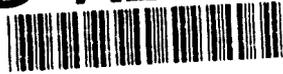




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1. AGENCY U

2

12/00/86

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE  
GROUNDWATER TREATMENT STUDY FOR SOUTH PLANTS AND BASIN A NECK, TASK 26,  
DRAFT FINAL TECHNICAL PLAN

5. FUNDING NUMBERS

6. AUTHOR(S)

DAAK11 84 D 0017

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

EBASCO SERVICES, INC.  
LAKEWOOD, CO

8. PERFORMING ORGANIZATION  
REPORT NUMBER

87007R42

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

ROCKY MOUNTAIN ARSENAL (CO.). PMRMA  
COMMERCE CITY, CO

10. SPONSORING/MONITORING  
AGENCY REPORT NUMBER

DTIC  
ELECTE  
NOV 10 1994  
S G D

11. SUPPLEMENTARY NOTES

94-34867



421 257

12a. DISTRIBUTION / AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

TASK 26 INVOLVES DEVELOPING A CONCEPTUAL DESIGN FOR FACILITIES WHICH WILL CONTROL AND TREAT THE GROUND WATER IN THE SOUTH PLANTS AND BASIN A NECK AREAS. THIS TECHNICAL PLAN DESCRIBES THE ACTIVITIES THAT WILL BE PERFORMED TO COMPLETE THE DESIGN. THE OBJECTIVES OF TASK 26 INCLUDE:

1. DETERMINE THE GROUND WATER FLOW RATES AND MIGRATION PATTERNS
2. DETERMINE DEWATERING RATES FOR A GROUND WATER TREATMENT PLANT
3. EVALUATE THE IMPACT OF GROUND WATER CONTROL ON THE LAKES
4. CONCEPTUALLY DESIGN GROUND WATER CONTROL AND DEWATERING SCHEMES AND TREATMENT FACILITIES

5. DEVELOP COST ESTIMATES FOR THE SYSTEM.

SECTIONS OF THIS PLAN DETAIL INFORMATION ON THE FOLLOWING:

1. GEOLOGY AND HYDROGEOLOGY OF THE AREA
2. FIELD INVESTIGATION PROGRAM
3. GROUND WATER TREATMENT SYSTEM

DTIC QUALITY INSPECTED 5

14. SUBJECT TERMS  
GEOLOGY, HYDROGEOLOGY, QA/QC, GEOTECHNICAL REQUIREMENTS, WELL SAMPLING

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION  
OF REPORT  
UNCLASSIFIED

18. SECURITY CLASSIFICATION  
OF THIS PAGE

19. SECURITY CLASSIFICATION  
OF ABSTRACT

20. LIMITATION OF ABSTRACT

94 051



DRAFT FINAL TECHNICAL PLAN

TASK 26

GROUNDWATER TREATMENT STUDY FOR  
SOUTH PLANTS AND BASIN A NECK

December 1986

Contract No. DAAK11-84-D-0017

*as sent to MOA parties  
includes 15 Dec update*

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Unannounced	<input type="checkbox"/>
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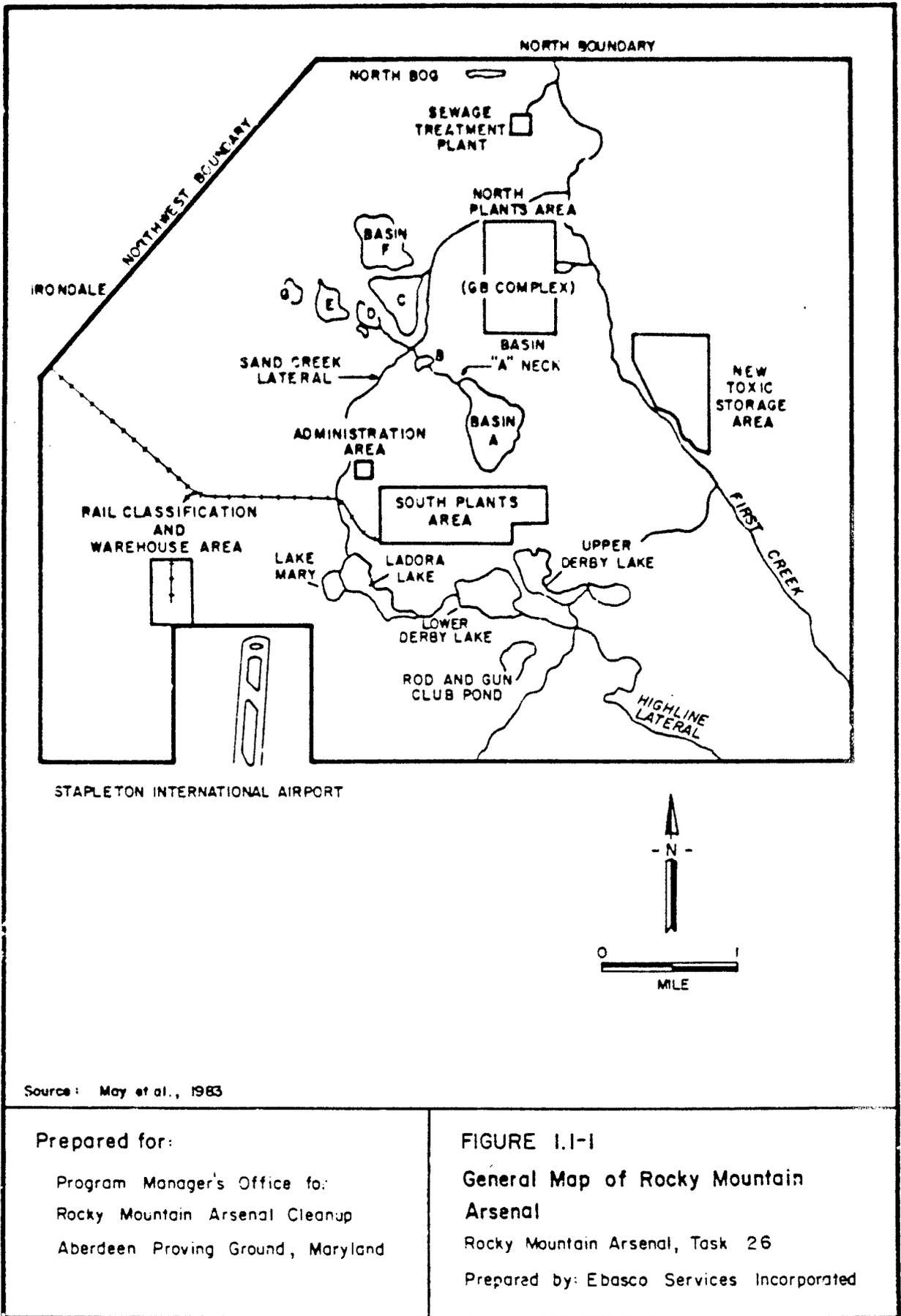
## 1.0 INTRODUCTION

### 1.1 BACKGROUND

The Rocky Mountain Arsenal (RMA) is located in western Adams County, northeast of Denver, Colorado. Figure 1.1-1 is a general site map of the facility. RMA was established in 1942 as a manufacturing facility for the production of mustard gas. Subsequent military uses included the production, handling, or demilitarization of GB nerve agent, agent VX, lewisite, arsenous chloride, chlorine, cyanogen chloride (CK), phosgene (CG), and incendiary bombs. In 1946, excess facilities at the South Plants area were leased by the Julius Hyman Company for the production of insecticides. The chemical division of the Colorado Fuel and Iron (CF&I) Company leased several facilities in the South Plants area in the early 1950s. Products manufactured by CF&I included chlorobenzene, naphthalene, chlorine, and fused caustic. In the early 1950s, the Shell Chemical Company (Shell) began insecticide production in leased facilities within the South Plants area, generally as successor to the Julius Hyman Co. This activity continued until recent years, and Shell still leases facilities at the South Plants area. Shell has also reportedly constructed 66 buildings and 108 tanks in the South Plants area.

Most of the industrial wastes from operations of the government and its lessees were initially discharged through the chemical sewer system into Basin A, an unlined basin in Section 36. However, some wastewaters were discharged to unlined drainage ditches. Wastes were also discharged into unlined Basins B, C, D, and E, as well as Basin F, which was constructed with an asphalt liner. Some of the basins, pits, burn sites, sewers, and structures (buildings, pipes, and tanks) may have become sources of groundwater contamination.

In 1954, farmers near RMA claimed that their crops had been damaged by groundwater used for irrigation. In May of 1974, diisopropylmethyl phosphonate (DIMP) and dicyclopentadiene (DCPD) were detected in surface water at the northern boundary of the Arsenal. Later that year, the Colorado Department of Health (CDH) detected DIMP in a well north of the Arsenal. As a result, CDH issued Cease and Desist Orders in April 1975, directing Shell and



Source: May et al., 1983

Prepared for:

Program Manager's Office for:  
 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland

FIGURE I.1-1

General Map of Rocky Mountain  
 Arsenal

Rocky Mountain Arsenal, Task 26

Prepared by: Ebasco Services Incorporated

RMA to immediately stop the off-post discharge of DIMP and DCPD in surface and subsurface water.

As a result of CDH Cease and Desist Orders, a contamination control program at RMA was established to insure compliance with federal and state environmental laws. As a result of this program, sources of contamination have been identified, pathways by which contaminants migrate into the environment have been delineated, and three groundwater treatment systems have been installed at the northern and northwestern boundaries of RMA to intercept, treat, and replace contaminated groundwater prior to its movement off post.

The South Plants area and the Basin A area have been identified as possible sources of groundwater contamination. The general groundwater flow, from at least a portion of the South Plants area and the Basin A area, is north and northwest through the Basin A Neck area (May, 1983). The Basin A Neck is a subsurface valley between two bedrock highs northwest of Basin A. This feature channels the northwest-trending groundwater flow. Preventing the migration of the contaminated groundwater beneath these areas will provide a major step in controlling the migration of contaminants off post. Treatment of the contaminated groundwater will be required as part of the U.S. Army's efforts to clean up contamination on the Arsenal caused by past operations.

The Program Manager's Office for the Rocky Mountain Arsenal Contamination Cleanup (PMO) has requested that a conceptual design be developed for an interim response action to construct facilities which will control and treat the groundwater in the South Plants and Basin A Neck areas. This Technical Plan describes the activities that Ebasco Services Incorporated will perform under Task Order 26 to complete this design.

Ebasco's Final Technical Plan for Task 2 (South Plants) (Ebasco 1985) serves as a reference document for this Technical Plan and all plans subsequently generated. The South Plants Technical Plan contains detailed background information on the general contamination problems at RMA and for this reason is referenced by this Task 26 Technical Plan for South Plants Groundwater Treatment.

## 1.2 OBJECTIVES

The objectives of Task 26 are as follows:

- o To determine the groundwater flow rates and migration patterns under the South Plants area, the Basin A/Basin A Neck area, and surrounding areas, and to determine appropriate dewatering facilities and dewatering rates for a groundwater treatment plant;
- o To evaluate the impact of groundwater control and dewatering facilities on the Lower Lakes;
- o To develop a database of available information on the types and concentrations of contaminant constituents in the groundwater for the conceptual design of a groundwater treatment plant;
- o To conceptually design groundwater control and dewatering schemes and groundwater treatment facilities for the South Plants and Basin A/Basin A Neck areas; and
- o To develop cost estimates for the design, construction, and operation of the groundwater collection, treatment, and disposal systems.

## 1.3 TECHNICAL APPROACH

The task objectives presented above will be accomplished through the development of the conceptual design, as described below and in more detail later in this plan. The final report for this task will also include a detailed evaluation of historical records, groundwater sampling analyses, previous hydrogeological studies, existing treatment systems performance reports, bench and pilot scale treatment process evaluations, and reports on previously evaluated groundwater control and treatment systems. This detailed evaluation will be supplemented with numerical simulations of hydrogeological systems in the study area and with a field investigation program. The field program will include the installation of groundwater monitoring wells, chemical analyses of groundwater samples, and aquifer tests.

Although a considerable number of hydrogeological studies have been conducted at RMA, a detailed interpretation of these studies has not been made. This interpretation is needed to provide sufficient information on groundwater flow and water quality characteristics to design a groundwater control, collection, and treatment system for the South Plants and Basin A/Basin A Neck areas. The focus of the hydrogeological portion of this study will be to define these characteristics in the study areas, and to evaluate the impacts of a groundwater collection system on surrounding hydrologic features such as the Lower Lakes. A field investigation program will be utilized to fill specific gaps in the information available from the literature review.

The treatment and disposal systems evaluation will concentrate on previous studies and evaluations conducted at RMA for treatment of the groundwater. The previous investigations will be critically reviewed with respect to the most recent chemical analysis data for the study areas and the latest developments in treatment technologies. A conceptual design of a groundwater collection, treatment, and disposal system will be developed, complete with estimated costs for construction and for operation and maintenance.

## 2.0 EVALUATION OF BACKGROUND INFORMATION

### 2.1 LITERATURE REVIEW

The major focus of this study will be to compile and evaluate all available information pertaining to groundwater characteristics, water quality characteristics, and treatment process studies for the South Plants and Basin A/Basin A Neck areas of RMA. Information will be gathered from hydrogeologic and engineering reports, chemical laboratory analysis data, and performance records for the existing groundwater treatment systems. This information will be supplemented with non-RMA information on hydrogeology and groundwater collection and treatment systems.

### 2.2 DATA COMPILATION

The information obtained from the literature review will be compiled into a database to facilitate designing a groundwater collection, treatment, and disposal system. Additionally, numerical simulations of the hydrogeological systems in the South Plants and Basin A/Basin A Neck areas will aid in determining hydrogeological responses to control, collection, and disposal systems. It is anticipated that the literature review will expose gaps in the hydrogeological data for the South Plants and Basin A/Basin A Neck areas. A field investigation program has been developed to provide the missing information. The field program may consist of aquifer hydraulic conductivity tests, installation of additional groundwater monitoring wells, and chemical analyses of groundwater samples. All of the data will be critically reviewed, and newly generated data will be utilized to develop a conceptual design of a groundwater control and collection system, storage and treatment facilities, and an appropriate disposal system.

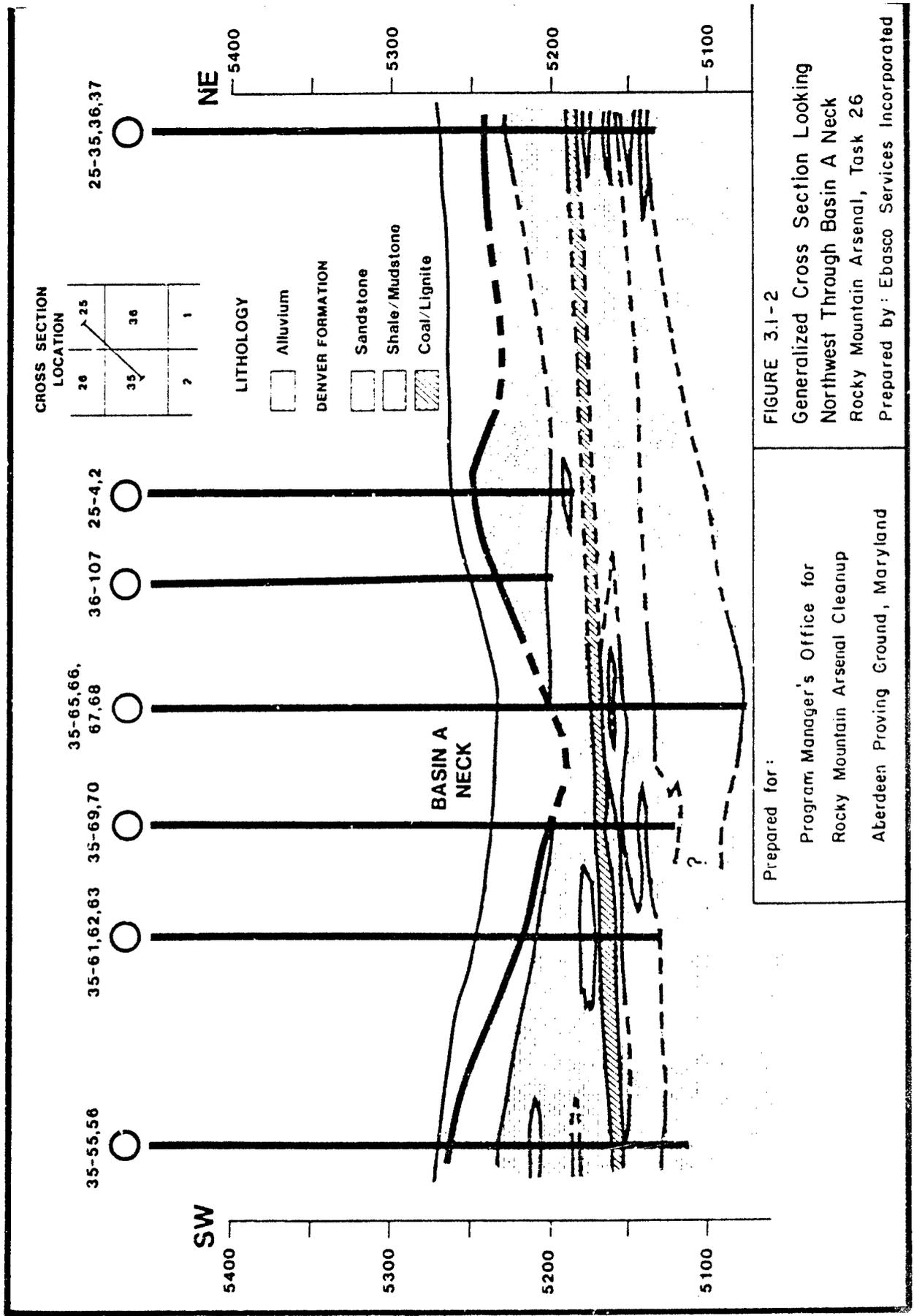


FIGURE 3.1-2

Generalized Cross Section Looking  
Northwest Through Basin A Neck  
Rocky Mountain Arsenal, Task 26  
Prepared by: Ebasco Services Incorporated

Prepared for:  
Program Manager's Office for  
Rocky Mountain Arsenal Cleanup  
Aberdeen Proving Ground, Maryland

### 3.0 TECHNICAL APPROACH

The technical approach for this task has been divided into three subtasks. The hydrogeology subtask will focus on defining the limits and groundwater flow characteristics of the contaminated aquifers in the study area. This determination will be used to identify the optimum locations for the installation of groundwater control and collection facilities. The field investigation subtask will provide data to fill critical information gaps identified in the hydrogeological evaluation. The groundwater treatment system subtask will evaluate control and collection facilities, treatment processes, and disposal options for inclusion into the system. This subtask will provide a conceptual design for the proposed interim response action.

### 3.1 HYDROGEOLOGY

#### 3.1.1 Geology

A brief description of the geology of the study area is presented in the following sections. An understanding of the geology is crucial to obtaining an understanding of the various aquifers, their groundwater flow characteristics, and the aquifers' interrelationships.

##### 3.1.1.1 Regional Geology

RMA lies just east of the Southern Rocky Mountain province within the Rocky Mountain Pediment physiographic province of the Interior Plains (Hammond, 1964). An understanding of the regional setting and the environments of deposition is important to develop an understanding of the complexity of the geology and hydrogeology at the Arsenal. The structural and depositional history of the area is directly related to the geologic history of the Southern Rocky Mountain province. More detailed geology of this region may be found in Kirkham and Ladwig (1980). Three mountain-building episodes, including the Ancestral Rockies (Pennsylvanian), Laramide (Late Cretaceous-Early Tertiary), and the Modern Southern Rocky Mountains beginning during the Miocene, have occurred. Up to 14,000 feet (ft) of eroded sediments from these mountains compose the rock formations in the basin today. The sediments were deposited in the north-south trending, doubly plunging, asymmetrical syncline known as the Denver Basin. The beds on the flanks of

the oval-shaped basin generally dip gently towards its long axis which is located near the western margin near Denver. However, along the Front Range structural zone, which is up to four miles wide, basement-controlled, moderate-to-high-angle reverse faults and monoclines are common, and beds dip steeply eastward. Locally, beds are offset by the faults as much as 9,000 ft and are vertical to overturned. It is possible that many of the monoclines in the area are underlain by faults which do not reach the surface. Although they are uncommon throughout most of the basin, listric growth faults are common along the northwestern margin of the basin in sediments above the Pierre Shale. This type of faulting is caused by a combination of slumping and additional sedimentary deposition, resulting in uneven thicknesses of bedded units across the fault. Numerous small displacement faults due to compaction and lithification are probably present throughout the basin.

The Permian to Pennsylvanian Fountain Formation unconformably overlies the Precambrian igneous and metamorphic basement. It represents a bajada complex, in which alluvial fans coalesced along the eastern edge of the Ancestral Rockies. The Fountain Formation is overlain by the fluvial and eolian Lyons Sandstone of Permian Age. The Lyons contributes 10 percent of the oil produced in the Denver Basin. It is conformably overlain by the Permo-Triassic shales and limestones of the Lykin Formation. A regional unconformity separates the Lykin Formation from the Upper Jurassic Ralston Creek Formation, which consists of interbedded limestone, clay, gypsum, and sandstone. Locally, the Upper Jurassic Morrison Formation rests unconformably upon the Ralston Creek Formation. Varicolored continental deposits including shale, siltstone, and claystone are interbedded with thin beds of sandstone, limestone, and conglomerate. Dinosaur fossils are common in the Morrison Formation throughout the Rocky Mountains. The Lower Cretaceous Dakota Group is divided into the Lytle and South Platte Formations. A transgressing seaway deposited these sediments including the D and J sands of the South Platte Formation which have accounted for 80 percent of the oil produced from the basin. During the Upper Cretaceous, the marine shales and limestones of the Colorado Group and Pierre Shale were deposited. Uplift associated with the Laramide Orogeny caused a change from marine to continental deposition at the end of the Cretaceous. The Upper Cretaceous Fox Hills Sandstone was

deposited in delta-front and barrier bar environments. Noneconomic coal deposits indicate the transition from marine to continental environments. The Upper Cretaceous Laramie Formation rests on top of the Fox Hills Sandstone and consists of fluvial delta plain deposits. A thick wedge of bajada sediments formed the Arapahoe Formation along the mountain front. The Arapahoe Formation grades from coarse bajada sediments on the west to finer sediments deposited by meandering and braided streams towards the east. The Arapahoe is a major aquifer in the Denver area. The uppermost bedrock unit in the study area is the Upper Cretaceous to Paleocene Denver Formation. Because the Denver Formation is important to many aspects of this project, a more detailed description follows.

The boundary between the Cretaceous and Tertiary Periods has been identified within the Denver Formation near Golden and at Middleton. The Arapahoe, Dawson, and Denver Formations are equivalent in age, or nearly so. Because of this, many previous workers have considered them as one formation. This opinion remains in dispute by others.

The Denver Formation consists of 400 to 1,580 ft of medium-yellow to light-gray, olive, and gray-green claystone, siltstone, very fine- to medium-grained sandstone, andesitic conglomerate, and lignite. Oxidized sediments near the subcrop are olive-yellow. In addition to the sedimentary facies of the Denver Formation, at least two igneous bodies are recognized. Andesitic lava flows are interbedded with the upper Denver near Golden and a possible igneous dike (rhyodacite lava-quartz latite) crops out on Rattlesnake Hill at RMA (Kirkham & Ladwig, 1980). The Rattlesnake Hill dike may also represent a clastic dike rich in volcanic fragments. A borehole near Rattlesnake Hill penetrated a sill or dike at 40.4 to 41.8 ft which was logged as porphyritic basalt. A weathered lithic tuff was used on the eastern side of the Arsenal as a lithologic marker. Conglomerates rich in andesite cobbles, pebbles, and boulders are common along the mountain front and lignite beds are prevalent in the eastern portion of the basin. The coarser materials were deposited in point bars of meandering streams while the lignite beds were flood basin or delta plain deposits.

The abundance of andesitic conglomerates in the Denver has been used to distinguish it from underlying beds. While this is reasonable on the western portion of the basin, the lack of conglomerates eastward requires that other methods be used to distinguish the formation eastward. Morse (1979) suggests that the top of the formation can be defined by a change from andesitic to arkosic mineralogy along the mountain front. Denver sands described at the Arsenal contain quartz and chert gravel (May, 1982). No mention of andesites is made; however, volcanoclastic sediments of unknown composition are reported. The provenance of the andesites and volcanoclastic sediments may be volcanic sources from as far away as Salida (Epis & others, 1976). Alternatively, volcanic flows may have been eroded from the uplifting mountains during Denver time.

Review of available data on the Arsenal indicates that the lithology on the eastern side of the Arsenal is different than on the west. May (1982) reports that west of "C" Street the alluvial overburden is thicker and the Denver is predominantly clay-rich with rare thin lenticular silty sand bodies. East of "C" Street the Denver is typified by a more variable package of sediments including lignite, mappable volcanoclastic sediments, and thick, relatively permeable sand.

Pleistocene and recent alluvial and eolian deposits ranging from 0 to 127 ft overlie the Denver Formation. These sediments have been quarried at Rattlesnake Hill resulting in exposure of the Denver volcanic rocks. The thickest section (127 ft) occurs in a buried bedrock-surface valley in Section 33 of the Arsenal, near the Irondale well.

