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THE PURPOSE OF THE TASK 4 WATER SURVEY IS TO EXECUTE A ONE YEAR GROUND AND SURFACE WATER SURVEILLANCE PROGRAM CAPABLE OF:

1. SATISFYING THE VARIOUS REGULATORY REQUIREMENTS
2. DEVELOPING A LITIGATION QUALITY DATABASE
3. VERIFYING THE EXTENT AND NATURE OF KNOWN CONTAMINATION.

THE TECHNICAL ELEMENTS OF THIS SURVEY ARE:

1. REVIEW HISTORICAL DATA
2. DEVELOP A MONITORING PROGRAM
3. EXECUTE THE MONITORING PROGRAM
4. ASSESS THE DATA QUARTERLY FOR POSSIBLE ADJUSTMENTS
5. COMPILE THE DATA AT THE END OF THE PROGRAM.

SECTIONS OF THIS PLAN DETAIL INFORMATION ON THE FOLLOWING:

1. GEOLOGY AND HYDROGEOLOGY
2. GEOTECHNICAL PROGRAM

14. SUBJECT TERMS
SANITARY SEWER, RAIL CLASSIFICATION YARD, MONITORING WELLS

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Rocky Mountain Arsenal

Water Quantity/Quality Survey

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Draft Final Technical Plan

September, 1985
Contract Number DAAK11-84-D-0016
Task Number 4

PREPARED BY

ENVIRONMENTAL SCIENCE & ENGINEERING, INC.
Harding Lawson Associates Midwest Research Institute
Resource Consultants, Inc.

PREPARED FOR

U.S. ARMY TOXIC AND HAZARDOUS MATERIALS AGENCY

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LIST OF ACRONYMS AND ABBREVIATIONS
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AMC	U.S. Army Material Command
AR	Army Regulation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CDRL	Contract Requirements Lists
CFI	Colorado Fuel and Iron Corporation
cm	centimeters
cm/sec	centimeters-per-second
COR	Contracting Officer's Representative
DBCP	dibromochloropropane
DCPD	dicyclopentadiene
DDT	dichlorodiphenyltrichloroethane
DIMP	diisopropylmethylphosphonate
DMMP	dimethylmethylphosphonate
ESE	Environmental Science and Engineering, Inc.
ft	feet
gpd/ft	gallons-per-day feet
ha	hectares
HLA	Harding Lawson Associates, Inc.
IC	Irondale System
in	inches

LIST OF ACRONYMS AND ABBREVIATIONS
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IR-DMS	Installation Restoration Data Management System
km	kilometers
m	meters
MRI	Midwest Research Institute
NBC	North Boundary Control System
NWBC	Northwest Boundary Control System
NWS	National Weather Service
OSHA	Occupational Safety and Health Act
QA	Quality Assurance
QC	Quality Control
RCI	Resource Consultants, Inc.
RCRA	Resource Conservation and Recovery Act
RIC	Rocky Mountain Arsenal Resource Information Center
RMA	Rocky Mountain Arsenal
Shell	Shell Chemical Company
STP	Sewage Treatment Plant
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
HCCPD	hexachlorocyclopentadiene
GC/MS	gas chromatography/mass spectrometry
WBS	Work Breakdown Structure

1.0 INTRODUCTION

1.1 DESCRIPTION OF THE RMA PROBLEM

The Rocky Mountain Arsenal (RMA) occupies over 6,880 hectares (ha) (27 square miles) in Adams County, Colorado, and is located approximately 15 kilometers (km) northeast of downtown Denver (Figure 1.1-1). RMA was established in 1942 and has been used for the manufacture of chemical and incendiary munitions as well as chemical munitions demilitarization. Industrial chemicals were manufactured at RMA from 1947 to 1982.

The property occupied by RMA was purchased by the government in 1942. Throughout World War II (WWII), RMA manufactured and assembled chemical intermediate, toxic end-item products, and incendiary munitions.

During the period 1945 to 1950, RMA distilled stocks of Levinstein mustard, demilitarized several million rounds of mustard-filled shells, and test-fired 10.7 centimeter (cm) mortar rounds filled with smoke and high explosives. Also, many different types of obsolete WWII ordinance were destroyed by detonation or burning.

In 1947, certain portions of RMA were leased to the Colorado Fuel and Iron Corporation (CF&I) for chemical manufacturing. CF&I manufactured chlorinated benzenes and dichlorodiphenyltrichloroethane (DDT). Julius Hyman and Company assumed the CF&I lease in 1950 and Hyman produced several pesticides. Shell Chemical Company (Shell) later assumed the pesticide and herbicide manufacturing operations.

In the early 1950's, RMA was selected as the site for construction of a facility to produce chemical agent. This facility was completed in 1953, with the manufacturing operation continuing until 1957, and the munitions filling operations continuing until late 1969. Since 1970, RMA has been involved primarily with the disposal of chemical warfare material.

Disposal practices at RMA have included routine discharge of industrial waste effluents to unlined evaporation basins and burial of solid wastes at various locations. In addition, unintentional spills of raw

