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U.S. ARMY
MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

Proposed Final
Remedial Investigation Report
Volume VII
Eastern Study Area, Section 1.0
Version 3.2

May 1989

EBASCO SERVICES INCORPORATED
Applied Environmental, Inc.
CH2M HILL DataChem, Inc.
R.L. Stollar & Associates, Inc.

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Rocky Mountain Arsenal

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Contract Number DAAA15-88-D-0024

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U.S. ARMY PROGRAM MANAGER'S OFFICE
FOR ROCKY MOUNTAIN ARSENAL CONTAMINATION CLEANUP

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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Standard Abbreviations used in Eastern Study Area Report

1. Analyte Groups

VHO	Volatile halogenated organic compounds
VHC	Volatile hydrocarbons
VAO	Volatile aromatic organic compounds
OSCM	Organosulfur compounds, mustard-agent related
OSCH	Organosulfur compounds, herbicide related
OPHGB	Organophosphorous compounds, GB-agent related
OPHP	Organophosphorous compounds, pesticide related
DBCP	Dibromochloropropane
ONC	Organonitrogen compounds
PAH	Polynuclear aromatic hydrocarbons
SHO	Semivolatile halogenated organic compounds
OCP	Organochlorine pesticides
ICP Metals	Metals analyzed for by inductively coupled argon plasma, includes cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), and zinc (Zn)
As	Arsenic
Hg	Mercury

2. National Acts & Organizations

AMCCOM	Armament, Munitions, and Chemical Command
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
NCP	National Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
SARA	Superfund Amendments and Reauthorization Act
USACOE	United States Army Corps of Engineers
USAEWES	United States Army Engineer Waterways Experiment Station
USATHAMA	United States Army Toxic and Hazardous Materials Agency
USAEWES	United States Army Engineer Waterways Experiment Station
USDA-SCS	United States Department of Agriculture - Soil Conservation Service
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service

3. Local Terminology

BCF	Bioconcentration Factor
BCRL	Below Certified Reporting Limit
CAR	Contamination Assessment Report
CDH	Colorado Department of Health
CDOW	Colorado Division of Wildlife
CRL	Certified Reporting Limit
CSA	Central Study Area
EA	Endangerment Assessment
ESA	Eastern Study Area
ESP	Electrostatic Precipitator

FS	Feasibility Study
NCSA	North Central Study Area
NBCS	North Boundary Containment System
STP	Sewage Treatment Plant
PMO or PMRMA	Program Managers Office for the RMA Contamination Cleanup
RAA	Remedial Action Alternative
RI	Remedial Investigation
RIC	Resource Information Center
RMA	Rocky Mountain Arsenal
RMACCPMT	Rocky Mountain Arsenal Contamination Cleanup Program Managers Team
SAR	Study Area Report
SCS	Soil Conservation Service
TPP	Technical Program Plan

4. <u>Companies</u>

EBASCO	Ebasco Services Incorporated
ESE	Hunter/Environmental Science & Engineering, Inc.
G&M	Geraghty & Miller, Inc.
HLA	Harding, Lawson, & Associates
MKE	Morrison-Knudsen Engineers, Inc.

5. <u>Unified Soil Classification System (USCS) Textural Key</u>

CL	inorganic clay, low plasticity
CH	inorganic clay, high plasticity
GC	clayey gravel
GP	poorly graded gravel
MH	inorganic silt
ML	inorganic silt, low plasticity
SC	clayey sand
SM	silty sand
SP	poorly graded sand
SW	well graded sand

6. <u>Measurements</u>

ac-ft/yr	acre - feet per year
cfs	cubic feet per second
msl	mean sea level
ppm	parts per million
ppb	parts per billion
$\mu g/g$	micrograms per gram, equivalent to parts per million (ppm)
$\mu g/l$	micrograms per liter, nearly equivalent to parts per billion (ppb)
AA	atomic absorption
Co	ratio of contaminant concentration in an organism
CVAA	cold vapor atomic absorption
Eh	oxidation potential
f_{oc}	soil organic carbon content

GC/EC	gas chromatography/electron capture
GC/MS	gas chromatography/mass spectrometry
K_d	soil - water coefficient
K_h	Henry's Law constant
K_{oc}	organic carbon partition coefficient
K_{ow}	octanol - water partition coefficient

EXECUTIVE SUMMARY

The Eastern Study Area (ESA) Report summarizes a portion of the Remedial Investigation (RI) conducted at Rocky Mountain Arsenal (RMA). This report, Volume VII of the On-Post RI, integrates the study area history, geology, and hydrology with the results from soil, surface water, groundwater, air, biota, and structures investigations to identify contaminant sources, distribution patterns, and migration pathways.

The ESA encompasses approximately 10 square miles on the eastern tier of RMA, and includes all of Sections 5, 19, 29, 30, 31, and 32 and portions of Sections 6, 7, 8, 20, 24, and 25. The ESA shares information along the western boundary from five adjacent study areas, including the Southern, South Plants, Central, North Plants, and North Central Study Areas. The boundaries of the ESA were chosen to delineate an area which is east of the primary manufacturing and disposal facilities on RMA. As the boundaries are drawn, no groundwater contaminant plumes are identified within the ESA, and the entire length of First Creek within RMA boundaries is in the ESA.

The ESA was used historically as a buffer zone for RMA activities, although discrete sites were used for storage and disposal of munitions. Toxic gas, incendiary munitions, and agent-filled bombs were stored in the ESA as early as 1942. Spills and leaks associated with deteriorating containers or bomb casings and with transport of bombs among storage facilities became the object of RI investigations in these locations. As incendiary weapons became obsolete or deteriorated, the ESA was used for the detonation and burning of these munitions. Large scale burns were conducted on the surface and within trenches in the ESA. Other historical activities that have led to site investigations are solid waste landfilling and mortar round firing.

This report is organized in three sections. Section 1.0 characterizes the study area, Section 2.0 summarizes the distribution of contaminants in the individual media, and Section 3.0 assesses the extent of contamination, identifies potential contaminant transport mechanisms or specific migration pathways, and provides estimates of the volume of potentially contaminated soil.

Sites within the ESA are organized into six groups depending on similar history or similar contaminant distribution patterns. The six groups are: ESA-1, surface burn sites; ESA-2, burial trench sites; ESA-3, toxic storage sites; ESA-4, munitions activity sites; ESA-5, demilitarization activity site; and the balance of investigations. These groups are shown on Figure EXE-1. ESA sites are characterized as discrete, isolated areas containing relatively low concentrations of contaminants.

Compounds detected in soil samples from the four surface burn sites included ICP metals and polynuclear aromatic hydrocarbons. These relatively immobile compounds were observed in the surficial soil only.

Samples from the burial trench sites contained several organic compounds at low concentrations, and ICP metal concentrations were in the ten thousand parts per million range in some samples from these burial trenches. Most contaminant concentrations were detected within trench material, although limited downward migration of some organic compounds was observed.

Soil samples from the toxic storage sites contained agent degradation products in several suspected spill locations. Dithiane and 1,4-oxathiane were detected in near surface soil samples at these spill locations, although thiogdiglycol and chloroacetic acid were detected in deeper subsurface samples and may have migrated to groundwater.

The munitions activity sites are characterized by surficial ICP metal contamination. Scattered metal debris is on the ground, and few organic compounds were detected in these sites. No significant migration of contaminants was observed.

Only one organic compound, fluoroacetic acid, was detected in the demilitarization activity site. It was detected in an isolated boring, and no evidence of contamination was observed in other samples from the site.

The balance of investigations includes nonsource areas and sites in which detected compounds were not indicative of significant disposal activities. Within these sites, low concentrations of organic compounds and ICP metals occurred in isolated locations.

Surface water samples were collected repeatedly from seven First Creek stations in the surface water investigation. VHOs, OPHGB, OCPs and arsenic were detected in surface water samples, but in all cases, the detections occurred only once in multiple samples collected at any given location. All the ICP metals were detected once in the program, but only zinc was detected more than once at two sampling stations. First Creek does not currently provide a significant transport mechanism for contaminants.

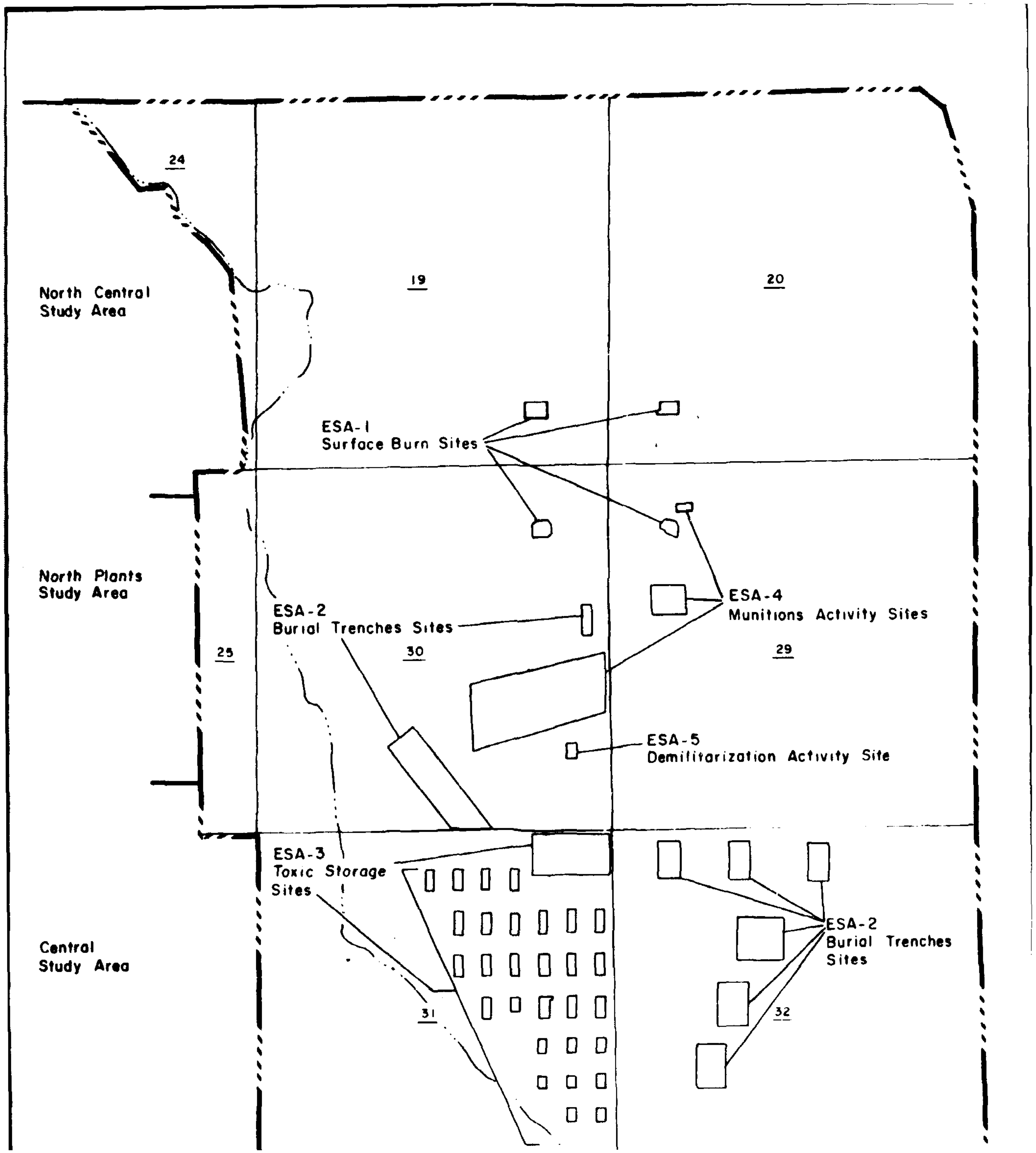
Contaminants detected in alluvial groundwater typically occurred only once in multiple samples collected. Alluvial wells located near the North Boundary Contaminant System repeatedly contained OSCH and OCP compounds. These are associated with plumes present in the North Central Study Area. No contaminated alluvial groundwater plumes were observed in the ESA, and no sites were identified as significant sources of alluvial groundwater contamination.

VHOs, VAOs, OSCHs, DBCP, OCPs, arsenic and ICP metals were detected in Denver Formation groundwater samples. Repeated detections occurred only from wells near the North Boundary Containment System except for samples from two wells in which benzene and zinc were detected repeatedly. No sources of Denver Formation groundwater contamination were identified in the ESA.

Contaminant classification of the sixty-two ESA structures revealed that only four are suspected to be contaminated. Volume estimates of potentially contaminated building material from these four structures is 67 yd^3. No structures were identified as sources of contamination to other media.

Contaminants detected in biota samples include dieldrin and arsenic. No sources of contaminants to biota were identified in the ESA.

Volume estimates of potentially contaminated soil in the ESA were calculated using a standard set of procedures and presented in Section 3.4. The total volume of soil estimated to be potentially contaminated by all organic analytes at any depth is 720,000 yd^3. The soil volume estimate for inorganic groups at any depth is approximately 400,000 yd^3. These total volume estimates were generated by eliminating overlapping volumes among analyte groups, thereby assuring that the same volume of soil was counted only once in the total estimate. These two maps are not additive however. Estimates indicate that a small number of sites account for the greatest volumes. These sites include the sanitary landfill, the Section 32 burn pits and the demolition area. Included in Section 3.4 are inferred volumes of contaminated soil based on historical information or resulting from areas not previously investigated.


24
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North Central
Study Area
ESA-1
Surface Burn Sites
North Plants
Study Area
ESA-2
Burial Trenches Sites
ESA-4
Munitions Activity Sites
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Demilitarization Activity Site
ESA-3
Toxic Storage
Sites
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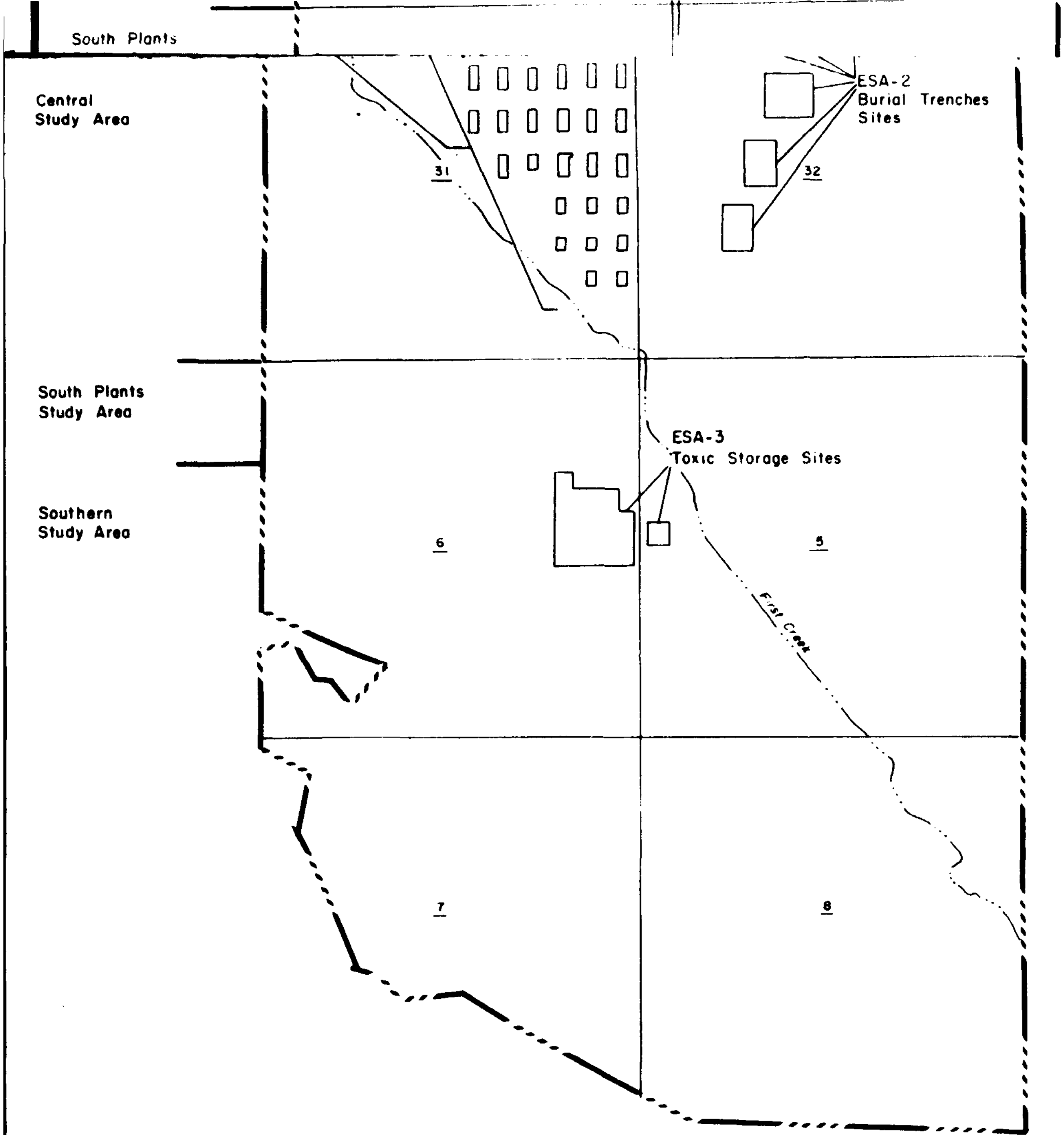
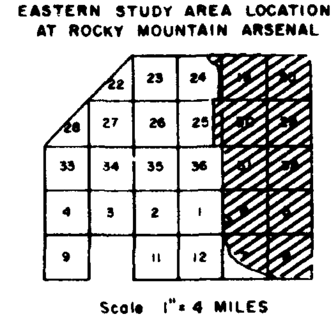
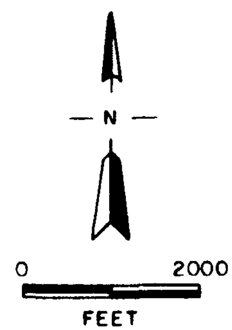






Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE EXE-1
Eastern Study Area Sites

Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated

1.0 STUDY AREA CHARACTERIZATION

This section presents the physiographic characteristics of the Eastern Study Area, (ESA) discusses the scope of the ESA Report (including a summary of historical and ongoing investigations), and presents an historical summary of sites and nonsource areas within the study area. General geologic and hydrologic characteristics of the area are discussed in detail sufficient to assess media contamination and initiate the evaluation of Remedial Action Alternatives (RAA).

1.1 PURPOSE AND SCOPE OF REPORT

The purpose of the ESA Report is to present the U. S. Army's Remedial Investigation (RI) results for the eastern portion of the Rocky Mountain Arsenal (RMA). This document is a formal RI Product in accordance with the proposed Consent Decree (1988), the Facilities Agreement (1989), the Settlement Agreement (1989), the RMA Technical Program Plan (TPP) (PMO, 1988/RIC 88131RO1), and the June 1985 RI Guidance Document U. S. Environmental Protection Agency (USEPA). The seven completed RI Study Area Reports (SARs), along with the RI media reports for air, biota, buildings, and water fulfill the requirements for defining the nature and extent of contamination, and completing a comprehensive RI for the On-Post Operable Unit of RMA as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Superfund Amendments and Reauthorization Act (SARA), and the National Contingency Plan (NCP). The ESA Report integrates known historical information, the results of previous investigations, and the results of the current RI programs for soil, surface water, groundwater, biota, air, and buildings to present an overall environmental contamination assessment of the study area as required under Contract Number DAAA15-88-D-0024. The ESA Report represents Volume VII of the overall RMA Remedial Investigation.

This report summarizes a portion of the RI conducted at RMA by the U.S. Army Program Manager's Office for Rocky Mountain Arsenal Cleanup (PMO). The RI was performed over a large and diverse area, and included many RI tasks reported in separate Contamination Assessment Reports (CARs). Subsequently, the RI results from each task conducted in a specific geographic area were compiled and summarized in seven SARs. Additionally, four media reports were compiled to summarize RI results of water, structures, air, and biota investigations at RMA. Brief descriptions of the results from these reports pertinent to the ESA have been incorporated in this SAR. The RMA On-post RI consists of twelve volumes. Volume I of the series, entitled Overview of RMA Media and SARs, introduces and briefly discusses each of the reports.

RMA REMEDIAL INVESTIGATIONS AND STUDY AREA REPORT VOLUMES

TOPIC	VOLUME
Overview of RMA Media and Study Area Reports	I
Water Remedial Investigation Report	II
Air Remedial Investigation Report	III
Biota Remedial Investigation Report	IV
Structures Survey Report	V
Southern Study Area Report	VI
Eastern Study Area Report	VII
South Plants Study Area Report	VIII
North Plants Study Area Report	IX
Central Study Area Report	X
North Central Study Area Report	XI
Western Study Area Report	XII
Final RI Report	XIII

This report, Volume VII-Eastern Study Area Report, integrates the site history, geology, and hydrology with the chemical analytical results from soil, surface water, groundwater, biota, and air samples. Collectively, these data have been evaluated to identify contaminant sources, distribution patterns, and migration pathways. The ESA Report is presented in three sections of which Study Area Characterization constitutes Section 1.0. Contaminant distribution, based on analytical results from the RI program, is presented in Section 2.0. Finally, Section 3.0 of this report summarizes contaminant distribution and migration assessments and provides recommendations for any additional feasibility study (FS) tasks that may be required to evaluate RAAs based on these findings. The remainder of this section presents summaries of previous and remedial investigations within the ESA.

1.1.1 Summary of Previous Investigations

A major component of the Army's RI program was an assessment of historical information and soil and groundwater studies conducted prior to 1984. Inferences and conclusions from previous studies were included in the design of the RI efforts initiated in 1984. Historical research in this study area included screening of numerous documents, deposition transcripts, databases, and conducting personal interviews. Available aerial photographs of the Arsenal from 1937 through 1987 were studied, interpreted, and observed features were verified in the field whenever possible.

Within the ESA, the most significant previous studies include:

- o Soil analyses for army agents in disposal trenches (1970, U.S. Army Technical Escort, Site 30-6);
- o Soil analyses for VX in toxic storage yard (1973, U.S. Army Technical Escort, Site 31-4);
- o Analyses of soil/ash mixture resulting from the incinerator ash/electrostatic precipitator dust program in Section 20 (Ursillo, 1974);
- o The USDA Soil Conservation Service (SCS) soil survey of Adams County (1974/RIC 81266R54) classifying the various soil types and describing typical properties;
- o Analyses of soil, surface water, and groundwater samples from potential contaminant sources in Sections 6, 30, and 31 (1982/RIC 81342R06, Geraghty & Miller, Sites 6-6, 6-Nonsource Area, 30-4, 30-5, 30-6, 31-4, and 31-Nonsource Area); and
- o The southern tier soil contamination survey evaluating the shallow soils of Sections 5, 6, 7, and 8 for the presence of incendiary compounds (Dames & Moore, 1985/RIC 85218R01).

1.1.2 Summary of RMA Remedial Investigations

Several source-specific and RMA-wide investigations have been conducted at RMA. Hydrologic, geologic, and contaminant studies were conducted from 1975 until 1984, when the RMA Decontamination Report (RMACCPMT, 1984/RIC 84034R01) was developed by the Army for planning purposes. It identified and classified over 150 possible contamination sources and provided a preliminary assessment of the extent, historical use, boundaries, and possible contamination profile for these sites. These sites were presented on an RMA-wide map that has become known as the "tricolor" map due to its use of three colors (pink, yellow, and blue) to graphically represent the likelihood of the site being an actual contamination source. Potential sources were delineated to concentrate the RI on areas where contamination was most likely to be found. Phase I investigations were conducted at each of these sites, and if further information was necessary upon completion of the Phase I program, a Phase II sampling effort was conducted. In addition, investigations were conducted in nonsource areas (i.e., those portions of RMA where there was no previous indication of potential contamination).

Within the ESA, Phase I investigations were conducted at 18 potentially contaminated sites, and at all or portions of 12 nonsource areas. Phase II programs were conducted in 13 sites and in six nonsource areas. These site and nonsource area investigations are summarized in Table ESA 1.1-1, including the site number, title, date and version of the Phase I CAR or Phase II data addendum, and the RI task under which it was investigated. Plate ESA 1.1-1 illustrates the location, boundaries, and site numbers of the potentially contaminated sites in the ESA. Each of the RI tasks within the ESA are described below:

- Task 4 - A groundwater and surface water contamination assessment evaluating monitoring wells and several surface water monitoring stations in the ESA. Well evaluation criteria were used to design the ESA monitoring and sampling program.
- Task 7 - A Phase I investigation of the extent of soil contamination at Site 30-4. The investigation provided site-specific physical and chemical information on which to base the development of a Phase II investigation.
- Task 9 - An investigation of the impacts of contamination on biota in and immediately surrounding RMA.