The alluvium consists of yellowish-brown to very pale orange clay, silt, sand, gravel, and boulders. Boulders up to 100 pounds were recovered from the buried bedrock valley during installation of Adams County production wells near 77th Avenue and Quebec Street. Large boulders of igneous rock, chert, quartz, and petrified wood form cap rocks on topographic highs such as Rattlesnake Hill and Henderson Hill. Sands have a variable grain size distribution, are subangular to subrounded, and are composed mainly of quartz

with lesser amounts of mica, chert, and heavy minerals. The sands grade into clay, silt, and gravel and occur primarily as lenticular bodies. Calcium carbonate cements are locally common and form a well-indurated conglomerate along the northern boundary of the Arsenal.

#### 3.1.1.2 Site-Specific Geology

Existing site-specific data relevant to the Denver Formation within the study area includes: depth to bedrock, facies and lithology patterns, and limited structural information. Various reports have been published interpreting the geology of Basin A/Basin A Neck areas and these are discussed in this technical plan. Similar information for the South Plants and Lakes areas has yet to be assembled and interpreted. Data from these regions need to be plotted as cross-sections, and isopach and structural maps before they will be convenient for analysis and incorporation into the available database.

In general, the bedrock erosional surface in the area dips towards the South Platte River through a series of terraces. Four bedrock highs, delineated by previous drilling, stand 70 ft or more above the surrounding erosional surface (Figure 3.1-1 in pocket). One east-trending ridge directly underlies the South Plants just south of Seventh Avenue and "D" Street. The second bedrock high forms Rattlesnake Hill in the east-central portion of Section 35. The third lies just east of "D" Street beneath Eighth Avenue, and the fourth is east of "D" Street and north of Eighth Avenue. Two bedrock erosional valleys separate Rattlesnake Hill from the other bedrock highs. The bedrock valley to the northeast of Rattlesnake Hill begins beneath Basin A and trends northwest through Basin A Neck in Section 35.

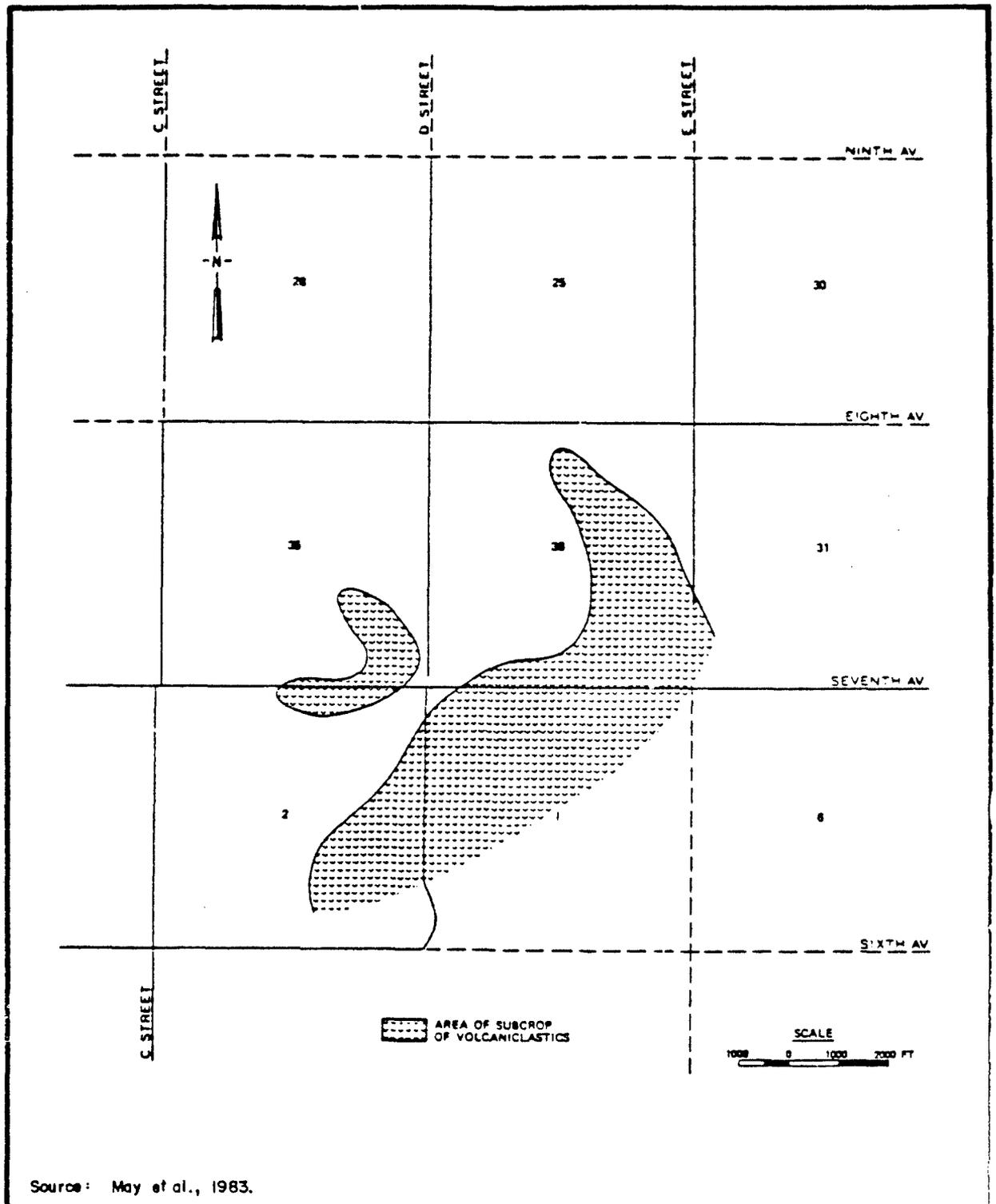
The Denver Formation in this area consists of volcanoclastics, claystone, mudstone, lignite, and sandstone. The total thickness of this formation for the immediate Basin A/South Plants vicinity is unknown; however, thicknesses of 240 to 450 ft have been reported at other sites on the Arsenal. May (1983) divides the Denver into an upper and lower unit using a continuous high-grade lignite bed as the top of the Lower Denver. This lignite seam is mappable in the subsurface from the Lower Lakes north to the center of Section 25.

Lithologic units in the Upper Denver include sandstone, a thick interbedded sequence of claystone, lignite, and volcanoclastics. Within the upper unit, a continuous paleochannel sand has been mapped which is up to 45 ft thick. It has been eroded in the bedrock valley of Basin A Neck where alluvium overlies it directly (Figure 3.1-2). Smaller lenticular siltstone-sandstone units are also present and may be interconnected by fault surfaces. In addition to the continuous lignite bed that separates the upper and lower units, four or more discontinuous lignite seams are present. The volcanoclastics are composed of highly weathered volcanic rock fragments in a matrix of bentonitic clays. These units are nearly 20 ft thick and lie near the top of the upper units beneath the southern and eastern borders of Basin A. Figure 3.1-3 shows the location of the volcanoclastics in the study area.

Although May included all of the section below the continuous lignite bed in his Lower Denver Formation, we separate this and other semicontinuous sands and silts associated with the lignite layers into an Intermediate Denver aquifer for the purposes of this study.

A semi-continuous sand body lies a few to 15 ft below the lignite bed (Figure 3.1-2). It is generally about 10 to 15 ft, but reaches to 25 ft thick to the southwest of Basin A Neck. In this study, we define the Lower Denver units beneath the Intermediate Aquifer to include a deep paleochannel sand and interbedded claystone, silt, and mudstone similar to those in the upper Denver units. The lower channel sand deposit is over 65 ft thick in the vicinity of Basin A Neck and lies at a depth of about 95 ft below the surface.

The alluvium is generally thinnest (5 ft or less) over the bedrock highs, such as the South Plants area, where it is composed primarily of wind-blown deposits; the alluvium is thickest over the bedrock depressions where it is a mixture of clay, silt, sand, and gravel. The thickest alluvium in the study area lies in the bedrock depression or valley just south of the Lower Lakes (55 ft) and in a smaller valley in Basin A neck (35 ft). May (1982) reports that the alluvium between Wells N3 (northwestern corner of Section 36) and SP2 (southeastern corner of Section 36) contains areas of low permeability, clayey



Source: May et al., 1983.

Prepared for:

Program Manager's Office for  
 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland

FIGURE 3.1-3

Paleogeologic (Subcrop) Map of  
 Volcaniclastics

Rocky Mountain Arsenal, Task 26

Prepared by: Ebasco Services Incorporated

sands, and silts. May also reports that the area beneath Basin A has a succession of beds which grade from fine at the bottom to coarser at the top. One explanation for this reversely graded sequence is that this area was a lake during Pleistocene times and gradually filled in with aeolian and fluvial deposits. Although this is an explanation, no varve structures have been reported which are characteristic of lake deposits. Further work is necessary to define, in three dimensions, the extent of sand and clay layers throughout the area.

### 3.1.2 Groundwater

#### 3.1.2.1 Regional Hydrogeology

The major aquifers beneath the Arsenal, from oldest to youngest, are the Fountain Formation, Lyons Formation, upper and lower Dakota Group, Laramie-Fox Hills Aquifer, upper Laramie Formation, Arapahoe Formation, Denver Formation, and alluvial-eolian surface deposits.

The Fountain Formation, Lyons Formation, and sandstones in the Dakota Group are rarely tapped for groundwater due to their great depth. Where these formations are tapped on the shallow fringes of the Denver basin; they yield about 5-50 gpm (gallons per minute).

The Laramie-Fox Hills Aquifer consists of the Milliken Sandstone member of the Fox Hills Formation and the A and B sands of the Laramie Formation, which have a combined thickness of 200-400 ft. These units underlie the Denver metropolitan area at a depth of 1,200-1,500 ft and are the major deep aquifer in the region. Approximately 600 wells, 80 percent of which are used for domestic or livestock use, tap the aquifer with typical yields of about 100 gpm or greater. Total pumpage from the aquifer is about 20 mgd (million gallons per day). Local water quality problems such as high concentrations of naturally occurring hydrogen sulfide, methane, iron, fluoride, and sodium exist, but in general the aquifer yields good quality water (Stollar & van der Leeden, 1981).

Thin (10-20-ft) sandstone beds of the upper Laramie Formation lie about 100-200 ft above the Laramie-Fox Hills Aquifer. These beds can supply 5-20 gpm water to wells, but are relatively undeveloped in the basin.

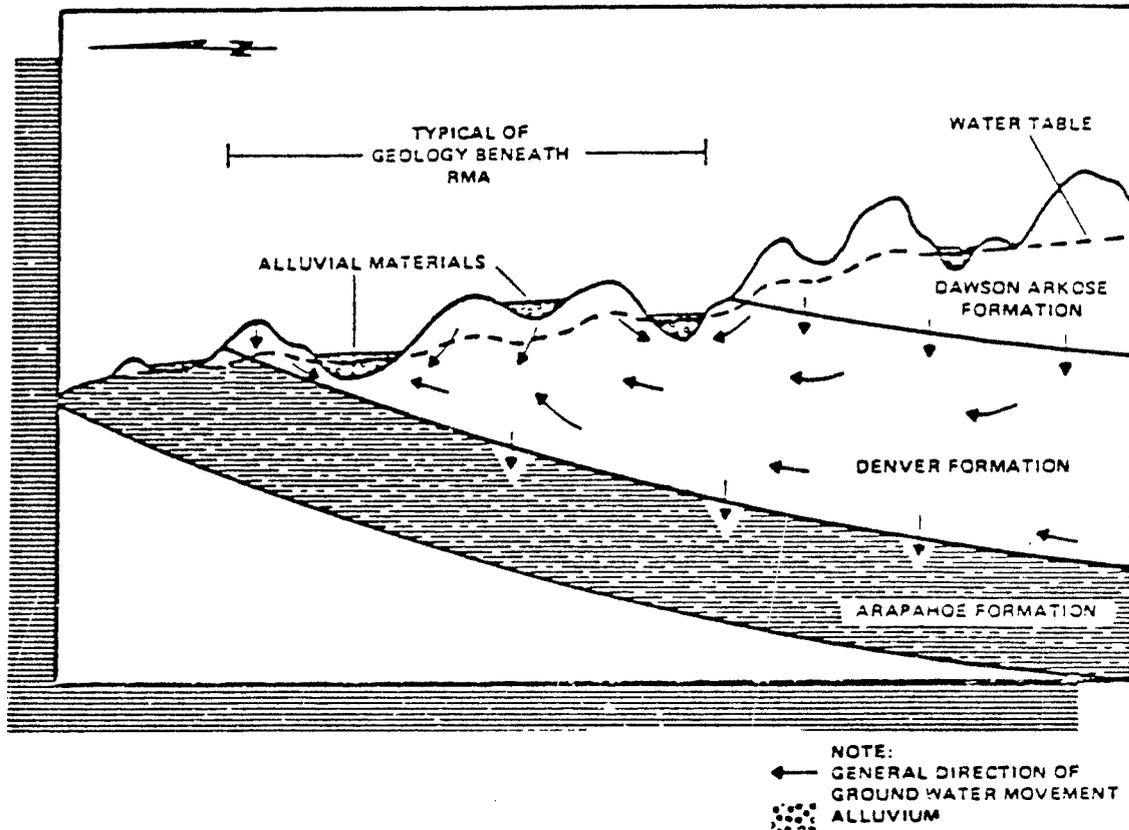
The Arapahoe Formation is an important bedrock aquifer in the basin. It is 500-600 ft thick, and yields good to excellent quality water to about 6,000 wells. Approximately 90 percent of these wells are for domestic or stock use including about 130 municipal wells which tap the aquifer. The Arapahoe underlies the Arsenal at a depth of about 700 ft along the southern boundary and about 300 ft along the northwestern boundary.

The Denver Formation overlies the Arapahoe at RMA. The fining-upwards sequences of the Denver Formation contain lenticular and sinuous sand bodies which are typical of a fluvial environment. Where thick sandstones in the Denver Formation are in contact with the overlying alluvium, they have a significant effect on the transport, concentration, and quantity of contaminants in the groundwater.

A thin cover of alluvial and eolian deposits overlies the Denver Formation. These deposits are locally thin or absent on bedrock highs and up to 35 ft and 55 ft thick in Basin A Neck and the bedrock valley south of South Plants, respectively. Generally, water from the alluvium is rather mineralized and of poor quality; however, Adams County currently taps an alluvial-filled bedrock valley just off the northwestern boundary of the Arsenal for domestic use. The better quality water available in this bedrock valley may result from recharge from the Denver Formation into the alluvium.

#### 3.1.2.2 Site-Specific Hydrogeology

There are two aquifer units that must be considered in the study area, the confined or semiconfined Denver Formation Aquifers, and the unconfined alluvial aquifer (Figure 3.1-4). In general, the deeper aquifers will not be considered. Groundwater flow at RMA in the deeper aquifers, such as the Fox Hills Sandstone and the Arapahoe, is to the northwest. The groundwater flow



Source: May et al., 1983.

**Prepared for:**

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 Aberdeen Proving Ground, Maryland

**FIGURE 3.1-4**

**Generalized Cross Section Across the  
 Denver Basin Showing Lateral Updip Flow in  
 the Denver Formation**

Rocky Mountain Arsenal, Task 26

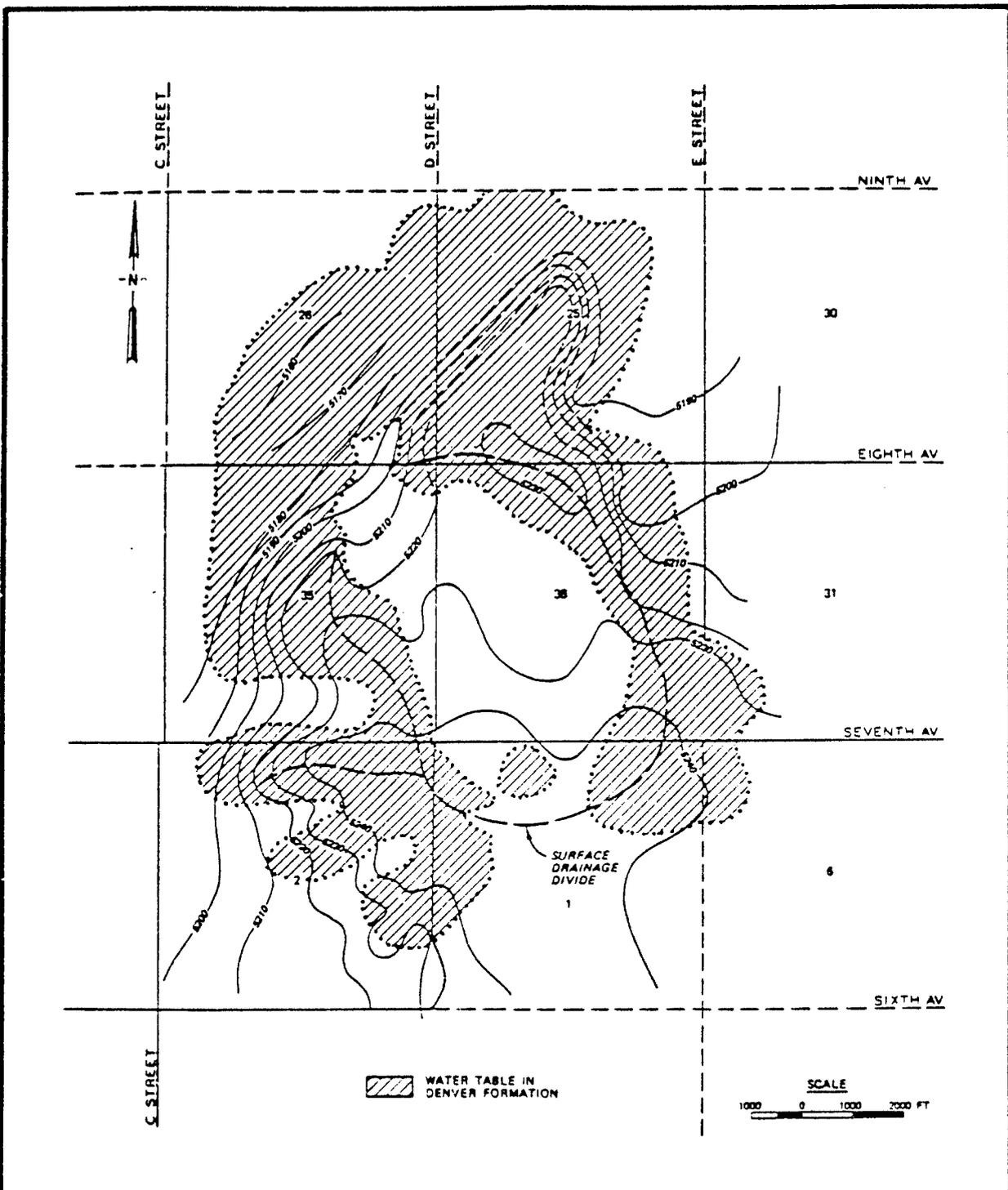
Prepared by: Ebasco Services Incorporated

direction in the upper aquifer units is generally to the northwest, but local variations are present. Groundwater flow in the Denver and alluvium flows southward in the area between the South Plants and the Lower Lakes. This reverse from the regional flow direction is the result of a groundwater mound underlying South Plants. Other local variations occur due to structural elements such as Basin A, bedrock highs, and man-made effects including leaking pipes and liquid waste disposal.

#### Denver Aquifers

The Denver Formation is a complex aquifer system. May (1982) divides the aquifer into a lower and upper zone, based on lithology. A coal seam in the formation is used as the demarcation between the zones. May's "upper aquifer" is the zone above the coal seam and the "lower aquifer" is the zone below the seam. More recently, as part of the ongoing water quality task (Task 4), Environmental Science and Engineering, Inc. (ESE) has divided the Denver Formation based on depth below the top of the bedrock surface. The upper 10 ft of the Denver is included in the alluvial aquifer. The "Upper Denver" is defined as the zone between 10 and 50 ft below the contact, and the "Lower Denver" is the zone greater than 50 ft below the contact. Hydrogeologic data suggest that these zones, although in long-term hydraulic equilibrium, are not in total hydraulic communication and may therefore be considered as discrete aquifer zones. A potentiometric surface map of the Upper Denver Aquifer generally corresponds with topography and with the groundwater level map of the alluvium (Figure 3.1-5). One of the goals of Task 26 will be to define, both geologically and hydrologically, the Denver Aquifer units within the Basin A/Basin A Neck/South Plants area and their interaction with the alluvial aquifer. These determinations are necessary for designing and locating groundwater control and collection systems for the response action.

The following descriptions of the Denver and alluvial hydrogeologic systems are based on interpretations made by May (1982). As in the alluvial groundwater table, an area of high water elevations is observed in the South Plants area with radial flow from that high. Northward into Basin A, however, the gradient in the Upper Denver Aquifer is markedly less than in the



Source: May et al., 1983.

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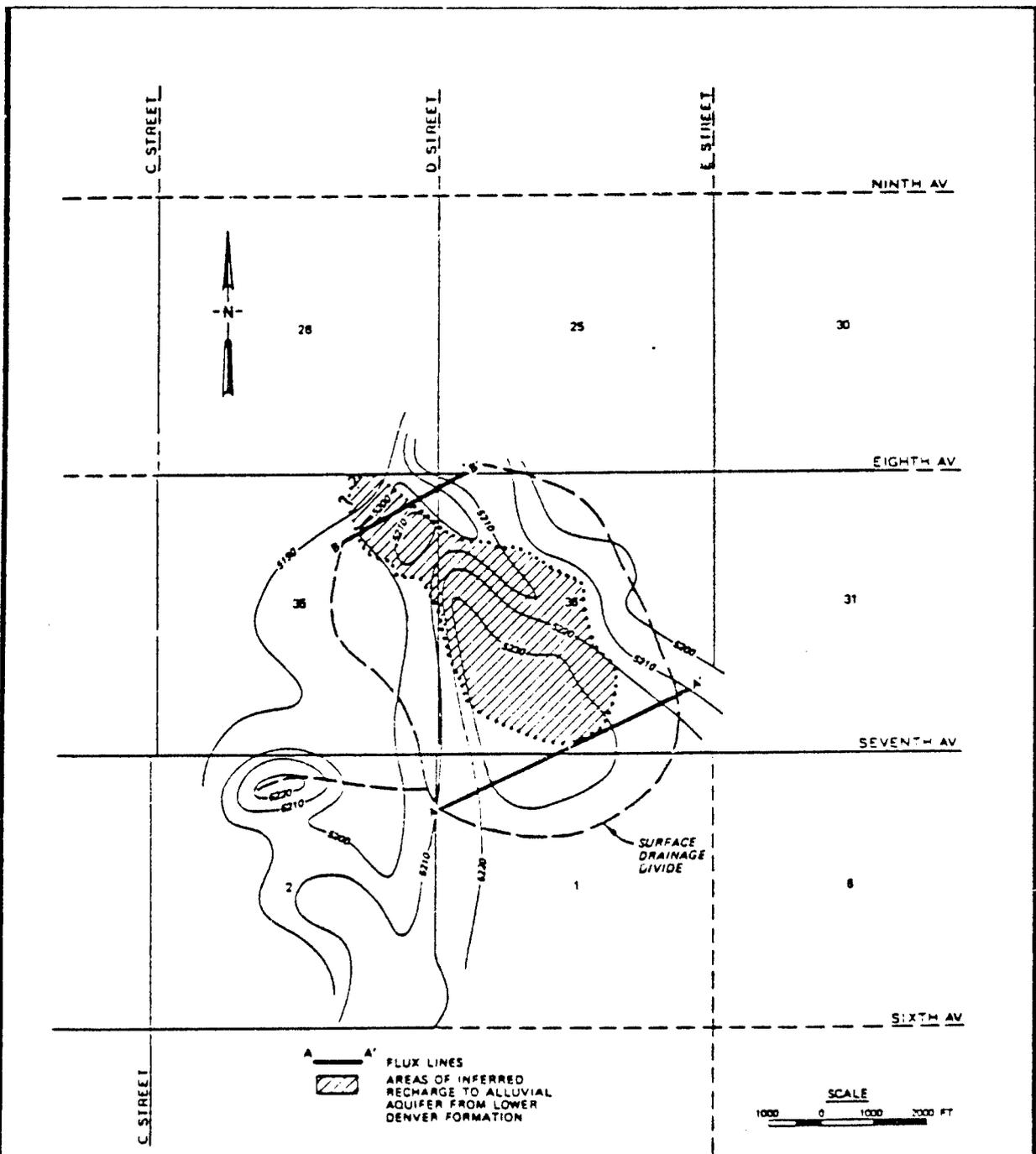
**FIGURE 3.1-5**  
**Potentiometric Map of Upper Denver**  
**Aquifer**  
 Rocky Mountain Arsenal, Task 26  
 Prepared by: Ebasco Services Incorporated

alluvium. This may be due to a lower initial head in the Upper Denver under the South Plants high. It could also result from completing the Upper Denver wells in sediments which are coarser than those of the alluvium. The hydraulic gradient is gentle in Basin A and steepens in the Basin A Neck before returning to a more gentle gradient further to the northwest.

The increase in gradient through Basin A neck is not as large as that in the alluvium, presumably because there is flow from the alluvium into the Upper Denver in this area. Groundwater flow to the Upper Denver aquifer is from the alluvium along the eastern boundary of Basin A, in the Basin A Neck area, and from the major buried valley and alluvium south of South Plants (Figure 3.1-6). Additional recharge comes from infiltration of surface water and precipitation in areas bordering Basin A and the northern half of Section 1, where the Denver is not fully saturated.

