page B-20 of Appendix B with the following sentences: "This is within the range of background detections from upgradient wells. However, the adjusted geometric mean of metals concentrations in the Denver aquifer is slightly greater than in background wells (Table RISR B.2-1)."

Comment 3. P. F2-48, Comment 29. We believe that the Army should include the following data in the VEC database or present reasons for their exclusion.

Well	Sampling Date	Analyte	Result (ug/l)
26130	80178	CPMSO	457
26148	88229	12DCLE	920
26157	88209	12DCLE	620
26157	89044	12DCLE	930

These are high concentration hits, which may be reflective of significant deep contamination. Moreover, the presences of DCLE in the vicinity of wells 26148 and 26157 has been verified on three occasions as indicated by the above data.

Response: Wells 26148 and 26157 are part of the CMP groundwater network and have been sampled several times since the 1988 and 1989 dates identified in the comment. Samples from these wells did not contain 1, 2-dichloroethane (12 DCLE) or related chlorinated solvents. Therefore the referenced samples for these wells were not included in the VEC database.

Well 26130 is not part of the CMP network. However, nearby Denver aquifer wells included in the CMP network (wells 26089, 26090, 35038, and 35039) have not contained chlorophenylmethyl sulfoxide (CPMSO) or related compounds. The referenced sample in well 26130 is from 1980 prior to implementation of the QA/QC requirements of the remedial investigation or the CMP. Because of these facts, it is considered unlikely that the 1980 sample at well 26130 is representative of present conditions in the Denver aquifer.

Comment 4. P. F5.2-6. The Army's response to this comment shows the illogical nature of the sampling methodology in this area. In the first sentence the Army states "The buried lake sludges were presumed contaminated with OCPs at the inception of the RI investigations; consequently, Phase I samples were collected from areas peripheral to the buried sludges," but then states in response to Comment 3b, "OCPs were not analyzed during the Phase II investigation on the basis of (1) no Phase I detections of OCPs and (2) inconclusive evidence from the Dames and Moore study regarding OCP contaminant occurrence." In other words, during Phase I the Army did not sample within the trenches because it assumed they were contaminated with OCPs. The Army did not sample the trenches for OCPs during Phase II because it did not find any OCP detections in Phase I and because it, without additional data, rejected its prior assumption. The Army must sample the trenches in this area for OCPs, as requested by the State and EPA in the FS data needs meeting.

Response: The State fails to comprehend the Army's response to Comment 3 of the State's Proposal to Improve the Remedial Investigation for the Southern Study Area, as presented on page F5.2-6 of Appendix F of the Proposed Final RISR. What the response says is that the buried lake sludges were presumed contaminated with OCPs, and Phase I bores were located in areas peripheral to them. No OCPs were detected in these Phase I bores; consequently, Phase II bores to further investigate the area of the Phase I bores were unwarranted. The response further states that three Phase II bores were located in trenches where buried sludges were presumed to be disposed; mercury was detected in samples from these bores, but OCPs were not analyzed for using OCP-specific GC methods because the sludges were already presumed to be OCP-contaminated. Semivolatiles were analyzed for using GC/MS, a method capable of detecting OCPs but with less sensitive detection limits (0.3 µg/g for aldrin and dieldrin) than the GC method. OCPs were not detected in these analyses. The Army did not reject its prior assumption that the buried lake sludges were contaminated with OCPs; on the contrary, it has acted in accordance with this assumption. The response further stated that reassessment of the area may be appropriate during the FS. Soil sampling of the buried lake sludges is currently planned as part of the FS Field Data Collection program.

Comment 5. P. 5.5-19, [sic] Comment 6. In the Army's response to this comment, it states, "because no contamination of the First Creek alluvial aquifer has been detected in Wells 36501, 36502 or 31501, and only single isolated, and nonrepeated detections of chlorophenylmethyl sulfide and DIMP in Well 31005, {sic} the conclusion regarding the Denver Formation as an effective barrier to groundwater flow or as an attenuator of contaminant migration is supported by the data." However, Wells 36502, 31005 and 31501 are not directly downgradient of CSA-1c, and can therefore not be used as indicators of contamination from the Army Complex Disposal trenches. Well 36501, which is located immediately downgradient of the eastern trenches, has not been sampled since 1987, and the 1987 data are stored in the Pre-QC file of the RMA database. Additionally, the 1987 data indicate the presence of elevated methylene chloride concentrations which are also found at much higher concentrations in the vicinity of up-gradient trenches in Anomaly C (see Figure 3-11 of the Army Complex Disposal Trenches Re-Evaluation Report). Therefore, the Army's conclusion that data from Well 36501 indicate that the trenches have not impacted the First Creek Alluvial Aquifer is not valid; the well must be resampled to determine the possible impacts of the trenches on the aquifer.

Response: The Army's response to Comment 6 of the State's Proposal for Rectification of Remedial Investigation Data Gaps in the Central Study Area, as presented on page F5.5-19 of Appendix F of the RISR, states in the final paragraph that four new wells will be installed and sampled twice as part of the Phase II FS Field Data Collection program in the area indicated by the State. In addition, two of the wells will be used for pump tests to determine aquifer hydraulic properties in order to support the FS in alternatives analysis.

Comment 6. The Army's Response [sic] to State Comment No. 31 is insufficient and presents unsupported conclusions regarding On [sic] versus Offpost [sic] biota contamination. The Army presented no justification for their choice of the "true differences between percentages" statistical test. The Army has not provided sufficient detail of their methodology to allow reproduction of the results or confirmation of the conclusion that, with the exception of dieldrin, "On-post versus off-post detection ratios for the other analytes were not significantly different." No explanation is given by the Army for changing "95 percent confidence" to "80 percent confidence" in the final version [sic] of the Remedial Investigation Summary Report. Finally, the Army has reached these conclusions without differentiating between ecologically similar sample groups. Rather, the above mentioned generalization has been made on the basis of pooled samples and, as such, is potentially misleading.

Response: This comment is similar to EPA's Comment 4 on the Proposed Final RISR (pages F6.1-3 and -4 of Appendix F of the Final RISR (version 3.2)), and the reader is encouraged to review the Army's response to that comment as well.

The "true differences between percentages" test was inappropriately cited in the text of the Proposed Final RISR as a test of the significance between on-and off-post detection ratios. In fact, the test is used to evaluate whether the sample populations are of sufficient size that the significance of the differences between the detection ratios can be established. The text in Section A3.5.3 of the Final RISR has been revised to clarify this. When the "true difference between percentages" test was applied to the pooled on-and off-post biota data for the seven contaminants of concern, only the dieldrin data were from a sample population sufficiently large to establish, at the 80 percent confidence level with 95 percent certainty, that the difference between on-and off-post detection ratios was significant. The text has also been revised in Section A3.5.3 to note that the comparisons between on-post and off-post data are for pooled terrestrial biota samples, and to caution against the use of these comparison results out of context. Finally, the "95 percent confidence" level was changed to "80 percent confidence" from the Draft Final to the Proposed Final RISR to assure, with a reasonable and not unrealistically stringent degree of confidence, that the significance of the difference between on-and off-post detection ratios for the seven contaminants of concern would not be masked by an unreasonably large required sample population, based on the results of the "true difference between percentages" test.