- o Task 14 - The development and execution of a Phase I soil remedial investigation for sites and nonsource areas contained within Sections 19, 20, 24, 25, 29, and 30 in the ESA. The historical investigation was used to determine the past uses of identified sites and possible additional areas of contamination not previously identified. The investigation provided site-specific physical and chemical information on which to base the development of Phase II surveys.
- o Task 15 - The development and execution of a Phase I soil remedial investigation for sites and nonsource areas contained within Sections 5, 6, 7, 8, 31, and 32. The historical investigation was used to determine the past uses of identified sites and possible additional areas of contamination not previously identified. The investigation provided site-specific physical and chemical information on which to base the development of Phase II surveys.
- o Task 18 - A monitoring task of ambient air quality and meteorological conditions at RMA.
- o Task 20 - A Phase II investigation of Site 30-4. Data resulting from this investigation are being used to further define the extent of contamination and estimate the volume of potentially contaminated soil.
- o Task 21 - A Phase II investigation of sites and sections initially investigated under Task 14 as deemed necessary after review of the Task 14 Phase I results. Data resulting from this investigation are being used to further define the extent of contamination and estimate the volume of potentially contaminated soil.
- o Task 22 - A Phase II investigation of sites and sections initially investigated under Task 15 as deemed necessary after review of the Task 15 Phase I results. Data resulting from this investigation are being used to further define the extent of contamination and estimate the volume of potentially contaminated soil.
- o Task 23 - An assessment and integration of all soils and groundwater contaminant data.

- o Task 24 - An investigation of Army buildings and structures throughout RMA. Historical information and building reconnaissance provided the basis for assessment of structures contamination.
- o Task 35 - An endangerment assessment for RMA that quantifies the magnitude and probability of actual and potential damage to humans from contaminants released at the Arsenal.
- o Task 44 - A hydrologic assessment for the RMA on-post area and data collection program for off-post areas. This assessment included development of a baseline program for hydrologic and contamination surveillance. Network design was followed by collection of surface water and groundwater samples, measurement of hydrologic parameters, and chemical analysis of water samples. These data were evaluated to document the extent of contamination and provide the basis for the Water RI Report.

To assess contamination within the ESA, results from the individual site investigations were combined with results in other environmental media. Several sites exhibit similar contaminant patterns and are organized into groups for discussion. Sites within groups share similar historical, physical, and contaminant distribution patterns, and conclusions in this report include comprehensive assessments of the site group, if possible. Site-specific conditions are presented when data do not support similar conclusions within the sites. Site groups in the ESA include: ESA-1, the surface burn sites (Sites 19-1, 20-1, 29-1, and 30-2); ESA-2, the burial trench sites (Sites 32-5, 32-6, 30-4, and 30-6); ESA-3, the toxic storage sites (Sites 5-2, 6-6, 31-4, 31-6, and 31-7); ESA-4, the munitions activity sites (Sites 29-4 and 30-1); and ESA-5, the demilitarization site (Site 30-5). Two RI sites and several nonsource area investigations are placed within the Balance of Investigations heading because either contaminants were not detected above CRLs, or the investigation did not support historical accounts of the site. Table 1.1-2 lists the group titles and the RI sites within them. Discussions in the text assess contaminants in both individual sites and groups of sites.

Plate ESA 1.1-2 illustrates the locations and boundaries of sites within the ESA. The site boundaries may differ from the Phase I RI site boundaries and reflect interpretations made of the extent of contaminants upon completion of the Phase II data collection effort.

1.2 LOCATION, PHYSIOGRAPHY, AND CLIMATE

The ESA encompasses approximately 10 square miles (mi^2) and includes all of Sections 5, 19, 29, 30, 31, and 32, and portions of Sections 6, 7, 8, 20, 24, and 25. Figure ESA 1.2-1 illustrates the boundaries of the ESA and the six other study areas at RMA. The ESA boundary was developed to incorporate the areas of the Arsenal east of the heavy manufacturing and disposal areas and outside the area of the major contaminated groundwater plumes. The ESA borders the Southern, South Plants, Central, North Plants, and North Central Study Areas, and incorporates data and interpretations from each to accurately assess the geologic and hydrologic characteristics near the boundaries.

The ESA is bordered on the north, east, and south by RMA boundaries formed by 96th Avenue, Buckley Street, and 52nd Avenue, respectively. The western boundary of the ESA generally follows "E" Street or First Creek, although it has been adjusted to exclude the Highline Lateral, as it crosses the southwestern quadrant of Sections 7 and 8, and Eastern Upper Derby Lake in Section 6. The ESA includes a portion of Section 25 east of the North Plants fence and south of the historic path of the Sand Creek Lateral. In Section 24, the boundary is along an historic channel of First Creek. The western boundary then follows the path of First Creek as it crosses the North Boundary Containment System and ends at the RMA northern boundary. Two drainage ditches extend from the North Plants facility to First Creek and will be discussed in both this and the North Plants Study Area reports. The North Boundary Containment System in Section 24 is assessed in detail in the North Boundary System Component Response Action Assessment (ESE, 1989b/RIC 89103R01); therefore, only limited information on the containment system is discussed in this report.

The ESA is characterized by generally flat to gently rolling grasslands. The ground surface elevation ranges from approximately 5,340 feet (ft) above mean sea level (msl) in the southeastern corner of Section 8 to approximately 5,140 ft msl along the First Creek channel in northern Section 24. Most of the ESA is within the First Creek drainage basin, although small portions of the ESA are within the Second Creek and Irondale Gulch basins. As a tributary to the South Platte River, First Creek flows from the southeast corner of the study area to the northwest corner. First Creek is an intermittently flowing stream, which encourages the growth of stands of cottonwood trees along its channel. There are no other prominent land features in the ESA other than Henderson Hill, a bedrock high in northern Section 19.

The climate of the RMA area has characteristic features of low relative humidity, abundant sunshine, relatively light rainfall, moderate to high wind movement, and a large daily range in temperature. The mean maximum temperatures range from 43°F in January to 88°F in July. The mean minimum temperatures are 16°F in January and 59°F in July. On the average, the mean annual maximum and minimum temperatures may vary by 28°F (NOAA, 1957-1976).

Occasionally a meteorological phenomenon, known as the Chinook winds, descends along the eastern slope of the Rocky Mountains from the west. These winds bring large and sudden temperature rises, as much as 25° to 35°F within a few hours. Chinook winds greatly moderate average winter temperatures in the RMA vicinity.

Precipitation in the RMA vicinity is approximately 15 inches per year. About half of the precipitation falls between April and July. The evapotranspiration rate ranges from 24 to 30 inches per year (NOAA, 1957-1976). Snow usually occurs from September to May, with the heaviest snowfall in March and possible accumulations as late as June. Thunderstorms occur frequently in the region, particularly during the spring and summer. They may be severe and are generally accompanied by heavy showers, severe gusty winds, and occasional hail.

Tornadoes develop during proper frontal action and convective instability commonly associated with intense thunderstorms in the RMA area. In June 1988 several small tornadoes touched down at the Arsenal, including one that caused minor damage in the Basin F area. In the summer of 1986, tornadoes damaged several work trailers in the eastern portion of the South Plants.

The prevailing winds at RMA are from the south and south-southwest, paralleling the orientation of the foothills west of Denver (Figure ESA 1.2-2). Wind speeds average about 9 miles per hour (mph) annually. Occasionally winds are from virtually all directions, including the north-northwest, north, and east. The windiest months are March and April, with gusts as high as 65 mph. These months come immediately after the driest period of the year (November through February) and have the highest potential for dust storms.

The ESA has been used primarily as a buffer zone between RMA activities and off-post land use, with the exception of specific designated areas used for storage, munitions testing, and bomb disposal. Portions of the study area have been leased for cattle grazing and farming at various times.

The off-post areas adjacent to the ESA are predominantly nonirrigated croplands. The Denver suburb of Montbello is located immediately south of the ESA, and farmland and rangeland are located to the east and north. Residential developments are located to the southeast.

1.3 HISTORY

The following historical summary of the ESA is an overview that summarizes significant historical events revealed from aerial photographs, operating records, facilities drawings, and information taken from the Shell and Juris database and depositions and interviews of key former employees and retired personnel.

1.3.1 Background

Prior to the inception of RMA in 1942, land use in the ESA was predominantly agricultural. Aerial photographs taken in 1937 show a patchwork of fields, rangeland, and homesteads over the entire 27 square mile area now occupied by RMA. By 1942, aerial photographs indicate that land use had remained virtually unchanged. Irrigated and nonirrigated cropland occupied approximately 85 percent of the ESA as observed from pre-RMA aerial photographs, although large portions of Sections 19, 29, and 8 were uncultivated. Aerial photographs were not available for the easternmost one-third mile strip of the ESA, but it is assumed that these areas were also agricultural.

Nine of the sections that comprise the ESA were acquired by the Army at the inception of RMA in 1942. The exception was Section 20, of which three-fourths was privately owned and leased to the Federal government until 1952. The government owned the remaining quarter section, which was used for farming and grazing until construction of the North Plants GB facility in 1952. Section 20 then served as a buffer zone for RMA activities. Eastern portions of Sections 5, 8, 29, 32, and 20 were also leased for cattle grazing between 1965 and 1970.

During the 1940s, portions of the ESA were used as storage areas for incendiary and cluster bombs. Sections 5, 6, 7, and 8 contained storage plots for open and covered storage of incendiary bombs as well as one ton containers of mustard and toxic gas in Sections 5 and 6.

In the 1950s, the ESA was used not only as a storage area for munitions, but also for open burning and disposal of obsolete bombs or empty drums. Parts of Section 36 and other central areas of RMA were used as munitions test facilities to support the Korean War. Weapons remaining after WWII were typically demilitarized by draining and neutralizing the contents in designated facilities on RMA and burning the remains in the ESA.

Many weapons were also demilitarized by controlled detonation in the ESA. Pits constructed in Section 32 were used extensively in the 1950s and 1960s for burning incendiary munitions. Four areas in Sections 19, 20, 29, and 30 were used from 1957 to 1959 for surface detonation and burning of over 20,000 500 lb incendiary bombs. In Section 30, shell casings and possibly white phosphorus-filled grenades were disposed of from 1954 to 1955. No burning or detonation occurred in these open trenches in Section 30.

The early to mid-1960s was a period of continued disposal of obsolete or deteriorating bombs, and the ESA continued in its role as a storage area and disposal location. The late 1960s saw another munitions production and testing period for RMA in support of the Vietnam conflict. These operations were conducted on the interior of RMA (Section 36) and did not directly affect the ESA. Transfers of material among various storage yards resulted in documented agent spills in the late 1960s. The eastern half of Sections 20, 29, 32, 5, and 8 were leased out for grazing during part of this decade, indicating little activity in this part of the Arsenal.

Little activity occurred in the ESA during the 1970s other than shifting of items in storage and maintenance of existing facilities. Consciousness of potential environmental hazards caused by ESA activities prompted trench excavations and soil testing programs during this decade.

During the 1980s a concentrated effort involving extensive soil, groundwater, air, biota, and structures investigations over the entire RMA was conducted in support of the remedial investigation.

The structures survey conducted in 1987 revealed 62 structures in the ESA. A list of the structures is presented in Table ESA 1.3-1 and their locations are shown on Plate ESA 1.3-1. Twenty-seven of these structures were acquired or built prior to 1945. Twenty-one magazines and igloos in the southern portion of Section 6 were built in the early 1940s, and twelve drum storage warehouses in Sections 6 and 31 were built in 1952 and -

1953. Five structures in Section 6 were used as support for the toxic storage yard, and 13 support structures and sheds are throughout Section 31. Other miscellaneous structures surveyed include a sewage treatment plant, pistol range house and an observation bunker. The contaminant classification of these structures is outlined in Section 2.4.

1.3.2 Similar Use Site Histories

As a result of the historical investigations and Phase I analytical results, each of the ESA sites was categorized by historical use and observed contaminant pattern into groups for discussion in this report. Reference to specific sites throughout the remainder of this report will be under group discussions.

Significant events from the individual site histories are presented in timeline form in Table ESA 1.3-2. Specific references are not included in these summaries, as complete historical accounts and references are provided in the individual CARs.

1.3.2.1 ESA-1--Surface Burn Sites

These sites are locations where surface burning and bomb detonation occurred. From 1957 to April 1959, the Army demilitarized 22,363 M-76 bombs on the ground surface at the four locations shown on Plate 1.1-2 as ESA-1a, ESA-1b, ESA-1c, and ESA-1d (Sites 19-1, 20-1, 29-1, and 30-2). The M-76 incendiary bombs were filled with PT1, a complex mixture based on a paste composed of magnesium dust, magnesium oxide, carbon, petroleum distillate, and asphalt. M-76 PT1 bombs were trucked to their respective disposal site, and a charge consisting of one-half pound of TNT and one-quarter pound of tetryl was placed in the burster well of each bomb. Primer wires were run from the bombs to a control bunker, which was apparently located on "F" Street, 2,500 ft from the intersection of Ninth Avenue and "F" Street. An electrical charge was sent from the control bunker through the primer wires, which caused the explosion of the TNT and tetryl and the detonation of the M-76 PT1 bombs. The planned layout of the demilitarization sites included construction of firebreaks 500 and 1,000 ft from the detonation area to control grass fires.

1.3.2.2 ESA-2--Burial Trench Sites

The four sites included in this group are below-surface pits and trenches used primarily for the disposal of incendiary munitions, ammunition, shells, and other solid waste. ESA-2a, the Section 32 burn pits (Sites 32-5 and 32-6) have a history of disposal and burning of several types of incendiary bombs. ESA-2b, the sanitary landfill (Site 30-4) was used for solid waste and general refuse disposal and has no documentation of chemical waste or munitions disposal. ESA-2c, the open trenches in Section 30 (Site 30-6) were used for grenade and mortar shell disposal with no history of burning.

Historical information indicates that a variety of incendiary weapons and munitions were incinerated in seven pits located in Section 32. These pits are shown on Plate ESA 1.1-2, and are numbered 1 through 7 for identification. The areas outlined on the plate represent the ground surface potentially affected by the pits, not the actual pit dimensions. The materials incinerated include:

- 500 and 1,000 pound cluster bombs containing magnesium, white phosphorus, and black powder;
- M-76 incendiary bombs;
- Goop-filled incendiary bomb clusters; and
- Rocket motors that contained solid propellants.

The pits were active in the 1950s and 1960s for controlled detonation and burning of incendiary munitions. Scrap metal from the pits was periodically cleaned out and sold. Typically, filled incendiary bombs in wooden crates were lowered into the pits for burning, although it is also likely that the crates were stacked on the ground surface near the pits and burned. Pits 1, 4, 6, and 7 were used most extensively, and Pits 2, 3, and 5 were used infrequently.

In 1953 and 1954, demilitarization of 86,119 white phosphorus-filled M-47A2 incendiary bombs occurred in the Section 32 pits. Boxed bombs were dumped into the pits and ignited, causing bomb detonation. Reportedly, each pit was allowed to cool for at least one day prior to being refilled for another burn.

Other incendiary munitions, including clusters and napalm bombs were disposed in the Section 32 pits. Aerial photographs taken while one of the pits was in use show flames originating from Pit 7 and a heavy smoke plume dissipating to the west. Other activities in the vicinity of the pits include a test conducted with simulant-filled M-55 rockets in 1963. The rockets had live explosives, and the remains were buried in the pits after the tests.

In 1964 and 1965, Shell hired the U.S. Army to decontaminate 1,200 drums by burning and then disposing of them. The drums once contained off-specification methyl parathion (an insecticide) but were empty when delivered to the Section 32 burn pits. This work was done in conjunction with the decontamination and disposal of government material. In 1968 or 1969, empty M-34 cluster bomb casings were burned in a Section 32 pit. The metal was sold as scrap once the casings were burned.

Two open trenches in Section 30 were used for disposal of M-34 white phosphorus-filled grenades and demilitarized artillery shells. The site was initially described as a liquid disposal area for M-34 GB-filled bombs; however, the site history was misquoted, and included disposal of M-34 white phosphorus grenades, not GB-filled bombs. Excavations of the trenches conducted in 1958 and 1970 revealed only empty 105mm and 155mm shells, M-125 bomblets, 90mm and 75mm rounds, and a few 4.2 inch rounds. Although some of these devices could have been filled at one time with Levinstein or distilled mustard, GB nerve agent, phosgene, white phosphorus, or PT1, there is no evidence that filled munitions were ever disposed in these trenches.

When the two trenches in Section 30 were excavated in 1970, analytical tests for distilled mustard (HD) were negative from a soil sample collected from around the pits. Subsequent soil samples collected between July 17, 1973, and August 7, 1973 (3 years after excavation), tested positive for phosgene oxime (CX). Details of the CX test such as number of samples, levels of CX present, and validity of the analysis are unknown. The presence of CX is unlikely at the Section 30 open trenches, even though a small quantity of CX was historically stored at RMA. The chemical agent identification test kit (M-18A2) did not detect CX during the Phase I investigation at this site.

The sanitary landfill in Section 30 has been used for disposal of general refuse from RMA activities since 1964. The area was within the mortar impact area from 1946 to 1951, and may have received 4.2 inch mortar fire. In 1964, the sanitary landfill was constructed immediately north of Eighth Avenue but was filled by 1974, and new landfill cells were constructed to the northwest. Currently, the landfill operates two days per week and accepts general refuse from the administration offices and operating facilities at RMA. It is estimated that the landfill accepts less than 5,000 cubic yards of refuse per month at its current level of operation, although daily records of the quantities of refuse received are not kept (Berry, 1989). At this rate, the landfill is not anticipated to reach capacity for several years. Few records were located which document the construction, regulatory controls, or types of waste historically or currently accepted in the landfill. There is no documentation that chemical wastes were disposed of in the landfill, but other wastes such as animal carcasses, asbestos and lumber were disposed of at this site.

1.3.2.3 ESA-3--Toxic Storage Sites

The primary toxic storage areas are located in Sections 5, 6, and 31 of the ESA, although portions of Sections 7, 8, and 32 were also used as temporary storage areas of incendiary munitions. ESA-3a and ESA-3b are the Section 5 and Section 6 storage yards (Sites 5-2 and 6-6), and ESA-3c and ESA-3d are the Section 31 storage yard and storage shed plots (Sites 31-4, 31-6, and 31-7). Each has a history of storing at least one of the following materials: one ton containers of distilled mustard and GB; GB-filled bomb clusters; incendiary clusters; mustard-filled bombs; bulk VX nerve agent; phosgene; crude mustard; and GB-filled Weteye bombs. Other materials documented to be stored in the toxic storage sites include GB demil salt drums and laboratory samples. Documented spills from leaking containers and bombs occurred in several locations within the toxic storage sites. Application of herbicides for weed control was also documented around the storage plots.

The original storage yard was ESA-3b, the Section 6 storage yard (Site 6-6), and it was used to store one ton containers and 55 gallon (gal) drums of Levinstein and distilled mustard beginning in the early 1940s. Incendiary bombs were stored in this site in October 1946. Chemical agents such as mustard, distilled mustard, and phosgene were stored in this yard until 1969. Several documented spills occurred over the 20 years of storage in the Section 6 yard. A 1969 presidential directive ordered an increase in security for the storage of chemical agents at all U.S. government storage sites. In compliance with this directive, chemical agents stored at the Section 6 toxic yard were moved to ESA-3c, the newer and more secure toxic storage yard in Section 31 (Site 31-4). Spills of phosgene were documented in the Section 6 yard, although the gaseous nature of phosgene is thought to have resulted in its volatilization into the air rather than its contamination of the soil. Other mustard leaks were documented at the site, although their exact locations are unknown.

ESA-3a, the toxic storage yard in Section 5 (Site 5-2), was an overflow storage area for the Section 6 yard and was used to store leaking drums of Levinstein and distilled mustard during WWII. In the late 1940s this yard was used to store approximately 1,000 mustard-filled 55 gal drums and ton containers. A proposal made in 1950 to decontaminate this area called for burning all vegetation, spraying a slurry mixture of unknown contents followed by chloride of lime, and performing follow-up tests. It is unknown if this decontamination procedure ever took place. The use of the Section 5 yard appears to have been reduced to a small area in the southern portion of the yard by 1952.

ESA-3c, the toxic storage yard in the northeast corner of Section 31 (Site 31-4) was constructed before April 1953 to store material including GB-filled ton containers and munitions. Materials to be stored were transported by railcar to a receiving dock south of the storage yard. The yard was used for toxic storage until the late 1970s or early 1980s. Chemical agents stored in the Section 31 yard included mustard, lewisite, phosgene, GB, and VX. During the late 1950s, M-34 cluster bombs were disassembled within the yard. After fuzes and bursters were removed, the bombs were taken to the

GB facility for agent draining and neutralization. Fuzes and bursters were taken to burn pits for disposal. During the early 1970s, VX-filled (nerve agent) munitions were demilitarized near a concrete pad in the yard, and soil samples taken in the vicinity in 1973 tested positive for VX. Storage of leaking GB-filled bombs in the corners of the yard was also documented.

ESA-3d, a series of twenty-nine dirt-floored toxic storage sheds (Sites 31-6 and 31-7) were also constructed in Section 31. The eastern two rows of storage sheds (Site 31-6) were built by the end of 1956 as part of an expansion of the ESA-3c toxic storage yard (Site 31-4). The floors of these sheds were to have been improved from the other storage facilities because they were constructed with a packed clay surface. No spills were documented as occurring within these plots. By 1980, 30 storage sheds on 12 dirt plots were used to store munitions, ton containers, salt drums from GB demilitarization activity, chemical agent identification kits, and laboratory samples. Between 1981 and 1982, the chemical agent identification kits and laboratory samples were incinerated in North Plants facilities, and by 1986 all drummed incinerator residue and GB demilitarization salts had been disposed off-site.

The western five rows of storage plots comprising ESA-3d (Site 31-7) were constructed in 1956 and 1958. When storage operations were moved from the Section 6 storage yard to the Section 31 storage yard in 1969, mustard, distilled mustard, and phosgene containers were moved and several spills occurred. Storage of GB-filled munitions continued through the late 1970s, and mustard, cyanogen chloride, 30 gal drums of lewisite, and 55 gal drums of heptachlor were also included in the inventory of items stored in these sheds during the late 1970s. Mustard spills were documented in Plots 21, 22, and 23 in 1969 (Plate 1.1-2), after which a fence was constructed and warning signs were posted. These spills were reportedly decontaminated and the drummed soil was stored either in Plot 28 or in an open storage area southwest of the plot. In June 1980, a ton container of phosgene was found to be leaking phosgene vapor on Plot 19. Plot 16 also had a reported spill of 5 gal of caustic soda.

Other historical information concerning the Section 31 toxic storage sheds (specifically Site 31-6) includes a documented trash pit near "F" Street (Ebasco, 1988e/RIC 88196R03). It has been speculated in the Site 31-6 Contamination Assessment Report to be immediately south of Plot 8.

Small portions of Sections 7, 8, and 32 were used in the late 1940s and 1950s for storage of incendiary bombs and M-34 clusters. A preliminary assessment of these temporary storage areas was made prior to Phase I field investigations, and all of these areas were incorporated into the nonsource area investigations.

1.3.2.4 ESA-4--Munitions Activity Sites

ESA-4a, the Section 30 impact area (Site 30-1), ESA-4b, the Section 29 demolition area trench (Site 29-4) and ESA-4c, a trench and soil mound in Section 29, comprise this group. Section 30 was part of the original buffer zone for RMA operations from 1945 until 1951, when the RMA boundary was moved one mile east to its present location. From 1945 to 1951, the Section 30 impact area was reportedly used as an impact range for 4.2 inch mortars in the southeast corner of Section 30. The firing range is assumed to be in the center of Section 35, as delineated by four observation posts located along the trajectory path from Section 35 to the Section 30 impact area. Previous documents suggest the impact area to have included the northeast corner of Section 30, as well as parts of Sections 19, 20, and 29, although Section 20 was outside the RMA boundary in the 1940s. It is now believed that the impact area is mostly confined to the southeast portion of Section 30.

Similarly, ESA-4b, the demolition area in Section 29 (Site 29-4), was used sometime after 1964, but prior to 1972, for the destruction of rocket motors, rocket propellants, and miscellaneous explosives. The site was also reportedly used for the disposal of 500 lb M-76 PT1 incendiary bombs. The Army also detonated explosives located by law enforcement agencies in the Denver area at this location in the mid-1970s. The primary area of demolition was a rectangular, bermed area in the west-central part of Section 29.