#### Lower Denver Aquifer

The measured water levels taken from within the Lower Denver (including the coal seam, the saturated sand unit directly beneath the coal, and the major paleochannel sand in the Lower Denver) are shown in Figure 3.1-6. The potentiometric surface of the Lower Denver is significantly different from the Upper Denver and alluvial aquifers, which reflect the surface topography. The Lower Denver potentiometric surface forms an extensive high that underlies the South Plants and Basin A, a second high west of South Plants in the north-central portion of Section 2, and a low in Basin A Neck. Flow is generally similar to that in the Upper Denver away from South Plants and Basin A, but at a lesser gradient. In the central portion of Basin A and Basin A Neck, the Lower Denver aquifer may be recharging overlying units. If so, contaminants will not migrate into the Lower Denver in these areas. Instead, relatively fresh water from the Lower Denver may be diluting the contamination concentration and also increasing the volume of overlying contaminated groundwater in the Upper Denver. Treatment facilities must therefore accommodate this greater volume of contaminated water. Any remedial action that requires dewatering of units in the Denver could substantially change the dynamics of this complex system and even initiate reversals in the flow of groundwater and contaminants.



Source: May et al., 1983.

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**FIGURE 3.1-6**  
**Piezometric Levels in Lower Denver**  
**Aquifer Zone**  
 Rocky Mountain Arsenal, Task 26  
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Aquifer test data are not available for the Lower Denver Aquifer zones, although the sand bodies may have properties approximately that of similar units in the Upper Denver. The hydraulic properties of the coal seam are difficult to assess because it is fractured. It is expected that the storativity is lower and the transmissivity higher than those of the sand units as a result of these fractures. Estimates of total flux through the primary units in the Lower Denver cannot be calculated because of insufficient data. There are, however, sufficient data to estimate flow through the semicontinuous sand unit (average 15-ft thickness) that underlies the coal seam. May (1983) estimates that the flux across Line A-A' of Figure 3.1-6, which is about 5,000 ft long is 8,500 gallons per day (gpd) and the flux across Line B-B' which is only 2,850 ft long is 9,700 gpd within this sand unit. The source of this increased flux across Line B-B' has not been determined.

#### Upper Denver Aquifer

The ability of the Upper Denver to store and transmit groundwater is highly variable depending upon the lithologic unit. Storativity values are estimated to be  $10^{-4}$  to  $10^{-8}$  (dimensionless) and measured hydraulic conductivity on the order of  $10^{-7}$  centimeters per second (cm/sec) for clayshale units. It is assumed that bentonite-rich volcanoclastic units have similar values. The shoestring paleochannels and interbedded sand lenses are believed to be important transmitters of groundwater in the Basin A and South Plants area. May (1982) reported storativities and hydraulic conductivities of  $10^{-1}$  to  $10^{-8}$  and  $10^{-3}$  cm/sec to  $10^{-4}$  cm/sec, respectively, for the Denver sands. An aquifer test conducted in Well APT-0 in the northwestern part of Basin A indicated a storativity of about  $6.5 \times 10^{-2}$  and a hydraulic conductivity of  $2.7 \times 10^{-3}$  cm/sec. This translates to transmissivities of 100 gallons per day per foot (gpd/ft) in the thin sand lenses and to about 300-2,300 gpd/ft in the paleochannels, depending upon their thicknesses.

Similarities between the Denver sands and the alluvium, and their proximity to each other suggest that the sands may be significant paths for contaminated

groundwater from the South Plants and Basin A areas. May (1983) calculated the groundwater flux through the Upper Denver under the study area. His estimates of the total flux through five cross-sections (Figure 3.1-7) of interest are:

	<u>Total Flux (gpd)</u>	<u>Cross-Sections</u>
Basin A Neck	69,000	A-A'
Eastern Boundary Basin A	17,000	B-B'
South of South Plants	15,000	C-C'
Discharge of Denver Paleochannel	14,000	D-D'
Discharge to Denver Paleochannel	20,000	E-E'

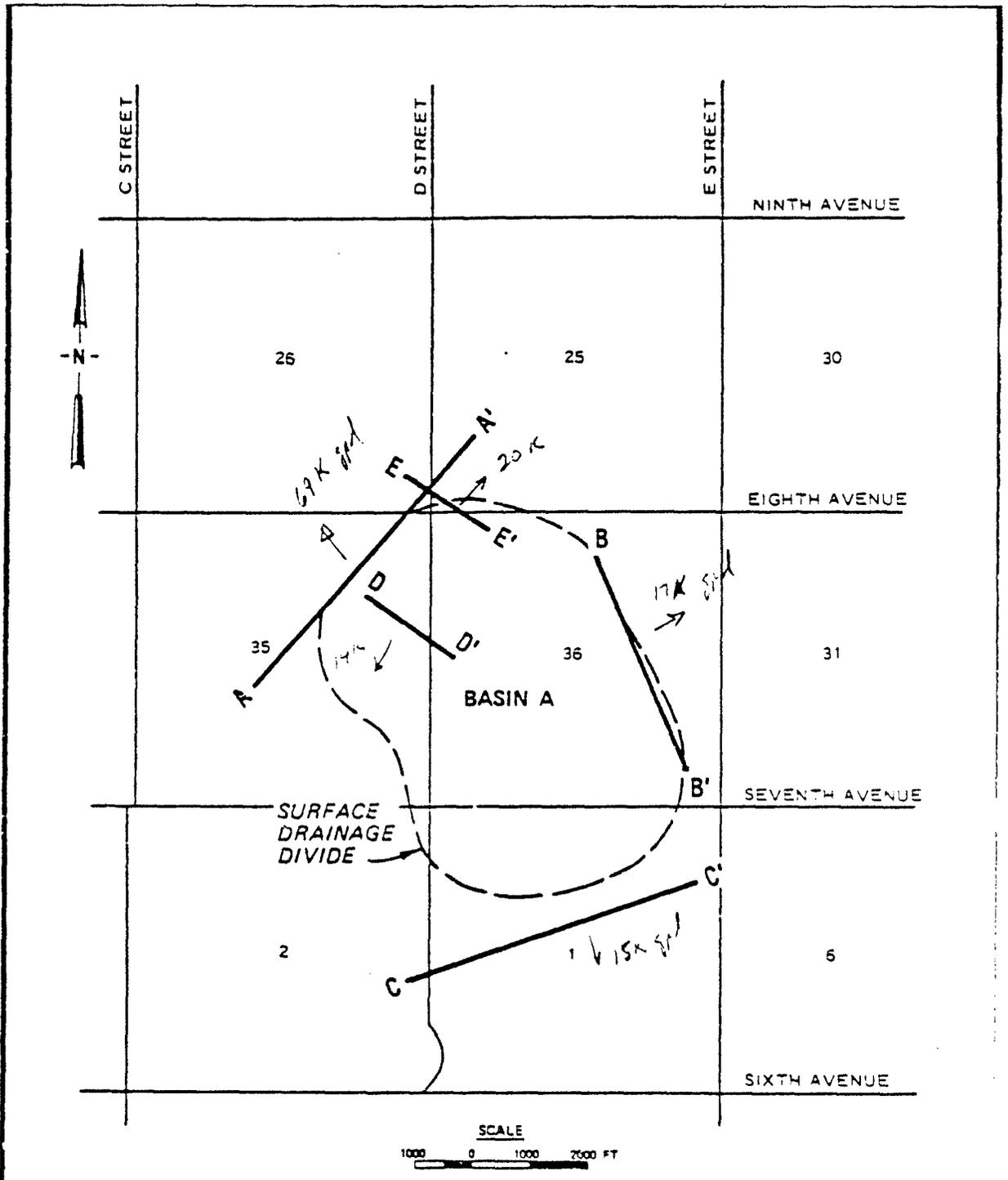
As part of Task 26, these estimates will be re-evaluated, particularly along the flow paths that are essential for the design of the treatment system.

May (1983) estimates that the flux through the Upper Denver major paleochannel is approximately one third to one half that of the alluvial flow. Thinner sand lenses and fractures within the less permeable clays and volcanoclastics complicate the system, but it is clear that any remedial containment and treatment system must address shoestring paleochannels.

#### Alluvial Aquifer

A thin and discontinuous layer of alluvium is the principal conduit for the discharge of groundwater out of Basin A and provides a hydraulic link between the Denver Formation and the lakes to the south of the South Plants area. Defining the direction, rate, and magnitude of contaminated groundwater flow in this unit is essential to designing and implementing control and treatment systems.

Figure 3.1-8 (in pocket) is a water table contour map of the alluvial aquifer. In areas where the alluvium is unsaturated, water-level measurements from the Upper Denver sands were plotted. In general, the water table surface



Source: May et al., 1983.

Prepared for:  
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 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland

**FIGURE 3.1-7**  
**Location of Upper Denver Aquifer**  
**Flux Estimates**  
 Rocky Mountain Arsenal, Task 26  
 Prepared by: Ebasco Services Incorporated

corresponds to surface topography and bedrock highs. Previous studies indicate that the groundwater high in the South Plants area has been accentuated by major water line leaks prior to 1980.

Generally, groundwater in the study area flows radially from the high in the South Plants area (Figure 3.1-8). ~~In the alluvium, groundwater flows north from the South Plants area through Basin A and Basin A Neck,~~ southeast toward Upper Derby Lake, and to the northwest through the Denver Formation and into a northwest-trending alluvial channel.

As groundwater flows northward into the southern portion of Basin A, it is reported to be recharged from the Upper Denver units via possible faults or saturated sand bodies in the Upper Denver (May, 1983). The slope of the water table within Basin A is relatively gentle compared to adjacent areas. Groundwater flowing from the alluvium to the Denver Formation probably occurs along the east-central and northern boundaries of Basin A. However, ~~most of the flow from the alluvium to the Denver probably occurs at the Basin A Neck~~ (May, 1983).

South of South Plants, the water table slopes gently towards the Lower Lakes. In this region, the groundwater flows from the Denver Formation to the alluvium and ultimately to Lower Derby and Ladora Lakes and to the Highline Lateral stream channel. To the west, the water table slopes steeply toward the Sand Creek Lateral and Lake Mary and, to the east, it slopes more gently towards First Creek.

It is anticipated that the storativity of the alluvial aquifer will range from about  $1.0 \times 10^{-3}$  for fine-grained materials up to about  $1.0 \times 10^{-1}$  for more coarse-grained deposits. May (1982) reports the hydraulic conductivity in the alluvium of Basin A Neck as ranging from  $2.4 \times 10^{-3}$  cm/sec to  $6.9 \times 10^{-3}$  cm/sec. Based on these values, the transmissivity for a saturated thickness of 1 to 40 ft, is estimated to range from 50 gpd/ft to about 5,900 gpd/ft. In other areas of the Arsenal where the alluvium is thicker and composed of coarser-grained materials, the transmissivity values range from

1,550 to 247,500 gpd/ft. The estimated discharge of groundwater through the alluvium at Basin A Neck is 6,600 cubic feet per day (ft<sup>3</sup>/day) or 49,000 gpd. The available data are insufficient to calculate discharge for other areas such as the South Plants and Basin A proper. Based on the objective of containing contamination, May (1982) recommended that a treatment system be designed for the Basin A area where transmissivities are relatively low.

### 3.1.3 Groundwater Chemistry

Recent groundwater chemistry results provided by the ESE Team verify that a complex plume of organic compounds, including organochlorine pesticides, dithiane/oxathiane, arsenic, and volatile organohalogens, underlies South Plants, Basin A, and Basin A Neck. The groundwater contaminants within the alluvium apparently originate in Basin A and South Plants and migrate through Basin A Neck to the northwest. Groundwater in the Denver Formation appears to be less contaminated. Contaminants in the Denver groundwater occur primarily northwest of Basin A Neck and in isolated centers within Basin A, South Plants, and the Lower Lakes. ~~Task 26 will investigate the~~

~~relationship between the groundwater flow and groundwater chemistry between the South Plants, Basin A, and Basin A Neck areas.~~

### 3.1.4 Hydrogeologic System Description

A conceptual description of the hydrogeological system comprising the South Plants area and Basin A must be constructed to test hypotheses regarding the movement of groundwater in that region. Construction of this system will also allow data gaps to be identified and thereby give direction to the field investigation. Finally, the hydrogeologic system description may be used to formulate a mathematical simulation which can be calibrated and then utilized to assess the impacts of changes in the flow regime caused by contaminant control schemes imposed on the system. This simulation will allow various schemes to be comparatively evaluated.

The simplest hypothesis of the flow system is based on interpretation of existing data. Task 26 will rely heavily upon the work of Jim May and ongoing tasks conducted by ESE. The system description may be more complexly

formulated by generating displays of parameters needed to describe the system. These displays may include data tabulations, maps, cross-sections, and sets of parameters derived from existing data. These will be included in the Task 26 Final Report. Such items may include, but are not limited to:

- o Water level maps for each aquifer unit
  - needed to determine gradients
  - used to determine directions of flow within each aquifer
  
- o Structural contour map for each aquifer and aquiclude
  - needed to describe the geometry of each hydrogeologic unit
  - used to construct isopach maps of each unit
  
- o Hydraulic conductivity map for each aquifer
  - needed to describe the spatial variation of the aquifers' ability to move water
  - used in conjunction with the isopach maps of aquifers to generate transmissivity maps
  
- o Hydraulic conductivity map for each aquitard
  - needed to describe the capacity for water to move through the confining units
  - used to determine the leakage between aquifers separated by the aquiclude
  
- o Storage coefficient map for each aquifer and aquitard
  - needed to predict the size of a cone of depression generated by a pumping well or the change in water level caused by a change in storage
  
- o Leakage between surface and groundwater bodies
  - needed to accurately describe potential loss and recharge through the exchange of water

- o Evapotranspiration/precipitation water balance
  - needed to describe gain and loss of water via exchange with the atmosphere
  
- o Boundary conditions including flow and no-flow conditions at appropriate hydrogeological features
  - needed because the scale of real flow systems are typically much larger than those that can be conveniently dealt with in conceptual and numerical modeling
  - used to define limits of the hydrogeologic system and to allow continuity to be applied to the numerical simulation
  
- o Maps of retardation coefficients for contaminants
  - needed to define ability of aquifers and aquitards to retard contaminant movement
  - used to calculate the velocity of a contaminant relative to the groundwater velocity
  
- o Maps of contaminant concentration distribution
  - needed to define the distribution of various contaminants at a moment in time
  - used as a starting distribution for evaluating the influence of imposed stresses on contaminant movement

Because the scope of the program is restricted to the movement of groundwater in the alluvium and the Denver Formation, the concept of the lower boundary condition of the flow system deserves special mention. The Denver Formation and the underlying Arapahoe Formation are both aquifers that contain usable groundwater. The exchange of groundwater between the two aquifers is an important consideration, both in the hydrogeologic system description and the mathematical simulation. The correctness of the hydrogeologic system description and the accuracy of the numerical simulation both depend upon a correct evaluation of the rate and distribution of flow between these units. Sufficient data needs to be accumulated and reviewed to allow a reasonable evaluation of the basal boundary condition.

The mathematical simulation of the groundwater system below the Basin A/South Plants complex will be an important tool in refining the system description and evaluating the various contamination capture and control scenarios. Numerous mathematical models are available for simulation purposes. However, relatively few have been sufficiently tested and documented to be used in situations where the formulation of the mathematical model itself should not be subject to question. While the specific numerical algorithm has not yet been selected, pertinent features will include, at minimum:

- o Good documentation and wide use by others,
- o Ability to be run on a high speed mainframe computer,
- o Flexibility in input/output options,
- o Use of a standard user language to minimize problems in mainframe support and compiling activities, and
- o Ease in transferring data from a flow model to a mass transport model.

The decision to utilize a high speed mainframe computer is predicated on the need to reduce the turn-around time of the computational simulation providing more time for evaluating output and analyzing problems that may occur during computational runs. Additionally, the use of mainframe computers will allow access to high-speed line printers needed for fast data dumps.

Plotters and graphics packages will be available in the office to display and evaluate data files generated as output by the computers. If more complex graphics are required, output can be collected on disk or tape and transported to the appropriate facility. It must be re-emphasized that the numerical simulation is not a final answer in itself, but rather a sophisticated way to test a conceptual model and to apply dynamic changes to a conceptual model which has been reasonably verified.

### 3.2 FIELD INVESTIGATION PROGRAM

#### 3.2.1 Purpose

One phase of the Task 26 study is to assess where available data on the

groundwater flow systems are sufficient, and to identify data gaps where additional information is necessary to determine the type, location, and size of groundwater collection, control, and treatment facilities. A field investigation program will collect information to fill these critical data gaps. The field program, as outlined below, will consist of aquifer testing, chemical analysis of groundwater samples, water level measurements, and the installation of monitoring wells (see Appendix B for installation procedures).

### 3.2.2 Identified Data Gaps

The following is a summary of data gaps that have been identified from the literature review. The portion of the field program designed to address each of these data gaps is also summarized. Figure 3.2-1 (in pocket) identifies the locations of the wells to be installed as part of the field program.

Following completion of these wells, the wells will be surveyed to establish their elevations and map coordinates consistent with the Colorado State Planar Coordinate System. All elevations will be surveyed to the nearest 0.1 foot vertically and 3 feet horizontally, consistent with U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) and PMO requirements.

#### 3.2.2.1 Basin A Neck

In general, the groundwater flow patterns in the alluvium are fairly well-defined; however, ~~the exchange between the Denver Formation and the~~  
~~alluvium is low.~~ In the Basin A Neck area, the Denver sands have been eroded away and the resultant erosional depression has been filled by alluvium. On the flanks of Basin A Neck, the Upper Denver aquifer is in direct contact with the alluvium. ~~Therefore, the contaminant migration patterns in this~~  
~~area are complex.~~



major sand channel located west of Basin A needs to be further defined. This channel may provide a path for movement of contaminants toward the Basin A Neck area that does not pass through the Basin A alluvium.

Well S-1 will be installed in the Intermediate Denver Aquifer as an addition to an existing well cluster consisting of Wells 52, 53, and 54 in Section 35. This well will aid in defining the sand channel located west of Basin A. The pilot core hole (see Appendix B) for this well will be drilled to the bottom of the Lower Denver sand unit to provide a continuous well log of the three Denver units. Well S-12 will be installed in the alluvium between South Plants and Basin A to monitor the movement of groundwater and contaminants towards Basin A.

Wells S-13 and S-14 will be installed next to Wells 71 and 72 immediately northwest of South Plants in Section 35. Well 71 is installed in the Upper Denver sand unit and will be used to monitor a pumping test that will be conducted using Well S-13, which will also penetrate this unit. A single pair of piezometers will be installed near Well S-13. These will be installed in the Denver shale, below the water table but above the Upper Denver sand. The piezometers will be used to monitor the response, if any, of the shale unit to the pump test. Well 72 is installed in the Lower Denver sand unit and Well S-14 will be installed in the Intermediate Denver sand unit associated with the coal seam. Environmental Science and Engineering, Inc. (ESE) has reported problems sampling this well. If these problems cannot be corrected, another well may be installed to provide chemical data and flow characteristics of the Lower Denver sand unit.

#### 3.2.2.3 Lakes Area

Very little interpretation has been previously completed on the interaction of surface water and groundwater in the region south of South Plants. Although the water levels in the lakes have been recorded during past years, the measuring points have only recently been surveyed and tied into the Arsenal-wide coordinate system. This data will be used with groundwater data to analyze the interactions.

Wells S-15, S-16, S-17, and S-18 will be installed in the alluvium next to the lakes to provide information which will assist in this analysis.

### 3.2.3 Aquifer Testing

In addition to the pump test described in the previous section, all new wells will be slug tested to provide estimates of aquifer characteristics. Some existing wells may also need to be tested. The procedures to be followed for aquifer testing are described in the Rocky Mountain Arsenal Procedures Manual (Ebasco, 1985).

### 3.2.4 Chemical Analyses

Most of the new wells will be sampled and analyzed for contaminants as described in the Procedure Manual (Ebasco, 1985) and Section 4.0 of this Technical Plan, respectively. Existing wells installed in the Lower Denver sands may also be sampled. These analyses will be used to determine the presence of contaminants in the Denver sands and also to determine the masses of chemical species from which treatment designs can be calculated.

## 3.3 GROUNDWATER TREATMENT SYSTEM

A complete groundwater treatment system contains three major facilities: collection and control facilities, treatment facilities, and disposal facilities. Each of these can be broken down into alternative systems or processes. A summary of the processes and systems described in this Technical Plan follows.

### Collection/Control Facilities

Containment barriers

    Sheet pilings

    Grout curtains

    Slurry walls

    In-situ vitrification

**Gradient barriers**

**Wells**

**French/tile drains**

**Interception trenches**

**Wells**

**Production wells**

**Well points**

**Treatment Facilities**

**Ion exchange**

**Activated alumina**

**Activated carbon**

**Chemical oxidation**

**Air stripping**

**Reverse osmosis**

**Biological treatment**

**Chemical precipitation**

**Flocculation and Filtration**

**Incineration**

**Disposal Facilities**

**Subsurface discharge**

**Surface discharge**

**Water Reuse**

**3.3.1 Potentially Applicable State and Federal Requirements**

On October 17, 1986 the President signed into law the Superfund Amendments and Reauthorization Act of 1986. These amendments to the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) include a new Section 121, which sets out a number of criteria to be considered in determining the appropriate cleanup standards to be applied to remedial actions taken pursuant to the Act. Subsection 121(b) makes clear that Section 121 applies to RMA cleanup.

New Section 121(e) provides that "no Federal, State, or local permit shall be required for the portion of the removal or remedial action conducted entirely

on-site, when such remedial action is selected and carried out in compliance with this section." Accordingly, no federal or state permit will be needed for any of the groundwater control, treatment and disposal alternatives discussed in this technical plan, since all these alternatives involve on-site remedial activities.

Section 121 also provides that where a response action will result in a hazardous substance, pollutant, or contaminant remaining on-site, the level of control of such contaminant must at least attain the level of control that would be provided by an "applicable or relevant and appropriate standard, requirement, criteria or limitation" ("ARAR"). ARARs may include both state and federal requirements. To assure compliance with this CERCLA requirement, the Army is in the process of determining which state or federal ARARs are applicable to each of the groundwater treatment and control alternatives to be considered as part of the Task 26 evaluation.

Section 121 also sets out certain exceptions to the general rule that remedial actions must attain state and federal ARARs. For example, an otherwise applicable ARAR need not be attained where compliance "is technically impracticable from an engineering perspective" [Section 121 (d)(4)(c)]. Therefore, Section 121 requires a determination of which of the Section 121 exceptions, if any, apply to each of the control, treatment and disposal alternatives addressed in this technical plan.

In summary, a determination of which state and federal ARARs apply to the various groundwater treatment, control, and disposal alternatives addressed in this technical plan, as well as a determination of which ARARs fall within the Section 121 exemptions, must be an integral part of the process of evaluating and comparing those alternatives. Where it is clear that a particular ARAR is applicable, such a requirement may pose specific design constraints and may affect the relative feasibility of the alternative under consideration. The

Army intends to solicit the opinion of Shell, the U.S. Environmental Protection Agency (EPA), and the State of Colorado as to which state and federal ARARs are applicable to the alternatives to be considered in this technical plan.

### 3.3.2 Existing Groundwater Treatment Facilities

Three groundwater containment and treatment systems are in operation at RMA. Groundwater was found to be contaminated in the 1970s when contaminants were found to be migrating in the shallow aquifer across the Arsenal's north boundary. In 1975, several monitoring wells were installed and a sampling and analysis program was initiated. Based on the data collected, a North Boundary Pilot Groundwater Contamination Control System started operation in 1982. This system has a bentonite barrier, 6,740 ft in length, 3 ft wide, and 20 to 40 ft deep, and utilizes 54 dewatering wells (35 in the alluvium and 19 in the Denver Formation) and 38 recharge wells. The treatment system consists of three carbon vessels with a capacity to treat 300 gpm.

A second control system was constructed on RMA by Shell in 1981 in the Irondale area. The system was designed to remove dibromochloropropane (DBCP) from the alluvial aquifer. This system is 2,100 ft in length, has a total of 38 extraction wells in two rows and a single row of 20 recharge wells to create a hydraulic barrier. The Irondale treatment system consists of two carbon vessels with a capacity of treating 1,100 gpm.

In 1984, the third containment system was constructed along the Northwest Boundary. This system is 2,400 ft in length and utilizes a design concept of a partial bentonite barrier 1,425 ft long, 3 ft wide, and 55 ft deep. There are 15 dewatering wells and 21 recharge wells. The treatment system consists of three carbon vessels and is capable of treating 1,000 gpm.

### 3.3.3 Collection and Control Facilities

The South Plants/Basin A area is believed to be the site of significant levels of contamination in both soils and groundwater. One goal of the current

program underway at the Arsenal is to collect and treat the contaminated groundwater in the subject area.

### 3.3.3.1 System Placement

Placement of a collection/control facility is primarily dependent upon the presence of contamination in an area and the direction of groundwater movement through the area. Secondary considerations concerning the placement of a system include the availability of a disposal site for treated water, the layout of the area, soil conditions, and possible hydrogeologic boundary conditions.

Water level contour maps of both the alluvium and the upper Denver Formation aquifer show a mound of water beneath the South Plants area. Additionally, ~~there is a major flow of water through the alluvium in the Basin A area.~~ May (1983) indicates also that some water may move out toward the northeast from Basin A through the Upper Denver Formation. A portion of the Task 26 work effort will involve re-evaluating these studies.

May (1983) indicates that ~~several buried channels in the Denver Formation may connect the Basin A area with the alluvium and may extend southward to the South Plants area. These channels offer a potential pathway for contaminated water to move from the subject area.~~

The lakes, which lie to the south of the South Plants area, may recharge the alluvial aquifer and may influence the movement of contaminated water from the South Plants mound. South of the lakes, the regional groundwater flow is generally from southeast to northwest. This movement will serve to prevent contaminated groundwater from the South Plants/Basin A area from moving southward.