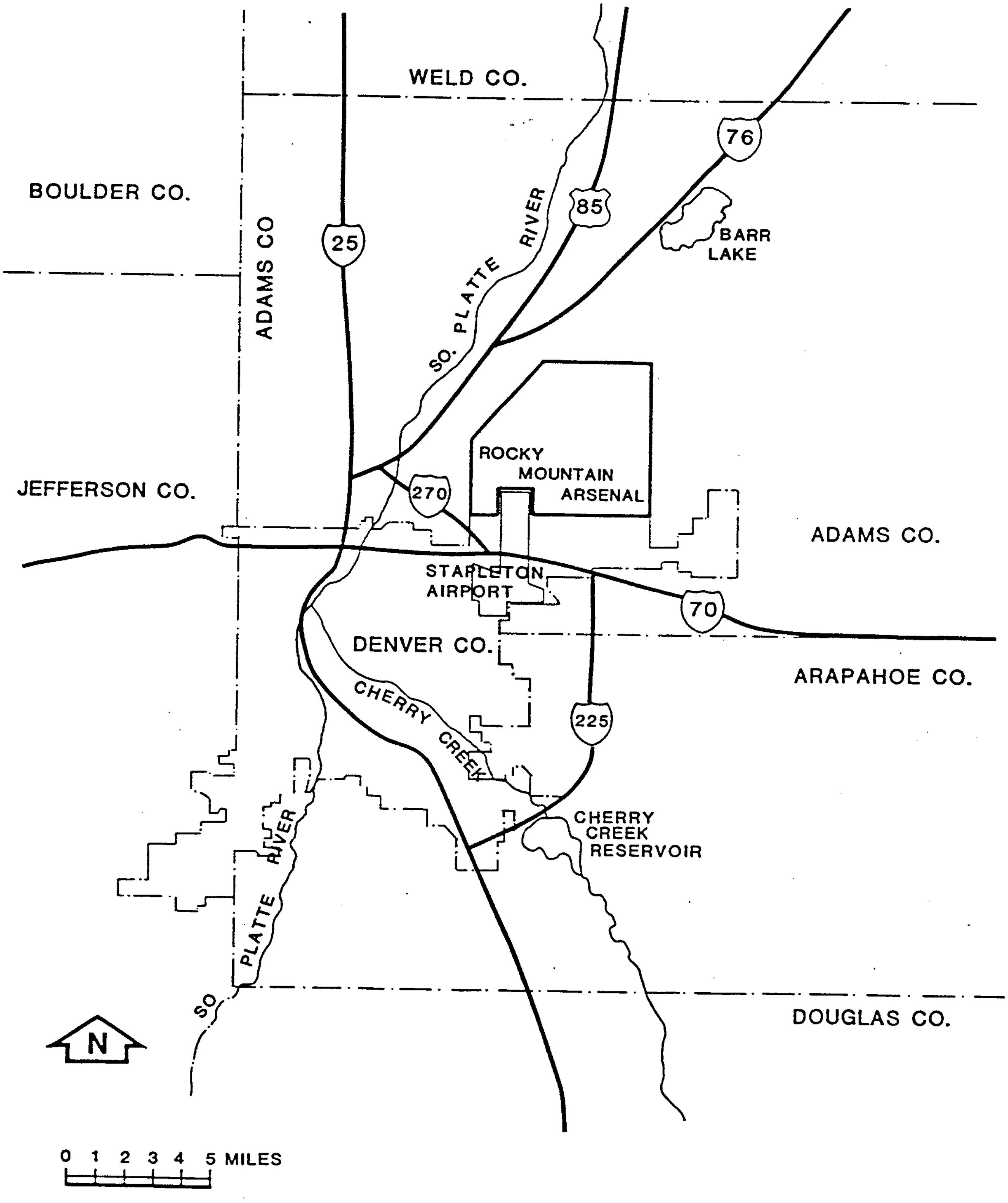

Figure 1.1-1
LOCATION MAP

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materials, process intermediates, and final products have occurred within the manufacturing complexes at RMA. Many of the compounds are mobile in surface and ground waters as well as air.

In 1954 and 1955 farmers to the northwest of RMA reported severe crop losses due to use of well water for irrigation. In 1974 two contaminants, diisopropylmethylphosphonate (DIMP), which is a by-product of manufacture of GB nerve agent, and dicyclopentadiene (DCPD), a chemical used in insecticide production, were detected in offpost surface water. Since 1978 offpost migration of dibromochloropropane (DBCP), a nematocide which had been shipped from RMA by rail from 1970 to 1975, has been observed in ground water.

In response to the detection of offsite contamination migration, the State of Colorado issued a Cease and Desist Order in 1975 which required RMA to initiate a regional hydrologic surveillance program. This program, known as the 360° Program, involves the quarterly collection and analyses of over 100 onpost/offpost surface and ground water samples. In addition to the 360° Program various other programs have been implemented. Similar to the 360° Program, the other programs are utilized for monitoring and surveillance to satisfy regulatory and operational requirements at RMA.

As part of the investigation of environmental conditions present at RMA, the necessity to establish a litigation quality data base for surface and ground water quantity and quality has been recognized. Task 4 addresses this need by providing the technical support necessary to develop a water balance and water quality assessment for RMA.

Under this task a one year ground water and surface water surveillance program will be performed throughout RMA to achieve the following objectives:

- o Satisfy compliance oriented regulatory requirements under Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and Resource Conservation and

Recovery Act (RCRA) and the intent of the Cease and Desist Order;

- o Develop a core data base for use in upcoming litigation and Remedial Investigation/Feasibility Study analyses for RMA; and
- o Confirm the existence and chemical nature of known contamination and monitor any changes in the lateral and vertical extent of contaminant migration.

All studies under this task will be performed in accordance with the requirements and technical specifications discussed in Section C-3 and Appendices A (U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) Quality Assurance Program, 1982) and B (USATHAMA Geotechnical Requirement, 1983) of Contract DAAK11-84-D-0016, except where modified as required for technical/litigation standardization. Standardized methods, protocols, and criteria will be consistent with those proposed in Tasks 1 and 2, and as standardized during subsequent meetings between the government and contractors. Services will consist of collection, analysis, and interpretation of environmental data for both surface and ground water. Data will be collected during a 12-month period and will include stream flow, ground water level, and water quality evaluations. Acquired data will be utilized as input into the litigation effort.

1.2 WATER QUANTITY AND QUALITY

1.2.1 GEOLOGY

RMA is located within the geologic province of the Denver Basin, a structural depression resulting from tectonic adjustments which occurred intermittently throughout time. The basin exhibits an elongate, north-south trending surface expression 500 km long and 300 km wide in north-central Colorado, Wyoming, and Nebraska. Cambrian to Quaternary Age sedimentary strata, composed of conglomerate, sandstone, shale and limestone lithologies rest on the Precambrian crystalline basement and fill the structural despression.

RMA lies on the bedrock surface formed by the late Cretaceous-early Tertitary Denver Formation. Quaternary alluvial and eolian deposits (locally referred to as alluvium) mantle the surface and obscure the

Denver Formation over most of RMA (Figure 1.2-1). Regional dip is to the southeast.