ESA-4c, a trench and soil mound located north of the demolition area, has no documented history. Wire, metal debris, and wooden crates are strewn about the surface at this location.

1.3.2.5 ESA-5--Demilitarization Activity Site

The primary demilitarization activities within the ESA occurred in structures in the southeast portion of Section 30 (Site 30-5), although short periods of demilitarization of VX-filled munitions and M-34 cluster bombs occurred in the toxic storage yard. The demilitarization (fuze removal) of GB-filled M-55 rockets and M-34 cluster bombs took place intermittently in the concrete-floored structures in Section 30 from 1962 through 1969. Water-filled pans were placed underneath the machines used to disassemble munitions, presumably to catch any agent that might leak out. The bombs were then taken to the GB plant for draining of agent and neutralization. There are no documented spills at this location.

1.3.2.6 Balance of Investigations

Two site investigations within the ESA do not fall into the groups previously discussed in regard to activity and distribution of contaminants. In addition, there are portions of each section that were not designated as sites of potential contamination. These areas are referred to as nonsource areas. These sites and nonsource areas are discussed in this section, and consist of a reported bomb disposal site in Section 29 (Site 29-5), a reported mustard training area in Section 30 (Site 30-3), and nonsource area investigations of Sections 5, 6, 7, 8, 19, 20, 24, 25, 29, 30, 31, and 32.

The reported disposal area of 100 lb M-47 bombs (plasticized white phosphorus) is situated along the southern boundary of Section 29, and extends into the northern part of Section 32 (Site 29-5). Historically, Section 29 was a buffer zone for RMA, although demolition activities occurred in the west-central portion of Section 29, and a small area in the northern part of this section was used for burning incendiary bombs. As a result of the sketchy Phase I historical account and low concentrations of contaminants detected in chemical analysis investigations, the bomb disposal area in Section 29 (Site 29-5) is thought to be mislocated. The actual disposal area of M-47 bombs indicated by historical records is limited to the ESA-2a Section 32 burn pits (Sites 32-5 and 32-6).

An area along the western border of Section 30 (Site 30-3) was identified in a 1954 aerial photograph as the location of a parked airplane used for mustard decontamination training exercises. This activity was described from interviews of RMA employees and no written record of this activity was found. Phase I results did not support this historical account.

Large portions of each section within the ESA are not designated as sites. These undesignated areas are referred to as nonsource areas. Throughout the history of RMA these areas may have been used for various purposes but are not believed to represent potential contamination sources.

Sections 5, 6, 7, and 8 were used for the storage of incendiary bombs during the late 1940s and early 1950s. There is no evidence to indicate that hazardous chemicals were used in these sections outside the designated sites. The storage areas were placed in nonsource area investigations prior to commencement of Phase I investigations. Sections 19, 29, and 32 were used as grazing land for cattle and as a buffer zone for RMA. There is no evidence to indicate that there was any activity outside of the designated areas that would contribute to environmental degradation.

Section 20 was used as a disposal site for ash and electrostatic precipitator (ESP) dust from the incineration of Levinstein mustard between 1972 and 1974. A diluted mixture of the ash and dust was plowed into the top 6 inches of soil in the south-central portion of the section. The site was later sown with a wheat cover crop. Tests conducted on soil in this area did not indicate contamination resulting from the ash/ESP dust disposal program.

The nonsource borings were located at an approximate spacing of 1,000 ft throughout the ESA, although several borings were relocated to investigate visible ground scars, discolored areas, devegetated areas or low areas. Many of the features previously identified are no longer visible and difficult to locate in the field; therefore, the grid pattern was unaltered. A screening of these features was done prior to the Phase I boring program or in the field at the time of the investigation. Reported ground scars, discolored or devegetated area, debris piles, storage pads, building floors, or other indicators of activity were investigated by borings whenever possible.

1.4 GEOLOGY

The ESA, like the rest of RMA, is located in the Denver Basin, a structural depression that was formed approximately 67 million years ago during the Laramide Orogeny. The basin is approximately 300 miles long and 200 miles wide, and the eastern flank of the basin is gently dipping. The western flank dips steeply, exposing several sedimentary units in outcrop along the Colorado Front Range. The ESA is located very close to the structural axis of the basin, and regional dip of geologic strata in this area is to the southeast at less than one degree. Surficial material, deposited unconformably atop this erosional surface, consists of several layers of alluvial gravels, sands, clays, and eolian material. These materials were deposited during glacial and interglacial events.
Only the two uppermost geologic units of sediments are being investigated at RMA in connection with the migration of potential contamination from surface sources. These two units include the surficial unconsolidated alluvium (stream and eolian deposits) and the Denver Formation, which consists largely of ancient deltaic deposits (May, 1982/RIC 82295R01). In the subsections that follow, the geologic character of the ESA is discussed with respect to the soil zone, alluvium, and the Denver Formation.

Information from numerous sources was researched and analyzed to characterize the surficial and bedrock geology in the ESA. Lithologic logs from monitoring wells and borings drilled during both prior investigations and RMA Tasks 4, 14, 15, 21, 22, and 44 were analyzed, interpreted, and incorporated into the subsurface characterization. Local geologic cross-sections were constructed to discern the spatial orientation of strata at depth. Lithologic units were correlated, projected, and mapped throughout the ESA. This information was correlated with regional studies in neighboring study areas. A regional and depositional perspective on the alluvial and bedrock geology in the ESA and surrounding area is presented in the Water Remedial Investigation Report (Ebasco, 1989/RIC 89067R08).

Four wells were drilled under the ESA investigation to specifically monitor the groundwater near the toxic storage shed plots and a Section 32 burn pit. The geologic logs and well construction information for Wells 31014, 31015, 31016, and 32004 are in Appendix ESA-B. Geologic information from these alluvial well logs did not significantly alter previous geologic interpretations of the ESA.

1.4.1 Soil

The thickness of the developed soil zone in the ESA typically extends to a depth of 59 to 70 inches (USDA-SCS, undated; Walsh, 1988). Shallower reported depths have characteristics of disturbed soils, including fill material varying in thickness from 4 to 21 inches, over truncated horizons of natural soils to a depth of 59 inches. Natural soils in the ESA are classified in the Bresser-Truckton, Ascalon-Satanta, Weld-Nunn, Aquic Haplustolls, and Bresser-Satanta Association (Walsh, 1988). These soils typically formed in fine to coarse textured alluvium and eolian deposits. Aquic Haplustolls have characteristics affected by seasonal saturation and are poorly drained. Typical soils in the upland associations range from nearly level to strongly sloping and are well drained. Textures vary in the profile from loamy sands, sandy loams, loams, and clay loams on the surface; to sandy clay loams, sandy loams, clay loams, and clays in subsurface intervals.

Six soil series, two subgroups, and one undifferentiated group (consisting of fill materials, sediments, soils and structures), comprising 26 mapping units, occur in the ESA (Walsh, 1988). The specific locations of the mapping units are shown in Plate ESA 1.4-1. The major soil series in the ESA are the Bresser sandy loams and the Satanta loams. Other less prominent soil series include the Ascalon sandy loams, Nunn clay loams, Truckton loamy sands, and Weld loams. Aquic Haplustolls predominate on alluvial terraces, floodplains and depressions along the First Creek drainage but do not extend well beyond this area. Typic Haplustolls occur along minor drainages and depressions and within remnant waterways subject to seasonal rises in the water table. These soils are not extensive in the ESA. In addition, portions of the soils in the ESA are disturbed and vary in texture from clays to sands.

Physical, hydrologic, and chemical properties of key soil series and subgroups that influenced contaminant migration in the ESA are summarized on Tables ESA 1.4-1 and 1.4-2. These representative characteristics are summarized from background information provided by the U. S. Department of Agriculture Soil Conservation Service (USDA-SCS, 1967; USDA-SCS, 1974/RIC 81266R54; USDA-SCS, undated). Texture, clay content, and hydraulic conductivity tend to vary with depth as well as between soil series. Sandier soils, such as the Ascalon, Bresser, and Truckton have low clay components, retain less water and have fairly low bulk densities, thus increasing the infiltration potential of contaminants. Cation exchange capacities tend to be highest in the soils containing argillic or clay horizons. Typically, this is most notable below a depth of 12 inches. The Weld, Nunn, and Satanta series and the Aquic and Typic Haplustolls contain clayey soils with high cation exchange capacities. The hydraulic conductivities of the key soil series range from slow to rapid and depend greatly on texture and slope gradient. Most soils are well drained, including the Typic Haplustolls, which receive runoff but are not saturated for extended periods. The Aquic Haplustolls receive runoff and may be saturated for extended periods. They have properties related to a seasonally high water table. The Aquic Haplustolls lack an argillic horizon and may be mottled below a depth of 12 inches. This map unit also contains many inclusions of Aqualls (wet areas) and Bresser soils with induced water tables.

Soil pHs of the ESA soils range from slightly acidic (6.2) to strongly alkaline (9.0) and increase with depth. This range of pH in ESA soils may tend to restrict vertical movement of metals. Bresser, Satanta, and Truckton soils contain solute-restrictive calcareous zones at depths from 8 to over 57 inches. Some intervals may contain up to

40 percent calcium carbonate equivalent (lime). The shrink-swell potential of most of these soils is low to moderate (with occasional high zones), which improves the propensity for increases in permeability, depending on moisture content. Surface water runoff potential ranges from very slow in level areas to moderate on steeper slopes. Erosion hazard ranges from moderately severe (Bresser series) to low (Satanta and Nunn series). Soil properties such as texture, organic matter, and clay content, as well as the degree of vegetation cover will affect the soil's propensity to blow during high winds.

Most of the soils in the ESA have low organic carbon content, varying from less than 0.1 percent to 1.7 percent. The highest values occur in the surface horizons. Values this low tend to have marginal effect in controlling contaminant behavior, particularly in the presence of clays. The sodium absorption ratio values for most soils in the ESA indicate that the soils are nonsodic and would not limit plant growth. The exception is in the Aquic Haplustoll soils, where the lack of adequate drainage has increased salt accumulation potential. Subsequently, the potential for breakdown of soil structure is enhanced under these conditions. The collapse of soil aggregates may cause a subsequent decrease in infiltration and hydraulic conductivity and increase in runoff to adjacent areas.

There is wide variability in physical, hydrologic, and chemical characteristics of disturbed areas near structures or manmade features. In general, the original surface horizons were removed and replaced with materials of unknown origin or mixture. Predominant textures of disturbed soils vary from loamy sands and sandy loams to loams. Finer texture materials may occur at depth. The sandier disturbed lands have properties resembling Bresser and Truckton soils, while the clay and loam disturbed soils resemble Satanta, Weld, and Nunn soils, all of which occur naturally in the ESA.

1.4.2 Alluvium

The ESA is covered with unconsolidated, Quaternary alluvial, eluvial, and eolian sediments collectively referred to as the alluvium, deposited during the Pleistocene and Holocene Epochs. Alluvial material was deposited on an eroded bedrock surface with paleochannels and bedrock highs that formed mainly as a result of Pleistocene erosional events. Within the ESA, a prominent north-south trending paleochannel has eroded the bedrock surface along the same trend where First Creek currently exists. Alluvial material at the base of the channel is coarse grained sand and gravel, intermixed with and overlain by finer grained silts and clays. Alluvial cover away from the paleochannel generally consists of medium to fine grained clay, silt, and sand. Wells and borings drilled in the ESA indicate an alluvial thickness ranging from 0 ft at Henderson Hill in Section 19, to 70 ft in the extreme southwest corner of Section 6. Throughout the First Creek paleochannel, the alluvial thickness ranges from 10 to 40 ft, and is approximately 10 ft in the portion of the ESA within the Second Creek paleochannel. Plate ESA 1.4-2 illustrates the depth of alluvium within the ESA, and shows the prominent First Creek paleochannel a separate, minor paleochannel trending northwest through Section 32, and a portion of the Second Creek paleochannel in the extreme northeast corner of the study area. In the north and northeast portions of the study area, alluvial cover is not influenced by these paleochannels and averages 10 to 20 ft in depth.

Seven distinct alluvial units have been identified at RMA and include, from oldest to youngest, the Verdos, Slocum, Louviers, Broadway, Loess/Eolian, Piney Creek, and Post Piney Creek Units (Lindvall, 1983). The Verdos Alluvium is the oldest alluvial unit at RMA and in the ESA and was unconformably deposited upon the weathered bedrock surface of the Denver Formation. Within the ESA, the occurrence of the Verdos Alluvium is restricted to an erosional remnant on Henderson Hill in Section 19. Fine grained loess/eolian deposits blanket virtually all remaining areas of the ESA and range from 10 to 20 ft in thickness. A thin (5 to 10 ft thick) deposit of Piney Creek Alluvium has infilled the First Creek channel.

The alluvial unit lithologies serve to differentiate individual units and are indicative of their mode of deposition. The Verdos Alluvium is light to reddish-brown, poorly sorted, stratified gravel with occasional lenses of clay, silt, sand, and thin beds of white volcanic ash. The Verdos Alluvium was deposited in a high energy alluvial environment. The loess/eolian unit consists of two members, a silty loess and eolian sands, silts, and clays.

The loess component is generally less than 10 ft thick, whereas the eolian sand deposits may be 30 ft thick at RMA (Lindvall, 1983). The Post-Piney Creek Alluvium deposit along First Creek consists of fluvially deposited silts, sands, and clays with local basal channel lag gravel facies. These deposits are restricted to tributary stream channels of the South Platte River system. Stratigraphic relationships between individual alluvial units are quite complex, since older alluvial units occupy higher erosional terraces on the bedrock surface than the younger units.

1.4.3 Alluvial-Denver Contact

The alluvial-Denver Formation contact was determined by examining numerous soil boring and well logs. In many logs the contact is not distinct, and weathering and reworking of the Denver Formation have caused minor uncertainties in the contact identification. Several boring logs have been relogged to specifically identify characteristics of the Denver Formation, particularly volcaniclastic material.

This contact is defined not only to determine the bedrock surface elevation, but to determine the location of subcropping Denver sand units. These locations become pertinent to the contamination migration potential when groundwater is present at these contacting geologic units. Both the bedrock surface elevation contours and identification of the subcropping unit are shown on Plate ESA 1.4-3. The lateral continuity and width of subcrop are indistinct because of the low density of control points.

1.4.4 Denver Formation

The Denver Formation is of concern because it directly underlies the uppermost saturated zone over much of RMA and, in places where the alluvium is thin or absent, comprises the uppermost saturated zone. In the ESA, depth from ground surface to the alluvial-Denver Formation contact ranges from zero feet, where the Denver crops out, to as much as 70 ft within paleochannels.

The Denver Formation is estimated to be 200 to 230 ft thick in the ESA, and is predominantly composed of claystones and siltstones with subsidiary sandstone, lignite, and volcaniclastic intervals. Each Denver zone within the Denver Formation represents a period of fluvial sedimentation and subsequent deposition of clays atop the sand-rich intervals. Lignitic zones were also deposited between the Denver zones, and serve as marker beds that help to characterize the Denver Formation stratigraphy. Fracturing, primarily in the claystone and lignite units in the Denver Formation, occurs in other study areas, and may be an important groundwater transport mechanism locally, since fractures, if uncemented, would increase bedrock permeabilities and allow flow between units. Data collected from other RMA study areas and extrapolated to the ESA indicate that fracturing is likely to occur in the Denver Formation, although the extent of fracturing cannot be determined.

The nomenclature scheme of RMA Denver Formation stratigraphy (Figure ESA 1.4-1) was developed based on the occurrence of a thick, laterally continuous, lignitic interval identified as Lignite A (LA). Other lignitic intervals were labeled LB, LC, and LD down-section from this marker. Using LA as the marker bed, Denver zones were assigned a number based on their relative position below the marker bed, with the stratigraphic zone immediately below LA called the number 1 upper (1U) Denver zone underlain by the number 1 through 9 Denver zones. Stratigraphic zones above LA were assigned a letter designation based on their proximity to the lignite marker, with the Denver zone A immediately above LA, and Denver zone B above the Denver zone A. A volcaniclastic interval (VC) and an associated clay-rich stratigraphically equivalent zone (VCE) were also identified and serve as marker beds to distinguish the A and B Denver zones.

The general regional dip of the Denver Formation is less than one degree to the southeast, causing the older, stratigraphically deeper units to subcrop in the northern portion of the ESA and the younger, stratigraphically higher units to subcrop in the south. Denver zones 1, 1U, and A subcrop in the northern four sections of the ESA, and Denver zone B subcrops in the southeastern portion of the study area. Lignitic seams A and B and a 10 to 35 ft thick volcaniclastic unit serve as marker beds and are easily distinguished in the ESA. These units are identified on Plate ESA 1.4-3.

The volcaniclastic zone (VC and VCE) was first identified as a distinct geologic unit by May et al. (1982; 1983/RICS 82295R01, 83244R01). The unit was deposited above the Denver zone A, and contains sediments that were deposited in airfall ash, volcaniclastic debris flows, and reworked fluvial deposits. Some interbedded fluvial sandstones and claystones also occur within the volcaniclastic interval. The volcaniclastic unit caps the Denver Formation in large portions of ESA, with average thicknesses of 10 to 35 ft.

Three cross-sections representing subsurface geology are presented in Figures ESA 1.4-2, 1.4-3, and 1.4-4. Cross-section location maps are presented at reduced scale on the figures and at equal horizontal scale on the Denver Formation subcrop map (Plate ESA 1.4-3). Geologic data were taken from the well logs noted on the cross-sections, from the Denver Formation subcrop map (Plate ESA 1.4-3), from the surface topography map (Plate ESA 1.5-1), and from the water table map (Plate ESA 1.5-2). Where the cross-sections intersect designated sites in the ESA, the location is noted. Geologic conditions beneath specific designated sites may be inferred from Plates ESA 1.4-3, 1.5-1, and 1.5-2.

Cross-section E1-E1' (Figure ESA 1.4-2) runs south to north through Sections 30 and 19 from north-central Section 31 to north-central Section 19. The line of section is at an oblique angle to the regional dip of the Denver Formation, which is toward the southeast. Denver Formation stratigraphy, characterized by alternating beds of lignites and claystones intermixed with sand lenses, helps to illustrate the regional dip direction in this cross-section. Subcropping bedrock units include the VC, Denver zones A, 1U and 1; and Lignites A and B. As shown in the cross-section, the water table in this portion of the ESA occurs in the Denver Formation and the alluvium is unsaturated. Designated sites intersecting the line of section include ESA-2b, the sanitary landfill (Site 30-4), and ESA-4a, the Section 30 impact area (Site 30-1).

Cross-section E2-E2' (Figure ESA 1.4-3) runs southeast to northwest across the study area, from the center of Section 8 to the northwest corner of Section 31. The line of section is at an oblique angle to the regional dip. The general trend of bedrock units dipping to the southeast is illustrated in this cross-section, primarily by the VC unit. Subcropping units include the VC and Denver Zones A and B. The paleochannel that underlies Eastern Upper Derby Lake can be seen between Wells 06002 and 07003. As shown in this cross-section, the water table occurs in the alluvium in this portion of the ESA, although the thickness of saturated alluvium is very thin in Sections 31 and 8.

Cross-section E3-E3' (Figure ESA 1.4-4) runs southwest to northeast across the study area, from the northwest corner of Section 31 to the northwest corner of Section 29. The line of section is oblique to the regional strike from southwest to northeast. Subcropping bedrock units include the VCE and Denver Zone A. As shown in the cross- section, the water table in this portion of the ESA is in the alluvium in the western portion and within the Denver Formation northeast of the sanitary landfill. The line of section crosses both First Creek and the First Creek Paleochannel, which occurs beneath the modern stream.

1.5 HYDROLOGY

The following discussion describes the hydrologic system within the ESA in sufficient detail to assess contaminant transport through this system. The four components of the hydrologic system discussed are surface water, infiltration in the vadose zone, the alluvial aquifer, and Denver Formation groundwater. Emphasis is placed on the surface water component in presenting the hydrology of the ESA, as First Creek is a primary potential contaminant transport pathway. The infiltration of surface water from precipitation events and from First Creek to the water table is presented in the vadose zone discussion. Finally, the alluvial aquifer and Denver Formation groundwater are discussed in this section, with discussion of the effects of groundwater entering the ESA from off-post and neighboring study areas. Any probable hydraulic interconnection of the groundwater systems is also presented.

1.5.1 Surface Water

The ground surface of the ESA influences surface water flow, and is gently rolling with few distinct topographic features. The surface elevation gradually slopes to the northwest, with an elevation of 5,340 ft msl in the extreme southeast corner of Section 8 to an elevation of 5140 ft msl in Section 24, where First Creek crosses the RMA north boundary (Plate ESA 1.5-1).

Surface water features within the study area include First Creek and its tributaries, as well as several manmade ditches. First Creek is an intermittently flowing stream, influenced primarily by heavy precipitation events, runoff, or snowmelt. Two minor tributaries intermittently contribute surface water flow to First Creek within ESA, one being a north-south trending drainage in the western half of Section 31 and another north-south trending natural drainage in the central part of Sections 30 and 19. Another flow channel is present in the southern part of Section 30 but does not directly connect with First Creek.

Manmade drainages in the ESA were created prior to and during RMA activity. A remnant network of ditches in this area is a result of pre-RMA crop irrigation. Presently, these ditches are most obvious in the eastern portions of Sections 29, 32, and 5.

Manmade drainages were constructed to facilitate road construction and various other RMA operations. In Section 6, an overflow ditch exits the northern end of Eastern Upper Derby Lake, then trends northeast to First Creek. Two ditches are located in the northeast part of Section 6. These ditches converge prior to connecting with First Creek. Two ditches constructed in Section 25 connect the North Plants facility with First Creek. The Sand Creek Lateral discharged to First Creek in the middle of Section 30 as early as 1948. This ditch was redirected with construction of the GB facility and discharged to First Creek in the northeast corner of Section 25 for several years. Currently, the Sand Creek Lateral stops before it connects to First Creek and surface water infiltrates or evaporates. A ditch also enters First Creek from the sewage treatment plant in Section 24. At the current effluent rate from the plant, surface water does not reach First Creek. The sewage treatment plant will be discussed in more detail in the North Central Study Area Report.

The Highline Lateral forms the boundary of the ESA in Sections 7 and 8, and is a channel which diverts irrigation water from the Highline Canal and discharges into Upper Derby Lake. It is generally dry except during the late spring and summer. The quantity of flow through it varies considerably because it is regulated upon RMA demand. The bottom of the lateral is well above the water table along its entire length and thus may act as a recharge source to the alluvial aquifer during periods of flow. A detailed discussion of the hydrologic characteristics of the Highline Lateral is found in the Southern Study Area Report.

The diagonal path of First Creek has the greatest influence on hydrology of the ESA, as approximately 90 percent of the ESA land area is within the First Creek drainage basin. Large portions of the Central and North Central Study Areas are also within the First Creek drainage basin, although overland flow is only estimated to reach First Creek from these areas during floods. The projected 100 year floodplain map (Figure ESA 1.5-1) defines those areas prone to flooding and indicates the corridor most likely to be affected by surface water transport of contaminants. The First Creek drainage basin originates in Arapahoe County, about 15 miles southeast of RMA. The basin is long and narrow, having a length of approximately 17 miles and a width of 4 miles (COE, 1983/RIC 84066R01). First Creek enters RMA at Section 8, flowing diagonally through the study area, and exist RMA from Section 24. It terminates at the intersection of O'Brian Canal, approximately one-half mile north of RMA. First Creek drains about 27 square miles upstream of RMA and 12 square miles within RMA for a total area drained of 39 square miles. The average gradient in the ESA is 26 ft/mile. The average runoff into the First Creek drainage system for the period 1971-1979 has been estimated at 687 acre-ft/year (Resource Consultants, 1982/RIC 82096R01).

Plate ESA 1.5-1 presents the topography of the ESA and illustrates the boundaries of the First Creek, Second Creek, and Irondale Gulch Drainage Basins. First Creek drainage basin soils typically display low and moderate infiltration rates, causing more runoff and increasing the tendency for a more well defined channel than in surrounding drainages that have higher infiltration rates. A natural topographic ridge in Section 20 forms the drainage divide between the First and Second Creek drainage basins, and most of Section 7 is within the Irondale Gulch drainage basin. Henderson Hill, a topographic high in Section 19, diverts the path of First Creek to the northwest in Section 24.