~~Based on these studies, several locations for the placement of collection facilities have been identified. Further study is required to determine the most appropriate location. However, a~~

[REDACTED]  
[REDACTED]  
[REDACTED]

The potential movement of groundwater to the northeast suggests [REDACTED] for a [REDACTED] along the northern side of Basin A. This control feature should penetrate both the alluvium and Denver Formation, as appropriate, and aid in redirecting the flow to a collection system in the Basin A Neck.

A groundwater mound beneath South Plants has developed within the Denver Formation which is overlain by a thin veneer of alluvium. The mound has apparently developed due to structural influences, natural recharge, leakage from process water pipes and sewers and low permeability soils. The flow pattern from this area is essentially radial. This shape of flow suggests that control systems may need to be constructed in curvilinear shapes, or influence the flow system in a radial pattern. These control structures would be constructed mainly in the Denver. An obvious location for placement of a collection system for the groundwater mound, besides a complete encirclement, is to the west and northwest, where the regional gradient will eventually direct all contaminant movement. Additionally, a control feature along the eastern side of Basin A could be extended farther south to insure capture of any contaminated groundwater moving eastward. The study of the interaction of the lakes with groundwater will assist in defining what impact, if any, control systems will have on the lakes.

All collection and control systems constructed in the Basin A/South Plants region will initially be considered to be part of a single system. They will be evaluated as entirely separate systems only if analysis indicates their interactions will be minimal.

#### 3.3.3.2 Control Techniques

There are numerous techniques available for controlling the flow of groundwater and collecting groundwater for treatment. In a broad sense, the

techniques may be divided into two major classes: containment barriers and gradient barriers.

Containment barriers generally involve reducing the hydraulic conductivity of a formation along a vertical plane perpendicular to the lines of flow. If practical, the plane should extend from an elevation above the existing water table to a depth equivalent to the base of the aquifer. ~~Generally, if the barrier is not taken to the base of the aquifer, the chance of successful containment is greatly reduced.~~

The desired reductions in permeability can be achieved in several ways. ~~Barriers~~ are commonly constructed with sheet pilings. These structures are most successful in uniform fine-grained materials. Cobbles and boulders will generally preclude successful installation.

~~Grout curtains~~ are typically installed in competent or moderately weathered bedrock, where flow is typically confined to fractures. This method involves drilling lines of boreholes (sometimes multiple overlapping rows) to a desired depth, and then pressure grouting with either a cement or chemical grout. The success of this method in interrupting flow through fractures is highly dependent upon the skill of the filling party. Grout curtains can also be installed with the vibrating beam method. In this method, an I-beam is vibrated into the soil to the desired depth. As the beam is raised, grout is forced under pressure into the remaining cavity. A grout wall is formed with the filling of adjoining cavities.

~~Slurry walls~~ utilizing soil-bentonite mixtures or cement-bentonite mixtures to replace excavated native soil are typically used in alluvium and heavily weathered bedrock as the method of choice for barrier construction. These walls can be constructed continuously using available equipment. Examples of slurry walls currently in existence at RMA are the North Boundary System and the Northwest Boundary System.

in subheadings  
still costly!

A containment barrier can also be created with [REDACTED] This process consists of using extremely high voltage electrical currents to transform the soils into an impervious glass-like matrix. Recent developments with this system have reduced its costs, making it a viable alternative.

[REDACTED] may include the [REDACTED] to remove or inject water to create barriers to groundwater movement without changing the physical characteristics of the aquifer. The Shell Irondale system is an example of this type of control feature currently in use at RMA. Well points, drilled wells, or even dug wells can be used for this type of control feature. In special circumstances, French and tile drains may also be used.

[REDACTED] are a hybrid technique in which a trench is cut to intercept a flow system and is filled with a material coarser than the aquifer material. Drain pipes or collection sumps with pumps are installed to maintain a constant drawdown in the trench. Eventually, the trench induces an extensive trough of depression along its length.

[REDACTED] systems of slurry walls and extraction/injection systems to [REDACTED] flow systems. The choice of such combinations is influenced by depth of the flow system, the relative permeabilities of the aquifer materials, and the radius of influence and yields of pumping wells. Two systems of this type are currently operating at RMA. [REDACTED] hydrogeologic and engineering analysis, it is not possible [REDACTED] collection systems [REDACTED] would [REDACTED] flow barrier and [REDACTED] permeabilities [REDACTED] flow barrier, [REDACTED] to keep the [REDACTED] from becoming [REDACTED].

The major problem in determining an appropriate containment barrier system in the subject area is [REDACTED] depth of the flow system. Additionally, if sand paleochannels in the Denver are significant conduits for



screening of new technologies to identify all promising alternatives. The list of applicable processes will be reduced based on the evaluation, and the final process candidates will then be incorporated into the final concept design. The groundwater treatment system will probably consist of several treatment processes with each process designed to remove, concentrate, or degrade a different type of contaminant. The treatment system will be detailed with respect to performance, reliability, and cost.

#### 3.3.4.1 Processes Previously Evaluated at RMA

Ion exchange is a physical-chemical process by which ions in solution are exchanged with ions attached to a solid surface. Ion exchange is used to remove a broad range of undesirable ions, such as calcium, magnesium, iron, ammonium, and heavy metals from waters and wastewaters. Two of the most widely used applications for ion exchange are for water softening (removal of calcium and magnesium) and for the production of demineralized water at industrial facilities. The exchange medium consists of a solid phase of either natural minerals or a synthetic resin having a mobile ion attached to an immobile functional acid or base group. The naturally occurring minerals are known as zeolites, and the synthetic ion exchange materials are resins or phenolic polymers. The synthetic resins are structurally stable, exhibit a high exchange capacity, and can show selectivity toward specific ions. All ion exchangers, whether natural or synthetic, have fixed ionic groups that are balanced by counterions of opposite charge to maintain electroneutrality. The counterions are the ions, either cations or anions, that exchange with ions in solution. Reliability of an ion exchange is adversely affected by the presence of suspended solids and organic matter, particularly organic matter that could support biological growth within the resin beds.

The ion exchange process has been used at RMA for water softening and pretreatment purposes in the South Plants Laboratory Treatment Facility; however, little documentation on its performance has been found.

### Activated Alumina Adsorption

Activated alumina adsorption is an ion exchange process utilizing a contact bed of activated alumina to remove certain chemical species, especially fluorides. Activated alumina is an insoluble, granular media with an isoelectric point at a pH of approximately 9.5. This isoelectric point enables the process to remove anions at a pH below and cations at a pH above this level. The affinity of alumina for an anion is inversely related to the solubility of its aluminum salt. Additional design factors include influent concentration of the chemical to be removed, pH of the solution, and grain size of the activated alumina media.

For removal of fluorides, the alumina media is initially treated with an acid solution. The optimum pH for the solution to be treated is between 5 and 8, with the most rapid uptake of fluoride occurring at a pH of 5.5. Regeneration of activated alumina contact beds used for fluoride removal is normally conducted with a sodium hydroxide solution.

An activated alumina pilot scale study has been conducted at the North Boundary treatment system for removal of fluorides (Rubel & Hager, 1978). The study demonstrated that fluorides can be effectively removed from the activated carbon column effluent. Both fresh and regenerated activated alumina columns were tested. The fresh activated alumina columns removed 85 percent of the total fluoride and produced an average effluent concentration of 1.04 parts per million (ppm). The regenerated columns removed 79 percent of the total fluoride and produced an average effluent concentration of 1.00 ppm.

### Activated Carbon Adsorption

Adsorption is the accumulation of material at the interface between two phases. In other words, it is a sorption process resulting in the accumulation of a dissolved chemical (solute) in solution at the surface of a solid. Removal of the solute to the solid phase and its concentration at the surface of the solid phase continues until the concentration of solute remaining in solution is in equilibrium with that on the surface

(Stearns-Roger, 1981). Factors influencing adsorption include solution pH, molecular attraction, solute molecular weight, type of adsorbent, and adsorbent surface area. Most organic contaminants in water will collect at interfaces; thus, adsorption processes are very effective in removing many chemical species from the liquid phase. Activated carbon is a widely used and developed technology. It is especially well-suited for the removal of mixed organics from aqueous waste streams.

Once the carbon surfaces are saturated with contaminants, the carbon should be regenerated or replaced with clean carbon. Otherwise, saturation of a packed bed reactor will occur, in which the contaminants flow through the column without being absorbed and are detected in the column effluent. This phenomenon is called "breakthrough".

Carbon longevity (or contaminant capacity) and influent concentration govern the operating costs of this process. The relationship between the amount of solute absorbed per unit weight of adsorbent and the concentration of solute remaining in solution is referred to as the adsorption isotherm. This relationship is very useful in designing the adsorption process and in predicting treatment system effluent concentrations.

Previously, activated carbon processes have been used in the South Plants groundwater treatment pilot plant study in an upflow mode (Stearns-Roger, 1981) and evaluated using "bog water" and "well water" (Galgon, 1977). During the pilot plant study, two tests were planned for carbon adsorption: 1) without pretreatment, and 2) with air stripping for pretreatment. This study indicated that the water from the South Plants/Basin A Neck area contained high concentrations of volatile contaminants and that activated carbon treatment without pretreatment probably would not be an appropriate treatment process for a full-scale plant (Stearns-Roger, 1981). The Galgon study indicated that activated carbon was capable of reducing various organic concentrations in the "bog water" from approximately 400 parts per billion (ppb) to less than 10 ppb. Another report (Anzolin, 1977) stated that

powdered activated carbon was more effective in reducing organic contaminants below detection limits in the "bog water" from Section 24 than reverse osmosis treatment. Activated carbon adsorption processes are incorporated into the three groundwater treatment systems currently in operation at the Arsenal.

#### Chemical Oxidation

Chemical oxidizing agents, such as oxygen, chlorine, ozone, hydrogen peroxide, etc., are used in water and wastewater treatment. Chemical oxidation is frequently used for treatment of cyanides and oxidizable organics in solution. Chemical oxidation is a process in which the oxidation state of a chemical compound is increased (through loss of electrons) resulting in the breakdown of the molecular structure of organic compounds and the formation of relatively simple and nontoxic compounds. One of the most common oxidants, ozone, has been used frequently in studies at RMA.

Ozone oxidation is an important process and is used in waste treatment to oxidize nitrogen compounds, chlorinated hydrocarbons, phenols, polychlorinated biphenols (PCBs), iron, and manganese. The application of ultraviolet light (UV) or hydrogen peroxide to enhance ozone oxidation has broadened the capabilities of the process. The presence of ozone during the UV irradiation process causes chemical bonds to break and reform as the ozone and molecules, excited by the UV, combine to form ozonide, which for organic compounds yields simpler compounds. The process repeats itself until compounds are incapable of further breakdown or oxidation. The degree of oxidation achieved depends upon variables encountered during the reaction, such as the concentrations of the reactants, the reaction time, the temperature, etc.

At RMA, the ozone/UV process has been successfully demonstrated as a viable treatment alternative for organic compounds (including pesticides, organic sulfur and organophosphorus compounds, diisopropyl methylphosphonate, and dicyclopentadiene), metals (iron, lead, mercury, arsenic, manganese, and sodium), and general minerals (RMA, 1978; Wynne, 1977; Khan & Thompson 1978).

### Air Stripping

Air stripping is used to remove volatile organic contaminants from water and wastewater. Volatile components in a liquid phase have a strong affinity for the gas phase and will leave the aqueous phase for the gas phase, if proper conditions are provided. The purpose of an air stripper is to maximize these environmental conditions. The volatility of compounds are compared using Henry's Law constants for the compounds. Generally, compounds with Henry's Law constants greater than 0.003 can be effectively and efficiently removed through air stripping (Conway & Ross, 1980).

Air stripping frequently is accomplished using packed towers filled with an inert media which provides a large surface area and a thin liquid film. The primary process variable driving the phase conversion is the air-water ratio. The packed tower design is generally operated in the countercurrent flow mode where the aqueous stream flows down through the packed media while air flows upward and is exhausted through the top. For proper operation, the liquid feed stream must be low in suspended solids and may need pH adjustment to improve the gas phase transfer process.

Air stripping may be only partially effective depending on the specific organic compounds in solution and is frequently followed by biological treatment or activated carbon adsorption. It is used most effectively for treatment of highly volatile organic contaminants. Air pollution is an important factor in the consideration of whether to utilize air stripping for removal of organic contaminants. The gas stream generated during treatment may require collection and subsequent treatment, and processes to accomplish this off-gas treatment are readily available, but generally expensive (USEPA, 1985).

At RMA, a packed column air stripper was utilized for the pilot plant study for the South Plants/Basin A Neck area (Stearns-Roger, 1982). A matrix of tests was performed in which air-water ratios were varied as well as pretreatment equipment, flow rates, and test duration. As expected, the

results showed that removal efficiencies increased with increased air-water ratios. Also, the results indicated the stripping efficiency was not a function of pH or water flow rate when the air-water ratio was held constant. Overall, there was 90 percent or greater removal efficiency for volatile organics.

#### Reverse Osmosis

Reverse osmosis is a membrane separation process used to reduce concentrations of dissolved organic and inorganic compounds and ions. Osmosis is the flow of solvent from a dilute solution through a semipermeable membrane to a more concentrated solution. In reverse osmosis, water containing dissolved solids (concentrated solution) is forced through the membrane under high pressure to overcome the osmotic pressure. The products are a dilute stream containing little dissolved solids and a concentrated waste stream containing the removed chemicals. Pretreatment of the feed water before reverse osmosis treatment may be required with such processes as softening, filtration, organics removal, and acid stabilization. Reverse osmosis units can be operated either in series or in parallel, providing flexibility in dealing with increased flow rates or concentrations of dissolved contaminants.

Normally, only high molecular weight organics and charged cations and anions are removed from water by this process; however, recent advances in membrane technology have made it possible to remove low molecular weight organics such as alcohols, ketones, amines, and aldehydes.

At RMA, reverse osmosis units were tested with pretreatment in the pilot plant study for South Plants/Basin A Neck area. The pilot plant tests indicated that, with proper pretreatment such as ion exchange softening, membranes can provide a 50 percent recovery of the feedwater at a feed pressure of 400 pounds per square inch gauge (psig) and a 97.5 percent reduction in total dissolved solids.

### Chemical Precipitation

Precipitation is a physicochemical process whereby materials in solution are transferred into a solid particulate phase. Alteration of chemical equilibrium relationships affects the solubility of the chemical species and results in precipitation. Chemicals are added to the wastewater to change the equilibrium relationships and form precipitates. Flocculating agents are frequently added to provide agglomeration of the precipitate particles. The particles are then separated from the liquid by sedimentation or filtration.

At RMA, chemical precipitation was used for softening (hardness removal) in the pilot plant study for the South Plants/Basin A Neck area. The pilot plant test indicated that softening by chemical precipitation was an effective pretreatment process for the reverse osmosis process.

### Flocculation

Flocculation is a process by which small particles suspended in a liquid medium are agglomerated into large particles. This process is commonly used following precipitation. Flocculation involves three steps: 1) addition of flocculating agent to the liquid stream, 2) agitation of waste stream to disperse the flocculating agent, and 3) slow mixing to provide contact and agglomeration between small particles. Typical flocculating agents are lime, aluminum and iron salts, and polyelectrolyte organic polymers. The polymers are generally used in conjunction with one of the other flocculating agents.

At RMA, flocculation was used with precipitation and filtration as a pretreatment process in the pilot plant study for South Plants/Basin A Neck area. The pilot plant study indicated that this process was effective in removing a high percentage of suspended solids.

### Filtration

Filtration is a physical process whereby suspended solids are removed from solution by forcing the waste stream through a porous medium. Filtration is a reliable means of removing low levels of solids from wastes.

At RMA, the South Plants/Basin A Neck pilot plant study tested, using filtration, the removal of suspended solids for the pretreatment of the groundwater. The entire series of processes included precipitation, flocculation, and filtration. The pilot plant test indicated that the series of processes removed a high percentage of the suspended solids.

#### 3.3.4.2 Alternate Processes

Many treatment processes, other than the above-described processes, have been used for treatment of contaminated water. Two of these will be discussed below, as they appear to have significant potential for this study. Following a thorough review of the literature, additional processes may be included in the evaluation.

#### Biological Treatment

The function of biological treatment is to remove organic contaminants from wastewater through microbial assimilation and degradation. The most widely-used forms of biological treatment are aerobic systems, although anaerobic systems are also very effective. Biological treatment systems may also be classified as either fixed film systems or suspended growth systems, depending on whether the microorganisms are grown on a surface or not. Combining the two major types of system classifications results in four distinct system classifications. All biological treatment systems can be classified as falling into one of these four classifications, with some systems containing characteristics of at least two of the classes. The four classes are listed in Table 3.3-1, with representative treatment systems for each class also shown. This list is not exhaustive and includes only the typical systems in use today.

There is considerable flexibility in the biological treatment process due to the variety of treatment systems and the adaptability of the microorganisms themselves (USEPA, 1985). Each of the four major classes of systems has characteristics which make it advantageous for a specific site, a specific waste, or a specific operating condition. In biological treatment, several generalizations can be made with regard to treatability of organics:

Table 3.3-1. Summary of Biological Treatment Systems.

<u>Aerobic Suspended Growth Systems</u>	<u>Anaerobic Suspended Growth Systems</u>
Air Activated Sludge (many variations)	Anaerobic Lagoons Anaerobic Reactors
Oxygen Activated Sludge	
Aeration Lagoons/Pond	
Sequencing Batch Reactors	
<u>Aerobic Fixed Film Systems</u>	<u>Anaerobic Fixed Film Systems</u>
Trickling Filters	Anaerobic Fluidized Bed Reactors
Rotating Biological Contractors	Anaerobic Packed Media Reactors
Aerobic Fluidized Bed Reactors	
Land Treatment	
In-situ Treatment	
	<u>Combined Systems</u>
	Facultative Lagoons
	Biological Activated Filters

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Source: USEPA, 1985a

- o Unsubstituted nonaromatics or cyclic hydrocarbons are preferred to unsubstituted aromatics;
- o Materials with unsaturated bonds, like alkenes, are preferred to saturated bonds;
- o Soluble organics are more easily degraded than insoluble materials;
- o The presence of functional groups affects biodegradability;
- o Halogenated-substituted compounds are the most difficult for biodegradation; and
- o Nitro-substituted compounds are easier to degrade than halogen-substituted compounds.

Despite the fact that some wastes (both organic compounds and heavy metals) inhibit biological treatment, the biomass can be acclimated, within limits, to tolerate elevated concentrations of the contaminants (USEPA; 1985). Several factors influence performance of this treatment process, such as the concentration of suspended solids, organic load variations, oil and grease, pH, alkalinity, acidity, phenols, sulfides, ammonia, and temperature; thus, some pretreatment may be necessary for effective results.

#### Incineration

Incineration is a treatment method which uses high temperatures under controlled conditions to degrade liquid or solids into relatively simple gaseous products or ash. Incineration can be used to destroy contaminants in liquid, gaseous, and solid waste streams and is frequently used to treat side streams from other processes. There are several incineration technologies applicable to hazardous waste treatment, however, only liquid injection incinerators are practical for treatment of a wastewater stream.

Liquid injection incinerators have been used successfully in the destruction of PCBs, solvents, still and reactor bottoms, polymer wastes, and pesticides (State of California, 1981). However, heavy metals and other wastes high in inorganics are unlikely to be destroyed. Frequently, these incinerators require supplemental fuel for proper operation.

Task Order 17 is evaluating incineration for treatment of Basin F wastes. Information from Task 17 will be used in the Task 26 process evaluation.

#### 3.3.4.3 Side Stream Treatment

Most of the treatment processes previously described generate side streams of contaminated wastes or wastewaters. Many of these will contain higher concentrations of contaminants than the untreated groundwater due to their inherent concentrating capabilities. Examples of these side streams include sludges from the biological and precipitation processes, concentrated wastewaters from the ion exchange and reverse osmosis processes, ash from the incinerator process, waste carbon from the activated carbon process, and spent membranes from the reverse osmosis process. Treatment and disposal of the various side streams will be evaluated as part of the overall evaluations of the processes. The treatment and disposal of side streams will probably be a major factor in these evaluations.

#### 3.3.5 Disposal Options

The options available for disposal of the effluent from any treatment system may be affected by water rights laws and regulations of the State of Colorado, depending on whether or not such laws and regulations are determined to be applicable as discussed in Section 3.3.1. Such a determination will be especially crucial for any disposal system that results in a consumptive use of water. Examples of consumptive use would include evaporative losses, incineration, and industrial use of the treated water. If the disposal system returns the water either directly or indirectly to the aquifers from which it is drawn, no water rights issues are anticipated; however, Underground Injection Control Regulations may apply.

#### 3.3.5.1 Subsurface Discharge

Several disposal system options are available for reinjecting the treated water from a groundwater treatment system into the groundwater aquifers. All of these systems will be evaluated as to performance, operation and maintenance problems, and construction costs.

Reinjection wells, either as smaller well points or as conventional wells, are commonly used for disposal of water into aquifers. All three groundwater containment and treatment systems presently on the Arsenal, the North Boundary System, the Northwest Boundary System, and the Irondale System, use conventional wells for reinjection of the treated water into the alluvial aquifer (Konikow & Thompson, Undated). The use of well points, which are smaller in diameter, generally would require a greater number of wells and a closer spacing to achieve an equivalent recharge capacity. In addition to recharging the alluvial aquifer, these systems are also applicable for recharging deeper aquifers such as the Lower Denver and Arapahoe Aquifers.

Subsurface discharge can also be accomplished using trenches and/or French drains. Recharge trenches would consist of linear trenches excavated to intersect the alluvial aquifer and would be backfilled with highly permeable material, such as sand and gravel. The treated water would be applied to the surface of the trenches where it would migrate through the permeable backfill into the aquifer. The water could also be applied through a French drain system consisting of perforated pipe laid horizontally in the recharge trenches at a depth equivalent to the aquifer depth. The addition of a French drain system would allow the top of the trench to be modified to minimize the amount of precipitation and surface water runoff entering the trenches. In general, these systems are practical for shallow aquifers only and would not be used for recharge of the deeper aquifers.

A modification to the trench and French drain design would be a disposal system similar to the leach field design of a typical septic tank or leach field treatment system. The trenches for this system are not excavated to a depth which intersects the alluvial aquifer. The trench and perforated pipe

system are installed just deep enough to prevent the treated effluent from freezing during the winter months. These shallow trenches allow most of the water to percolate into the underlying groundwater, but some water is also lost through evapotranspiration to the atmosphere.

#### 3.3.5.2 Surface Discharge

The most common disposal option for many treatment plants is surface discharge of the treated effluent to an adjacent stream, river, or other water body. A treatment system located in the Basin A Neck area, a surface discharge would be to the unnamed drainage basin that drains the Basins area (Resource Consultants, 1982). A surface discharge in the South Plants area would flow to either the lakes (Upper Derby, Lower Derby, Ladora, Mary) or to the Irondale Gulch drainage basin (Resource Consultants, 1982). Both the unnamed drainage basin and the Irondale Gulch drainage basin eventually exit the Arsenal along the northern boundary via the Sand Creek drainage basin.

Surface discharge to an evaporation/infiltration basin is also possible. The basin would be designed to maximize percolation of water through the basin bottom to the underlying aquifer, although evaporation of some of the water will occur. The bog at the North Boundary is being used as such a system to supplement disposal through the reinjection wells.

Discharge of treated, partially treated, or untreated groundwater to a nearby municipal wastewater treatment plant, such as the Denver Metropolitan Sanitation District's treatment plant or the South Adams County Water and Sanitation District's treatment plants, is considered not to be a viable option. The relatively low organic loadings and the presence of toxic compounds in the groundwater would likely present the owners of these plants with treatment or discharge permit problems.

#### 3.3.5.3 Reuse

Reuse of the treated effluent by an industrial concern, such as a manufacturing company, may be a viable option. Limitations to this option would be the quantity and quality of water required by the industrial concern and the proximity of the industrial concern to RMA.

Irrigation of cropland or municipal green belt areas is also a feasible disposal option; however, storage of the treated water during periods when irrigation is not feasible will be required. The limitations noted in the industrial reuse option also apply to this option.

The treated effluent could also be used on post as a flushing medium for the contaminated aquifer, if applied upgradient from the collection system at a location that is also upgradient from the known areas of groundwater contamination. The water could be applied by any of the disposal methods described previously. The water would allow for an increase in the groundwater flow through the contaminated zone and could result in decreased time for cleanup of the contaminated groundwater. This method is only applicable if the transmissivities of the aquifer are great enough to allow the increased flow.

### 3.3.6 Cost Estimates

Cost estimates will be developed for each of the systems determined to be applicable for the collection and treatment of groundwater at South Plants and Basin A Neck. The systems involved are:

- o Collection/control facilities,
- o Treatment facilities, and
- o Disposal facilities.

Estimated costs will be developed for various alternatives for each system in determining the most cost-effective combination of facilities. Capital cost estimates will include all equipment, labor, spare parts, associated equipment, and start-up expenses for each system. The operating and maintenance cost estimates will include labor, chemicals, fuel, utilities, and equipment required to keep the facilities working properly. Costs of indirect operations, such as engineering, construction management, permitting, monitoring, and contingencies, will also be included.