Alluvium

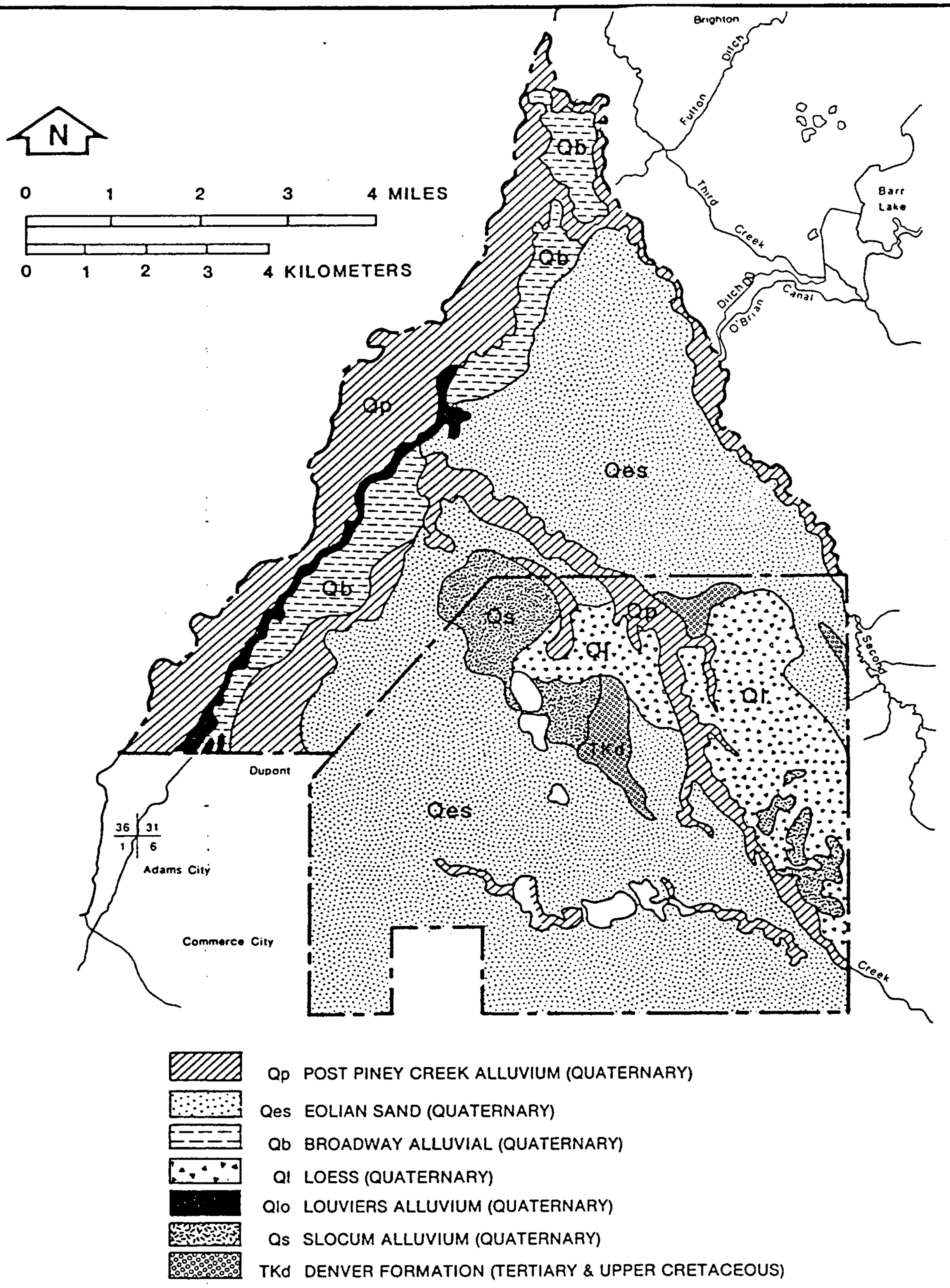
Sediments present at the land surface consist of unconsolidated alluvial and eolian deposits of the Quaternary age. The material is composed primarily of valley fill, dune sand, and terrace gravel which contains cobbles, boulders, and beds of volcanic ash as well as sands, gravels, silts, and clays. Combined thickness of the surficial materials ranges from 10 to 40 meters (m). The thicker deposits represent filling of paleochannels cut in the surface of the Denver Formation. Lithologic logs in the intrachannel areas indicate anomalously thick sequences of overburden drilled before penetrating the Denver. Colors range from yellow-brown to pale orange and are a product of oxidation. Locally, deposits may be consolidated where calcium carbonate has cemented sands and gravels to form conglomerates.

Denver Formation

The Denver Formation underlying RMA consists of 70 to 120 m of olive, bluish gray, green-gray, and brown clay shale and siltstone interbedded with poorly sorted, weakly lithified tan to brown, fine to medium grained, lenticular sandstone and conglomerate. The sand lenses are composed predominantly of poorly cemented sandstone which grades laterally and vertically into silts and clay shales. Lignite beds and carbonaceous shales are common, as are volcanic fragments and tuffaceous materials but to a lesser degree. Minor beds of bentonite may also be present. The predominant olive and green-gray colors resulting from erosion and weathering of andesitic and basaltic lavas help distinguish the formation.

1.2.2 GROUND WATER HYDROLOGY

The aquifers of primary concern at RMA are the alluvial aquifer and the Denver aquifer (Figure 1.2-2). The alluvial aquifer, also termed the upper aquifer, consists of interbedded sands, silts, clays and gravels of fluvial and aeolian origin. The contact between these deposits and the underlying Denver Formation is often marked by a zone of weathered



SOURCE: USGS, 1981

Figure 1.2-1
GEOLOGIC MAP OF RMA AREA

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Aberdeen Proving Ground, Maryland