First Creek was diverted from its natural course in Sections 6 and 19 at various times. In 1954, the creek was diverted in Section 5 just before entering the culvert beneath "F" Street. First Creek then entered a northerly flowing ditch in Section 6 that paralleled "F" Street, flowed through a culvert under Seventh Avenue, and entered the southwestern corner of Section 32. The ditch then curved westward, flowed through a culvert beneath "F" Street, and entered the southeastern corner of Section 31. In 1980, this northern branch of First Creek was abandoned and First Creek flowed into Section 6. In 1986, "F" Street was washed out between Sections 5 and 6, and Seventh Avenue was washed out between Sections 6 and 31, where First Creek crossed.

The other diversion of First Creek was first observed in 1975 aerial photographs of Section 24. A new channel was cut in the southeastern corner of Section 24 north to the intersection of First Creek, and served as the ESA boundary. The channel was cut to increase the flow capacity of the creek during storm events. It has not been recently maintained, and flow presently follows the natural course of First Creek. Construction of the North Boundary slurry wall in 1982 interrupted the flow of the creek for a period, although the creek currently flows undisturbed over the bentonite slurry wall. Recently the creek bed was widened north of the slurry wall, and culverts were replaced underneath the road forming the RMA north boundary for flood control.

First Creek was dammed at three locations in Section 31 beginning in 1954. Water has been observed to pond behind the earthen dams, which were constructed for flood control. The dams were breached in the early 1980s because their poor integrity created a potential flood hazard, and First Creek currently flows uninterrupted through Section 31.

1.5.1.1 Stream Gaging

Flow in First Creek is monitored by two stream gages installed in 1982 and in the summer of 1983. The south First Creek gaging station is located immediately north of Sixth Avenue in Section 5, and the north First Creek station was installed in Section 24 downstream of the sewage treatment plant effluent ditch (Figure ESA 1.5-2). Stream gage data are collected hourly, and are used to calculate hourly discharge values in cubic feet per second (cfs). The hourly discharge values are averaged to obtain monthly discharge volumes, and used in water balance computations presented in the next section.

1.5.1.2 Water Balance

The water balance summary (Table ESA 1.5-1) represents monthly overall gains or losses for First Creek. Water balance computation results are listed for the October 1985 - November 1987 period. The computations add the total flows measured at the south First Creek station and inflow into First Creek from the sewage treatment plant, then subtract measured flow at the north First Creek station.

The 26 month average of these data indicate that First Creek is generally an influent stream, losing flow to groundwater. Losses as great as 120 acre-ft per month were calculated, although this assessment is complicated by data along specific reaches of First Creek that indicate it was gaining water. Water balance calculations for First Creek show that the south gage averages approximately 990 acre-feet per year (ac-ft/yr) while the north gage averages 830 ac-ft/yr. This indicates that 160 ac-ft/yr were lost between the two gages. Actually, approximately 96 percent of the inflows reach the north gage when the north gage discharges exceed 20 cfs. The most substantial losses occur in late summer as the discharges at the south First Creek gage are increasing from mid-summer low flows. Gaining periods generally correspond to high precipitation periods during which surface runoff and an elevated water table contribute to First Creek. Nevertheless, First Creek experiences an overall net loss of water to the alluvial aquifer in the ESA.

1.5.2 Vadose (Unsaturated) Zone

The vadose zone consists of partially saturated subsurface material between the water table and the ground surface, where water in pore spaces exists at pressures less than atmospheric. Water is introduced to the vadose zone in the ESA by rainfall, streamflow, and snowmelt, but the quantity of water infiltrating is dependent on the types of vegetation on the surface and the amount of transpiration occurring. Three separate types of water can be identified in the vadose zone, including soil water, intermediate vadose water, and capillary fringe water.

Water contained in the vadose zone is lost from this zone by transpiration, evaporation, and percolation when oversaturation occurs. Water is held in soil by molecular attraction and capillarity acting against the force of gravity. Molecular attraction tends to hold water as a thin film on the surface of each soil particle. Capillarity retains water in the smallest pore spaces between soil particles. When the water holding capacity of the capillary forces is exceeded, fluid in the interconnected pore spaces will percolate downward under gravitational forces.

Generally, intermediate vadose water content tends to remain constant as residual water; therefore, when the upper soil water zone is oversaturated, the excess water will percolate downward through the intermediate vadose zone and ultimately recharge the water table. Pore structures (pore size, shape, and distribution) and the relative degree of residual saturation within the intermediate zone are important factors when investigating groundwater contamination. These factors, in conjunction with the type of surface induced contamination, govern contaminant distribution and potential downward migration to the water table.

The depth to water table map (Plate ESA 1.5-3) shows the thickness of the vadose zone in the ESA. The map is based on water table elevations from April to June 1987, typically a season of high water table. Along First Creek, the depth to water was typically less than 5 ft. Depth to water was also shown along other drainages which are tributary to First Creek, but are typically not as shallow as the depth along First Creek.

Further from First Creek, the depth to water increased up to 70 ft in the west-central portion of Section 29 and up to 100 ft in the northern portion of Section 19. The greater depths generally correspond to topographically high areas. The average depth to water underlying sites in the ESA was approximately 30 ft.

The water table fluctuates up to 5 ft in the ESA based on water level data collected from spring 1981 through winter 1987. The greatest fluctuation is observed in wells near First Creek due to infiltration of runoff from precipitation events. The water levels in wells near First Creek fluctuate more dramatically from seasonal hydrologic events than wells located away from this intermittently flowing stream. Figure ESA 1.5-4 shows two well hydrographs in the ESA and illustrates the influence of First Creek on local water table elevations. The hydrograph from Well 19001, located adjacent to First Creek, fluctuated up to 5 ft seasonally (from 2 to 7 ft below ground surface). This hydrograph shows fluctuation patterns with the highest water levels in the spring of the year and the lowest in the late summer or fall. Well 06002 is located approximately 2,500 ft from First Creek in the southwestern portion of the study area. Water levels have fluctuated approximately 3 ft (from 11 to 14 ft below the surface) from 1981 to 1988, and there is less correlation than Well 19001 to seasonal influences, or to flows in First Creek.

Fluctuations in the water table along First Creek range from about 1.5 to 5 ft in the study area. Fluctuations appear to be slightly greater in the northern portion of the study area than in the southern portion. This difference may be an artifact of monitor well density near First Creek in the southern portion of the ESA. Water elevations in the late winter and spring months are indicative of increased snowmelt and rainfall. Although the fluctuations presented above may differ somewhat from year to year, varying seasonal recharge from direct infiltration of precipitation and from First Creek are primarily responsible for the observed seasonal water table fluctuations.

To assess the communication between surface water and groundwater through the vadose zone, the First Creek stream bed elevations were compared with groundwater elevations from the summer of 1986. The results are presented in Figure ESA 1.5-5. The stream bottom elevation and the water table elevation are projected along a north-south line incorporating all of the ESA. Locations where the stream bottom elevation is higher than the water table elevation are found throughout the southern reaches of First Creek. Generally, First Creek is a losing stream throughout Sections 8, 5, and 31. Locations which are not depicted on Figure ESA 1.5-5 as losing reaches include an east-west trending ditch in the Section 31 toxic storage shed plots. This ditch is frequently observed to have standing water. Also, small depressions in the stream bed have also allowed water to collect behind the dams in Section 31. The dams were breached, and surface water is no longer expected to pond in these areas. As First Creek enters Section 30, the stream bottom elevation is frequently lower than the water table. Recharge of First Creek from groundwater occurs throughout Section 30. As the creek enters Sections 25 and 19, the water table is shallow and both recharge and discharge of surface water occur in relation to time of year and precipitation events. Near the North Boundary Containment System and the RMA north boundary, surface water tends to recharge the alluvial aquifer. Estimates of the volume First Creek recharges to the unconfined aquifer were made by ESE and MKE as 300 and 174 acre-ft per year, respectively (Ebasco, 1989/RIC 89067R08).

1.5.3 Alluvial Aquifer

Water level data from Tasks 4 and 44 were used to generate an RMA-wide water table elevation map (Figure ESA 1.5-3) representing April to June 1987 data. Plate ESA 1.5-2 illustrates the unconfined flow system in the ESA, which is in both the alluvial sediments and weathered Denver Formation bedrock. Contours drawn through areas of unsaturated alluvium are inferred due to the density of wells which monitor unconfined water levels in the ESA. The unconfined water table occurs at elevations ranging from 5,300 ft msl in the southeastern corner of the ESA to 5,140 ft msl near the RMA north boundary. The primary flow direction of the alluvial aquifer is to the north-northwest. Hydraulic gradients do not vary appreciably across the study area and average about 0.006 ft/ft (ESE, 1987b/RIC 87253R01). The saturated thickness map (Plate ESA 1.5-4) provides greater detail on the alluvial aquifer flow system than the water table elevation map. The following discussion presents conclusions from both plates.

Saturated alluvium is thin or absent near high bedrock areas and where bedrock crops out. The thickest sequence of saturated alluvium, up to 50 ft, occurs in an east-west trending paleochannel which enters the study area in the southwest corner of Section 6. Another occurs within the First Creek paleochannel in Section 30. A large area of unsaturated alluvium has been identified between the First and Second Creek paleochannels and another area largely within Section 5. The water table occurs within the Denver Formation in these areas.

The areas of saturated alluvium closely follow the path of First Creek in Sections 25 and 30, where adjacent areas of high bedrock have caused the paleochannels to become narrow and well defined. Seasonal water level fluctuations may alter the boundaries of the saturated alluvium, causing the 0 to 40 ft saturated thickness to be greater in winter and spring than in summer and fall.

The hydraulic conductivity of alluvial sediments in the ESA has been estimated based on comparisons of the hydraulic conductivities calculated in alluvial materials across RMA. The highest hydraulic conductivities occur through the coarse basal sand and gravel that infill paleochannel features eroded in the bedrock surface. In the ESA, the highest hydraulic conductivities occur along the First Creek paleochannel where values up to 2×10^{-1} cm/sec have been measured during pumping tests. The lowest hydraulic conductivities of the alluvium occur away from the axes of paleochannels where values of 4×10^{-2} cm/sec have been measured during pumping tests (Ebasco, 1989/RIC 89067R08). The hydraulic conductivities of the upper layers of eolian deposits can be substantially less than that of the coarse basal materials, but generally do not control lateral flow through the alluvium. The limited number of aquifer tests conducted in these fine grained materials indicates that hydraulic conductivity is generally two orders of magnitude less. Based on the range of hydraulic conductivities, an average hydraulic gradient of 0.006 ft/ft, and a porosity of 30 percent, average linear velocities in the alluvium would vary from about 800 ft/year to 4,000 ft/year.

Specific yield, a measure of the amount of water released by gravity in an unconfined aquifer during a unit drop in potentiometric level, was also evaluated by examining pumping test data from the ESA and adjacent areas at RMA. Much of this data was presented in the North Boundary System Component Response Action Assessment Final Report (ESE, 1989b/RIC 89103R01). The specific yields varied from 0.01 to about 0.20 percent. The lower values generally corresponded to fine to clayey sands and the higher values corresponded to coarse materials predominant in the First Creek paleochannel.

Although the primary alluvial groundwater flow direction is to the north-northwest in the ESA, minor flow contributions may be received from bordering study areas. A minor alluvial flow path may enter the ESA from Eastern Upper Derby Lake in the Southern Study Area. Contributions of alluvial flow from the South Plants Study Area are minor because a bedrock high is on the boundary of the ESA and the South Plants Study Area. Fluctuations in the water table caused by Eastern Upper Derby Lake may allow a minor component of alluvial flow to enter the ESA. Contributions from the Central Study Area are minor, as a bedrock high trending along the eastern boundary of Section 36 redirects alluvial flow to the north. Limited alluvial flow may be received from the North Plants and North Central Study Areas into the ESA near the north boundary.

1.5.4 Denver Formation Groundwater

All available well and boring logs were used to characterize the Denver Formation hydrogeology in the ESA. Regionally, the Denver Formation consists of relatively thick sequences of shale and siltstone interbedded with locally continuous lenses of sandstone. Sandstone bodies, because of their relatively high permeability to other lithologic units in the Denver Formation, are the dominant flow pathways for lateral movement. Permeabilities in Denver zones relative to alluvial sediments are low. Due to widely spaced control points in the ESA, lateral continuity of specific sandstone units is uncertain. The more permeable sandstone units generally represent fluvial channel and overbank deposits that grade laterally and vertically into finer materials. Due to the nature of the depositional environment, there is a high degree of variability in transmissivity and storativity values from one area to another on RMA.

In the ESA the water bearing sandstone units tend to be confined, and the upper units have a potentiometric surface a foot or two below the alluvial water table surface. Discrete sandstone units are generally separated by claystone and shale layers that restrict vertical flow because of their relatively low permeability. In areas where Denver Formation sandstones subcrop into the alluvium, the water levels of the subcropping units are similar to the alluvial water table. The more permeable sandstones subcropping in the ESA include Denver Zone A in Sections 30 and 31 and Denver Zone 1 in Section 19 (Ebasco, 1989/RIC 89067R08).

If water level elevations are lower in wells screened within Denver Formation sandstones compared to water level elevations in wells screened in the alluvial aquifer, a potential for downward movement of water exits. In well clusters within the ESA, all but one cluster in Section 32 indicate the potential for downward movement of alluvial groundwater into the Denver Formation. The cluster in Section 32 indicated an upward potential for flow from the Denver into the alluvial system.

The thickness of sandstone units also varies significantly depending upon their depositional environment. The thickest units measured up to 50 ft in ESA borings and generally correspond to fluvial channel deposits. Thinner units, some less than 10 feet in thickness, are generally attributed to overbank deposits.

Groundwater flow directions within the Denver Formation in the ESA are generally to the north and northwest based on available data. Potentiometric surfaces within the upper Denver zones are presented in Figures ESA 1.5-6 through 1.5-8. Generally, a more northwesterly direction is noted for upper zones (Denver Zone A) within Sections 29, 30, 31, and 32, which mirrors flow directions within the alluvial aquifer. A more northerly flow direction is observed in lower zones (Denver Zone 1U and Denver Zone 1) in these four sections. Near the RMA north boundary, flow within the lowest zones (Denver Zones 2, 3, and 4) is to the northwest. Although hydraulic gradients vary considerably within zones locally, the regional gradients are similar for different zones and average about 0.006 ft/ft.

Hydraulic conductivity values for Denver Formation sandstones were determined from slug tests and pumping tests performed in the ESA and adjacent to the study area. These data are presented in detail in the Water RI Report (Ebasco, 1989/RIC 89067R08) and the North Boundary System Component Response Action Assessment Final Report (ESE, 1989b/RIC 89103R01). The hydraulic conductivity of sandstone units varies greatly because of their heterogeneous nature. Hydraulic conductivities of up to 3 x 10^{-3} cm/sec are noted for medium to coarse grained sandstones, and hydraulic conductivities of less than 1 x 10^{-4} cm/sec are representative of silt and silty sandstone. The maximum hydraulic conductivity values would result in average linear velocities of 60 ft/yr. In contrast, hydraulic conductivity values in alluvial material result in average linear velocities of 4,000 ft/yr. The hydraulic conductivities of confining layers are generally at least two to three orders of magnitude less than that of the sandstone units.

The vertical hydraulic conductivity of the less permeable shale and claystone layers within the Denver Formation will control the amount of vertical flow between the alluvial aquifer and confined water bearing zones of the Denver Formation. The discussion presented in the Water RI Report (Ebasco, 1989/RIC 89067R08) and the North Boundary System Component Response Action Assessment Final Report (ESE, 1989b/RIC 89103R01) indicate that the vertical hydraulic conductivity of semiconsolidated clayshales generally ranges from 1 x 10^{-7} to 1 x 10^{-9} cm/s. A vertical hydraulic conductivity of 1.4 x 10^{-8} cm/s was estimated from a Denver Formation pumping test at Well 24154 where a confining layer 20 ft thick was noted. The vertical hydraulic conductivity value from this well is within the range specified by the two previously mentioned reports and considered indicative of intact clayshale layers within the Denver Formation.

Fracturing within fine-grained rock of the Denver Formation can create localized areas in which vertical groundwater movement is more rapid than through intact layers. These fractured zones may provide the primary pathway for localized vertical migration of contaminants from the alluvium to confined units of the Denver Formation in the ESA.

1.6 BIOTA

This section is an overview of information presented in the Biota RI Report (ESE, 1989a/RIC 89054R01). Both terrestrial (vegetation and wildlife communities) and aquatic ecosystems were inventoried and characterized on a regional basis in studies conducted from 1985 to 1988. Biological samples were collected in order to measure any differences between biota at sites of potential contamination and biota at control areas. Effects in biota attributed to contamination sources at RMA are discussed in the Biota RI Report.

A summary of the characteristics of the biota in the ESA is included in this section. A summary of the biota sampling program conducted in the study area is presented in Section 2.6, along with the chemical analysis results. Each species' position in the food chain, as it relates to potential contaminant migration pathways and bioaccumulation, is detailed in Section 3.3 for species in the ESA.

1.6.1 Vegetation

The ESA is dominated by the following vegetation community types (Figure ESA 1.6-1): weedy forb, cheatgrass/weedy forb, native perennial grass, and areas replanted with crested wheatgrass. Areas along First Creek support a variety of riparian communities, particularly cottonwood/willow stands, and cattail marshes. Minor plant communities in upland areas include native stands of sand sagebrush and rubber rabbitbrush shrubland, scattered clumps of New Mexico locust, and groves of ornamental trees and shrubs. Shade-tree groves consists of various species, particularly elms, cottonwoods, Russian-olives, ponderosa pine, and junipers.

Additional information on the vegetation community types across all of RMA, including unpublished data by Morrison-Knudsen Engineers, is summarized in the Biota RI Report (ESE, 1989a/RIC 89054R01).

1.6.2 <u>Terrestrial Wildlife</u>

Wildlife abundance at RMA is related primarily to habitat quality and diversity, low levels of human disturbance, and the absence of hunting and livestock grazing. The great diversity of habitats on RMA provide cover, food, and reproductive habitat for many wildlife species, and in combination with the factors listed above, have led to wildlife populations that are greater on RMA than in similar habitats off-site for many species.

Because of the diversity of habitats in the ESA, many of the wildlife species found on RMA are within the ESA boundaries. A complete inventory of RMA wildlife species and details on their distribution on all study areas is found in the Biota RI Report (ESE 1989a/RIC 89054R01). The discussion below will detail the important wildlife species occurring in the ESA.

1.6.2.1 Small Mammals

Black-tailed prairie dogs are the most conspicuous mammal on RMA, with extensive colonies covering approximately 5,000 acres (1961 hectares) (Clippinger, 1987). Prairie dog colonies cover a large percentage of the surface area in the ESA and are present in large numbers in all but Sections 6 and 8. Thirteen-lined and spotted ground squirrels, fox squirrels in riparian woodlands, and muskrats on First Creek are among the larger rodents inhabiting the ESA. A great variety of smaller species including deer mice, plains harvest mice, western harvest mice, northern grasshopper mice, prairie voles, meadow voles, Ord's kangaroo rats, hispid pocket mice, and silky pocket mice occur here as well.

Desert cottontails and black-tailed jackrabbits are abundant across most of RMA. In the ESA, desert cottontails frequent the areas near prairie dog towns, while black-tailed jackrabbits seem to be most numerous in the upper northeast corner of Section 20 and the shrublands in Section 8. Jackrabbits are not nearly as common here as in the Western Study Area. Eastern cottontails may occur in thickets and small riparian areas, while white-tailed jackrabbits are reported only in small numbers over the entire area of RMA.

The small mammals are primary consumers (herbivores) in the food chain and are preyed upon by coyotes, badgers, weasels, foxes, and raptors in the ESA.

1.6.2.2 Deer

Both mule and white-tailed deer are common in the ESA. Total counts for RMA made by the Colorado Division of Wildlife (CDOW) in December 1986 were 133 mule deer and 22 white-tailed deer. Total ground counts from 1986 to 1987 by MKE produced numbers as high as 207 mule deer and 56 white-tailed deer. These numbers are high for the region, and both species are more abundant on RMA than at off-post comparison areas. The ESA is frequently used by both deer species, but more frequently by white-tailed deer. White-tailed deer may be found along First Creek and the southern four sections of the area, and they use this area more than any other on RMA.

Deer are primary consumers (herbivores) in the food chain. The only possible predators for weakened or young deer in the ESA are coyotes, but dead deer may be scavenged by any of the raptors or carnivores.

1.6.2.3 Carnivores

Coyotes are the largest and most conspicuous carnivores that inhabit RMA. The species is widespread on RMA and are most often seen in or near prairie dog towns. Coyotes are relatively abundant on RMA compared to off-post locations (ESE 1989a/RIC 89054R01). Coyotes range across all sections of the ESA.

Badgers are also common at RMA and were observed in prairie dog towns of the ESA during night surveys. The night spotting surveys for the endangered black-footed ferret yielded no sightings (ESE, 1987c/RIC 87194R02). Red fox, gray fox, and swift fox were observed on RMA during ESE biota assessment studies from 1985 to 1987, but abundance data from the Eastern Study Area were not collected (ESE, 1989a/RIC

89054R01). Other carnivores present in the ESA include raccoons, striped skunks, and long-tailed weasels.

Carnivores are at the third trophic level as secondary consumers. Coyotes are practically omnivorous, and will consume plant material and insects as well as a variety of vertebrates, including carrion. Badgers are more selective, feeding mostly on small mammals. Their diggings have been observed primarily on prairie dog colonies in the ESA. Foxes and the smaller carnivores at RMA all prey upon a variety of small mammals, bird and bird eggs, reptiles and insects.

1.6.2.4 Raptors

RMA has a distinctively high density of raptors. The abundance of prey, the distribution and abundance of suitable nesting and perching habitat, and the relative lack of human disturbance contribute to high population densities of hawks and owls. The ESA contains habitat frequently used by raptors on RMA, including a winter communal roost for bald eagles. Seventeen species of raptors were observed on RMA (including the ESA) by biologists from the United States Fish and Wildlife Service (USFWS), ESE, and MKE.

Recently, a census (ESE, 1988z/RIC 88293R01) of winter raptors indicates that the ferruginous hawk is the most abundant wintering raptor on RMA. Rough-legged hawks, Cooper's hawks, sharp shinned hawks, red-tailed hawks, and golden eagles are also common at RMA during the winter. Wintering owls include long-eared, short-eared, barn, and great horned owls. During the summer, red-tailed hawks, Swainson's hawks, Northern harriers, and American kestrels are the most common breeders on RMA. Great-horned, long-eared, short-eared, and burrowing owls are also identified as breeders as well as prairie falcons. Ferruginous hawks, rough-legged hawks, eagles, and kestrels are found most often near prairie dog towns and other open habitats. Red-tailed hawks are more often found near woodlands and thickets, while owls are often observed near woodlands, riparian areas, structures, and warehouses in the ESA. The most evident exception among the owls are the burrowing owls, which nest exclusively in pre-existing burrows and cavities on or near the ground. Burrowing owls depend on prairie dog burrows for nesting habitat and have been observed in prairie dog colonies in the ESA. Bald and golden eagles have a winter roost in the ESA, while hawk roosts were located in large trees across RMA.

Twenty-one raptor nests were located across RMA in 1987. The locations of the nests in the ESA are presented in Figure ESA 1.6-2. The ESA contains a majority of the raptor nests that were located, mostly in the large trees along First Creek. It is likely that some nests were missed, especially the long-eared owl and burrowing owl nests, which may be hidden in dense trees and below ground, respectively.

Two species of Federal interest, the bald eagle (a Federally endangered species) and the ferruginous hawk (a species studied for listing by the USFWS) are present on RMA and the ESA in large numbers during the winter months. More than 20 bald eagles roosted in the ESA during the past two winters. Studies indicate that bald eagles wintering on RMA feed primarily on prairie dogs and rabbits, many of which are stolen from ferruginous hawks. Bald eagle feeding and perching locations in the ESA were observed in the winters of 1986 to 1988 (Figure ESA 1.6-2). The ESA is an area of high use for eagles, presumably because it contains abundant prey, including the largest contiguous prairie dog colony on RMA. In addition, the large number of poles and trees in the ESA provide suitable perch sites for eagles and other raptors. A complete explanation of methods in the ESE studies on the bald eagles of RMA, along with results and discussion of these studies are found in the 1986 to 1988 Bald Eagle Studies Report (ESE, 1988z/RIC 88293R09).