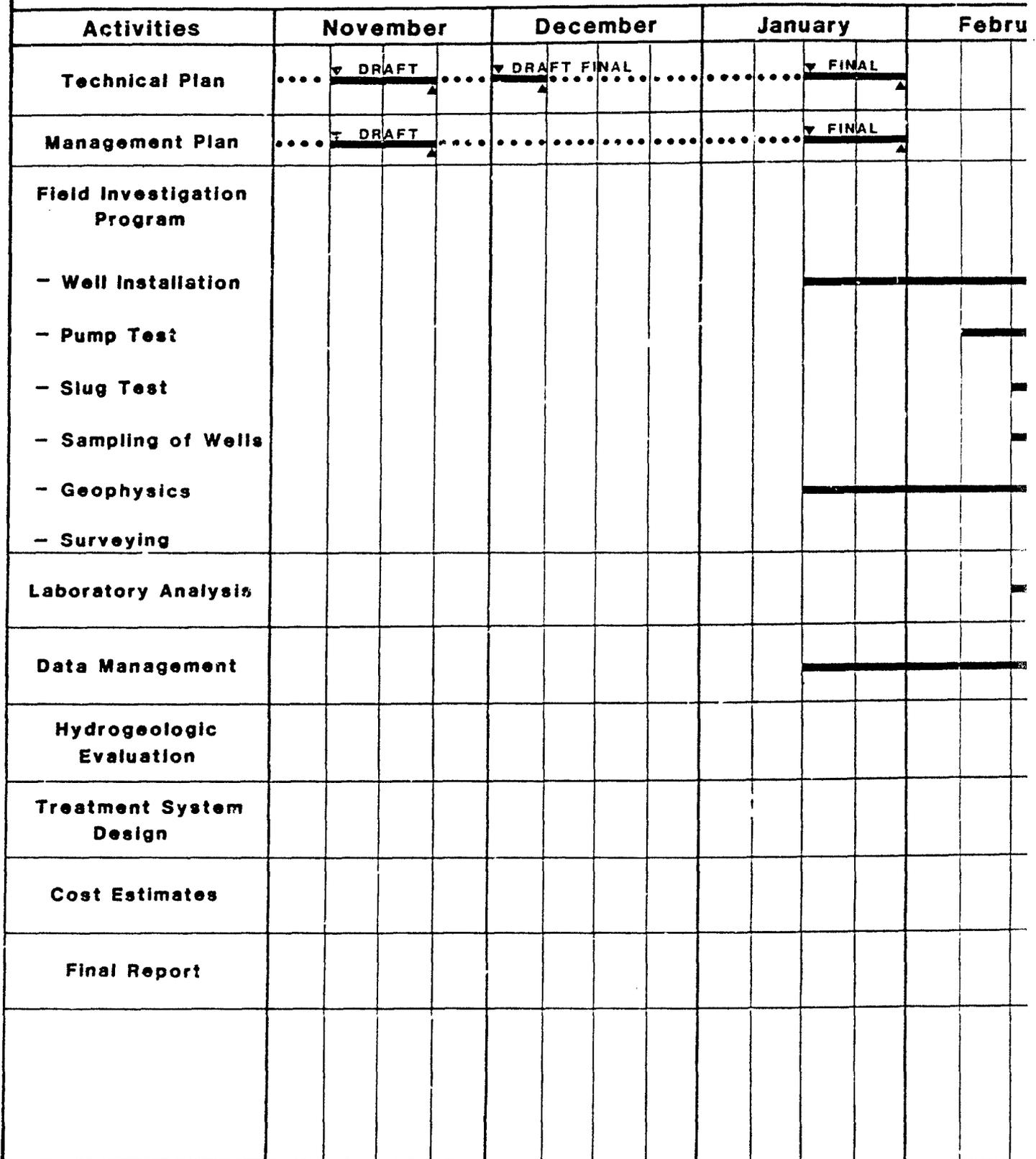
The capital costs and operating and maintenance costs will be evaluated in determining the total cost for treating the estimated volumes of water involved. The cost estimates will also reflect treatment rates and length of time required for treatment. A present worth analysis of all costs will aid in determining which systems and combinations of processes are the most cost-effective for this interim response action.

Information on these cost estimates will come from a variety of sources, including various EPA documents, (USEPA 1985b, 1985c), Engineering News Record indices, the Environmental Law Institute document (1985), and quotations from vendors and contractors. All costs will be in 1987 dollars and will be indexed to the Denver area.

#### 3.4 TASK SCHEDULE

Figure 3.4-1 presents the estimated schedule for completing Task 26. Each of the major work elements associated with this task and the major components of the field investigation program are illustrated. No allowance is made for unexpected delays.

**FIGURE  
PROJECT S  
TASK  
ROCKY MOUNT**



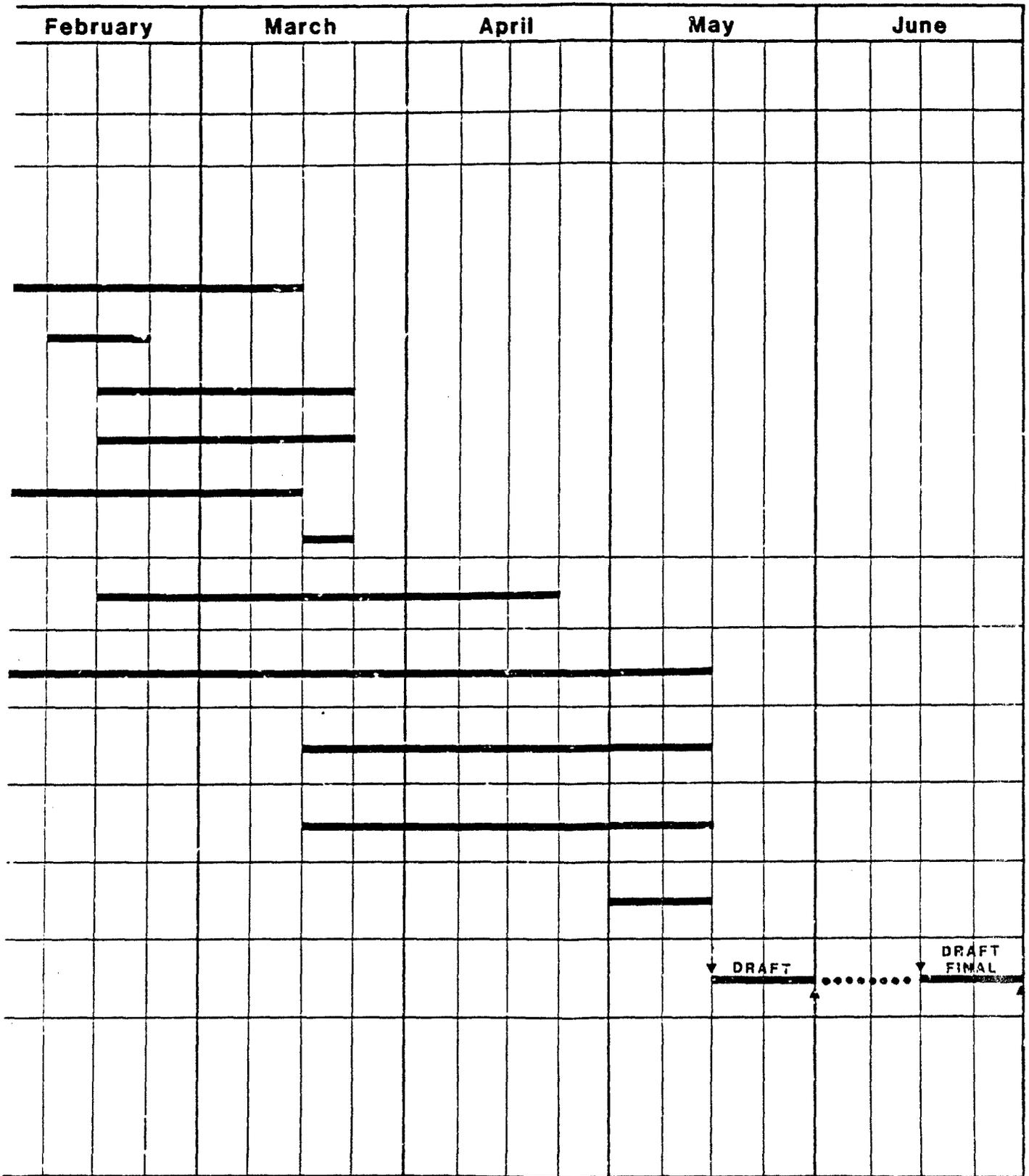
C

FIGURE 3.4-1

JECT SCHEDULE

TASK 26

MOUNTAIN ARSENAL



②

#### 4.0 CHEMICAL ANALYSIS PROGRAM

##### 4.1 INTRODUCTION

The chemical analysis program was designed to be consistent with the projected sampling program for Task 26. Analytical methods for this task are described in more detail below. The majority of the referenced analytical methods in this Technical Plan were those specified during meetings of the Analytical Services Teams for Tasks 1 and 2. These analytical methods were divided between the four contractor laboratories for method development prior to the initiation of Task 2 field activities. Once a method was developed, it was distributed to all contractor laboratories for certification. Certification has been completed under Task 2 for most of these methods.

Water samples collected from the monitoring wells will be screened for target analytes and unknown contaminants. Analytical methods, including desired analyte concentration, high range concentration, sample holding times, certification level, reference method, and principle of method, are identified in Table 4.1-1. These samples will be assayed by the specific quantitative methods to provide data on the extent of contamination at each specific source of interest.

Samples taken for possible analysis for worker exposure (e.g., volatile organics in air) will not be USATHAMA/PMO Certified. The sample matrices are listed in Table 4.1-2. Data from these samples will be used as an initial assessment and to identify the potential for worker exposure to organic vapors. A summary of laboratory analyses indicating preservation guidelines, analytical methods required, level of certifications, total analytical requirements, and weekly laboratory rates of analysis is given in Section IV of the RMA Procedures Manual (Ebasco, 1985).

##### 4.2 ANALYTICAL METHODS FOR LIQUID MATRICES

Analytical methods, target analytes, and desired target detection limits for liquid matrix analytes are discussed in this section and summarized in Table 4.1-1. All liquid matrix methods are USATHAMA/PMO Certified at the quantitative level. Liquid matrix analytical methods are included in

Table 4.1-1. Analytical Methods/Liquid Matrix for Task 26.

Analysis/Matrix/Analytes	Detection Limits <sup>a</sup>	High Range Concentration <sup>b</sup>	Hold Time	Level of Certification	Reference Methods
<b>Volatile Halo Organics/Water</b>			14 days (1)	Quantitative	EPA 601 (1)
Chlorobenzene	1.0 ug/l	50 ug/l			
Chloroform	1.0 ug/l	50 ug/l			
1,1-Dichloroethane	1.0 ug/l	50 ug/l			
1,2-Dichloroethane	1.0 ug/l	50 ug/l			
1,1,1-Trichloroethane	1.0 ug/l	50 ug/l			
1,1,2-Trichloroethane	1.0 ug/l	50 ug/l			
Tetrachloroethylene	1.0 ug/l	50 ug/l			
Trichloroethylene	1.0 ug/l	50 ug/l			
1,2-trans-Dichloroethylene	1.0 ug/l	50 ug/l			
Dichloromethane	1.0 ug/l	50 ug/l			
Carbon tetrachloride	1.0 ug/l	50 ug/l			
<b>Volatile Arom. Organics/Water</b>			7 days (1)	Quantitative	EPA 602 (1)
Benzene	1.0 ug/l	50 ug/l			
Toluene	1.0 ug/l	50 ug/l			
Xylenes	1.0 ug/l	50 ug/l			
Ethyl benzene	1.0 ug/l	50 ug/l			
<b>Organochlorine Pesticides/Water</b>			7 days for the water and 40 days for the extract (1)	Quantitative	EPA 608 (1)
Aldrin	0.1 ug/l	10 ug/l			
Endrin	0.1 ug/l	10 ug/l			
Dieldrin	0.1 ug/l	10 ug/l			
Isodrin	0.1 ug/l	10 ug/l			
Chlordane	0.1 ug/l	10 ug/l			
Hexachlorocyclopentadiene	0.1 ug/l	10 ug/l			
P,p'-DDT	0.1 ug/l	10 ug/l			
P,p'-DDE	0.1 ug/l	10 ug/l			

Table 4.1-1. Analytical Methods/Liquid Matrix for Task 26 (Continued).

Analysis/Matrix/Analytes	Detection Limits	High Range Concentration <sup>b</sup>	Hold Time	Level of Certification	Reference Methods
1,2-Dibromo-3-chloropropane/Water	0.1 ug/l	10 ug/l	Extract within 7 days, analyze within 30. See EPA 625 (1)	Quantitative	Developed by MRI for USATHAMA Certification
Dicyclopentadiene and Bicycloheptadiene/Water	0.3 ug/l	25 ug/l	Extract within 7 days, analyze within 40. See 4 (1)	Quantitative	Developed by MRI for USATHAMA Certification
Organosulfur Compounds/Water					
Chlorophenylmethyl sulfide	2.0 ug/l	50 ug/l	Extract within 7 days,	Quantitative	USATHAMA 4P
Chlorophenylmethyl sulfoxide	2.0 ug/l	50 ug/l	analyze within 30.		
Chlorophenylmethyl sulfone	2.0 ug/l	50 ug/l	See EPA 625 (1)		
1,4 oxathiane dithiane	2.0 ug/l	50 ug/l			
Phosphonates/Water					
Diisopropylmethylphosphonate	2.0 ug/l	100 ug/l	7 days See EPA 625 (1)	Quantitative	USATHAMA 4S for DIMP
Dimethylmethylphosphonate	2.0 ug/l	100 ug/l			ESE will develop method for DMMP

Table 4.1-1. Analytical Methods/Liquid Matrix for Task 26 (Continued).

Analysis/Matrix/Analytes	Detection Limit <sup>a</sup>	High Range Concentration <sup>b</sup>	Hold Time	Level of Certification	Reference Methods
<b>Organophosphorous Pesticides/Water</b>					
Malathion	0.1 ug/l	5.0 ug/l	7 days	Quantitative	EPA 8160(Z)
Parathion	0.1 ug/l	5.0 ug/l	See EPA 625 (1)		modified for water
azodrin	0.1 ug/l	5.0 ug/l			
Supona	0.1 ug/l	5.0 ug/l			
Vapona	0.1 ug/l	5.0 ug/l			
<b>Metals by AA/Water</b>					
Arsenic	10 ug/l	100 ug/l	6 mos (S)	Quantitative	EPA 206.2 (S)
Mercury	0.1 ug/l	10 ug/l	28 days (S)	Quantitative	EPA 245.1 (S)
<b>Metals by ICP/Water</b>					
Chromium	50 ug/l	5,000 ug/l	6 mos (S)	Quantitative	EPA 200.7 (S)
Cadmium	50 ug/l	5,000 ug/l			
Lead	50 ug/l	5,000 ug/l			
Zinc	50 ug/l	5,000 ug/l			
Copper	50 ug/l	5,000 ug/l			
Magnesium	10 mg/l	1,000 ug/l			
Calcium	100 mg/l	1,000 ug/l			
Sodium	100 mg/l	1,000 ug/l			
Potassium	see (S)	-			

Table 4.1-1. Analytical Methods/Liquid Matrix for Task 26 (Continued).

Analysis/Matrix/Analytes	Detection Limits <sup>a</sup>	High Range Concentration <sup>b</sup>	Hold Time	Level of Certification	Reference Methods
<b>Anions/Water</b>				Quantitative	EPA 300 (5) and Contractor developed method
Sulfate	2.0 mg/l	200 mg/l	28 days (5)		
Nitrate	2.0 mg/l	200 mg/l	48 hrs (5)		
Chloride	1.0 mg/l	100 mg/l	28 days (5)		
Fluoride	2.0 mg/l	200 mg/l	28 days (5)		
Phosphate	1.0 mg/l	100 mg/l	48 hrs (5)		
<b>Water Quality/Water</b>					
Hardness	10 mg/l	400 mg/l	7 days	None	EPA 130.1 or 130.2 (5)
Alkalinity	10 mg/l	200 mg/l	7 days	None	Standard Methods 403 (6)
Total Dissolved Solids	10 mg/l	20,000 mg/l	7 days	None	EPA 160.1 (5)
pH	-	-	-	None	EPA 150.1 (5)
<b>GC/MS Confirm/Extracts</b>	--	--	40 days (1)	None	EPA 624 + 625 (1)

Table 4.1-1. Analytical Methods/Liquid Matrix for Task 26 (Continued).

a Actual detection limits for certified methods are identified in Section IV of the RMA Procedures Manual (Project Specific Analytical Methods Manual) for each laboratory. Detection limits for uncertified methods and methods to be certified are desired detection limits.

b Reflects an estimate of the linear range of the method and is proposed to minimize dilutions.

References:

- (1) EPA-600/4-R2-057, July 1982 "Methods for Organic Chemical Analysis of Principal and Industrial Wastewater".
- (2) EPA SW-846, 2nd ed., "Test Methods for Evaluating Solid Waste".
- (3) Personal Communication from Chris Wathington, Ebasco QA Manager.
- (4) ESE-AMP-2-UD-II<sub>2</sub>O.1, July 22, 1982.
- (5) EPA-600/4-79-020, Revised March 1983, "Methods for Chemical Analysis of Water and Wastes".
- (6) American Water Works Association, 16th Edition, 1985, "Standard Methods for the Examination of Water and Wastewater".

Table 4.1-2. Analytical Methods/Air Matrix for Task 26.

Analysis/Matrix/Analytes	Detection Limit	High Range Concentration	Hold Time	Level of Certification	Reference Methods
Organics Screen/Air-Charcoal	-	-	4 weeks in freezer	None	UBTL method developed for NIOSH
Organics Screen/Air-Tenax	-	-	4 weeks in freezer	None	UBTL method developed for NIOSH

Section 10.0, Laboratory Project Analytical Procedures Manual, Section IV, RMA Procedures Manual (Ebasco, 1985).

#### 4.2.1 Volatile Halogenated Organics

The analytical method for volatile halogenated organics in water is based on EPA Method 601 (EPA 600/4-82-057). This analytical procedure is a purge and trap method, assayed on a packed column (1 percent SP-1000 on Carbopack B) by gas chromatograph (GC) equipped with a Hall electrolytic conductivity detector. Water samples will be spiked with 1,2-dibromethane, or other suitable internal standard based on prior experience, to monitor purge efficiency. Volatile halogenated organic analyses and desired detection limits are identified in Table 4.1-1.

#### 4.2.2 Volatile Aromatic Organics

The volatile aromatic hydrocarbon methods are based on EPA Method 602 (EPA 660/4-82-057) for water and EPA Method 8020 (EPA-SW-846) for soils and solids. Analysis of volatile aromatics in water will be by a purge and trap method, analyzed by GC equipped with a photoionization detector using a packed column (1 percent SP-1000 on Carbopack B). Table 4.1-1 lists the volatile aromatic organic constituents and target detection limits.

#### 4.2.3 Organochlorine Pesticides

The analytical methodology for organochlorine pesticides is based on EPA Method 603 (EPA 600/4-82-057) for water and EPA Method 8080 (EPA-SW-846) for soil and solid samples. An 800 milliter (ml) portion of water will be extracted three times with 50 ml methylene chloride. The extract shall be reduced in volume and exchanged with hexane to a final volume of 10 ml or less. The concentrated extract will be analyzed by GC with an electron capture detector using a fused silica capillary column. Organochlorine pesticides and their target detection limits are listed in Table 4.1-1.

#### 4.2.4 1,2-dibromo-3-chloropropane (DBCP)

The procedure for the analyses of DBCP was developed by Midwest Research Institute for both water and soils. A 90-ml portion of water sample will be

placed in a 100-ml volumetric and saturated with sodium chloride. The sample will be extracted twice with 1.0 ml hexane, the extracts combined, and then brought to a final volume of 2.0 ml. An aliquot of the extract is analyzed on a fused silica capillary column by GC equipped with an electron capture detector. The target detection limit for DBCP will be 0.1 micrograms per liter (ug/l).

#### 4.2.5 Dicyclopentadiene (DCPD) and Bicycloheptadiene (BCHD)

The specific procedures for DCPD and BCHD were developed by Midwest Research Institute for both water and soil matrices. A 100-ml portion of water sample will be extracted with 5.0 ml methylene chloride. The extract will be assayed on a fused silica capillary column by GC equipped with a flame ionization detector. The target detection limit for both DCPD and BCHD will be 10 ug/l.

#### 4.2.6 Organosulfur Compounds

The organosulfur compounds that will be target analytes are listed in Table 4.1-1. Methodologies for organosulfur analyses were developed from USATHAMA Method 4P for water. In a water matrix, a 800-ml sample will be extracted three times with 50-ml methylene chloride. The extract volume shall be reduced in a K-D apparatus and exchanged for isooctane. The isooctane extract will be assayed on a packed column (5 percent SP-1000 on Chromosorb) by GC with a flame photometric detector. The target detection limit for organosulfur compounds in water will be 2.0 ug/l.

#### 4.2.7 Phosphonates

The phosphonates include diisopropylmethyl phosphonate (DIMP) and dimethylmethylphosphonate (DMMP). Specific analytical methodologies for phosphonates were developed from USATHAMA Method 4S for water. Water analysis for phosphonates will involve extracting an 800-ml sample three times with methylene chloride. The extracts shall be combined, the volume reduced in a K-D apparatus and exchanged with isooctane. The isooctane extract will be analyzed on a fused silica capillary column by GC equipped with a nitrogen/phosphorous detector. The target detection limit for phosphonates in water will be 2.0 ug/l.

#### 4.2.8 Organophosphorous Pesticides

Organophosphorous compounds targeted for analysis are listed in Table 4.1-1. Analytical methods for these compounds are derived from EPA Method 8140 (EPA-SW-846) for water. In a water matrix, the five organophosphorous compounds will be extracted from a 800-ml sample with three 50-ml volumes of methylene chloride. The extract will be concentrated and exchanged with isooctane to a final volume of 5.0 ml. An aliquot of the extract will be assayed on a fused silica capillary column by GC equipped with a nitrogen/phosphorous detector. Target detection limits for the five organophosphorous pesticides in water will be 0.1 ug/l.

#### 4.2.9 Metals

Twelve metals will be assayed in liquid matrices. The metals and principal analytical method will be as follows: arsenic and mercury by atomic absorption; and chromium, cadmium, copper, lead, zinc, magnesium, calcium, potassium, and sodium by inductively-coupled argon plasma emission spectrometry (ICP).

The method for arsenic analysis is derived from EPA Method 206.2 (EPA 600/4-79-020) for water. A 100-ml sample of water will be digested with hydrogen peroxide and concentrated nitric acid. The digest will be assayed by graphite furnace atomic absorption spectrometry. Target detection limits for arsenic in water will be 10 ug/l.

The mercury method is derived from EPA Method 245.1 (EPA 600/4-79-020) for water. In the water method, a 100-ml sample will be treated with sulfuric acid, nitric acid, potassium permanganate, and potassium persulfate. Excess permanganate will be destroyed with hydroxylamine sulfate. Mercury will be reduced with stannous sulfate and assayed by cold vapor atomic absorption spectrometry. The target detection limit for mercury in water will be 0.1 ug/l.

The method for ICP metals in water was derived from EPA Method 200.7 (EPA 600/4-79-020). Target analytes and desired detection limits for ICP

metals in the liquid matrix is shown in Table 4.1-1. As explained in the EPA method, the detection limit for potassium is highly dependent on the instrument and operating conditions. All water samples for ICP metals will be digested by adding nitric and hydrochloric acid and heating before analyses to dissolve any precipitates that may have formed after sampling. The sample digest will be filtered, brought to a final volume of 50 ml, and assayed by ICP.

#### 4.2.10 Anions

Five anions, including sulfate, nitrate, chloride, fluoride, and phosphate, will be surveyed in selected samples. Detection limits for these anions are listed in Table 4.1-1. For sulfate, chloride, and fluoride in water, EPA Method 300 (EPA 600/4-79-020) will be used. Nitrates and phosphates in water will be assayed by contractor developed methods which will be USATHAMA/PMO Certified.

In water, the sample will be filtered and analyzed for sulfate, chloride, and fluoride directly by ion chromatography using suppressor/separator columns. Nitrate and phosphate will be assayed on an autoanalyzer. Sulfate, chloride, and fluoride ions will be determined in a single run without post column reaction using peak areas to determine concentration. Nitrate and phosphate ions will be determined colormetrically.

#### 4.2.11 General Water Quality Parameters

The four parameters to be analyzed for general water quality are pH, total hardness, alkalinity, and total dissolved solids (TDS). The analysis of these parameters do not require USATHAMA/PMO Certified methods.

The analysis for pH (negative logarithm of the hydrogen ion concentration) will be determined by EPA Method 150.1. Total hardness will be determined by either the automated method, EPA Method 130.1, or the manual method, EPA Method 130.2 (EPA 600/4-79-020). Both methods are based on a magnesium EDTA exchange with calcium and/or cations on an equivalent basis. These cations form a more stable EDTA chelate than magnesium, thus the amount of total

hardness can be determined by measuring the magnesium concentrations. Alkalinity will be determined by Method 403 in Standard Methods (AWWA, 1985). The method involves the titration of a volume of the water sample with a standard sulfuric acid or hydrochloric acid solution. Two endpoints are determined: the phenolphthalein endpoint and the methyl orange endpoint. The total alkalinity of the sample is the amount of acid used to reach the methyl orange endpoint expressed as mg/l of calcium carbonate. The relationship between the phenolphthalein alkalinity and the total alkalinity can be used to define the various species of the total alkalinity: hydroxide alkalinity, carbonate alkalinity, and bicarbonate alkalinity.