Era	System or Period	Series	Geologic Unit	
Cenozoic	Quaternary	Recent and Pleistocene	**Quaternary surficial deposits**	Stream channel, flood-plain and terrace deposits; eolian sand, etc.
	Tertiary	Oligocene	Castle Rock Conglomerate	
			Tertiary intrusive and extrusive rocks	
Cenozoic and Mesozoic	Teriary and Cretaceous	Paleocene ---?--- Upper Cretaceous	Dawson Group	**Dawson Arkose**
				Denver Formation
				Arapahoe Formation
Mesozoic	Cretaceous		Laramie Formation	**Upper part**
				B sandstone
				A sandstone
			Fox Hills Sandstone	**Milliken Sandstone**
				lower part
			Pierre Formation	
			Niobrara Formation	Smoky Hill Shale
				Fort Hayes Limestone
			Brenton Formation	Carlile Shale
				Greenhorn Limestone
				Graneros Shale
		Lower Cretaceous	Dakota Group	**South Platte Formation**
				Lytle Formation
	Jurrassic	Upper Jurassic	Morrison Formation	
			Ralston Creek Formation	
Palezoic	Triassic and Permian		Lykins Formation	Strain Shale
				Glennon Limestone
				Bergan Shale
				Falcon Limestone
				Harriman Shale
	Permain		**Lyons Sandstone**	
	Pennsylvanian		**Fountain Formation**	
			Glen Eyrie Formation	
	Mississipian		Madison Limestone	
			Williams Canyon Limestone	
	Ordovician and Cambrian		Manitou Dolomite	
	Cambrian		Sawatch Sandstone	
Precambrian			crystalline rocks	

Principal Aquifers in Boldface Type

Figure 1.2-2
GENERALIZED COMPOSITE SECTION OF THE GEOLOGIC UNITS OF THE DENVER BASIN
SOURCE: ROMERO, 1976

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bedrock. Where present, the zone is thin and should not be confused with the thicker Denver Sands that can be in contact with the alluvium. The zone is considered to be part of the alluvial aquifer system.

As determined from pumping tests the hydraulic conductivity (permeability) of the alluvial aquifer ranges from approximately 1.0 to 1.0×10^{-3} centimeters per second (cm/sec) (May, 1982), with the higher values associated with buried channels. The transmissivity ranges from 1,500 to 250,000 gallons per day per foot (gpd/ft) while the storage coefficient ranges from less than 10^{-5} to more than 0.4 (RMA-CCPMT, 1983).

The Denver aquifer, also referred to as the lower aquifer, bedrock aquifer or Denver Sands, is composed primarily of lenses of weakly cemented sandstone or compact fine to medium grained sands. These lenticular sands grade laterally and vertically into relatively impermeable silts and clay shales.

As determined from slug tests and laboratory tests, the hydraulic conductivity of the Denver Sands is approximately 10^{-3} to 10^{-4} cm/sec compared to 10^{-7} cm/sec for the clay shales (May, 1982). The transmissivity of the sands ranges from 10 to 1×10^{-5} gpd/ft and storage coefficients are highly variable ranging from 10^{-1} to 10^{-8}.

The ground water flow paths of the two primary aquifers at RMA are complicated by the following factors:

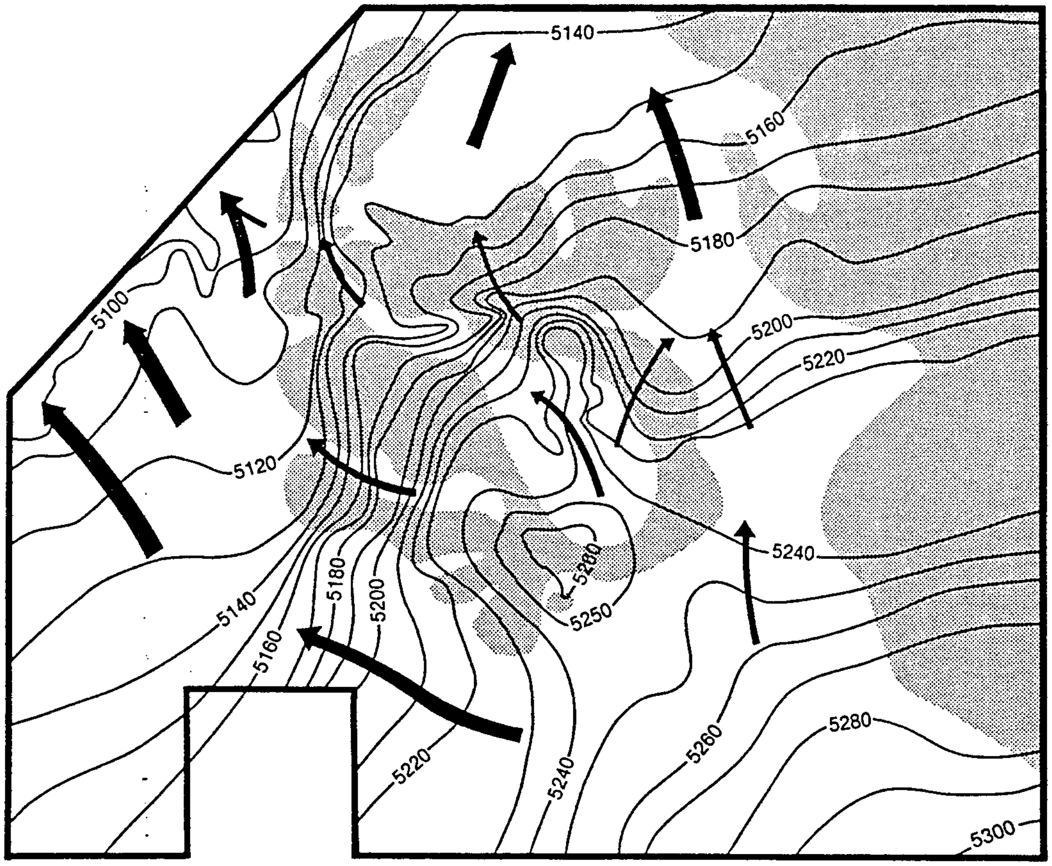
- Contrasts in permeability between the buried channels, adjacent alluvium, and weathered bedrock that make up the alluvial aquifer;
- Contrasts in permeability between the Denver Sands, adjacent clay shales and overlying alluvial materials;
- The complex relationships between the two aquifers and;
- The geometry of the recharge and discharge areas.