Raptors, like the carnivores, are at the third trophic level as secondary consumers. Eagles and large hawks depend primarily on prairie dogs, rabbits, and carrion in the ESA. Owls and small hawks typically will consume smaller rodents, while kestrels feed upon a variety of small birds, small mammals and insects.

1.6.2.5 Water Birds, Upland Game Birds, and Songbirds

Waterfowl are not a prominent wildlife feature in the ESA. Aside from a few geese or ducks in or around First Creek, water birds do not frequent the ESA. Pheasants and mourning doves are common upland game birds on the Arsenal, and both are commonly found in riparian and tall grass vegetation types throughout the ESA.

1.6.2.6 Reptiles

The most conspicuous reptiles in the ESA are the bullsnakes, which are frequently observed sunning themselves along roadways. Other snakes regularly encountered are the western hognose snake in sandy terrain, the common gartersnake and plains gartersnake near water, and the yellow-bellied racer in a variety of habitats. Plains rattlesnakes are commonly reported by various field personnel and have been observed in upland areas.

1.6.3 Aquatic Ecosystems

The only natural flowing water body in the ESA is First Creek. Quantitative sampling in First Creek revealed populations of plains killifish and fathead minnows, as well as a few small green sunfish. The irregular flows and generally poor perifluvial habitat that currently characterize most of First Creek undoubtedly limit its value as an aquatic resource.

Table ESA 1.1-1. List of Pertinent RI Reports and Other Studies Page 1 of 4.

Report Name	Old Site Number	New Site Number	Title	Version	Date	Task
Final Phase I Contamination Assessment Report	5-UNC	NA	Nonsource Area	3.1	1/88	15
	5-2	ESA-3a	Potential Mustard Contamination	3.2	5/88	15
	6-UNC	NA	Nonsource Area	3.1	6/88	15
	6-6	ESA-3b	Former Toxic Gas Storage Yard	3.2	6/88	15
	7-UNC	NA	Nonsource Area	3.2	12/87	15
	8-UNC	NA	Nonsource Area	3.3	12/87	15
	19-UNC	NA	Nonsource Area	3.1	12/87	14
	19-1	ESA-1a	Incendiary Burn Site	3.2	1/88	14
	20-UNC	NA	Nonsource Area	3.1	5/88	14
	20-1	ESA-1b	Incendiary Burn Site	3.2	5/88	14
	24-UNC	NA	Nonsource Area	3.2	6/88	14
	25-UNC	NA	Nonsource Area	3.1	9/88	14
	29-UNC	NA	Nonsource Area	3.2	3/88	14
	29-1	ESA-1c	Incendiary Burn Site	3.1	12/87	14
	29-4	ESA-4b	Incendiary and Explosives Disposal Site	3.2	4/88	14
	29-5	NA	Bomb Disposal Site	3.1	4/88	14
	30-UNC	NA	Nonsource Area	3.1	4/88	14

na = *Not applicable.*

Table ESA 1.1-1. List of Pertinent RI Reports and Other Studies Page 2 of 4.

Report Name	Old Site Number	New Site Number	Title	Version	Date	Task
Final Phase I Contamination Assessment Report	30-1	ESA-4a	Mortar Impact Area	3.3	1/88	14
	30-2	ESA-1d	Incendiary Burn Site	3.2	9/88	14
	30-3	NA	Mustard Training Area	3.1	5/88	14
	30-4	ESA-2b	Sanitary Landfill	3.2	7/87	7
	30-5	ESA-5a	M34 Demilitarization Area	3.3	1/88	14
	30-6	ESA-2c	Disposal Trenches	3.2	2/88	14
	31-UNC	NA	Nonsource Area	3.2	12/87	15
	31-4	ESA-3c	Toxic Storage Yard	3.1	6/88	15
	31-6	ESA-3d	Toxic Storage Sheds	3.2	6/88	15
	31-7	ESA-3d	Toxic Storage Sheds	3.1	5/88	15
	32-UNC	NA	Nonsource Area	3.1	6/88	15
	32-5	ESA-2a	Burn Pits	3.2	7/88	15
	32-6	ESA-2a	Burn Pits	3.2	8/88	15
Final Phase II Data Addendum	5-2	ESA-3a	Potential Mustard Contamination	3.1	10/88	22
	6-UNC	NA	Nonsource Area	3.1	10/88	22
	6-6	ESA-3b	Former Toxic Gas Storage Yard	3.1	10/88	22
	19-1	ESA-1a	Incendiary Burn Site	3.1	8/88	21

na = *Not applicable.*

Table ESA 1.1-1. List of Pertinent RI Reports and Other Studies Page 3 of 4.

Report Name	Old Site Number	New Site Number	Title	Version	Date	Task
Final Phase II Data Addendum	25-UNC	NA	Nonsource Area	3.1	9/88	21
	29-UNC	NA	Nonsource Area	3.1	8/88	21
	29-4	ESA-4b	Incendiary and Explosives Disposal Site	3.1	8/88	21
	30-UNC	NA	Nonsource Area	3.1	8/88	21
	30-1	ESA-4a	Mortar Impact Area	3.1	9/88	21
	30-4	ESA-2b	Sanitary Landfill	3.1	10/88	20
	30-5	ESA-5	M-34 Demilitarization Operation	3.1	9/88	21
	30-6	ESA-2c	Liquid Disposal Trenches	3.1	9/88	21
	31-UNC	NA	Nonsource Area	3.1	10/88	22
	31-4	ESA-3c	Toxic Storage Yard	3.1	10/88	22
	31-6	ESA-3d	Toxic Storage Sheds	3.1	10/88	22
	31-7	ESA-3d	Toxic Storage Sheds	3.1	10/88	22
	32-UNC	NA	Nonsource Area	3.1	10/88	22
	32-5	ESA-2a	Burn Pits	3.1	10/88	22
	32-6	ESA-2a	Burn Pits	3.1	10/88	22

na = Not applicable.

Table ESA 1.1-1. List of Pertinent RI Reports and Other Studies Page 4 of 4

Report Name	Version	Date	Task
Groundwater Investigations			
Water Quantity/Quality Survey - Final Initial Screening Program Report Vol. 1, Vol. 2, Vol. 3	—	August 1987	4
Water Quantity/Quality Survey Final Screening Program Report 3rd/4th Quarter 1987	—	May 1988	4
Draft Final Water Remedial Investigation Report	—	February 1989	44
Other Investigations/Reports			
Determination of Partition Coefficients for the Primary Contaminant Sources of Section 36 Draft Final Report	2.2	September 1988	23
Overall Soil Assessment and Groundwater Integration Interim Draft Final Report	2.1	September 1988	23
RI Program Draft Final Phase I Introductions to the CARs	—	April 1987	23
Biota Remedial Investigation Draft Final Report	2.1	January 1989	9
Final Structures Survey Report	2.2	October 1988	24
Air Remedial Investigation Report	3.1	August 1988	18

na = Not applicable.

ESA Tab 1.1-1/ESA-1
5/10/89

Table ESA 1.1-2. Eastern Study Area Site Designations. Page 1 of 2.

ESA Sites Site	Name	*ESA Formerly Designated Sites* RMACCPMT/Phase I CAR	Site	Phase II	Addenda Site
ESA-1 Surface Burn Sites					
ESA-1a	Section 19 Surface Burn	19-1	Incendiary Burn Site	19-1	Burn Site
ESA-1b	Section 20 Surface Burn	20-1	Incendiary Burn Site	20-1	n/a
ESA-1c	Section 29 Surface Burn	29-1	Incendiary Burn Site	29-1	n/a
ESA-1d	Section 30 Surface Burn	30-2	Incendiary Burn Site	30-2	n/a
ESA-2 Burial Trench Sites					
ESA-2a	Section 32 Burn Pits	32-5	Burning Pits	32-5	Burning Pits
		32-6	Burning Pits	32-6	Burning Pits
ESA-2b	Sanitary Landfill	30-4	Sanitary Landfill	30-4	Sanitary Landfill
ESA-2c	Open Trenches	30-6	Liquid Disposal Trenches	30-6	Liquid disposal Trenches
ESA-3 Toxic Storage Sites					
ESA-3a	Section 5 Storage Yard	5-2	Potential Mustard and Distilled Mustard Contamination	5-2	Potential Mustard and Distilled Mustard Contamination
ESA-3b	Section 6 Storage Yard	6-6	Former Toxic Gas Storage Yard	6-6	Former Toxic Gas Storage Yard
ESA-3c	Section 31 Storage Yard	31-4	Toxic Storage Yard	31-4	Toxic Storage Yard
ESA-3d	Section 31 Storage Shed Plots	31-6	Toxic Storage Yard Storage Sheds	31-6	Toxic Storage Yard Storage Sheds
		31-7	Toxic Storage Yard Storage Sheds	31-7	Toxic Storage Yard Storage Sheds
ESA-4 Munitions Activity Sites					
ESA-4a	Impact Area	30-1	Impact Area	30-1	Impact Area
ESA-4b	Demolition Area/Trench	29-4	Disposal Site, Explosives and Incendiaries	29-4	Disposal Site, Explosives and Incendiaries
ESA-5 Demilitarization Activity Site					
ESA-5	Bomb Demilitarization Site	30-5	M34 Demilitarization Operation Area	30-5	M34 Demilitarization Operation Area

na = not applicable

Table ESA 1.1-2. Eastern Study Area Site Designations. Page 2 of 2.

ESA Sites Site	Name	*ESA Formerly Designated Sites* RMACCPMT/Phase I CAR Site		Phase II Addenda Site	
Balance of Investigations					
Balance of Investigations		29-5	Bomb Disposal Site	29-5	n/a
		30-3	Mustard Training Area	30-3	n/a
		5-NSA	Section 5, Nonsource Area	5-NSA	n/a
		6-NSA	Section 6, Nonsource Area	6-NSA	Section 6, Nonsource Area
		7-NSA	Section 7, Nonsource Area	7-NSA	n/a
		8-NSA	Section 8, Nonsource Area	8-NSA	n/a
		19-NSA	Section 19, Nonsource Area	19-NSA	n/a
		20-NSA	Section 20, Nonsource Area	20-NSA	n/a
		24-NSA	Section 24, Nonsource Area	24-NSA	n/a
		25-NSA	Section 25, Nonsource Area	25-NSA	Section 25, Nonsource Area
		29-NSA	Section 29, Nonsource Area	29-NSA	Section 29, Nonsource Area
		30-NSA	Section 30, Nonsource Area	30-NSA	Section 30, Nonsource Area
		31-NSA	Section 31, Nonsource Area	31-NSA	Section 31, Nonsource Area
		32-NSA	Section 32, Nonsource Area	32-NSA	Section 32, Nonsource Area

na = not applicable

Table ESA 1.3-1 Structures in the Eastern Study Area. Page 1 of 2

STRUCTURE NUMBER	SECTION	STRUCTURE FUNCTION	YEAR BUILT
395	6	Toxic Yard Sewage Plant	1942
785	6	Drum Storage Warehouse	1952-1953
786	6	Drum Storage Warehouse	1952-1953
787	6	Drum Storage Warehouse	1952-1953
788	6	Drum Storage Warehouse	1952-1953
791	31	Drum Storage Warehouse	1952-1953
792	31	Drum Storage Warehouse	1952-1953
793	31	Drum Storage Warehouse	1952-1953
794	31	Drum Storage Warehouse	1952-1953
795	31	Drum Storage Warehouse	1952-1953
796	31	Drum Storage Warehouse	1952-1953
797	31	Drum Storage Warehouse	1952-1953
798	31	Drum Storage Warehouse	1952-1953
851	19	Pistol Range House	1942
853	30	Observation Pit/Mortar Range	1945
864	6	General Structure	1952
865	6	Warehouse	1953
866	6	Toxic Yard Office and Change House	1942
867A	6	Toxic Yard Metal & Wood Shop	Acquired 1942
867B	6	Flammable Materials Storehouse	Acquired 1942
871A	6	Magazine	1945
871B	6	Magazine	1945
871C	6	Magazine	1945
871D	6	Magazine	1945
872A	6	Magazine	1945
872B	6	Magazine	1945
872C	6	Magazine	1945
872D	6	Magazine	1945
873A	6	Magazine	1945
873B	6	Magazine	1945
873C	6	Magazine	1945
874A	6	Magazine	1945

Table ESA 1.3-1 Structures in the Eastern Study Area. Page 2 of 2

STRUCTURE NUMBER	SECTION	STRUCTURE FUNCTION	YEAR BUILT
874B	6	Magazine	1945
874C	6	Magazine	1945
874D	6	Magazine	1945
881	6	Igloo Storage	Prior to 1945
882	6	Igloo Storage	Prior to 1945
883	6	Igloo Storage	Prior to 1945
884	6	Igloo Storage	Prior to 1945
885	6	Igloo Storage	Prior to 1945
886	6	Igloo Storage	Prior to 1945
1730	31	Sentry Station/Gatehouse	1953
1734	31	Change House	1955
1735	31	Loading Dock	*
1736	31	Toxic Storage Yard	1955 & 1959
NN0601	6	Loading Dock	*
NN0602	6	Long Metal Shed	*
NN0603	6	Metal Shed	*
NN0501	5	Abondoned Schoolhouse	*
NN2001	20	Antenna Installation	*
NN2002	20	Tank Pad	*
NN3001	30	Metal Shed	*
NN3002	30	Metal Shed	*
NN3101	31	Metal Shed	*
NN3102	31	3 Sets Shed Siding	*
NN3103	31	Storage Building	*
NN3104	31	Shack	*
NN3105	31	Shed	*
NN3106	31	Shed	*
NN3107	31	Antenna Station	*
NN3108	31	Shed	*
NN3109	31	Shed	*

* = *Date of construction not located*

able ESA 1.3-2. Timeline of Historical Activity in the Eastern Study Area. Page 1 of 1.

	PRE-RMA	1942	1950	1960	1970	1980	1990
gricultural use	------------------	(42)					
RMA established		(42)					
ection 6 toxic storage yard Primary storage area of filled containers of toxic gas.		('42 - '43 ---------------------------------- '69)					
ection 5 overflow storage yard Stored "leaking" drums of mustard		('45 ----- early '50s)					
outheast portion of Section 30 Used as an impact range for 4.2-inch mortars		('45 ------------ '51)					
ection 32 burn pits Used for burning of incendiary munitions			('50s -------------------- '69)				
ection 31 toxic storage yard Built for agent-filled munitions storage			('53)				
ection 30 disposal trench Used to dispose of M34 white phosphorus granades and ammunition shells			('54 - '55)				
ection 31 storage shed Built for agent-filled munitions storage				('56)			
emainder of Section 31 storage sheds Built to store toxic gas and agent- filled munitions				('58)			
urface burn areas Used for controlled detonation of over 22,000 500-lb M76 bombs				('57 - '59)			
ection 30 demilitarization buildings Used to remove fuzes from M34 GB-filled bombs					('62 - '69)		
,200 empty drums Had contained off-spec methyl para- thion; were burned and disposed of in Section 32 pits					('64 - '65)		
Section 30 sanitary landfill established					('64)		
ection 29 bermed area Used as demolition area for destruc- tion of rocket motors, rocket propel- lants, explosives					(after '64 ----------- '72)		
Section 30 trench excavated				('58)		('70)	

Table ESA 1.4- 1. Summary of Physical and Hydrologic Properties of Soils.

Soil Series	Texture 1/	Typical Depth of Profile (Inches)	% Clay 2/	Bulk Density (g/cm^3)	Hydraulic Conductivity (in/hr) 2/	Available Water Holding Capacity (in/hr) 2/	Erosion Hazard 2/
Ascalon	SM, SC, CL, SM/SC	67	14 – 28	0.91 – 1.6	0.14 – 0.17	0.12 – 0.17	Slight – Severe
Bresser	SM, SM/SC, SC	60	6 – 18	1.5 – 1.8	0.14 – 7.0	0.09 – 0.14	Moderate – Severe
Nunn	CL, CL/ML, CH, SC, SM/SC, SM	69	36 – 44	1.3 – 1.5	0.001 – 1.4	0.21 – 0.24	Slight – Moderate
Satanta	ML, CL, CL/ML, SM, SC	60	7 – 30	1.5 – 1.6	0.14 – 14	0.09 – 0.20	Slight – Moderate
Truckton	SM, SM/SC, SM/SP	60	10 – 16	1.4 – 1.6	1.4 – 14	0.09 – 0.12	Moderate
Weld	ML, CL/ML, CL, SM, SM/SC	70	27 – 50	1.2 – 1.4	0.001 – 7.0	0.18 – 0.23	Moderate – Severe
Aquic Haplustolls	MI, CL, SC	62	16 – 30	NA	0.14 – 70	0.14 – 0.22	Moderate – Severe
Disturbed Land	SM, SM/SC, SP	3/	3/	1.4 – 2.1	3/	3/	3/
Typic Haplustolls	SP, SM/SC, SM, ML	72	22 – 24	NA	1.4 – 7.0	0.14 – 0.16	Moderate

1/ = *Textural key: CH = inorganic clay (high plasticity); CL = inorganic clay (low to medium plasticity); GP = poorly graded gravel; MH = inorganic silt; ML = inorganic silt with very fine sand; SC = clayey sand; SM = silty sand; SP = poorly graded sand; texture varies dependent on position in profile.*

2/ = *Typical pedon characteristics (vary with depth).*

3/ = *Properties too variable to be estimated.*

NA = *Information not available.*

Sources: USDA-SCS, 1967; Helling, 1971; USDA-SCS undated; Walsh, 1988.

Table ESA 1.4-2. Summary of Chemical Properties of Soils. Page 1 of 1.

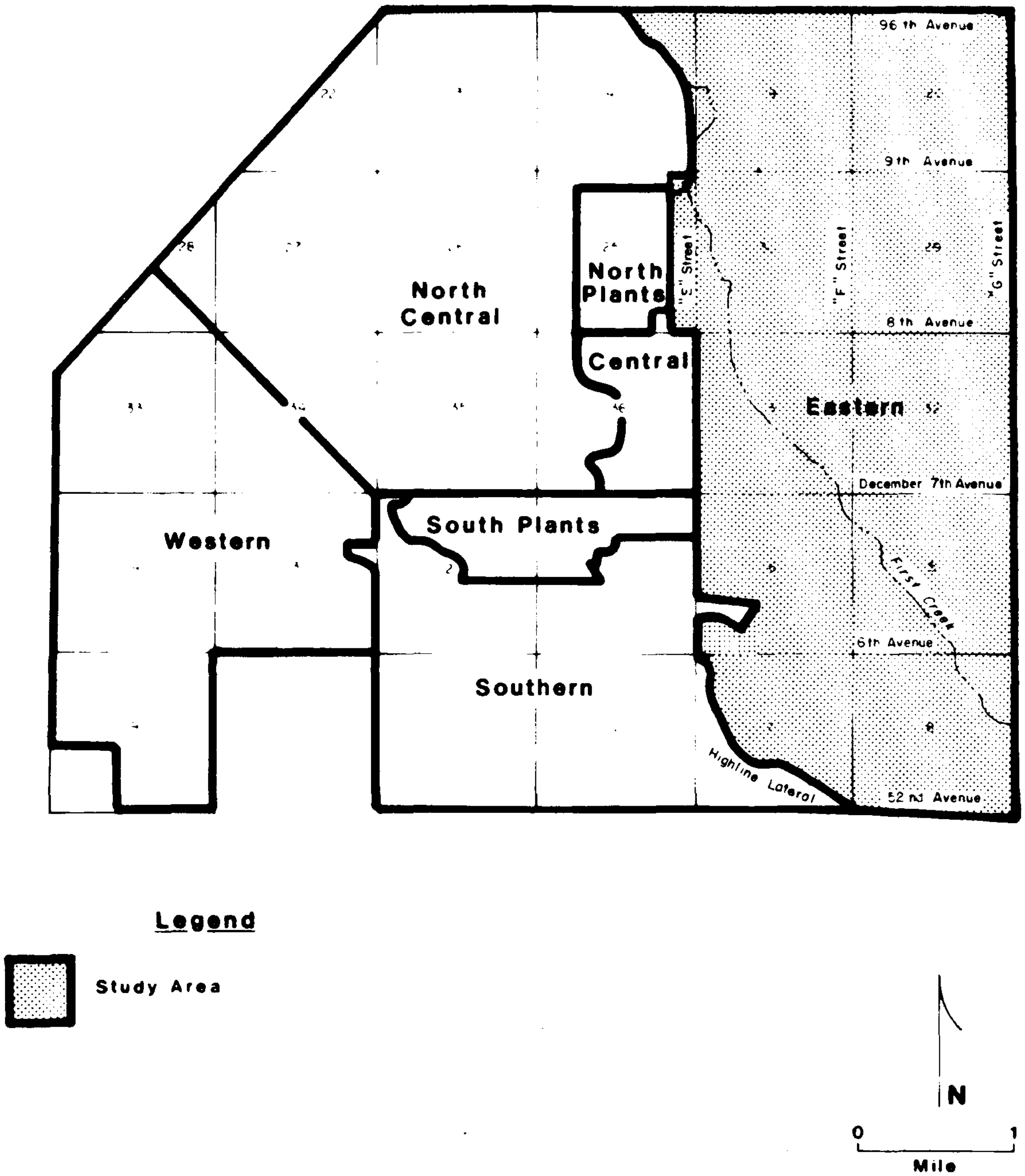
Soil Series	Soil pH 1/	% Organic Carbon 1/	Cation Exchange Capacity (meq/100g) 1/	% Lime 1/	Sodium Absorption Ratio
Ascalon	6.7 – 8.5	LT 0.1 – 0.9	8.3 – 29	0.21 – 21	0.1 – 2.5
Bresser	6.6 – 8.1	0.1 – 0.7	5.3 – 20	0.3 – 20	0.9 – 1.3
Satanta	6.3 – 9.0	0.1 – 1.7	5.7 – 26	0.1 – 17	0.5 – 11
Truckton	6.5 – 8.5	0.1 – 0.9	1.6 – 26	0.3 – 40	0.7 – 2.4
Weld	6.2 – 8.4	0.2 – 1.7	19.8 – 39	0.3 – 34	0.4 – 2.4
Aquic Haplustolls	6.9 – 8.4	0.2 – 1.5	7.4 – 27	0.5 – 28	0.9 – 15
Disturbed Land	7.0 – 8.4	0.1 – 0.7	6.4 – 19	0.6 – 10	1.6 – 8.3
Typic Haplustolls	6.1 – 8.4	0.1 – 0.9	17 – 29	1.5 – 15	0.7 – 1.5

LT = Less than
1/ = Typical pedon characteristics (vary with depth)
Sources: USDA-SCS, 1967; Helling, 1971; USDA-SCS undated; Walsh, 1988

Table ESA 1.5-1. First Creek Water Balance Summary (units are acre-feet per month)

Item	Oct 85	Nov 85	Dec 85	Jan 86	Feb 86	Mar 86	Apr 86	May 86	Jun 86	Jul 86	Aug 86	Sep 86	Oct 86	Nov 86
FIRST CREEK WATER BALANCE														
A. Total measured flow at South First Creek gage over the month	68.1	92.7	116.3	99.6	100.8	65.0	301.4	95.0	49.2	3.9	6.7	7.6	29.2	53.7
B. Inflow from Sewage Treatment Plant	1.2	0.9	0.6	0.6	0.3	0.5	1.4	1.8	1.6	1.2	0.8	0.6	0.9	1.4
C. Total measured flow at North First Creek gage over the month	65.0	193.0	127.5	195.3	87.2	61.8	262.9	69.5	5.4	0.0	0.0	0.0	0.0	0.0
D. Measured gain or loss across RMA for the month	-4.3	99.4	10.6	95.1	-13.9	-3.7	-39.9	-27.3	-45.4	-5.1	-7.5	-8.2	-30.1	-55.1

Item	Dec 86	Jan 87	Feb 87	Mar 87	Apr 87	May 87	Jun 87	Jul 87	Aug 87	Sep 87	Oct 87	Nov 87	Average Value
FIRST CREEK WATER BALANCE													
A. Total measured flow at South First Creek gage over the month	67.4	139.8	67.8	82.9	68.0	222.4	239.3	21.4	6.3	4.4	34.8	93.5	82.2
B. Inflow from Sewage Treatment Plant	1.6	0.7	0.6	0.9	1.2	1.0	0.4	1.0	1.2	0.9	1.0	0.7	1.0
C. Total measured flow at North First Creek gage over the month	0.0	20.4	55.8	99.2	63.7	235.9	257.5	0.1	0.0	0.0	0.0	0.0	69.2
D. Measured gain or loss across RMA for the month	-69.0	-120.1	-12.6	15.4	-5.5	12.5	17.8	-22.3	-7.5	-5.3	-35.8	-94.2	-13.9