TDS or total filterable residue will be determined by EPA Method 160.1 (EPA 600/4-79-020). A 100-ml sample is filtered through a glass fiber filter with the collection of all filtrate. The filtrate is transferred to a preweighed evaporating dish and dried at 180°C. The TDS is determined gravimetrically as the difference in weights of the evaporating dish divided by the sample volume.

#### 4.2.12 GC/MS Confirmation

Approximately 10 percent of the total number of liquid samples which were found to contain quantifiable target organic compounds by GC will be screened by gas chromatograph/mass spectrometry (GC/MS) to confirm analyte identity and purity. The presence or absence of co-eluting unknown peaks will be the single criterion used to confirm purity of target analytes. The GC/MS confirmation will be performed within the prescribed holding time for sample extracts using columns and conditions similar to those used in the original GC analyses. This GC/MS confirmation method will provide positive or negative verification of target compound identity and purity only, and will be performed without prior certification. New unknowns will not be identified during the GC/MS confirmation program. It is anticipated that low concentrations of certain target analytes may not be applicable to this confirmation technique.

#### 4.3 ANALYTICAL METHODS FOR AIR MATRICES

As noted on Table 4.1-2, volatile organic compounds in the air will be captured with activated charcoal and Tenax for analysis. This method was designed by UBTL for the National Institute of Occupational Safety and Health (NIOSH). It is designated for use in this program as a screening tool to identify the potential for each sampling team's exposure to volatile organic contaminants in air during the Task 26 program. The charcoal is desorbed with methylene chloride and Tenax is desorbed with isooctane. Extracts will be analyzed by packed column or fused silica capillary column GC/MS in order to identify significant unknown compounds. This method will not be USATHAMA/PMO Certified (see Section IV of the RMA Procedures Manual for method).

## 5.0 QUALITY ASSURANCE/QUALITY CONTROL PROGRAM

### 5.1 PROJECT QA/QC Plan

An integral part of the Task 26 Technical Plan is the project-specific Quality Assurance/Quality Control (QA/QC) Plan describing the application of Ebasco's procedures to monitor and control field and analytical efforts at RMA. Ebasco has developed a Project QA/QC Plan applicable to geotechnical sampling and analytical activities. For Task 26, Ebasco will adhere to, and comply with, the established QA/QC requirements for any drilling, well construction, and sampling conducted during the task. The plan is presented in the RMA Procedures Manual Section IV (Ebasco, 1985). The specific objectives of the Ebasco Quality Assurance Program for RMA are to:

- o Ensure adherence to established PMO QA Program guidelines and standards;
- o Ensure precision and accuracy of measurement data;
- o Ensure validity of procedures and systems used to achieve project goals;
- o Ensure that documentation is verified and complete;
- o Ensure that deficiencies affecting quality of data are quickly determined;
- o Perform corrective actions that are approved and properly documented;
- o Ensure that the data acquired will be sufficiently documented to be legally defensible; and
- o Ensure that the precision and accuracy levels attained during the USATHAMA/PMO analytical certification program are maintained during the project.

The overall project QA/QC responsibility rests with the Project QA Coordinator. He is assisted by the Field and Laboratory QA/QC Coordinators.

The Field QA/QC Coordinator assures that all quality control procedures are implemented for drilling, sampling, chain-of-custody, and documentation. His responsibilities include:

- o Reviewing all field data and documentation for completeness and accuracy;
- o Ensuring implementation of the chain-of-custody procedures, sample security, and document security;
- o Determining deficiencies in implementing drilling quality control protocols and seeking corrective actions;
- o Preparing weekly reports to the Project QA Coordinator of technical problems and corrective actions; and
- o Having available documentation for review by Ebasco Project QA Coordinator of USATHAMA during audits.

Ebasco is using two laboratories for the performance of chemical analytical services. Both laboratories comply with the Project QA/QC Plan. Each laboratory has appointed a Laboratory QA/QC Coordinator. Their responsibilities include:

- o Monitoring the quality control activities of the laboratory;
- o Recommending improvements to the laboratory quality control protocol, when necessary;
- o Logging in samples, introducing control samples in the sample train, and establishing sample testing lot sizes;
- o Approving all data before its submission to permanent storage;

- o Maintaining all quality control records and chain-of-custody documents;
- o Assuring document and sample security;
- o Informing Ebasco's Project Quality Assurance Coordinator of noncompliance with the Project QA/QC Plan; and
- o Preparing and submitting a weekly report of quality control data to the Ebasco Project Quality Assurance Coordinator.

Prior to the performance of the actual field program, a QA/QC training session will be conducted by the Project QA Coordinator, or his designees, to indoctrinate field, laboratory, and project personnel in the specific procedures detailed in the Project QA/QC Plan.

Also, prior to analysis of samples, the Project QA Coordinator will visit the laboratories to review analytical procedures with chemical analysis personnel and instruct the Laboratory QA/QC Coordinators in the requirements of the Project QA/QC Plan and data validation procedures. In addition, the Project QA Coordinator performs audits of field and laboratory work on a bimonthly basis to ensure compliance with the Project QA/QC Plan. Specific project QA/QC requirements are described in the following sections.

## 5.2 SPECIFIC PROJECT REQUIREMENTS

### 5.2.1 Geotechnical Requirements

The project geotechnical requirements are described in Section 7.0 of the Quality Assurance Plan (RMA Procedures Manual, Section IV). These requirements are based on the geotechnical guidelines established by PMO. Specifically, this section addresses the geotechnical requirements for well drilling operations, borehole logging, well installation, development and testing, well diagrams, well acceptance, topographic surveying, selected data management entries, and geotechnical reports. Ebasco will have a geologist present and responsible at each operating drill rig for logging samples and monitoring drilling operations.

### 5.2.2 Field Sampling

The management of samples, up through the point of shipment from the field to the laboratory, is under the supervision of Ebasco's Field QA/QC Coordinators (FQA/QC). Samples must be collected in properly cleaned containers, and properly labeled, preserved, and transported according to the prescribed methods. Section 8.0 of the Project QA Plan describes the procedures to monitor adherence to approved sampling protocol. If the FQA/QC determines that deviations from the sampling protocol have occurred, resulting in a compromise of the sample integrity, all samples taken prior to the inspection are discarded and fresh samples are taken. The FQA/QC are responsible for field chain-of-custody documentation and transfer, and for supervision of strict adherence to chain-of-custody procedures.

### 5.2.3 Laboratory Quality Assurance Procedures

Section 10.0 of the Project Quality Assurance Plan describes the Laboratory QA Procedures. Both laboratories, along with their internal quality assurance program, adhere to the Project QA/QC Program.

The Laboratory QA/QC Program begins with the receipt of the samples from the field. All samples are shipped to UBTL for logging in, sample splitting, and distribution for analyses. The Laboratory QA/QC Coordinator is responsible for monitoring the laboratory activities. He is also responsible for determining testing lot sizes and introducing laboratory control samples into the testing lot in an inconspicuous manner.

The samples must be analyzed within the prescribed holding time by the approved analytical methods. Analytical methods are described in Section 4.0 of this Technical Plan.

### 5.2.4 Laboratory Analytical Controls

Daily quality control of the analytical systems ensures accurate and reproducible results. Careful calibration and the introduction of control samples are prerequisites for obtaining accurate and reliable results. Procedures for instrument calibration and analytical controls are described in Section 12.0 of the Project QA Plan.

The Laboratory QA/QC Coordinator for each laboratory monitors the analytical controls. The out-of-control situation can be detected by the control charts. When an out-of-control situation is detected, efforts are initiated to determine the cause. Corrective actions are taken to bring the process under control. Full documentation of an out-of-control situation and the subsequent corrective action are recorded by the Laboratory QA/QC Coordinator.

5.2.5 Laboratory Data Management, Review, Validation, and Reporting Procedures

Sections 13.0 through 16.0 of the Project QA Plan detail the procedures for laboratory data review, validation, and reporting procedures. The laboratories utilize highly automated systems for analytical data collection and reduction. The analytical supervisor, along with the Laboratory QA/QC Coordinator, reviews all analytical data after data reduction and prior to the transfer of the data report to Ebasco. The laboratory data reporting procedure is described in Section 15.0 of the Project QA Plan which is based on the established PMO reporting procedures for analyses performed at quantitative and semi-quantitative levels. The laboratories adhere to these reporting procedures.

## 6.0 DATA MANAGEMENT PROGRAM

### 6.1 PLAN OVERVIEW

This plan presents the data management procedures to be used by Ebasco for the Environmental Program at RMA. As specified in the contract, all data is presented to PMO in appropriate format and entered into the IR-DMS UNIVAC 1100/61. PMO has provided a Tektronix 4051 system and IR Data Management User's Guide, Version 85.6 (PRI, 1985) to Ebasco for this purpose. Data is controlled as necessary. Presentation of project management data and report communication is discussed in Ebasco's Management Plan.

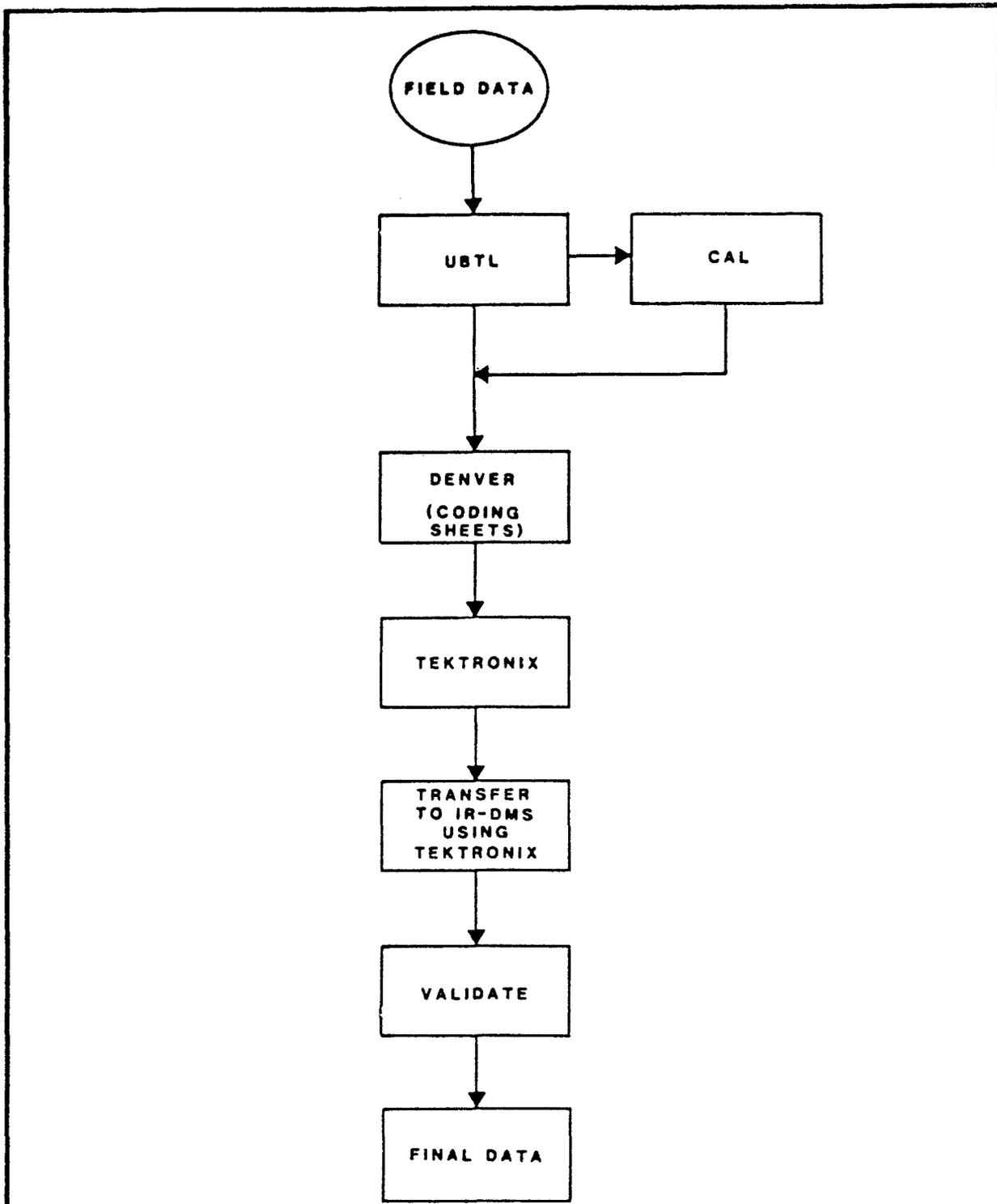
Figure 6.1-1 schematically shows the process Ebasco uses to coordinate data management activities between itself, UBTL, CAL, and IR-DMS. This is detailed in Section 6.3 of this Technical Plan. As shown in Figure 6.1-1, Ebasco's primary data entry terminal for the IR-DMS is through the Army-owned Tektronix terminal in Ebasco's Denver office. A second Army-owned terminal is maintained in Ebasco's Santa Ana office for backup data entry purposes. Specifics of data collection, data entry, data validation, and data analysis are discussed herein.

### 6.2 FIELD ACTIVITIES

#### 6.2.1 Sample Handling

The Sample Coordinator is responsible for field data collection, documentation, and logging of the sampling program. In addition, the Sample Coordinator ensures that all field data are properly accounted for and transferred to the Field QA/QC for review at Ebasco's Denver office. To accomplish this, the Sample Coordinator assures that proper sample collection, sample control identification, and proper chain-of-custody procedures are followed.

Sample control identification numbers are assigned to each sample collected in the field by the Sample Coordinator. These sample identifiers are recorded on the sample tag, in the field data log book, and on the sample chain-of-custody record at the time of sample collection. The chain-of-custody record also serves as the analytical request form, verifiable by the analytical request



Prepared for:

Program Manager's Office for  
Rocky Mountain Arsenal Cleanup  
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FIGURE 6.1-1

Data Flow Between Ebasco, UBTL,  
CAL and IR-DMS

Rocky Mountain Arsenal, Task 26

Prepared by: Ebasco Services Incorporated

list on the sample tag. The Sample Coordinator checks sample tags, chain-of-custody forms, and field data logs to assure complete and correct field data entry. Field identification numbers remain with each sample throughout the data collection, shipment, analysis, and report phases of the program.

As part of the logging in of field data, the Sample Coordinator copies pertinent information from the chain-of-custody form into the field sample control logbook, packages and seals the samples for shipment to the laboratory, and ensures the shipment of these samples. The Sample Coordinator forwards the necessary written field records to the Field QA/QC Coordinator at Ebasco's Denver office for review.

#### 6.2.2 Geotechnical Program

Geotechnical boring logs, containing pertinent data regarding bore-hole lithology, are coded onto PMO data coding sheets by the geologist within two weeks of completion of the drilling. These data are entered into the Field Drilling Files by the Ebasco Denver office.

Upon completion of the drilling of borings at each site, a surveying crew determines map coordinates and ground elevations for the location of each boring. These survey data are coded immediately onto PMO data coding sheets, and are entered into the IR-DMS Map Files by the Ebasco Denver office. It is critical that these files be entered into the data management system before the completion of chemical analyses, as each sample location must be associated with a map location.

#### 6.2.3 Laboratory

When samples are received at UBTL, the sample receipt officer signs the chain-of-custody record, logs in sample shipment, verifies sample integrity, assigns sample lots, prepares split samples, and identifies samples to be sent to CAL or to be retained by UBTL for chemical analysis. Each laboratory, UBTL and CAL, submits weekly sample status reports to Ebasco's Data Manager. These weekly status reports are used to aid in planning the rate of field sampling and the distribution of laboratory workloads.

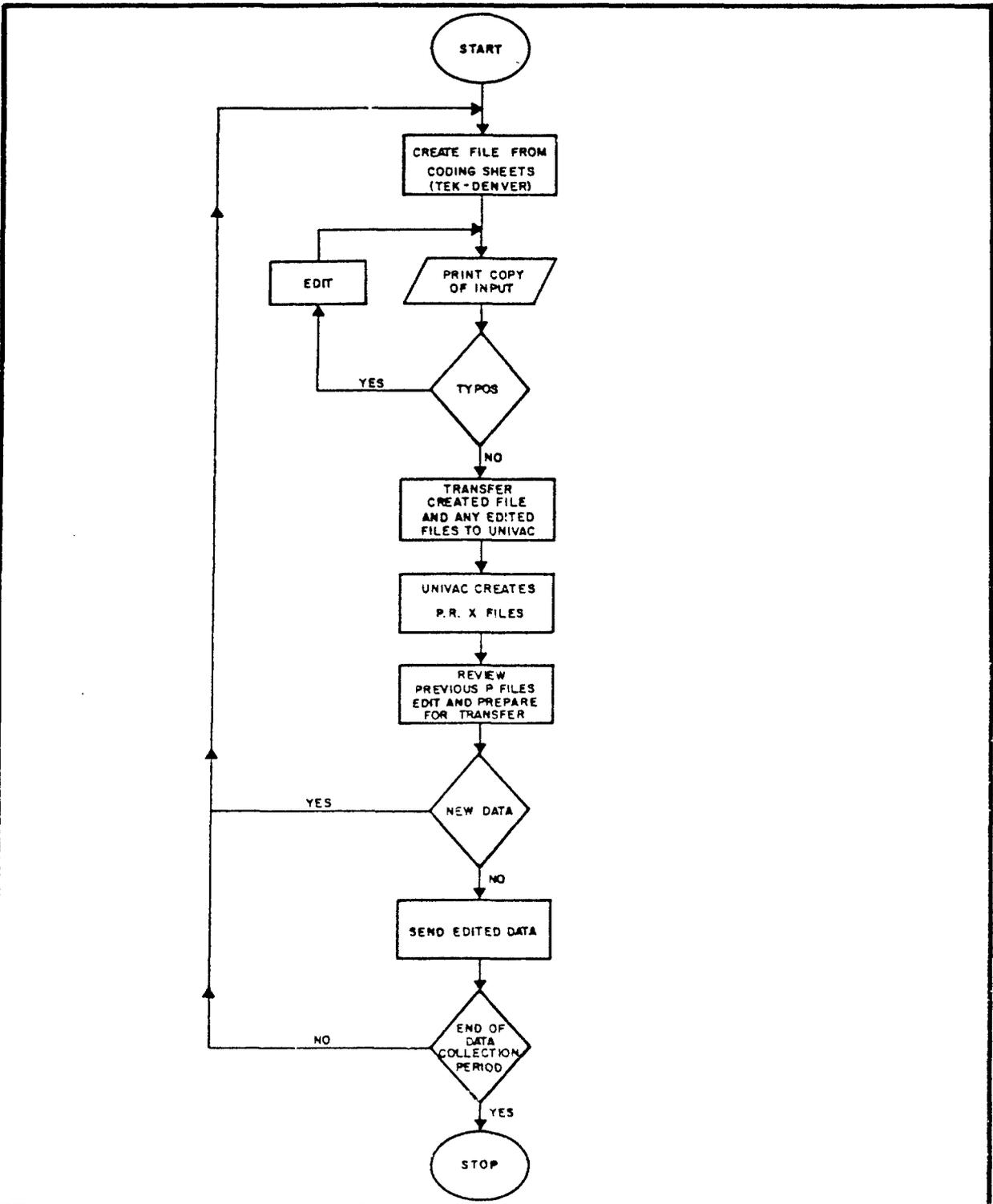
Field and laboratory sample control identification and chemical analysis data are transcribed to the data coding sheet by UBTL and CAL, then verified using the program's laboratory control procedures. The verified data coding sheets are then delivered, by courier, to Ebasco's Data Manager for entry into the IR-DMS data base.

### 6.3 DATA ENTRY AND VALIDATION

Figure 6.3-1 illustrates the flow of data to enter laboratory results into the IR-DMS UNIVAC 1100/60. The first step in data entry is to create a magnetic tape copy of the coding sheets on the Tektronix 4051 terminal by keypunching. The Tektronix operator enters only a subset of a complete file at one time. These file subsets are later merged to a single file using the UNIVAC. After keypunching, the operator obtains a printed copy of the data subset using the Tektronix printer and verifies that the data in the Tektronix tape file is identical to that on the coding sheets. The operator corrects any data entry typographic errors using the Tektronix editor, then obtains a second printing of the file to confirm that the changes were properly made. Methods certification data and map location data are entered first because validation routines make use of it.

Once the operator is certain that there are no remaining data entry errors on the Tektronix tape, the operator uses the Tektronix 4051 as a remote terminal to transfer the data to the UNIVAC 1100/60. To do this, the operator loads the data entry software, catalogs a Level 1 (pre-acceptance) file on the UNIVAC, and transmits the data over the telephone lines using a modulator-demodulator (modem). Ebasco's operators transfer Tektronix entry tape files to Level 1 UNIVAC files at least once per week, and maintain a log of terminal usage and communication with the UNIVAC.

Once data is transferred, the operator makes use of provided IR-DMS utilities to convert English units of measurement to International Standard (SI) units and to convert State Planar, or UTM grid system coordinates, to local origin coordinates, if necessary.



Prepared for:

Program Manager's Office for  
Rocky Mountain Arsenal Cleanup  
Aberdeen Proving Ground, Maryland

FIGURE 6.3-1

Laboratory Data Flow to the IR-DMS  
UNIVAC 1100/61 System

Rocky Mountain Arsenal, Task 26

Prepared by: Ebasco Services Incorporated

Next, the operator invokes the IR-DMS data acceptance routines to perform the final data verification and create a Level 2 (temporary read-only) file. The acceptance routines identify any errors in format or coding and any inconsistencies with corresponding map records previously loaded. If the acceptance routine does find errors at this stage, the operator checks the "R" file. The "R" file contains the rejected records that the acceptance routine creates. The UNIVAC editor is used to correct the verified entries, then they are resubmitted to the UNIVAC for acceptance. After acceptance, the IR-DMS automatically creates chemical and geological Level 2 files.

Ebasco's operators run the Level 1 data files through the data acceptance routines within seven days of their transfer to the UNIVAC system. They delete Level 1 files once these data are accepted at Level 2. The final step in the data entry and validation process, the creation of a Level 3 (final version, read-only) file, is undertaken by the PMO APG-EA data processing staff.

#### 6.4 ANALYSIS AND PRESENTATION

Ebasco scientists access the PMO IR database and perform analyses, as required, to support all contamination assessment and feasibility work. The data analysis efforts include graphic representations of data using data gridding, contouring, and three-dimensional surface representations.

Several techniques are used to access the data. If possible, IBM PCs are used in terminal emulation mode to capture Level 3 data from the IR database in order to perform analyses and prepare material for presentation. The Tektronix 4051 terminals in Denver and Santa Ana are also used in a direct link to the UNIVAC to prepare analyses and graphic representations. Ebasco scientists may establish communication links between IBM PCs to interchange data and facilitate data analysis.

## 7.0 HEALTH AND SAFETY PROGRAM

### 7.1 GENERAL

#### 7.1.1 Project Health and Safety Plan

The purpose of this section is to provide an overview of the safety program Ebasco will employ to ensure the safety of its employees and that of subcontractors engaged in the field investigation activities at RMA. All employees involved in on-site downrange work undergo a complete Tox II Baseline physical and are continuously monitored in Ebasco's Medical Surveillance Program, per Occupational Safety and Health Act (OSHA) regulations (29 CFR 1910.20).

A draft of the project Health and Safety Plan (HASP), prepared according to the Ebasco Corporate Health and Safety Program, is included in Section V of the RMA Procedures Manual. All personnel working at RMA are familiar with this document and have been indoctrinated in all aspects of the safety program.

Overall responsibility for safety during the site investigation activities rests with the Project Health and Safety (PHS) Officer. The PHS Officer is responsible for developing the site-specific HASP at RMA and, through the on-site Health and Safety Coordinator, assumes its implementation responsibility. Specifically, the PHS staff are responsible for:

- o Characterizing the potential specific chemical and physical hazards to be encountered;
- o Developing all safety procedures and operations for on-site activities;
- o Ensuring that adequate and appropriate safety training and equipment are available for project personnel;
- o Arranging for medical examinations for specified project personnel;
- o Arranging for the availability of on-site emergency medical care and first aid, as necessary;

- o Determining and posting locations and routes to site work zones;
- o Notifying installation emergency officers (i.e., police and fire departments) of the nature of the team's operations and making emergency telephone numbers available to all team members; and
- o Indoctrinating all team members in safety procedures.

In implementing this safety program, the PHS Officer will be assisted by an on-site Health and Safety (HS) Coordinator. The HS Coordinator's function is to ensure that the established health and safety procedures are properly followed for all on-site activities. The details of the safety organization, administration, and responsibilities are described in Section I of the project HASP (Section V, RMA Procedures Manual).

In particular, the following specifics of the project HASP are especially important to the South Plants, Basin A, Basin A Neck, and other Task 26 investigation activity areas. These specifics are:

- o Safety organization, administration, and responsibilities;
- o Initial assessment and procedures for hazard assessment;
- o Safety training;
- o Safety operations procedures;
- o Monitoring procedures;
- o Safety considerations for sampling; and
- o Emergency procedures.

#### 7.1.2 Task 26 Health Hazards

The South Plants area consists of over 300 buildings. It was the site of the manufacture and demilitarization of chemical and incendiary munitions and a variety of pesticides, insecticides, and herbicides; including chlorinated benzenes, dibromochloropropane (DBCP), DIMP, dichlorodiphenyltrichloroethane (DDT), and dicyclopentadiene (DCPD). Basin A was the original disposal area for waters and wastewaters resulting from all industrial operations at RMA,

including those in the South Plants area. Based on the evaluation of past activities, incidents, accidents, and investigations, the presence of chemicals and wastes were found to be present throughout the South Plants and Basin A areas in the form of solids, liquids, and gasses. The characteristics of these wastes are known to be toxic and hazardous to human health.