Flow within the alluvial aquifer generally occurs in a north to northwesterly direction, perpendicular to the water table gradient

(Figure 1.2-3). Variations to this general pattern occur as a result of the strong control on permeability exerted by the buried channels within the alluvium. Variations are also a result of recharge from spills and leaking water lines in the South Plants Area and infiltration of surface water in Basin A, which have resulted in a large ground water mound in this area. Other sources of recharge to the alluvium include infiltration of precipitation, regional flow that enters the alluvial aquifer to the south of RMA, and recharge from upward flow from the underlying Denver Sands. Ground water in the alluvial aquifer beneath RMA flows offsite beneath the north and northwest boundaries and eventually discharges to the South Platte River or is removed from the aquifer by high capacity municipal and agricultural supply wells located downgradient of RMA.

Ground water flow within the Denver Sands also occurs in a generally north to northwesterly direction. Due to the confining effect of the clay shales, and the fact that the Denver aquifer is recharged by the overlying Dawson Arkose south of RMA, artesian conditions exist in much of the aquifer. Recharge to the Denver occurs as downward flow from the overlying Dawson Aquifer to the south of RMA, infiltration of precipitation on the outcrop area along the margins of the Denver basin, and locally as downward flow from the overlying alluvial aquifer (Figure 1.2-4). Discharge from the Denver aquifer occurs primarily from flow into the underlying Arapahoe aquifer, recharge to the overlying alluvial aquifer, and discharges associated with domestic and irrigation wells.

As a result of the artesian nature and heterogenity of the Denver Aquifer and the erosional contact between it and the overlying alluvium, a complex relationship exists between the Denver and alluvial aquifers. Beneath RMA, flow within the Denver generally occurs up dip resulting in discharge to the overlying alluvial aquifer (Figure 1.2-5). The majority of this flow occurs within the sand lenses with a lesser amount in the surrounding clays and shales. Due to the erosional contact between the Denver sands and the alluvium, flow within the sands varies from confined to semi-confined to unconfined beneath RMA.



NUMBERS ON THIS FIGURE ARE IN FEET ABOVE MSL TAKEN IN 3RD QUARTER 1981.

SHADED AREA REPRESENTS AREAS WHERE WATER TABLE IS BELOW THE ALLUVIAL-DENVER CONTACT

0 1 2 MILES

FLOW COMPONENTS

Figure 1.2-3
PRIMARY FLOW COMPONENTS AT RMA

SOURCE: RMA-CCMT, 1983

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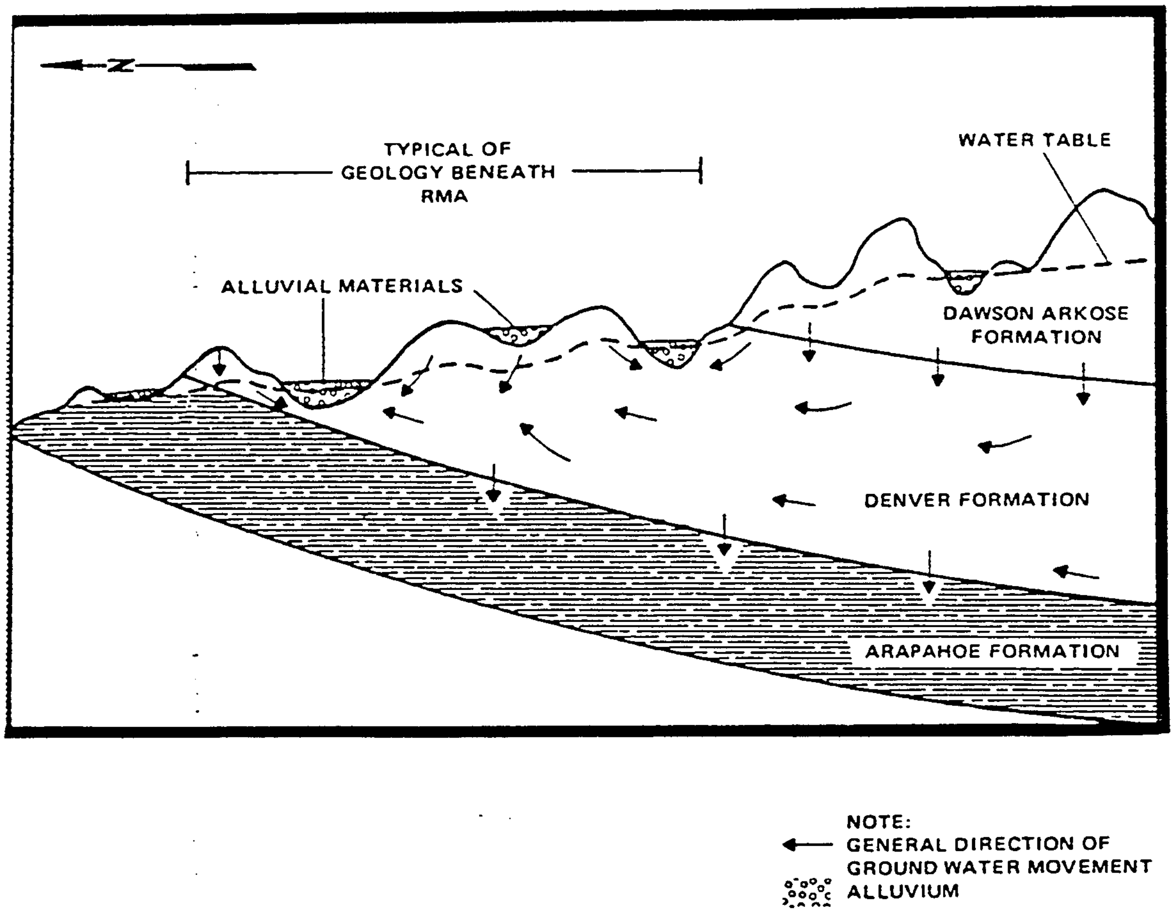