Prepared for:

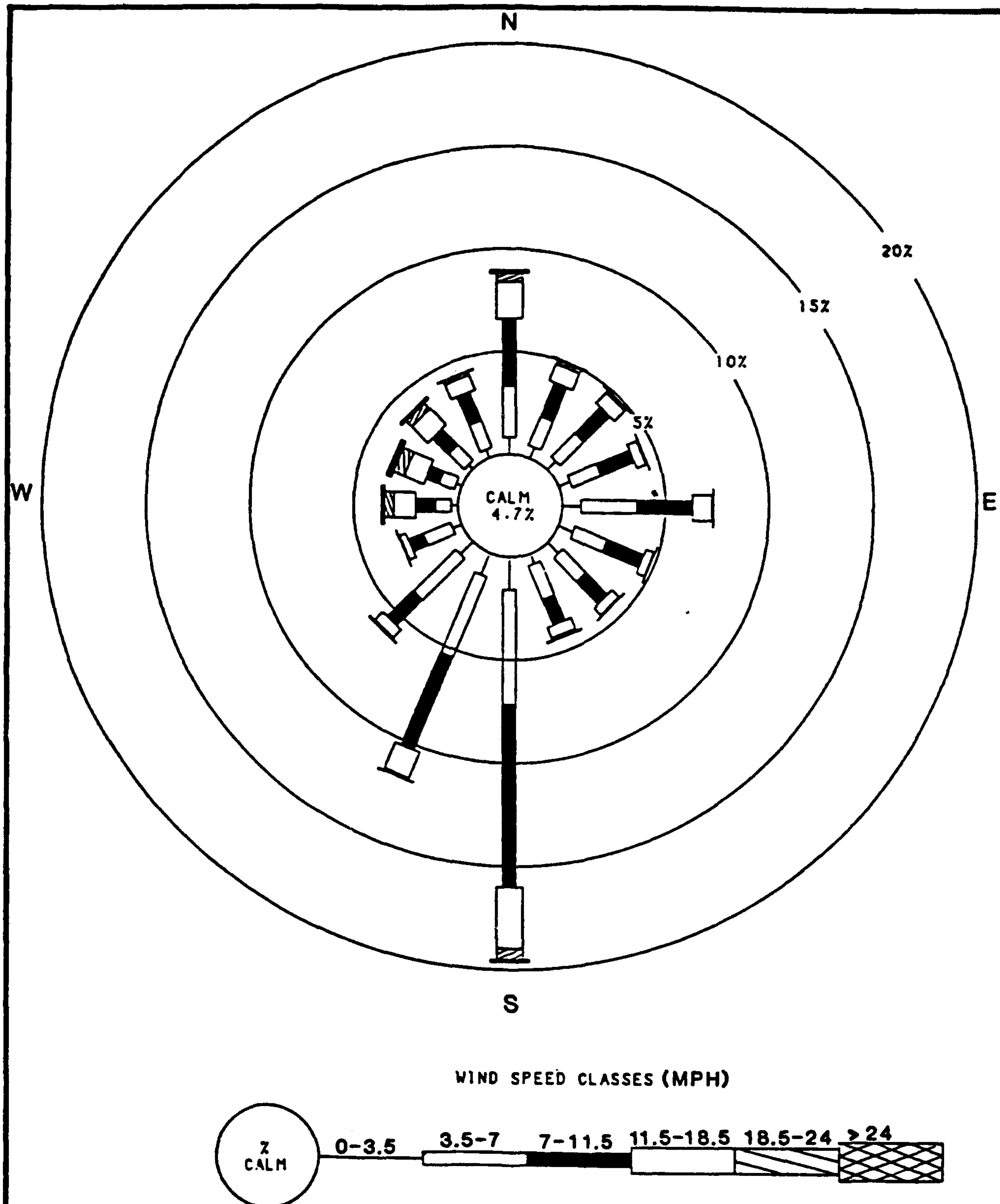
Program Managers Office for Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.2-1

Rocky Mountain Arsenal Study Areas

Rocky Mountain Arsenal

Prepared by Ebasco Services Incorporated



Source: Air Remedial Investigation Report. ESE, 1988.

Prepared for:

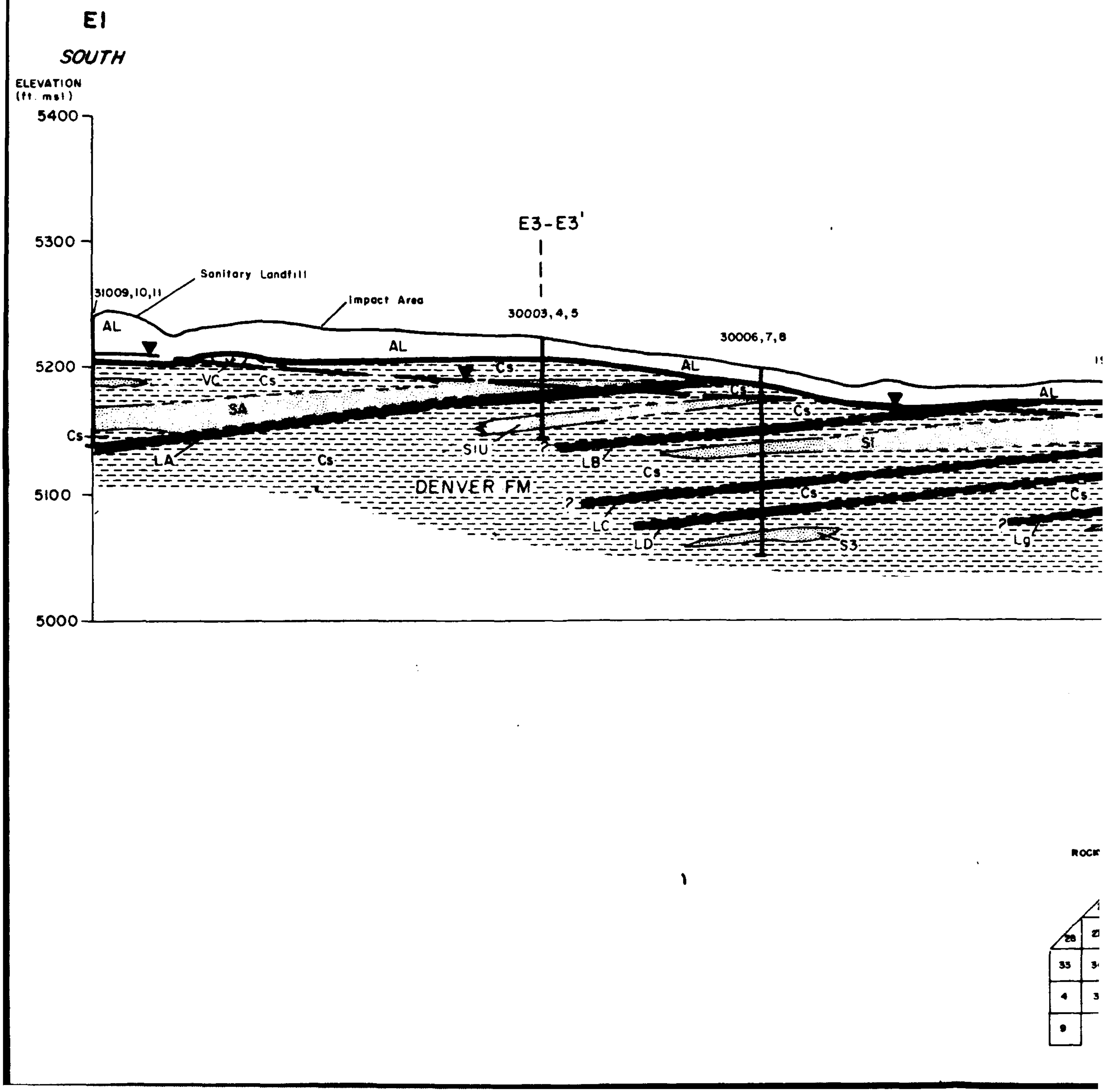
Program Manager's Office for
Rocky Mountain Arsenal Cleanup

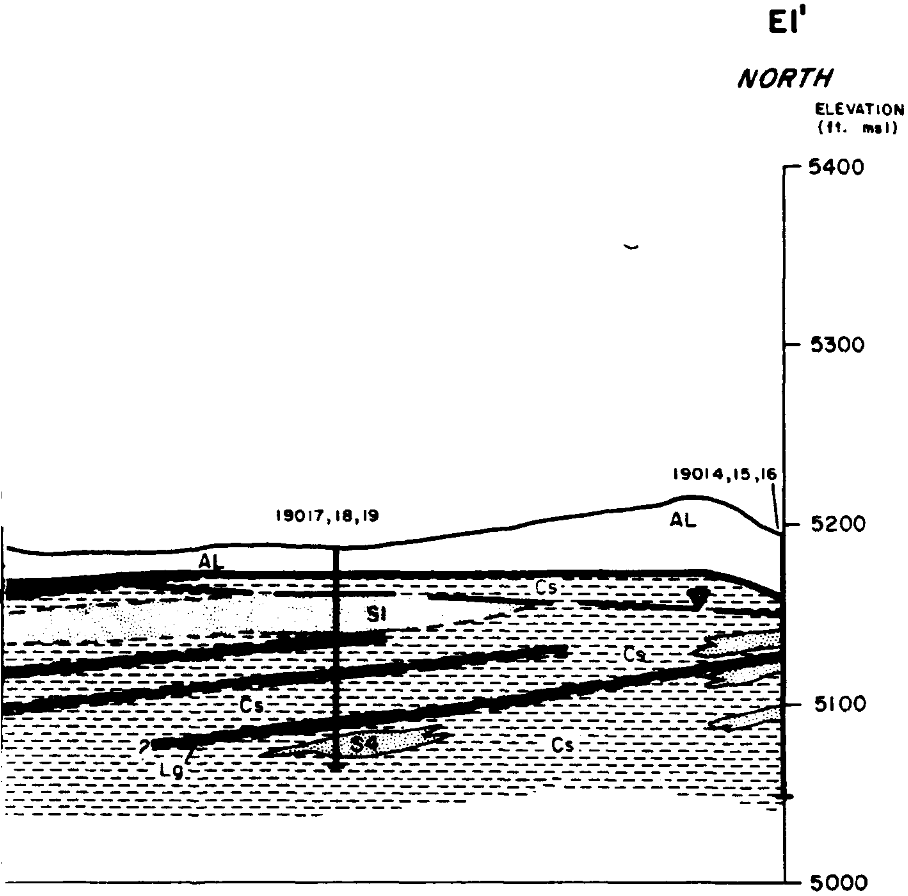
FIGURE ESA 1.2-2

Annual Wind Rose for RMA Vicinity
(Stapleton International Airport 1975-1979)

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated

T18D-AR-004


E1
SOUTH
ELEVATION (ft. msl)
5400
5300
5200
5100
5000
E3-E3'
Sanitary Landfill
Impact Area
31009,10,11
30003,4,5
30006,7,8
AL
VC
Cs
SA
LA
SIU
LB
SI
LC
LD
S3
Lg
DENVER FM
ROCK



LITHOLOGY

AL — Alluvium undifferentiated

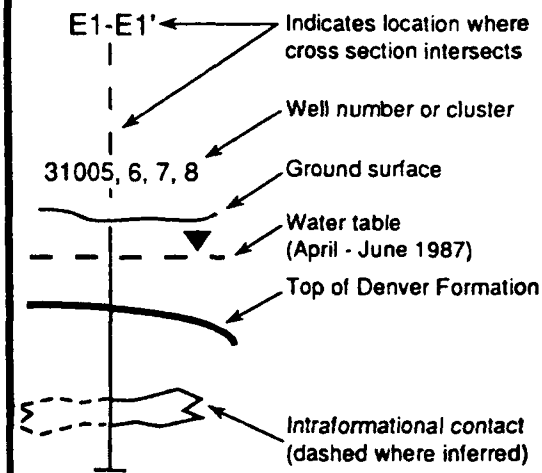
DENVER FORMATION

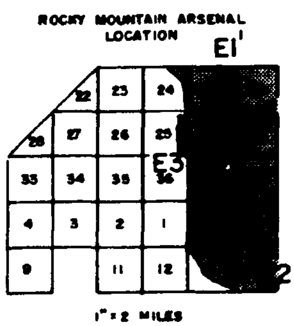
VC Volcaniclastic material and laterally equivalent claystone and sandstone

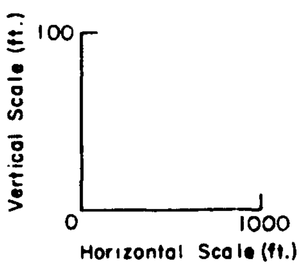
Sandstone Units: SA, S1U, S1, S2, S3, S4
Very fine to coarse grained, poorly to well sorted, silty and clayey interval or claystone and siltstone lenses and laminations common in thinner deposits

Claystone Units: Cs
Massive to laminated, organic-rich zones containing plant remains or lignitic material common; minor silty to sandy lenses or laminations

Lignite Units: LA, LB, LC, LD
Brown to black, hard to brittle, breaks in blocky to platey manner



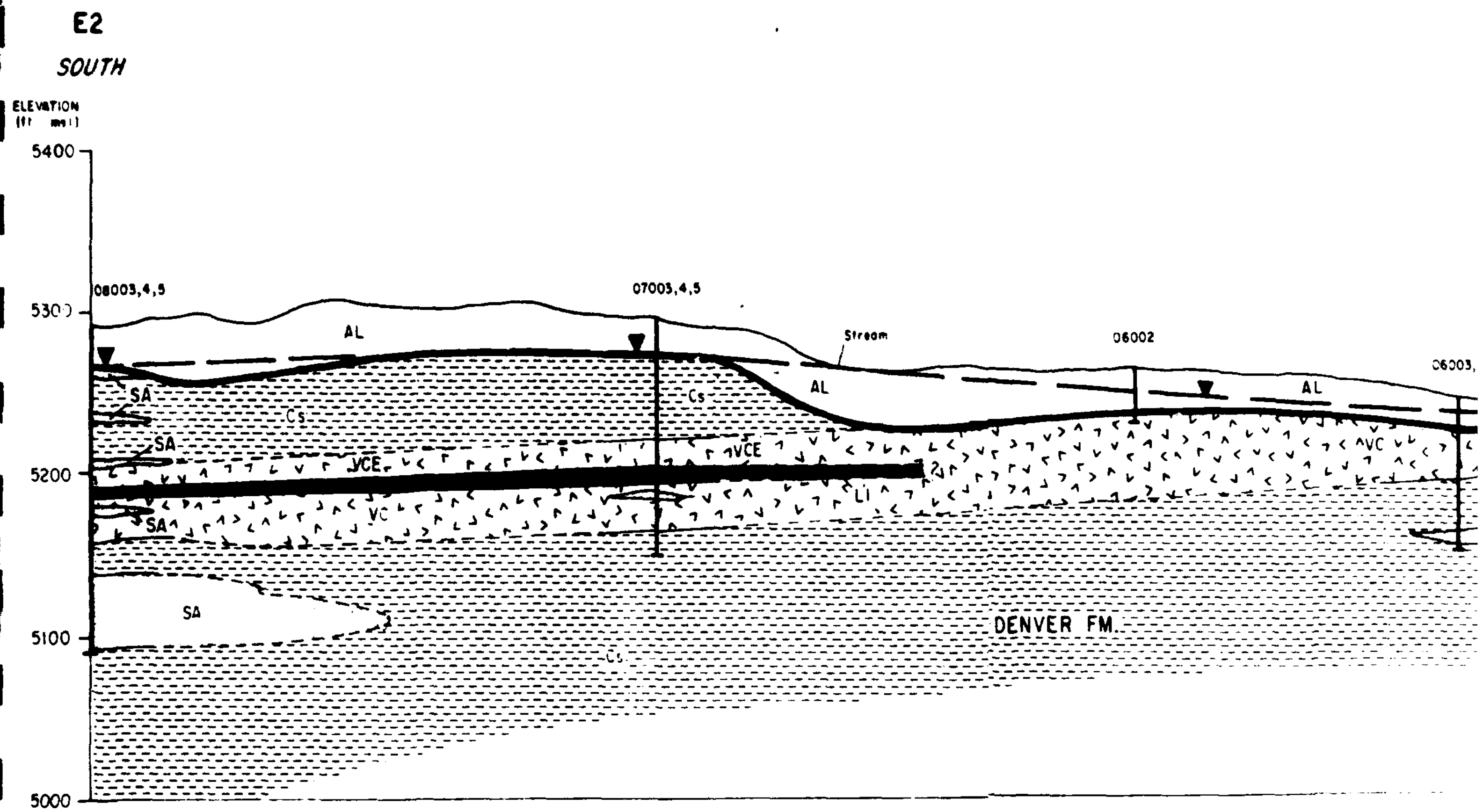




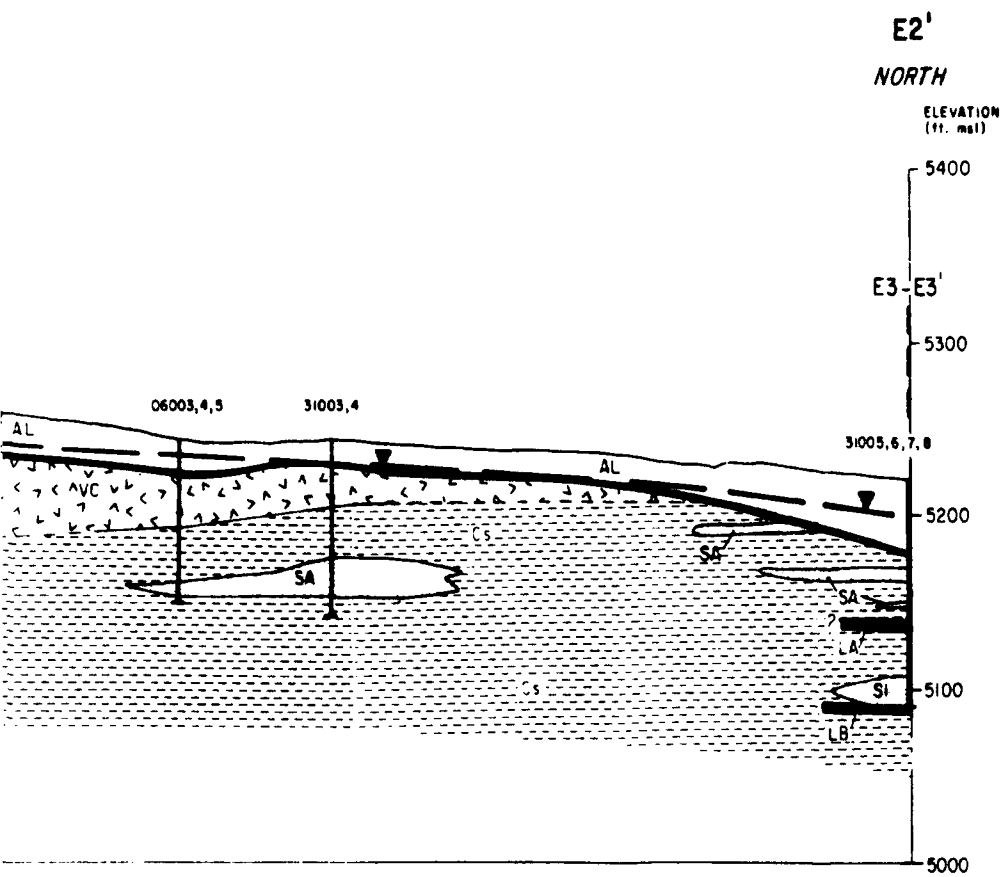
Prepared for:
Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.4-2
Cross Section E1-E1'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



E2
SOUTH
ELEVATION
5400
5300
5200
5100
5000
08003,4,5
07003,4,5
06002
Stream
AL
SA
Cs
VCE
VC
LI
DENVER FM.



LITHOLOGY

AL — Alluvium undifferentiated

DENVER FORMATION

VC — Volcaniclastic material and laterally equivalent claystone and sandstone

Sandstone Units: SA, S1U, S1, S2, S3, S4 — Very fine to coarse grained, poorly to well sorted, silty and clayey interval or claystone and siltstone lenses and laminations common in thinner deposits

Claystone Units: Cs — Massive to laminated, organic-rich zones containing plant remains or lignitic material common; minor silty to sandy lenses or laminations

Lignite Units: LA, LB, LC, LD, LI — Brown to black, hard to brittle, breaks in blocky to platey manner

E1-E1' — Indicates location where cross section intersects

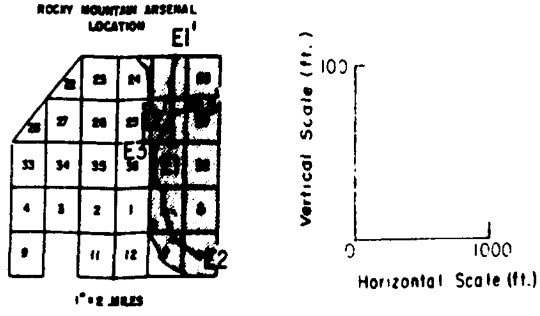
31005, 6, 7, 8 — Well number or cluster

Ground surface

Water table (April - June 1987)

Top of Denver Formation

Intraformational contact (dashed where inferred)

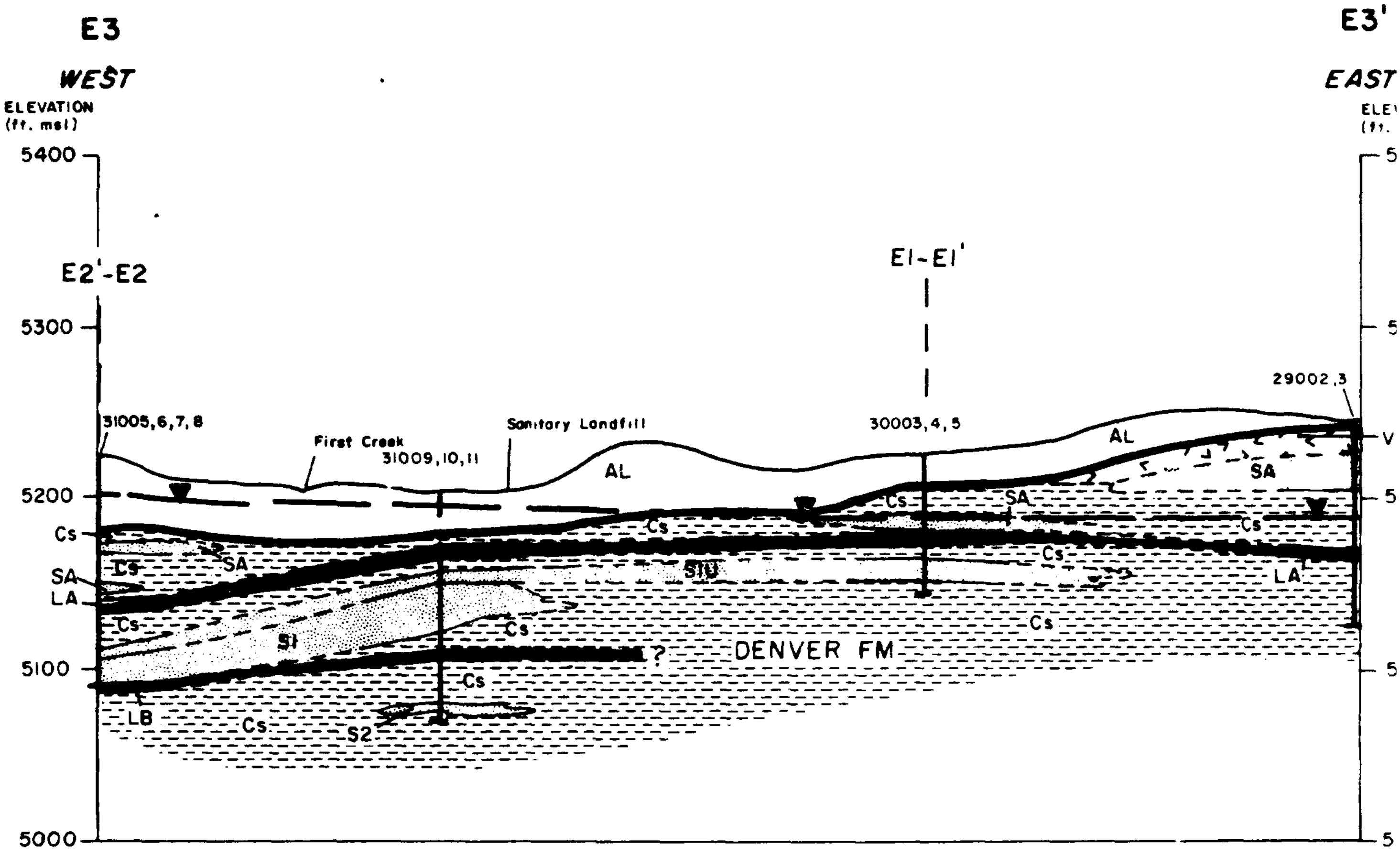


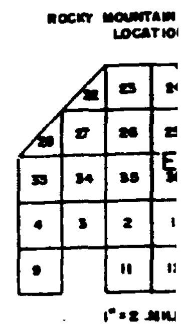
Prepared for:
Program Manager's Office for Rocky Mountain Arsenal Cleanup