The conclusion on the RMA hazard assessment, based on historical evidence, is that the overall hazard assessment is extremely variable and is entirely dependent upon location and operation. Section VI of the project HASP describes the procedures to be employed to determine hazard of a specific building or sampling location for the identification of the preliminary level of protection requirement.

#### 7.1.3 Training

Section VII of the HASP explains the training program for the RMA project. The training focuses on the general health and safety considerations and provides site-specific safety instructions.

#### 7.1.4 Safety

Section VIII describes in detail the safety operations procedures. The important aspects of the safety operations procedures are:

- o Zone approach for field work,
- o Personnel protection, and
- o Communications.

A three-zone approach (Support Zone, Contamination Reduction Zone, and Exclusion Zone), where possible, will be utilized for all field work at RMA. The Support Zone will contain the Command Post with appropriate facilities such as communications, first aid, safety equipment, support personnel, hygiene facilities, etc. This zone will be manned at all times when field teams are operating downrange. Adjacent to the Support Zone will be the Contamination Reduction Zone (CRZ), which will contain the contamination reduction corridor for the decontamination of equipment and personnel (the

actual decontamination procedures are discussed in Section XI of the HASP). All areas beyond the CRZ will be considered the Exclusion Zone. For well drilling or soil boring operations the Exclusion Zone will be established at a 30-ft radius from the drill rig. These support facilities are discussed and illustrated in Section VIII of the HASP.

The level of protection to be worn by field personnel will be defined and controlled by the on-site HS Coordinator and will be specifically defined for each operation in an information sheet (Facility Information Sheet, FIS). The preliminary FIS will be developed based upon historical information and data. This will be upgraded and utilized for future operations based upon the results of the Health and Safety portion of the soil and water sampling programs. For these programs, Level "C" type protection will generally be provided for investigation team members, however, Level "D" type protection may also be utilized as appropriate based on assessment by the PHS Officer and the on-site HS Coordinator. If determined necessary, changing from Level "C" to "B" protection can be easily achieved in the field. This can be accomplished in a matter of hours. Basic levels of protection (i.e., Levels "A", "B", "C", or "D") for general operations are defined in Section VIII of the project HASP.

Maintaining proper communications among team members (investigation team and Health and Safety team members) during field investigation work is of the utmost importance for the protection of investigation team members. The methods of communication that will be employed are:

- o Walkie talkies,
- o Air horns,
- o Hand signals, and
- o Voice amplification systems.

For external communication, telephones and sirens will be utilized.

#### 7.1.5 Monitoring

Section IX of the HASP explains the health and safety monitoring procedures. A continuous monitoring of the working environment will be performed to ensure the adequacy of the level of personnel protection. Depending on the history of the sampling location, the presence of the following parameters will be monitored:

- o Army agents,
- o Oxygen levels,
- o Explosive conditions,
- o Organic vapor levels, and
- o Inorganic gas levels.

The type of on-site monitoring instruments to be utilized includes, but is not limited to, the following and will be based on the potential for the instrument-specific contaminants to be present:

- o M18A2 Chemical Agent Kit for Army agents;
- o M8 Alarm for nerve agents;
- o Oxygen meter for oxygen levels;
- o Combustible gas indicator for explosive conditions;
- o Photoionization Detector (PID) and Flame Ionization Detector (FID) for organic vapors; and
- o For inorganic gases, a gold film mercury monitor, a chlorine monitor, a carbon monoxide monitor, and a hydrogen sulfide monitor.

In addition, air samples will be collected at the breathing zone with charcoal and Tenax sample tubes and analyzed for volatile contaminants, as described in Section 4.0 of this Technical Plan. Based on the monitoring results (real time and field or laboratory analyses of the health and safety samples) the on-site Health and Safety Field Specialist can stop field investigation work. The upgrading or downgrading of the level of personal protection must be approved by the on-site HS Coordinator.

#### 7.1.6 Sampling

Section X of the HASP explains the safety considerations during the actual sampling event. It describes the safety procedures to be followed for drilling operations, soil, surface water and liquid waste sampling, building sampling, and sampling in a confined space.

#### 7.1.7 Emergency Procedures

The emergency procedures are described in Section XIII to XV of the HASP. Section XIII explains the basic emergency situations; Section XIV describes how to get emergency services (i.e., medical, fire protection, ambulance, etc.) and Section XV outlines the evacuation procedures in case of emergency such as fire, explosion, or a significant release of toxic gases.

### 7.2 TASK 26 SITE-SPECIFIC HEALTH AND SAFETY CONSIDERATIONS

#### 7.2.1 Well Installation/Development/Pump Test/Slug Test

The field phase of this task may involve drilling, constructing, and testing wells. This activity has similar hazards to soil boring operations. All persons entering the worksite will conform to the protective procedures and rules outlined in the project HASP for invasive activities. Protective equipment will be the same as for the boring activities. Well development and testing has the additional hazard of splashing potentially contaminated water. During this phase of the field work, a face shield and splash apron must be worn in addition to other protective equipment. Development water will be tested on a regular basis with the M18A2 kit to detect the presence of chemical agents.

The groundwater in the South Plants/Basin A areas is expected to be contaminated. An evaluation of the potential airborne concentration will be conducted. If volatilization calculations (using worst-case conditions) indicate that airborne concentrations may be significant, or the presence of chemical agents is detected, then Level "B" protection is utilized until the levels of contaminants can be determined to be significantly below the Permissible Exposure Levels set by OSHA. Air samples will be collected at the breathing zone and analyzed for volatile contaminants. If the levels are

found to be insignificant, then the level of protection can be downgraded as appropriate. Personnel will carefully decontaminate, as indicated by the on-site HS Coordinator.

#### 7.2.2 Well Sampling

The level of protection will be based on monitoring results, following the same procedures as those covered in the section above, and as outlined in Section X in the HASP. The sample water itself and materials used in the sampling process are likely to be contaminated with agents, pesticides, or other chemicals. The outside of the sample containers plus all other tools and materials used in the sampling operation will be fully decontaminated after sample collection. The sample containers will also be subject to monitoring and inspection by Health and Safety personnel prior to being shipped to the laboratory. Any excess water from the sampling activity must be drummed and marked "contaminated" with the site location and date.

Ebasco team members will check with the on-site HS Coordinator for additional health and safety recommendations.

## APPENDIX B

### WELL INSTALLATION AND CONSTRUCTION PROCEDURES

#### Introduction

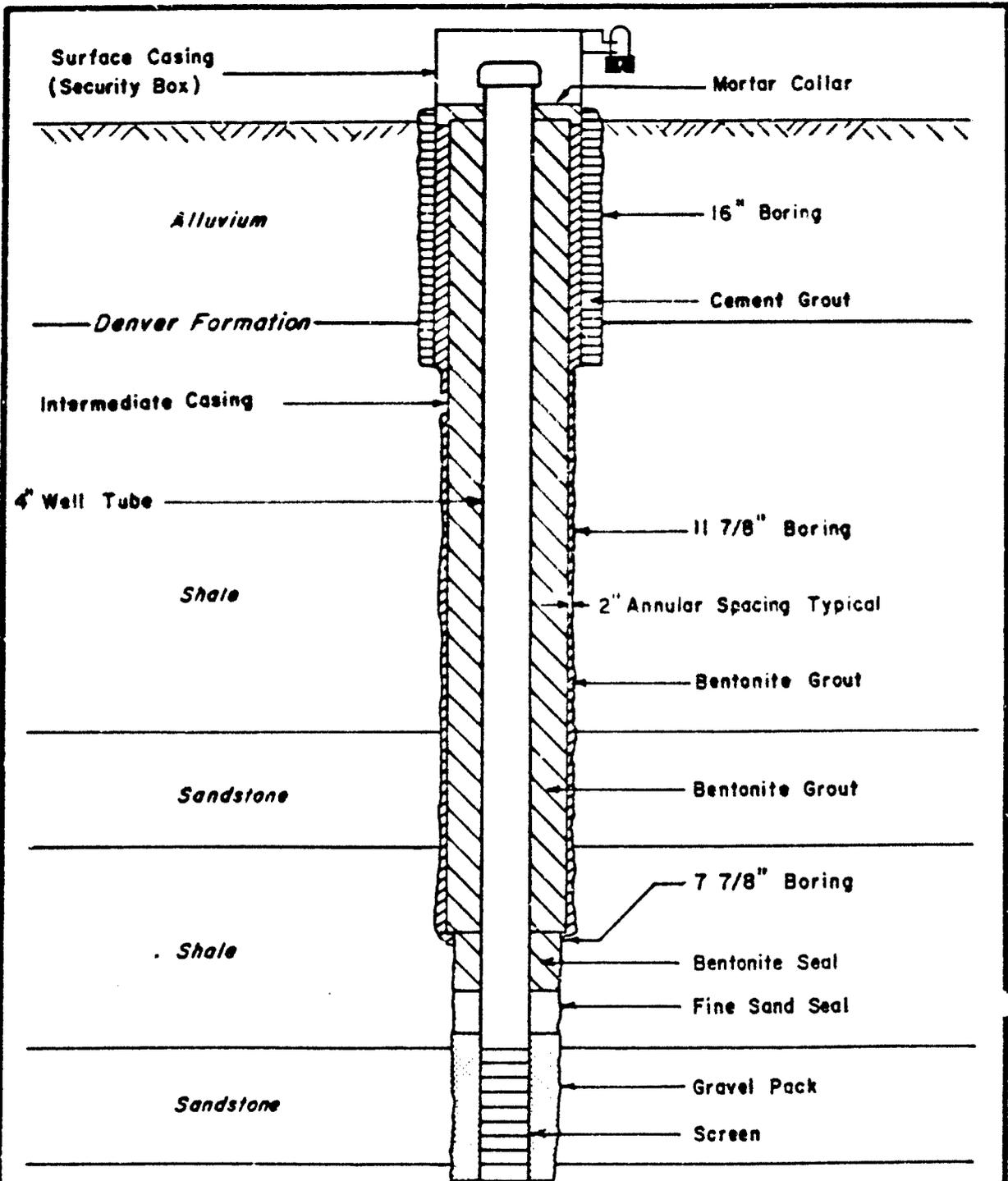
The well installation, and construction procedure described below is for monitoring wells to be completed for Task 26 and is intended to be applied to wells drilled and constructed on the Rocky Mountain Arsenal when conditions indicate that maximum isolation between groundwater zones is required. This method of construction is primarily intended for use in aquifers located below the alluvial aquifer. The method isolates various aquifer units as drilling progresses so that hydraulic communication is never established between the zones. Redundant overlapping seals are in place between the formations when construction is finished. Figure B-1 illustrated this construction technique. The method for shallow well construction where only one groundwater zone is encountered, is presented in the Rocky Mountain Arsenal Procedures Manual to the Technical Plan (Ebasco, 1985). The various stages of construction for the deeper wells are discussed below.

#### Pilot Core Hole

Prior to the construction of any Denver Formation wells at a wellsite, a small diameter pilot core hole will be drilled to the maximum proposed depth to obtain the information needed to make a detailed stratigraphic interpretation of the site and to correctly locate the well screens. Cores will be collected utilizing either a standard core barrel or a wire line type coring device. Surface casing will be installed to keep the borehole open within : : unconsolidated overburden. Coring will be done utilizing water and/or bentonite mud for a drilling fluid.

Cores will be described by an on-site geologist according to the Procedures Manual. The on-site geologist may retain cores for possible laboratory permeability and grain size analysis studies and such cores will be stored in polybutyrate tubes to prevent change in natural moisture content.

B-1



NOTE: Dimensions may vary

No Scale

Prepared for:

Program Manager's Office for  
Rocky Mountain Arsenal Cleanup  
Aberdeen Proving Ground, Maryland

Drafted 11/21/86

FIGURE B-1

Typical Multiple Tube Monitoring  
Well Construction

Rocky Mountain Arsenal, Task 26

Prepared by Ebasco Services Incorporated

Geophysical logging may be performed in the open boring as described in the Geophysical Borehole Logging section. When the geophysical logging is complete, the core hole will be grouted closed to prevent cross-contamination of formations. Grouting will be performed through a conductor pipe to insure uniform placement from the bottom to top. The grout should be either bentonite, or a bentonite/portland cement mixture with no aggregate added.

#### Surface Casing

Figure B-1 is a schematic of a typical monitoring well. The surface casing is the first casing installed, and refers to a casing set through the unconsolidated overburden to the first competent material. Because this casing penetrates an unconsolidated unit, it is constructed in a two stage method. The purpose is to prevent caving of the unconsolidated overburden during drilling and to seal out water in the zone during the remainder of the drilling process. However, when the unconsolidated unit is unsaturated, the surface casing may be eliminated if alternate techniques for prevention of overburden caving are used.

The initial boring will be drilled from the surface to the top of the first Denver shale unit. The boring will be drilled with a rotary rig utilizing water. The boring will continue to penetrate the shale unit up to a depth of 1 ft. When the desired depth of drilling is achieved, the surface casing is to be set. This depth will ensure the casing will isolate lower sand units from the alluvial aquifer. The casing is grouted in-place utilizing the through the casing method.

Grouting through the casing involves placing a quantity of grout inside the surface casing and forcing it out and into the annular space between the casing and the formation with a grouting shoe. Sufficient grout should be used so that excess grout is expelled at the surface. When grout emplacement is completed, the grout should be allowed to cure for a minimum of 24 hours before further work is performed.

Depending on the field conditions, an alternate method may be used for installing the surface casing. The alternate method consists of installing a temporary drive casing in the alluvium with a casing hammer. The material remaining in the drive casing is removed with an auger and the permanent surface casing is grouted into place. This is done by placing a volume of cement grout into the drive casing and floating in the permanent casing which has been plugged at its base with a suitable plug. The drive casing should be about 4 inches greater in diameter than the permanent casing, allowing about a 2-inch annular space in which to displace the grout. Centralizers may be used to maintain a uniform annular space. After the permanent casing is floated into place, the drive casing is withdrawn with a hammer or hydraulic jacks. When the casing is withdrawn, any annular space remaining between the permanent casing and the formation is to be filled with a cement grout. The top of the casing may be stabilized at the ground surface with a coarse aggregate concrete if desired. The top of the permanent surface casing should be left with sufficient stick-up to be completed as a security enclosure. The grouted permanent surface casing should be allowed to cure for a minimum of 24 hours before any further work is performed.

#### Intermediate Casing

The intermediate casing is installed to seal out the water-bearing bedrock formation or formations above the aquifer unit to be monitored and sampled (see Figure B-1). To install the intermediate casing, a drilling bit slightly smaller than the surface casing is utilized. The boring will be drilled with a rotary rig utilizing water. Drilling through the Denver shale is expected to generate a mud which is expected to stabilize the bore hole.

The intermediate boring will be drilled from the base of the surface casing to the top of the Denver shale unit overlying the sand unit to be screened. The boring will continue to penetrate the shale unit up to a depth of 5 ft. When the desired depth of drilling is achieved, the intermediate casing is to be set. This depth will ensure the intermediate casing will isolate the desired sand unit from upper aquifers. The casing is grouted in-place utilizing the through the casing method.

B-4

Grouting through the casing involves placing a quantity of grout inside the intermediate casing and forcing it out and into the annular space between the casing and the formation with a grouting shoe. Sufficient grout should be used so that excess grout is expelled at the surface. When grout emplacement is completed, the grout should be allowed to cure for a minimum of 24 hours before further work is performed.

#### Well Casing

The final stage of construction involves drilling within the intermediate casing, through the remaining shale unit, and into the sand unit to be monitored and sampled (see Figure B-1). A bit slightly smaller than the intermediate casing will be used. This bit size should also permit a minimum 2-inch annular space around the 4-inch monitoring well tube being installed. The final drilling depth should continue 2 feet into the shale underlying the sand unit being sampled. Drilling should be performed with a rotary rig utilizing water and/or bentonite drilling mud.

When the total depth proposed for drilling is reached, the drilling fluid is to be circulated until the boring is free of cuttings. The well screen and riser pipe should be set into the finished boring through the intermediate casing utilizing centralizers to maintain a uniform annular space.

The well screen should be schedule 40 polyvinyl chloride (PVC) with .030 mill slot if the well is to be used as a monitoring device only. The required screen slot may be modified based on examination of the core samples. If the well is to be used as a pumping well for an aquifer test, the screen should be a continuous slot PVC screen with the slot size chosen based on a sieve analysis of a core sample, if available. The riser pipe for the well should be of 4-inch flush joint, threaded, schedule 40 PVC pipe. The entire well tube is to be floated into place through the fluid column in the bore hole.

When the well casing is in place, a gravel pack should be placed from the bottom of the borehole to 5 feet above the top of the well screen. The gravel pack size will be compatible with the formation and slot size. The gravel

pack will be placed through a tremie pipe. When the gravel pack is in place, a 2 foot layer of fine sand, followed by a 5 foot thick bentonite seal will be placed directly above the filter pack to prevent infiltration of the grout seal material.

The entire annular space between the riser pipe and the intermediate casing will be sealed with a bentonite grout. No portland cement or polymers will be added. This grout will be pumped in through a pipe so that the annular space is filled from the bottom upward. After 24 hours, the grout column will be checked and topped off if settlement has occurred. A mortar collar will be installed, and the well will then be developed as described in the Procedures Manual (Ebasco, 1985).

#### Materials Specifications

All drive casing, surface casing, and intermediate casing used will be constructed of steel. Joints will be either flush threaded or welded. Collar joints are to be avoided.

The monitoring well casing and screen are to be constructed of schedule 40 polyvinyl chloride. All joints are to be flush threaded. Screens used for monitoring wells will be of a uniform factory mill-slot type. Screens for wells to be used for aquifer tests will be of a continuous slot PVC design to permit maximum screen opening.

Gravel pack materials for monitoring wells will conform to the Procedures Manual (Ebasco, 1985). Gravel packs used in wells designed for pumping tests will meet the Procedures Manual requirements and in addition will be properly sized for the screen size and formation grain-size distribution.

#### Drilling Mud Handling

Drilling through the Denver shale units with water is expected to produce a mud. The mud will be displaced from the borehole during grouting and casing procedures. The flow of mud from the boring is to be controlled at all times and collected in drums until proper disposal can be arranged.

The purpose of this construction procedure is to minimize cross contamination of formations during drilling. Consequently, the mud generated during installation of the intermediate casing should be removed before drilling into the sampling zone proceeds. Fresh water and/or mud should be used to fill the casing as drilling processes.

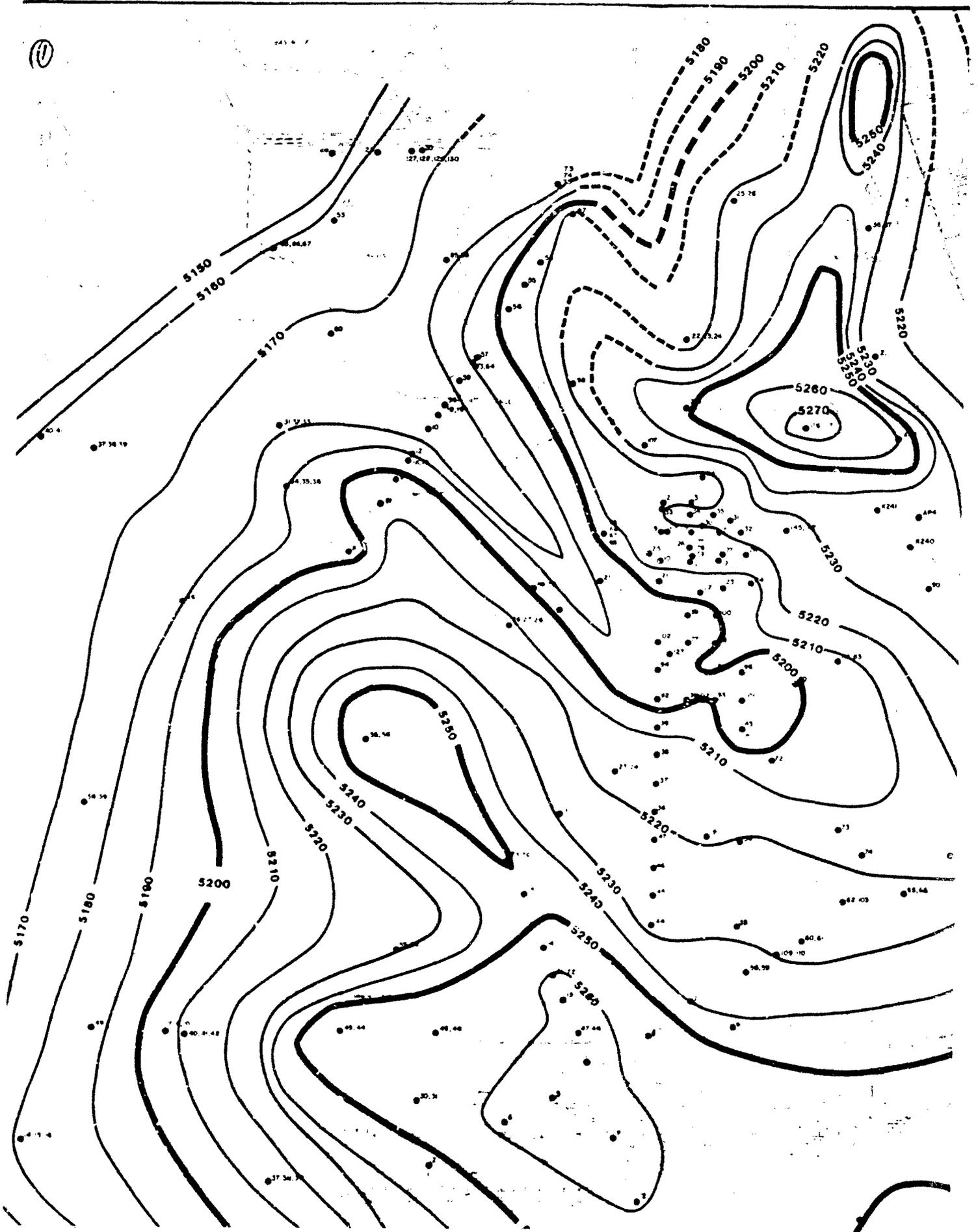
#### Grouting

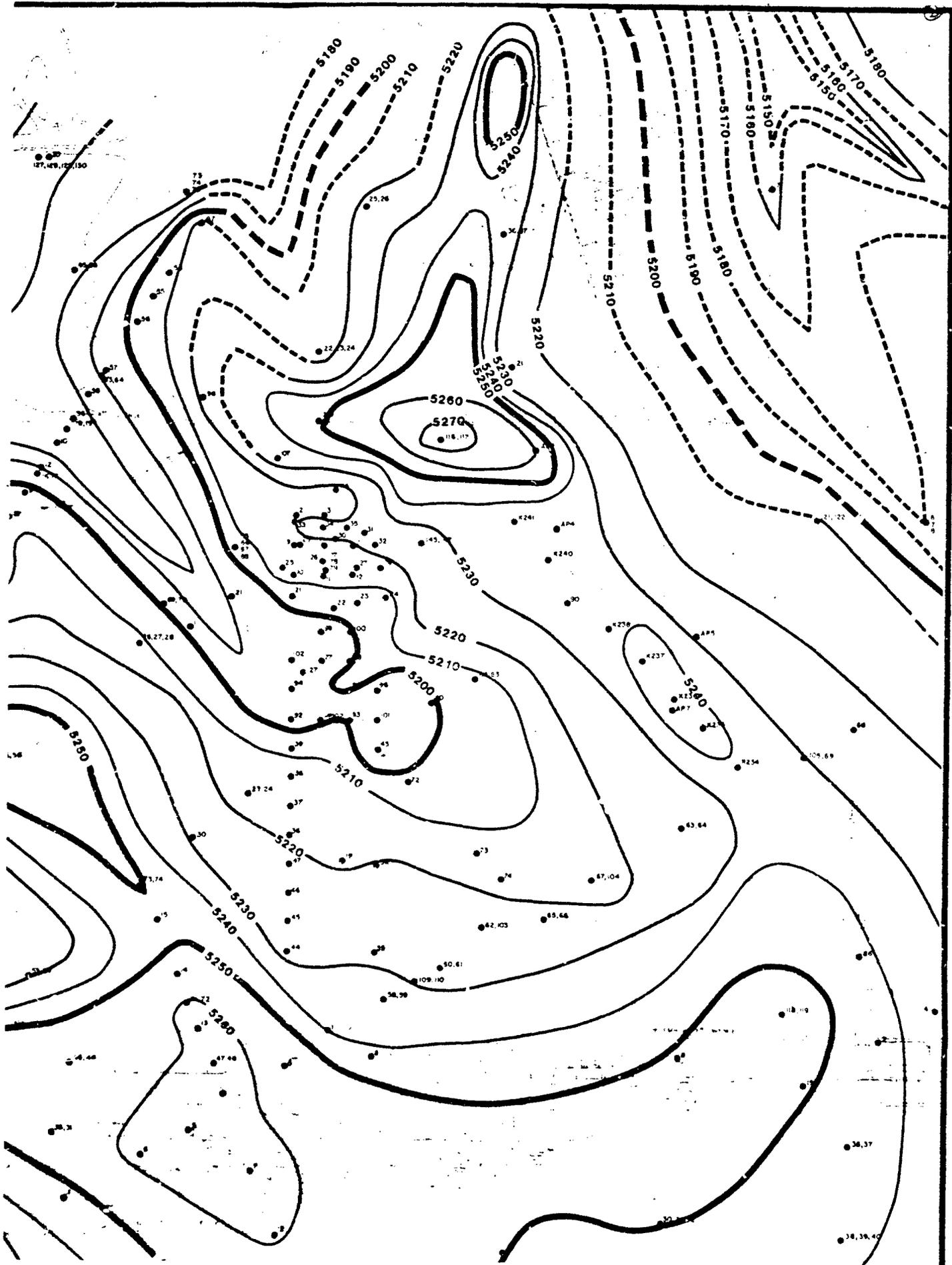
The surface casing will be grouted into place with a Portland cement/bentonite slurry mixed according to the Procedures Manual.