Figure 1.2-4
REGIONAL HYDROGEOLOGIC FLOW SECTION IN THE VICINITY OF RMA

SOURCE: RMA-CCMT, 1983

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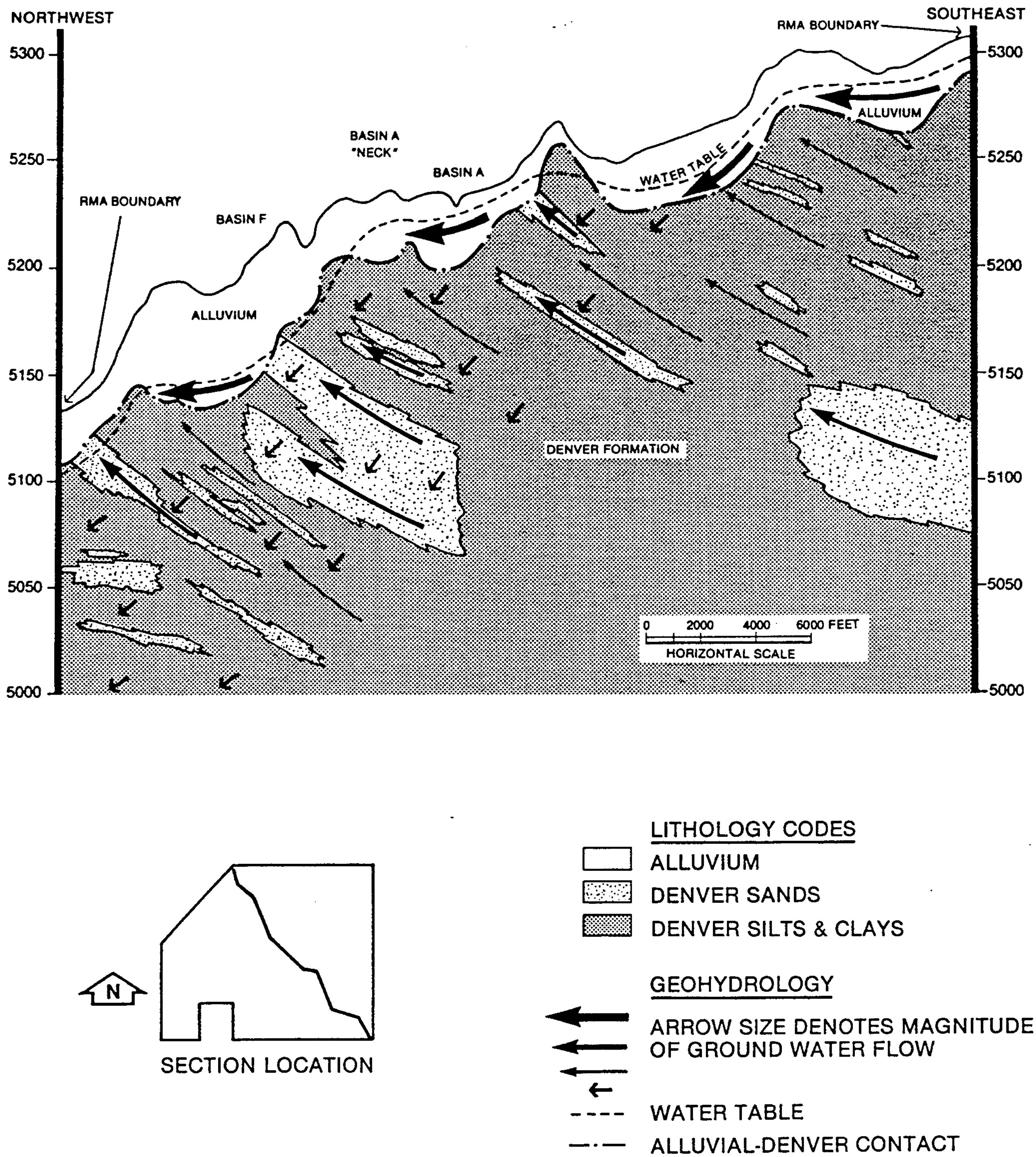

Figure 1.2-5
HYDROGEOLOGIC SECTION ACROSS RMA

SOURCE: RMA-CCMT, 1983

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1.2.3 SURFACE WATER HYDROLOGY

The surface water hydrology at RMA is dominated by two major drainage basins; Irondale Gulch and First Creek (Figure 1.2-6). First Creek has a well defined channel that crosses the east and north boundaries of RMA. During the spring and major storm events, flow within First Creek is continuous. Flow at other times is intermittent. Effluent from the RMA wastewater treatment plant contributes to flow in the creek at the north boundary.

Irondale Gulch is characterized by many small basins which are connected only during major flood events. Irondale Gulch has poorly defined channelization. The drainage area is much smaller than that of First Creek and have been modified by construction of subdivisions, the Lower Lakes, man-made channels, and storm drains. There are four major flow routes within this drainage basin:

- The Highline Lateral is a man-made channel which serves as an overflow for creeks in southeastern Denver. Flows are occasional and controlled by man-made structures. Water in the Lateral ultimately reaches Lower Derby Lake or Upper Derby Lake;
- The Uvalda Interceptor collects storm runoff from the residential area south of RMA and transports it to Lower Derby Lake or Upper Derby Lake. This is a well defined unlined channel which has been breached during major flood events;
- The flows in the Havana Interceptor consist of storm and nuisance flows from Stapleton, a large industrial complex, and portions of the Montbello residential area. The flows empty into a large surface impoundment, known as Havana Pond, that acts as a source of recharge to the ground water. Water from the pond can also be released through an unlined ditch that runs east and to the Sand Creek lateral; and
- The final major flow route within the Irondale Gulch drainage is the Lower Lakes. The Lower Lakes consist of four man-made lakes and one pond. Upper Derby Lake serves as an overflow in case of flood. Lower Derby Lake, which receives the local storm runoff is in direct contact with the water table. Lake Ladora serves as a cooling water source for the RMA power station. Approximately two hundred and fifty thousand gallons per day