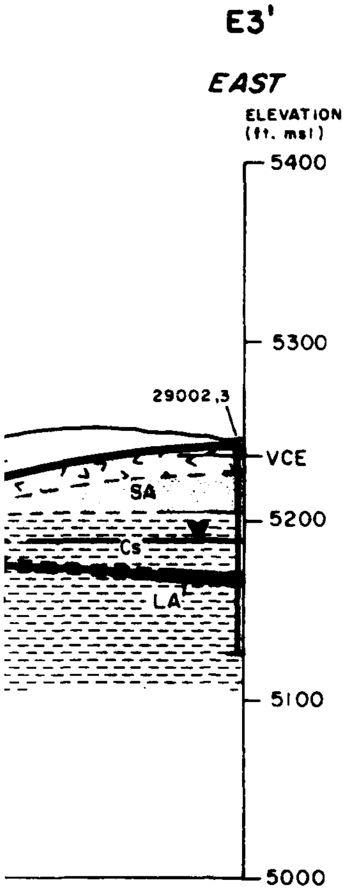
FIGURE ESA 1.4-3

Cross Section E2 - E2'

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated


E3
WEST
ELEVATION (ft. msl)
E3'
EAST
5400
5300
5200
5100
5000
E2'-E2
E1-E1'
31005,6,7,8
First Creek
31009,10,11
Sanitary Landfill
30003,4,5
29002,3
AL
SA
Cs
LA
S1
S1U
LB
S2
DENVER FM


ROCKY MOUNTAIN
LOCATIO



LITHOLOGY

AL — Alluvium undifferentiated

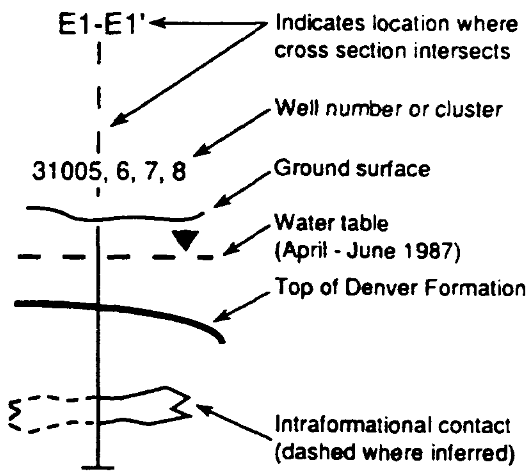
DENVER FORMATION

VC Volcaniclastic material and laterally equivalent claystone and sandstone

Sandstone Units: SA, S1U, S1, S2, S3, S4
Very fine to coarse grained, poorly to well sorted, silty and clayey interval or claystone and siltstone lenses and laminations common in thinner deposits

Claystone Units : Cs
Massive to laminated, organic-rich zones containing plant remains or lignitic material common; minor silty to sandy lenses or laminations

Lignite Units: LA, LB, LC, LD
Brown to black, hard to brittle, breaks in blocky to platey manner



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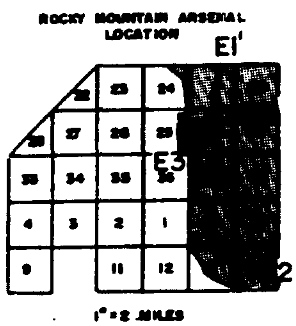


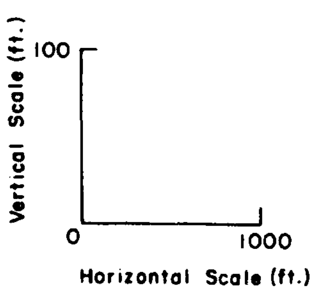
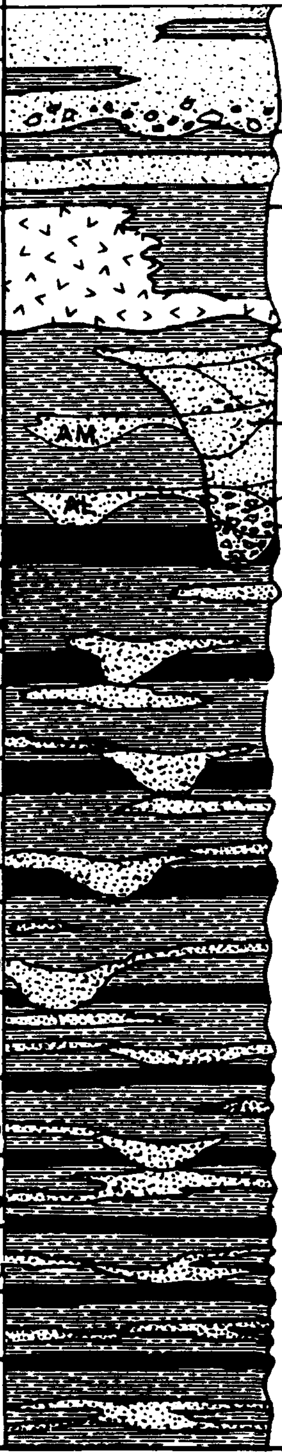


FIGURE ESA 1.4-4
Cross Section E3-E3'

Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated

8-88. T 44



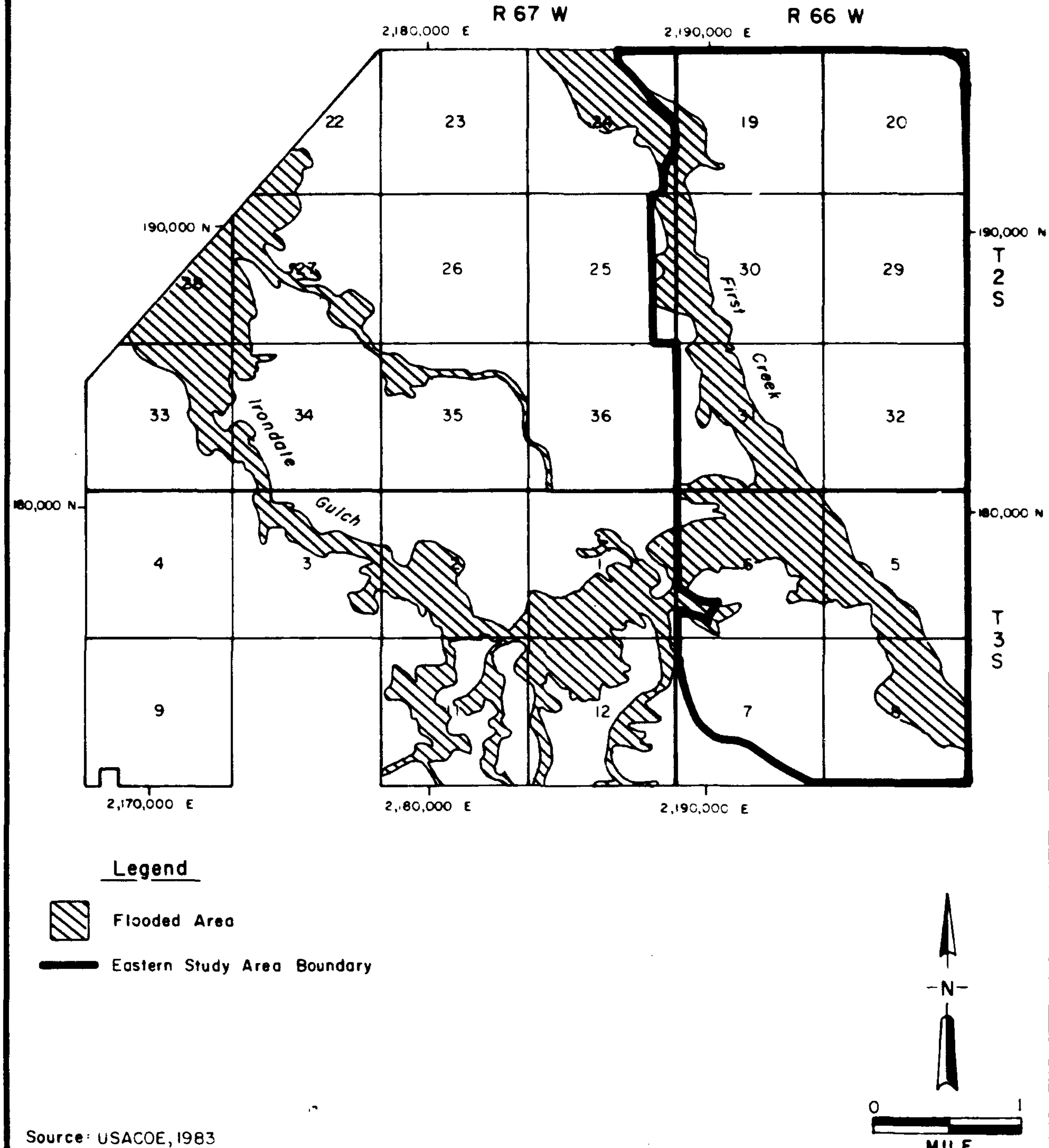
SYSTEM	ZONE & THICKNESS		LITHOLOGIC DESCRIPTION
QUATERNARY	*Alluvium*	0-120'	Gravels, silty sands, sandy silts, and clays; laterally variable
CRETACEOUS - TERTIARY DENVER FORMATION	*B*	0-25' (0-19')	B Sandstone and claystone
	Volcani-clastic	0-50'	Volcaniclastic material and laterally equivalent claystone and sandstone
	A	0-75'	AU (0-13'); AM (0-20'); AL (0-20'); AS (0-46'); Sandstone, claystone, and lignite
	Lignite A	0-11'	Interbedded claystone, siltstone, sandstone and lignite (see Water Remedial Investigation Report Ebasco, 1989)
	1U	0-40' (0-36')	
	Lignite B	0-12'	
	1	0-60' (0-54')	
	Lignite C	0-13'	
	2	0-55' (0-41')	
	Lignite D	0-13'	
	3	0-45' (0-33')	
	4	0-50' (036')	
	5	0-25' (0-19')	
	6	to 30' (to 23')	
	7	to 30' (to 20')	
	8	to 40' (to 27')	
	9	to 20' (to 6')	

Note: Thickness not to scale, net sandstone thickness shown in parentheses.

Source Ebasco, 1989

Prepared for:
Program Manager's Office for Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.4-1
RMA Denver Formation Stratigraphic Column
Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated



Source: USACOE, 1983

Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

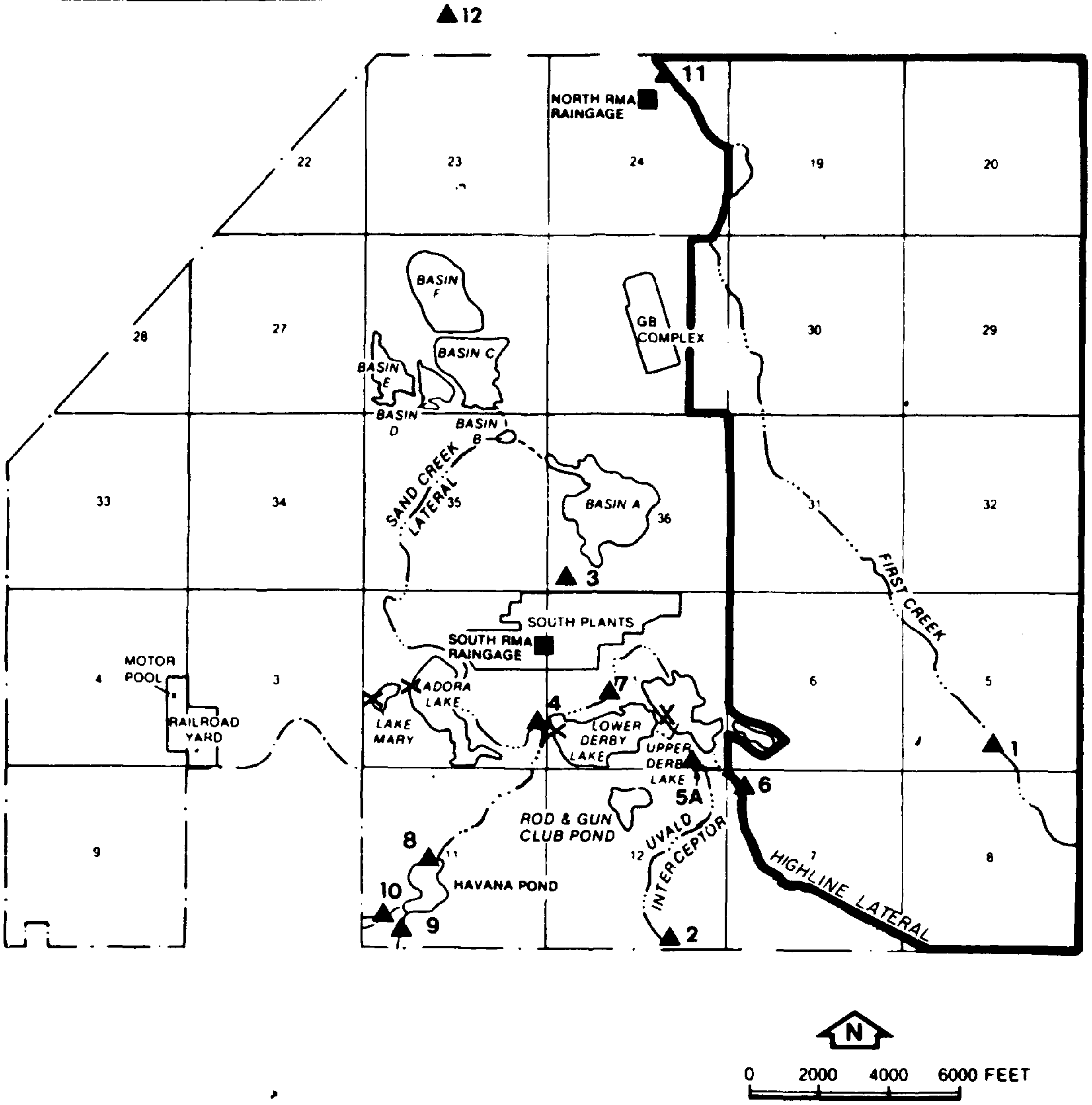
FIGURE ESA 1.5-1

Projected 100 Year
Floodplain Map

Rocky Mountain Arsenal

Prepared by Ebasco Services Incorporated

RMA TASK 4 4/86



▲ SURFACE WATER FLOW GAGES

1 First Creek (entering RMA)
2 South Uvalda Interceptor
3 Basin A Inflow
4 Ladora Weir
5A North Uvalda Interceptor (relocated)
6 Highline Lateral
7 South Plants Ditch
8 Havana Detention Pond
9 Peoria Ditch
10 Havana Interceptor
11 North First Creek
12 North Offpost Area

X Lake Staff Gages
■ Raingage Sites
● Well Locations
▬ Eastern Study Area Boundary

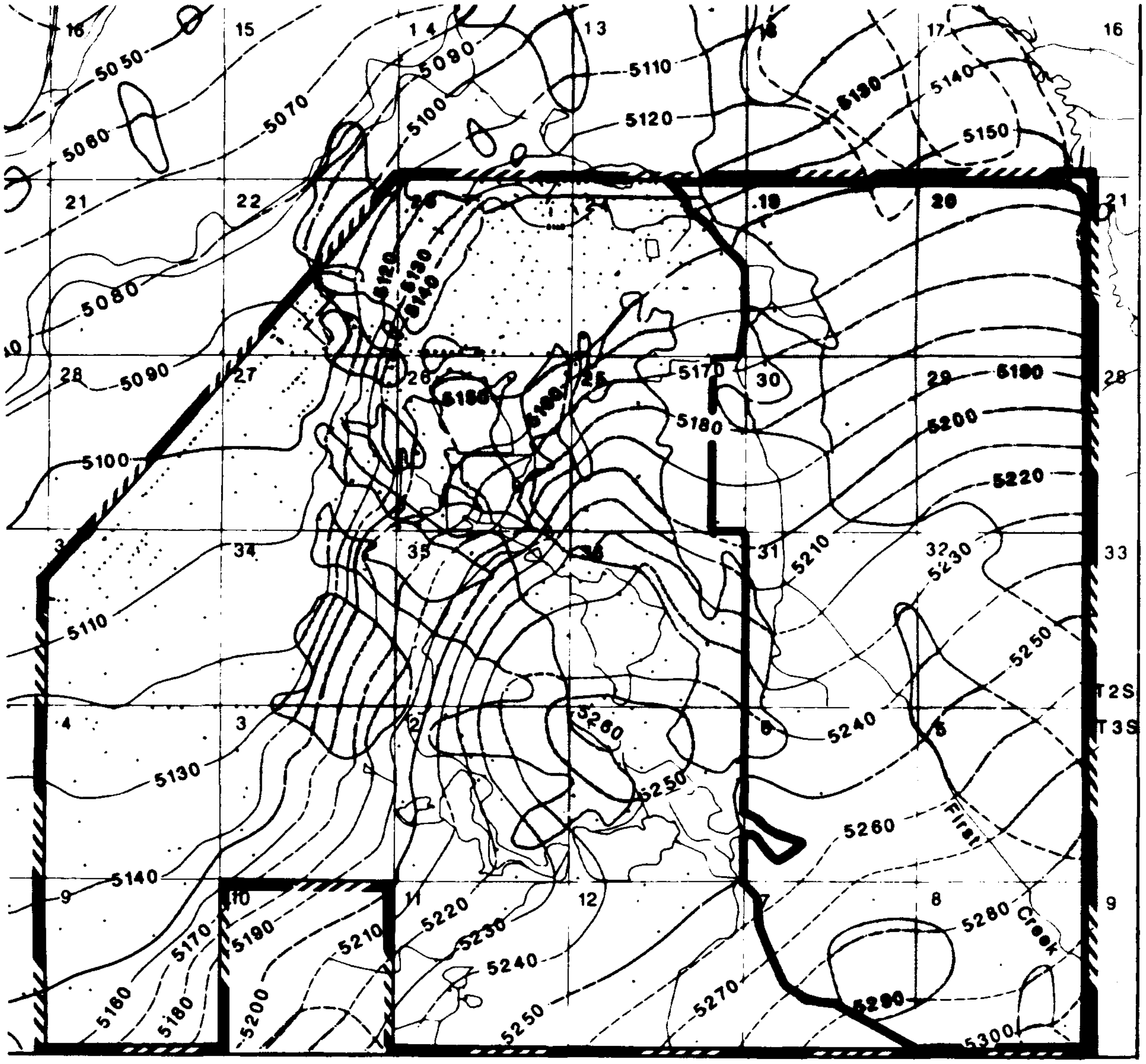
Source: ESE, 1987

Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.5-2
RMA Stream Flow Monitoring Stations

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



LEGEND

Contour Interval Equals 10 Feet

Elevations in Feet

Datum Mean Sea Level

Unsaturated Alluvium

Inferred Contour

Interpreted Contour

Data Point Well

Arsenal Boundary

Eastern Study Area Boundary

N

0 5000

Scale in Feet

Prepared for:

Program Manager's Office for Rocky Mountain Arsenal Cleanup

FROM: Ebasco, 1989

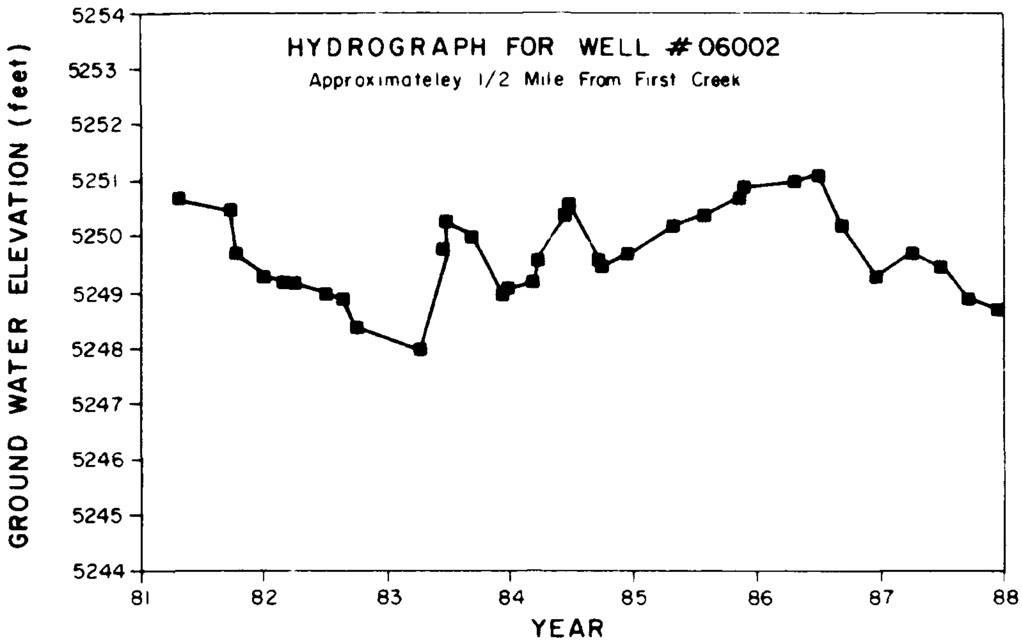
FIGURE ESA 1.5-3

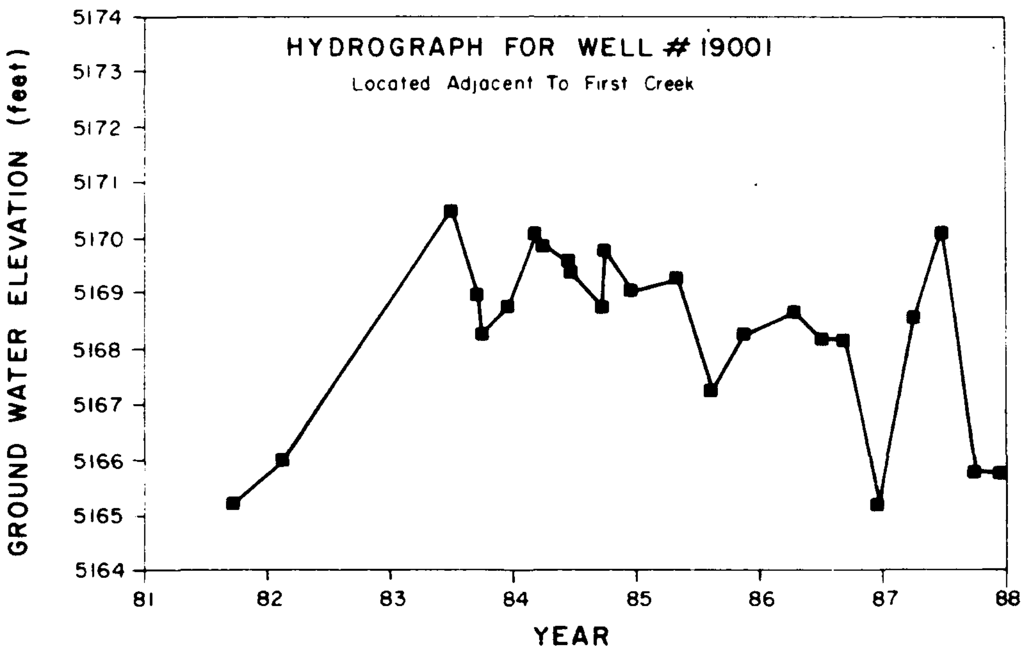
Water Table Contour Map,

April-June 1987

Rocky Mountain Arsenal

Prepared by Ebasco Services Incorporated





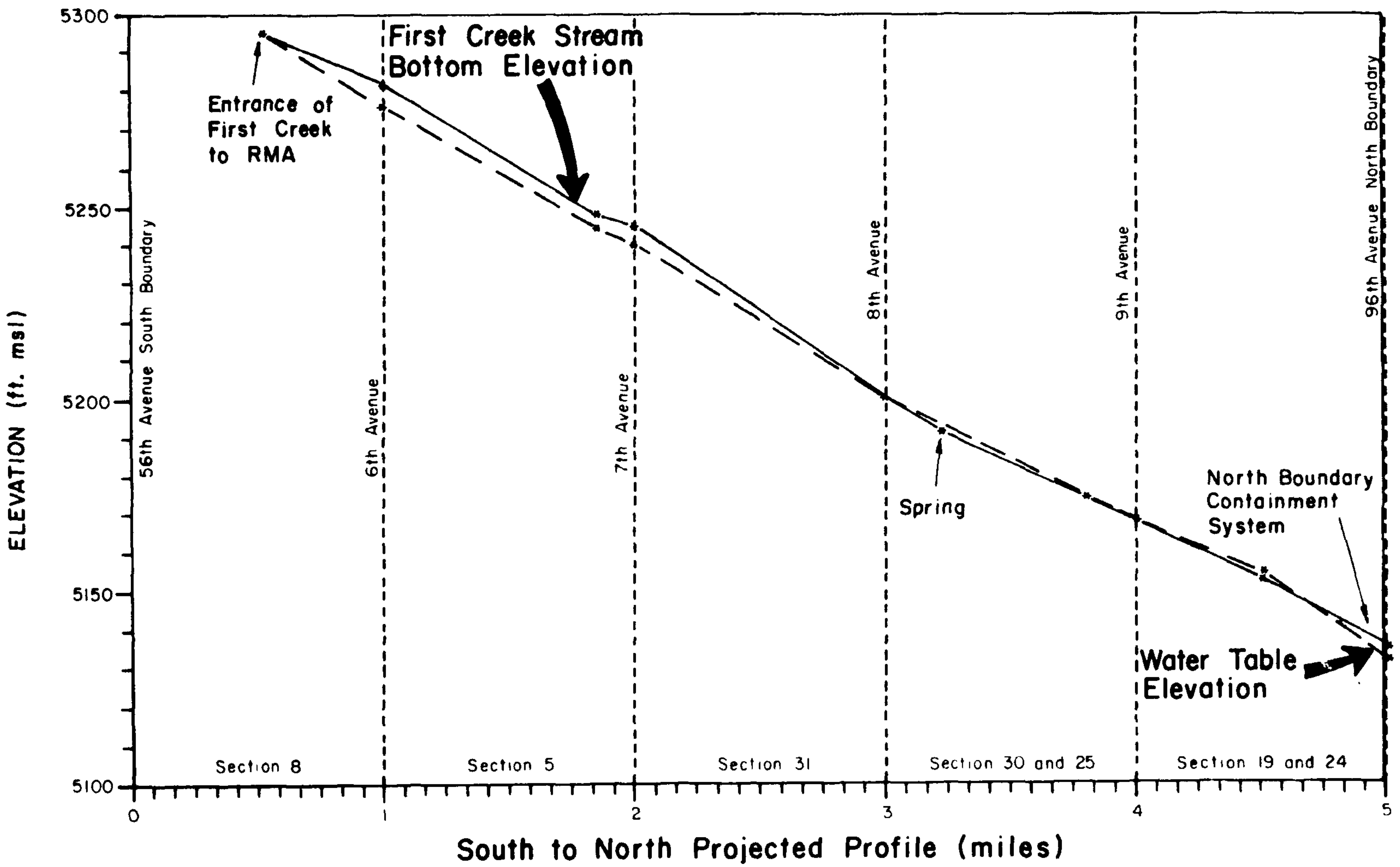
Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.5-4
Hydrographs for Well 06002 and Well 19001