The intermediate casing and well casing will be grouted utilizing the Portland cement/bentonite grout or Volclay Grout, a product of the American Colloid Company. This product is a bentonite clay of the same type used to manufacture pellets. It is to be mixed as a slurry and put into place utilizing the methods discussed above.

#### Geophysical Borehole Logging

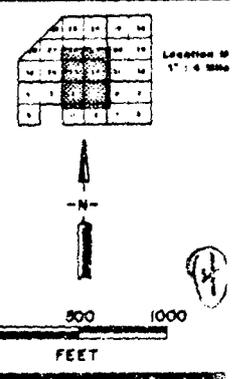
Borehole geophysical logs will be run on selected pilot core holes. They will aid in defining contacts between sand and shale units at a given borehole when core recovery is less than optimal. The recommended suite of logs includes resistivity (e.g., Laterlog), spontaneous potential (SP), gamma ray, acoustic and compensated neutron logs. Resistivity, SP, and natural gamma ray logs will enable the geologist to correlate lithologies from site to site. The acoustic and compensated neutron logs will help determine porosity values for lithologic units at each borehole and will also facilitate geologic correlation efforts.

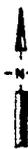
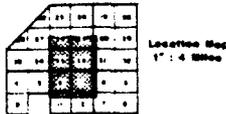






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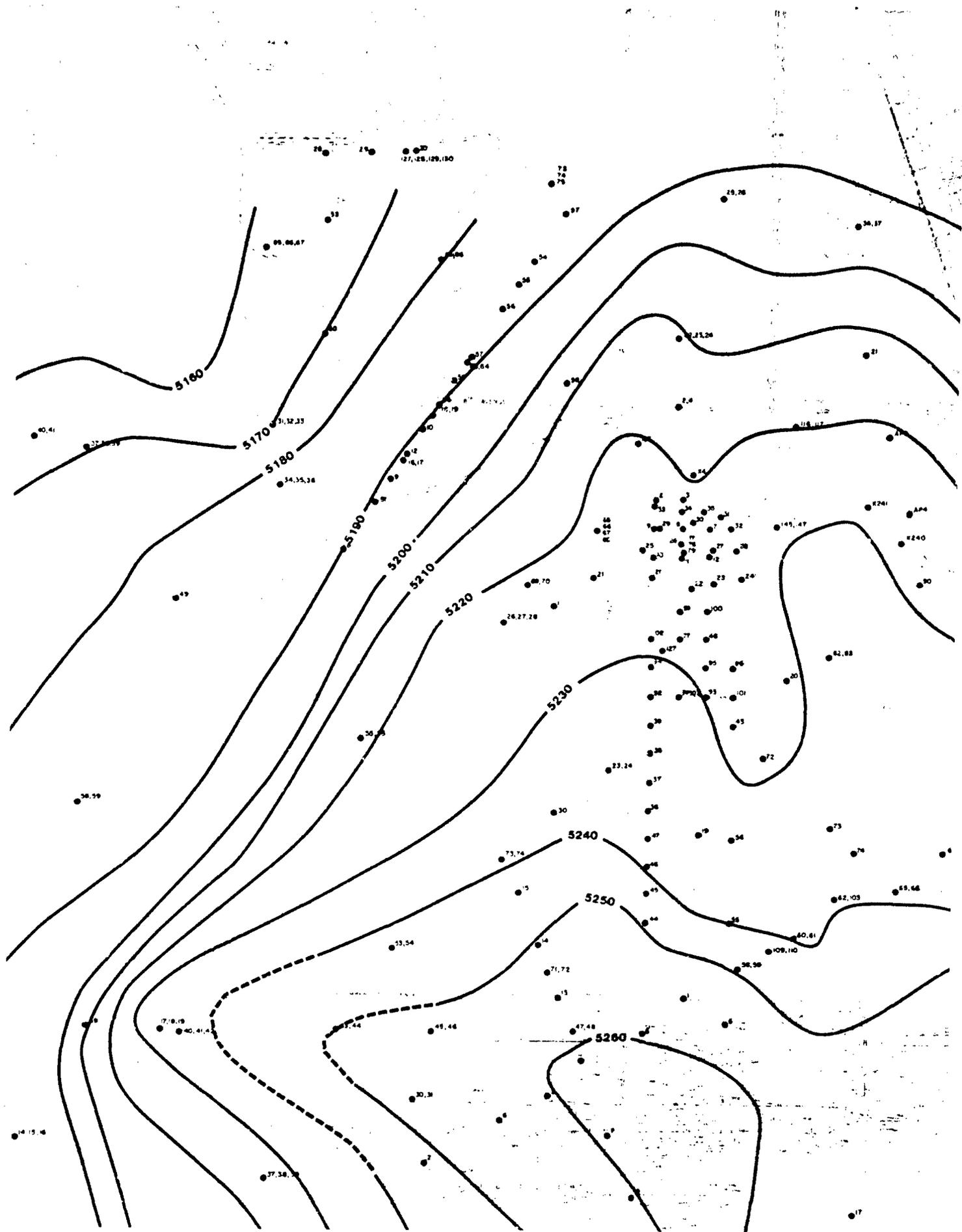


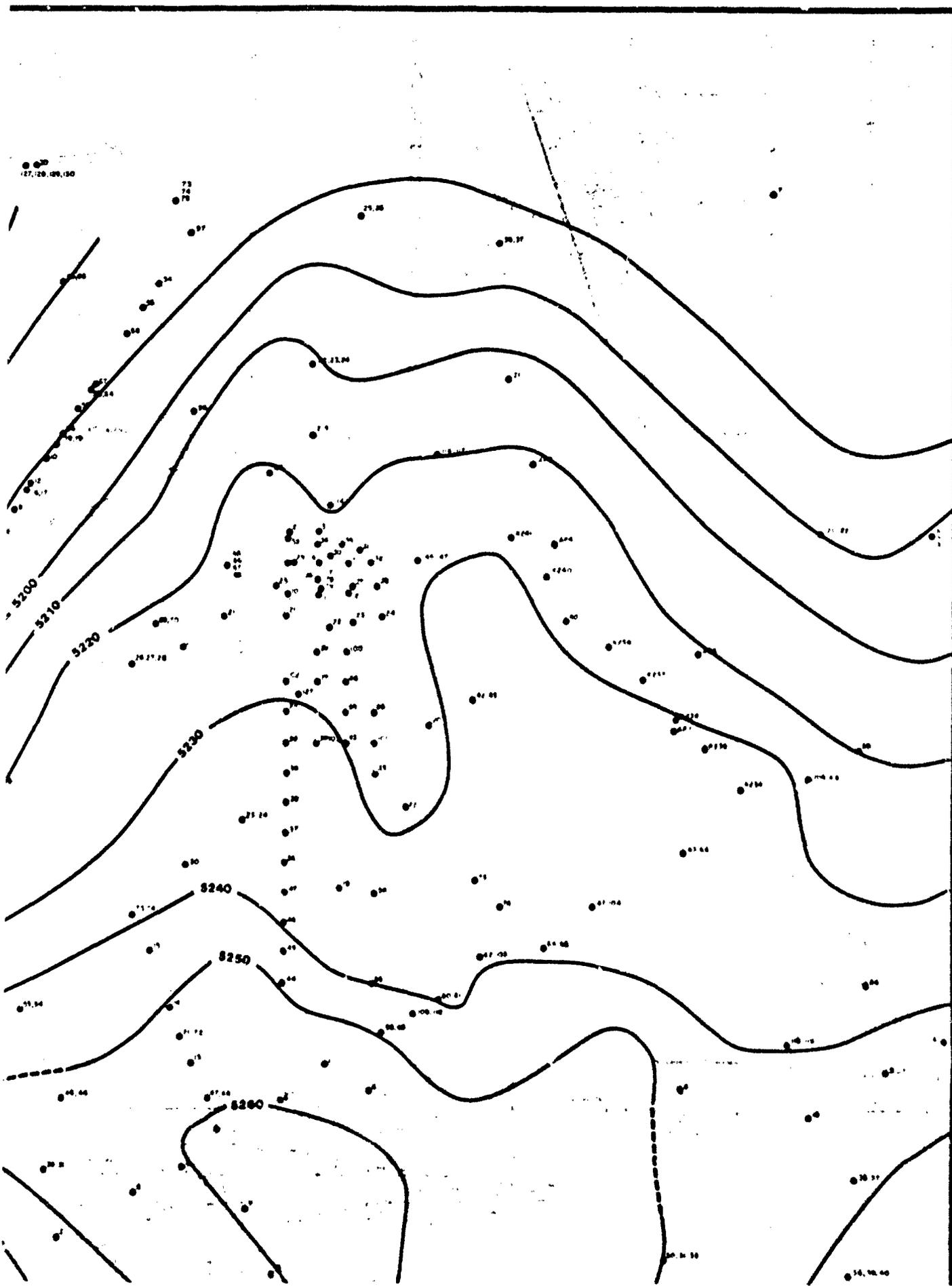


Prepared for:  
 Program Manager's Office for  
 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland  
 Drafted: 11/12/85

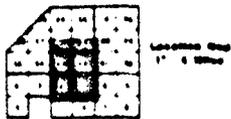
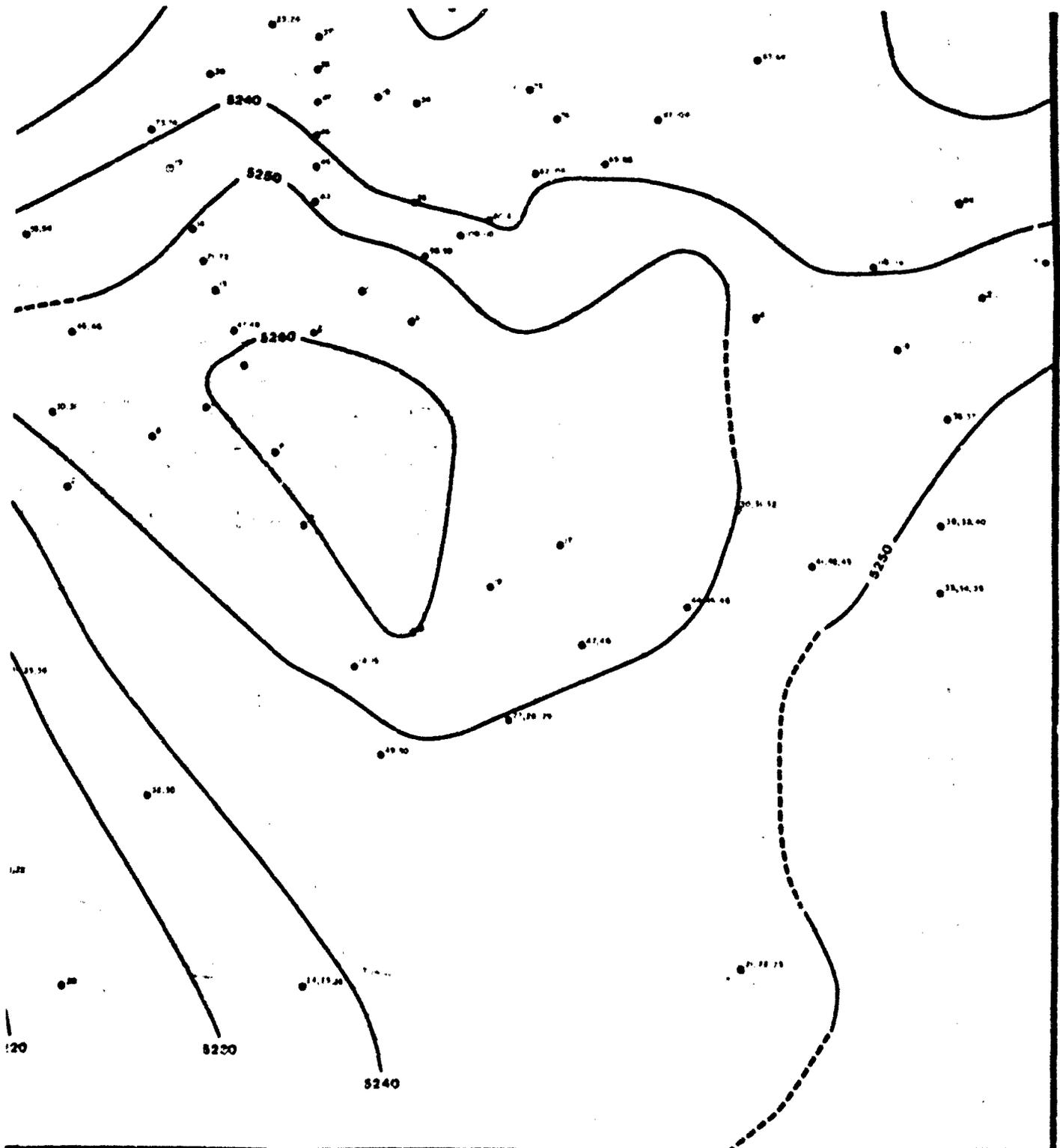
**FIGURE 3.1-1**  
**Structure Contour Map**  
**Top of the Denver Formation**

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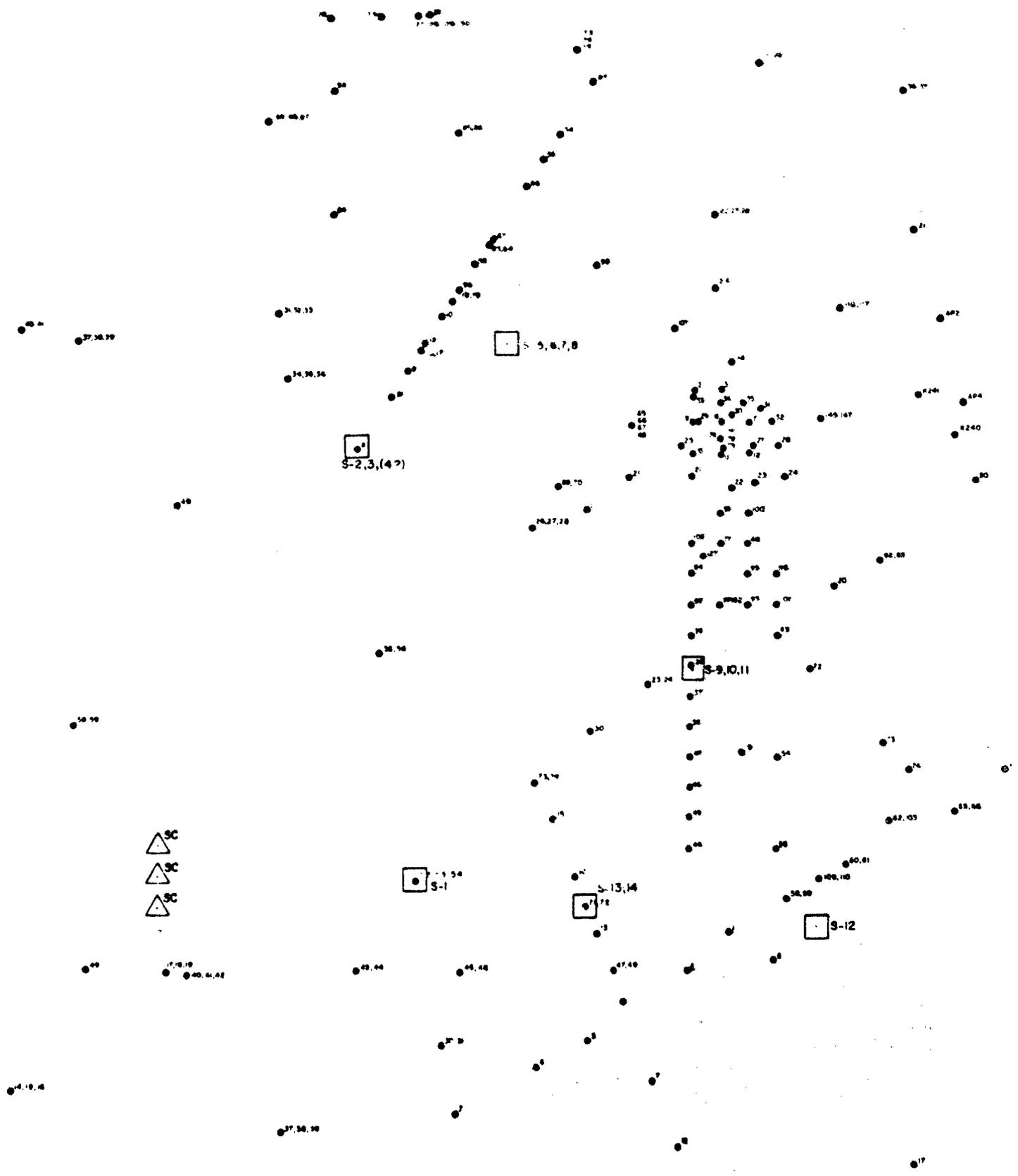






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 Program Manager's Office for  
 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland  
 Dated: 11/12/86

**FIGURE 3.1-8**  
**Water Table Contour Map**  
**Spring, 1986**  
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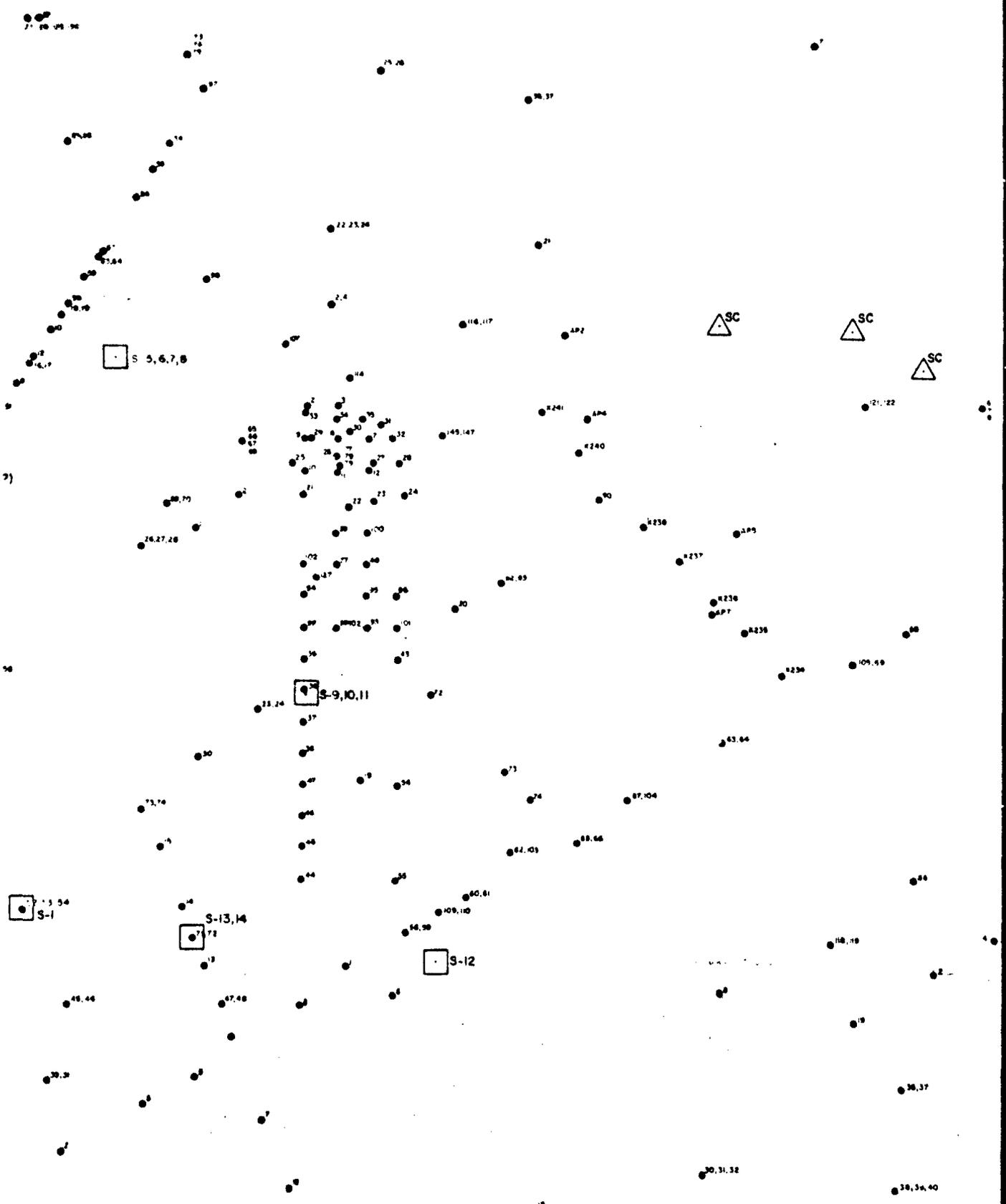
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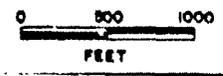
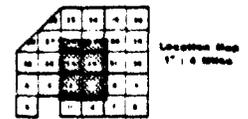
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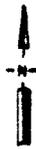
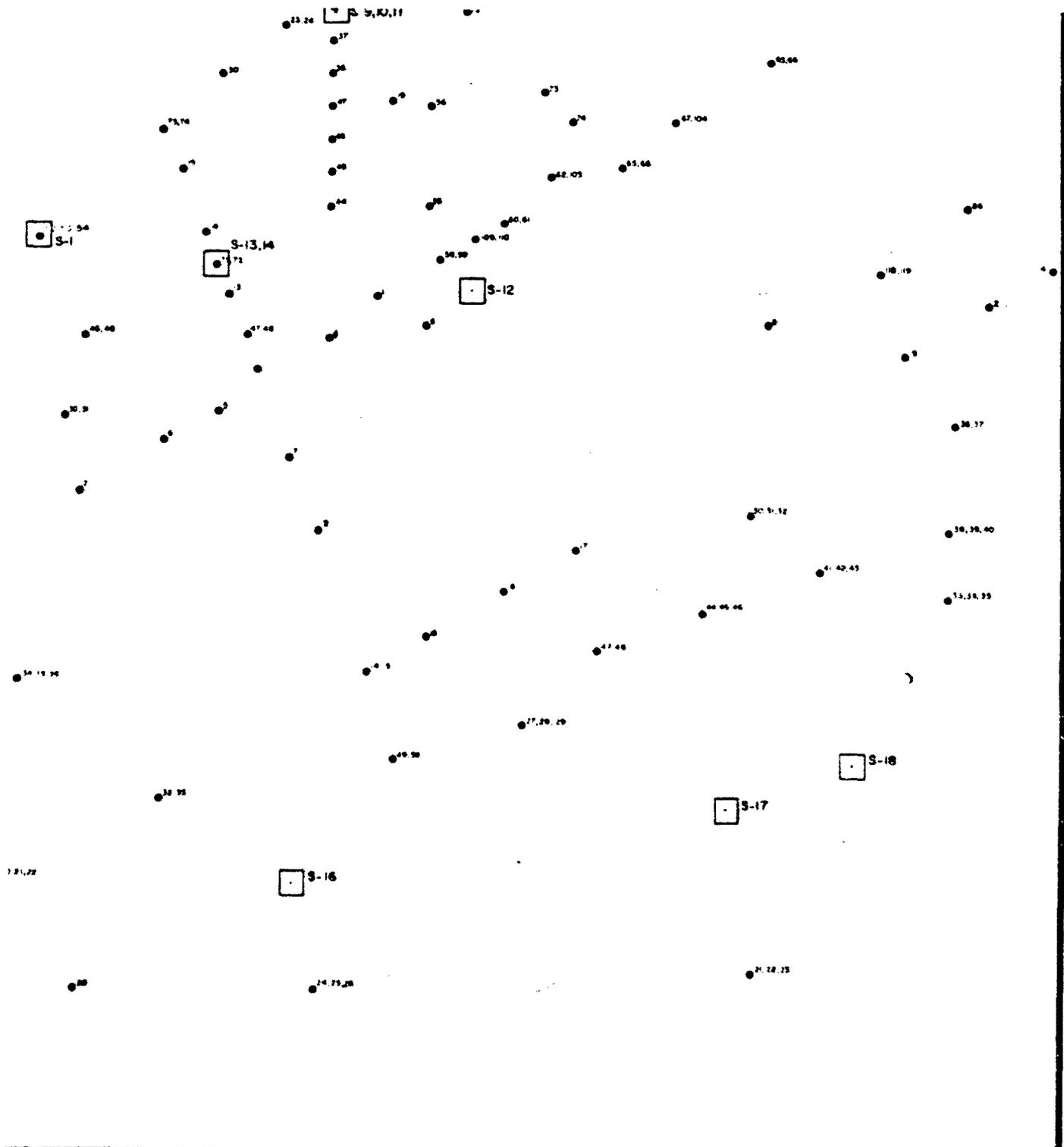




**LEGEND**

- <sup>1,2,13</sup> Existing Wells to be Used in Study
- △<sup>SC</sup> Proposed Shell Wells
- <sup>S-2</sup> Proposed Task 26 Wells





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 Program Manager's Office for  
 Rocky Mountain Arsenal Cleanup  
 Aberdeen Proving Ground, Maryland  
 Drafted: 11/12/86

**FIGURE 3.2-1**  
**Proposed Well Locations**  
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