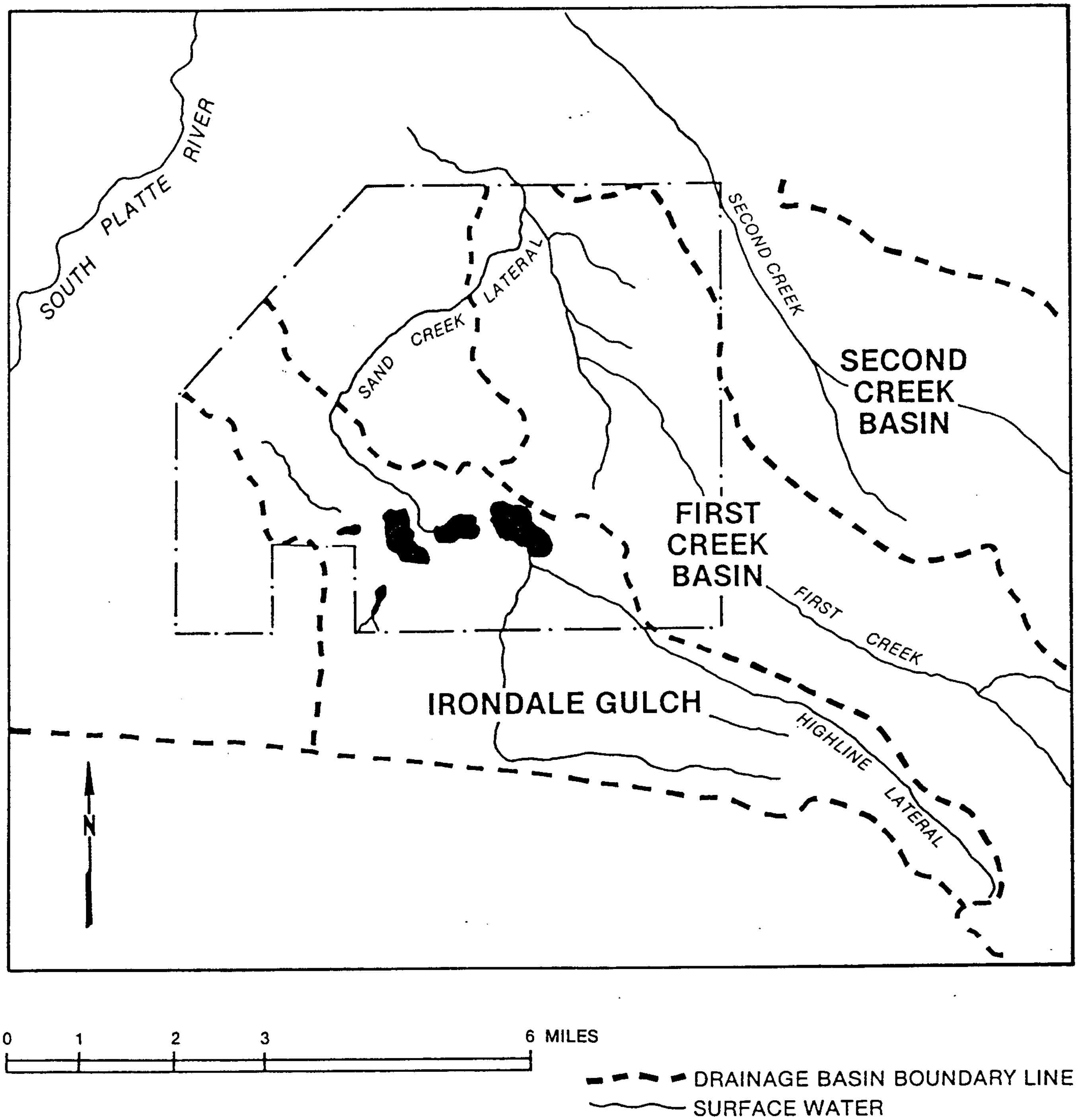


Figure 1.2-6
BOUNDARIES OF MAJOR DRAINAGE BASINS THAT FLOW ACROSS THE ROCKY MOUNTAIN ARSENAL
SOURCE: RMA-CCPMT, 1983

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

have lost to evaporation and leaking pipes. The remainder is recharge to the ground water through Lake Ladora which is also in direct contact with the water table. The Derby and Ladora Lakes are both recharge and discharge areas. During periods of high flow (March through August), ground water is replenished through these lakes. During periods of low surface flows (September through February), ground water is released to surface water through the lakes. Lake Mary, located west of Ladora, is not in contact with the water table and therefore is primarily a recharge area. The Rod and Gun Club Pond was created during a major flood. This pond is usually dry except during major flood events when it receives overflow from the Uvalda Interceptor and Lower Derby Lake.