Rocky Mountain Arsenal

Prepared by Ebasco Services Incorporated

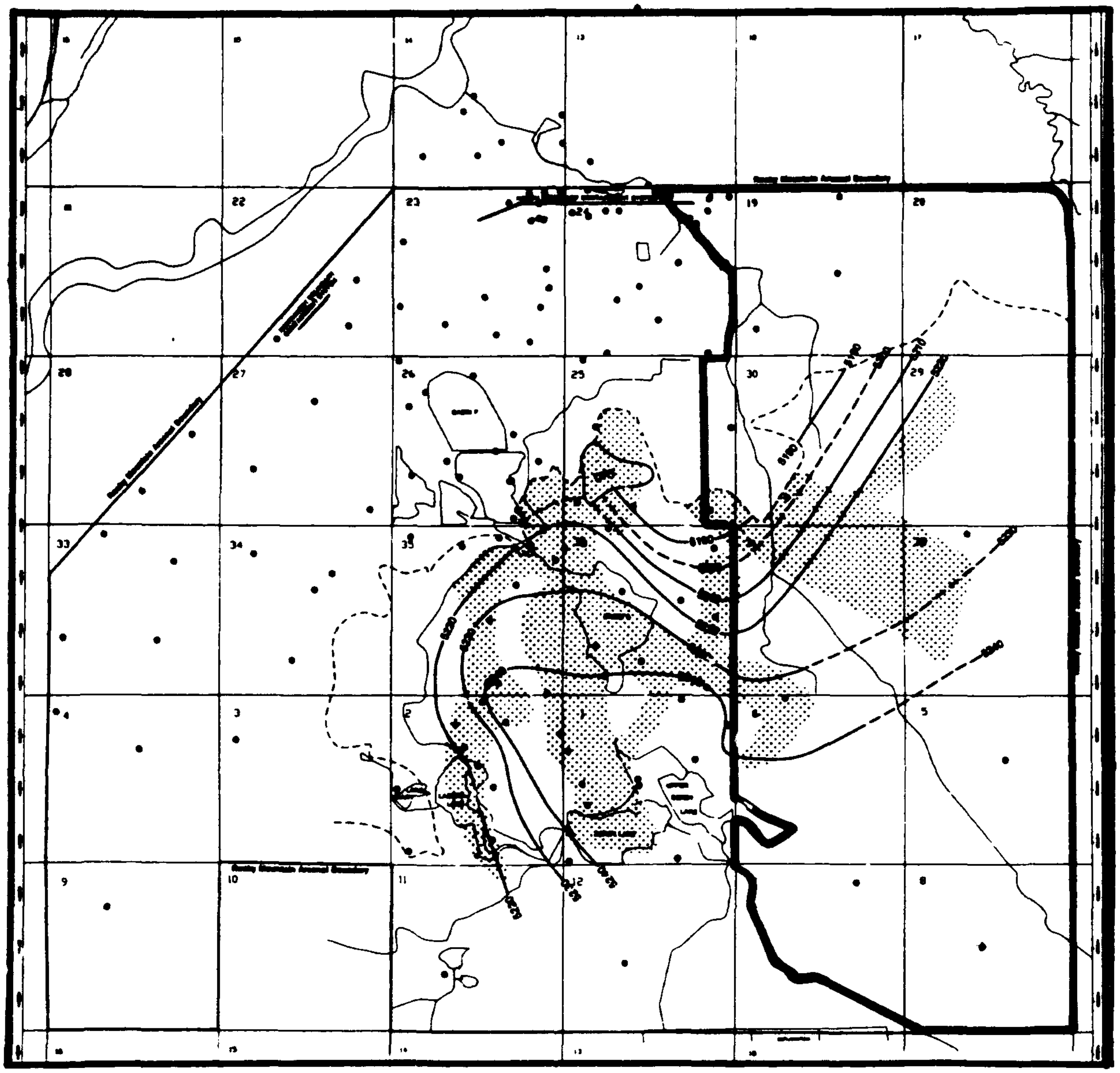


* Data Point
Note: Water table elevations taken from the April to June 1987 contour map.
Source: Ebasco, 1988

Prepared for:
Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.5-5
First Creek Surface Water / Groundwater Interactions

Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated



Legend

5200 — Elevation Of The Potentiometric Surface, Feet Above Mean Sea Level, Dashed Where Inferred

Contour interval is 10 feet

Zone A Net Sandstone Occurrence >10' Thick

Eastern Study Area Boundary

• Data Control Point

N

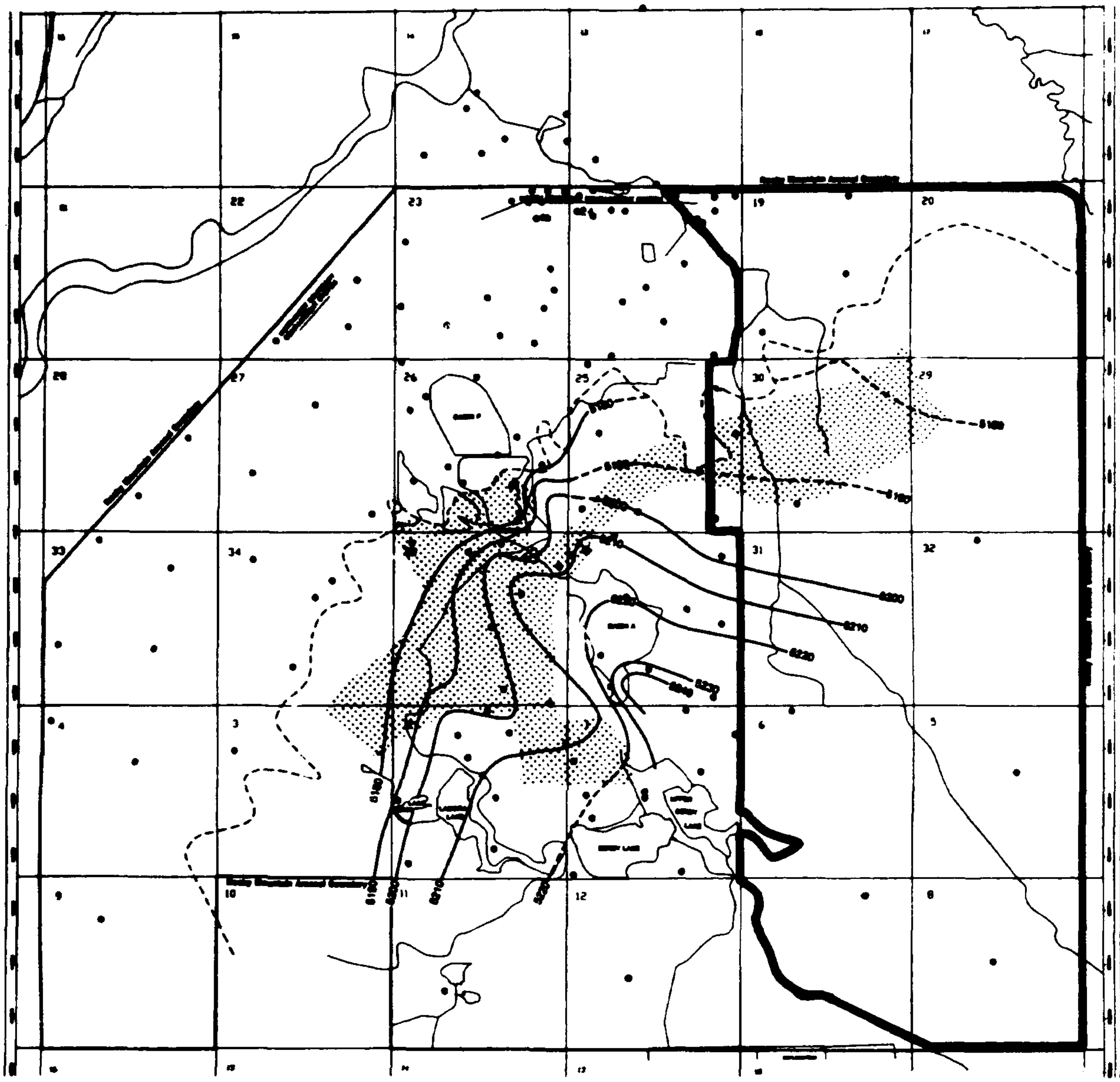
0 2500 5000

Scale In Feet

Source Ebasco, 1989

Prepared for
Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.5-6
Potentiometric Surface of Denver Zone A, April-June 1987
Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Legend

5200 — **Elevation Of The Potentiometric Surface, Feet Above Mean Sea Level, Dashed Where Inferred.**

Contour interval is 10 feet

Zone 1U Net Sandstone Occurrence >10' Thick

Eastern Study Area Boundary

• Data Control Point

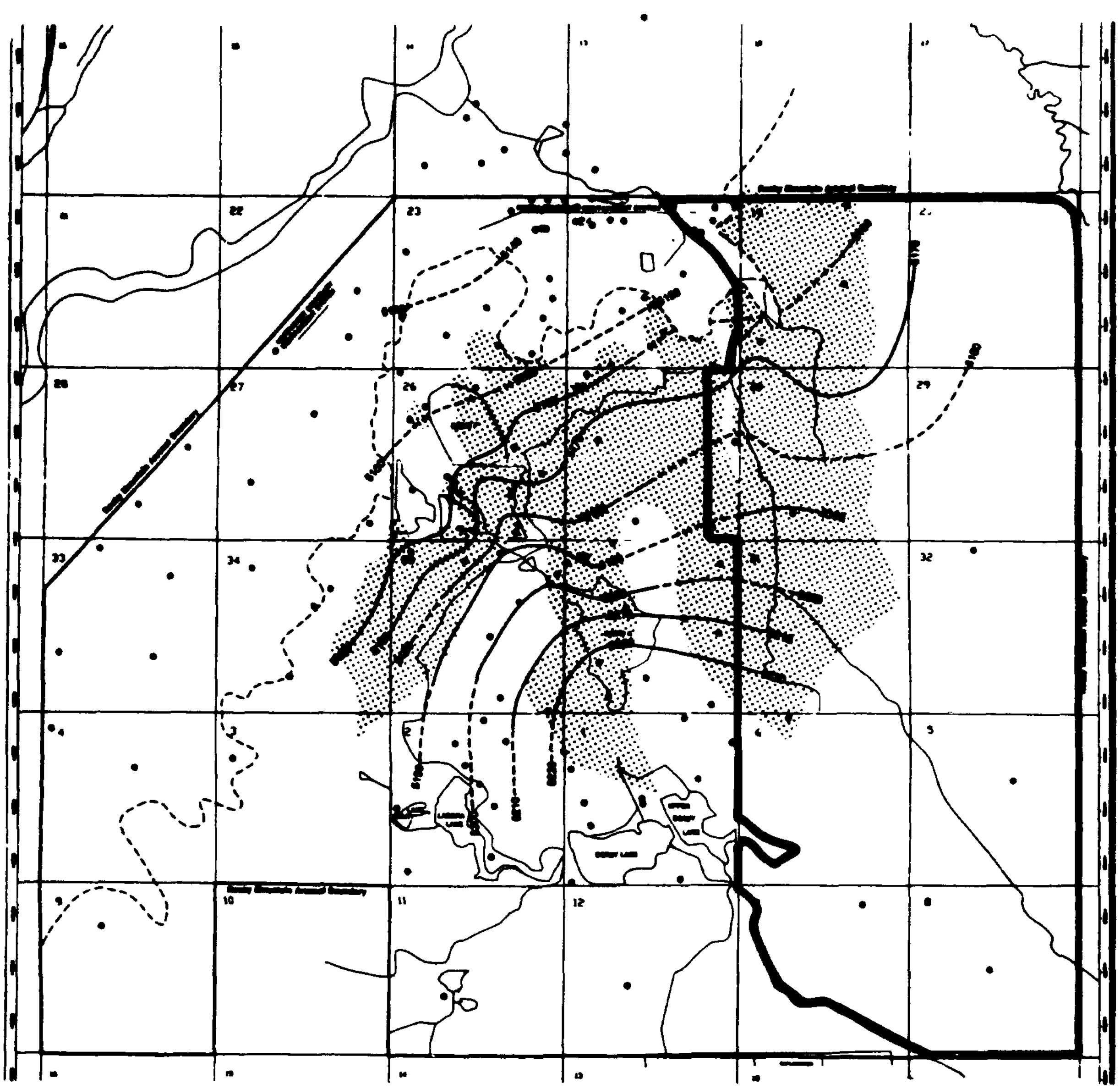
N

0 2500 5000

Scale In Feet

Source Ebasco, 1989

Prepared for: Program Manager's Office for Rocky Mountain Arsenal Cleanup	FIGURE ESA 1.5-7 Potentiometric Surface of Denver Zone 1U, April-June 1987 Rocky Mountain Arsenal Prepared by Ebasco Services Incorporated



Legend

Elevation Of The Potentiometric Surface, Feet Above Mean Sea Level, Dashed Where Inferred (5200)

• Data Control Point

Contour interval is 10 feet

Zone 1 Net Sandstone Occurrence >10' Thick

Eastern Study Area Boundary

N

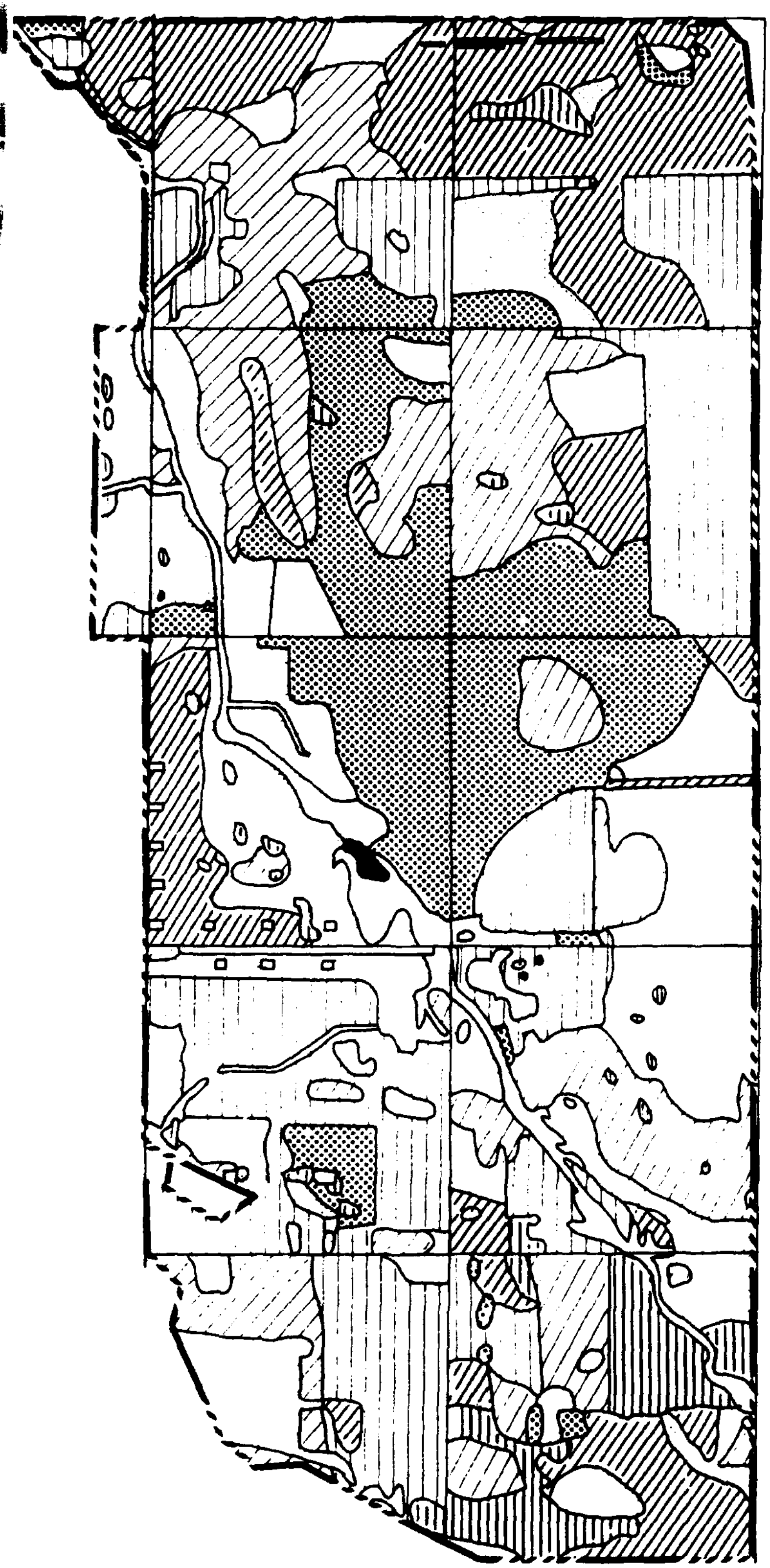
0 2500 5000
Scale in Feet

Source Ebasco, 1989

Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

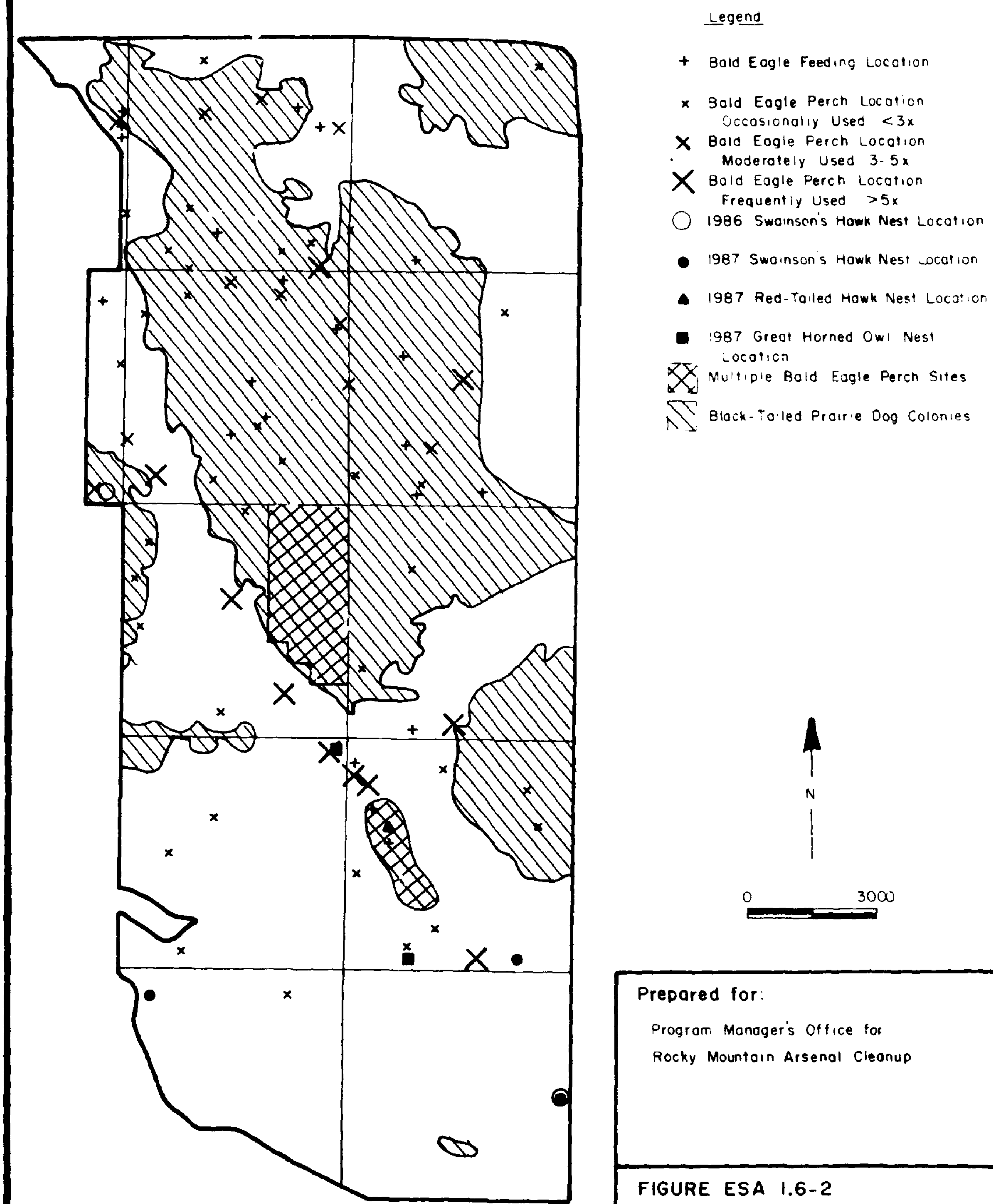
FIGURE ESA 1.5-8
Potentiometric Surface of Denver Zone 1, April-June 1987
Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated



Prepared for:
Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.6-1
Vegetation Map of
Eastern Study Area

Rocky Mountain Arsenal
Prepared by: Ebasco Services Incorporated



Prepared for:

Program Manager's Office for
Rocky Mountain Arsenal Cleanup

FIGURE ESA 1.6-2

Prairie Dog and Raptor Distribution Map

Rocky Mountain Arsenal
Prepared by Ebasco Services Incorporated