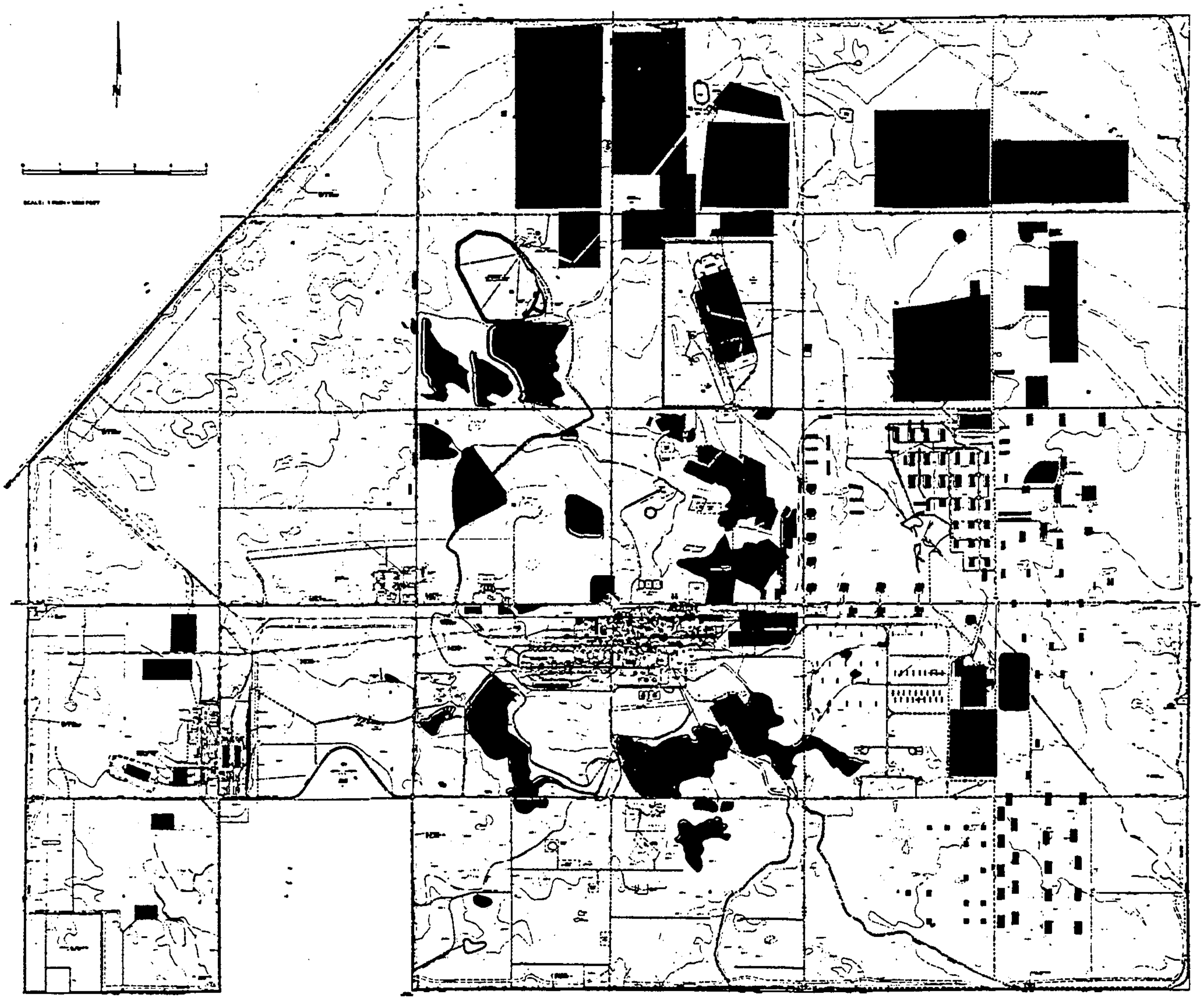
In addition to the First Creek and Irondale Gulch drainage basins, many minor flow paths exist on RMA. The Sand Creek Lateral is a man-made conduit which was used to transport contaminated effluent and fresh lake water to basins in Section 26. An active flow route for storm runoff extends from the South Plants Area to Basin A where the water ponds and eventually evaporates or infiltrates. The North Plants Area also has an active storm drainage outfall which transports flow to First Creek. All of these flow paths are unlined and have a high potential to provide recharge to the ground water system. Another well defined drainage, Second Creek, crosses the extreme northeast corner of RMA. Only a very small portion of RMA is affected by this drainage.

1.2.4 CONTAMINANT SOURCES

The primary sources of ground water contamination at RMA are the South Plants Area, Basins A, B, C, D, E, and F, the sanitary sewer system, and the rail classification yard (Figure 1.2-7). These sources occur in five general vicinities discussed below.

1.2.4.1 South Plants and Basin A

Operations at the South Plants Area began in 1942 with the manufacture of chemical munitions and subsequent production of pesticides and



ROCKY MOUNTAIN ARSENAL

EXPLANATION

- Primary Migration Source
- Potential Migration Source
- Balance of Areas Investigated

Figure 1.2-7
AREAS INVESTIGATED AS MIGRATION SOURCES ON RMA

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herbicides. Chemical wastes from these operations were discharged into the lime settling ponds which at times have overflowed into Basin A, or were directly discharged to Basin A via the chemical sewer system. In addition to the controlled discharge of wastes, numerous uncontrolled discharges have occurred in this area including a major benzene spill in 1948, pesticide spills, discharges of wastes to small disposal ponds throughout the area, infiltration and exfiltration of contaminants from the sewer system, and infiltration of contaminated water from building basements and sumps. All of these processes have contributed to the overall degradation of the ground water quality at RMA and the generation of several contaminant plumes.

1.2.4.2 Basin F

Basin F was constructed in 1956 in response to the need for expanded waste storage. In order to restrict contaminant migration, the 93 acre basin was constructed with an asphalt lined bottom protected with a 12 inches (in) thick layer of sand. Over time numerous processes have effected the performance of the Basin F System. These include:

- o Wave action along the shoreline;
- o Tears in the asphalt liner;
- o Cylic exposure of the liner to liquid wastes, sunlight, and weather conditions, and;
- o Incompatibility of some of the wastes and the asphalt liner.

These problems have resulted in discharges of wastes to the underlying alluvial aquifer and the generation of contaminant plumes that originate at Basin F.

1.2.4.3 Basins C, D, and E

Basin C is an unlined evaporation pond which was designed to receive discharge from the GB Plant. The basin also has held large quantities of fresh water from the Sand Creek lateral. In addition, approximately 100 million gallons of liquid wastes were pumped into Basin C from Basin F during repair of Basin F liner in 1957.

Basins D and E are also unlined and were used to hold overflow from Basin A prior to construction of Basin F.

Due to the magnitude of the contaminant plumes originating from the South Plants Area and Basin A, it has been difficult to determine whether fluids in Basins C, D, and E have contributed to these documented ground water plumes as all basins have contained similar chemical compounds.

1.2.4.4 Sanitary Sewer System

The sanitary sewer system is considered to be a major source of ground water contamination. Several sections of the system are below the water table and numerous breaks and leaks from the lines have occurred. The main problems areas occur in Basin A, the Basin A "neck", the South Plants Area, and Basin F. The sewer system thus contributes to the overall ground water contamination problems in these areas.

1.2.4.5 Rail Classification Yard

The rail classification yard has been identified as the source area of the pesticide contamination that was detected in the Community of Irondale supply wells in 1980. This contamination has resulted from a major spill within the rail classification yard. Smaller spills may have occurred in this area but are not considered significant. The major spill has resulted in the generation of a distinct set of ground water contaminant plumes which are currently being mitigated by the Irondale Containment System.

1.2.5 GROUND WATER QUALITY

A significant effort has been devoted to monitoring RMA ground water quality over the last 10 years. Approximately 2,000 ground water monitoring wells exist onpost at RMA. The majority of the wells have not been sampled on a routine basis.

Ground water quality data has been compiled in the USATHAMA data base and utilized to generate contaminant contour maps for the shallow ground water system. The data used to construct these maps are primarily from alluvial wells.

Figure 1.2-8 shows the configuration of ground water which exceeds water quality standards with respect to selected organic compounds. This

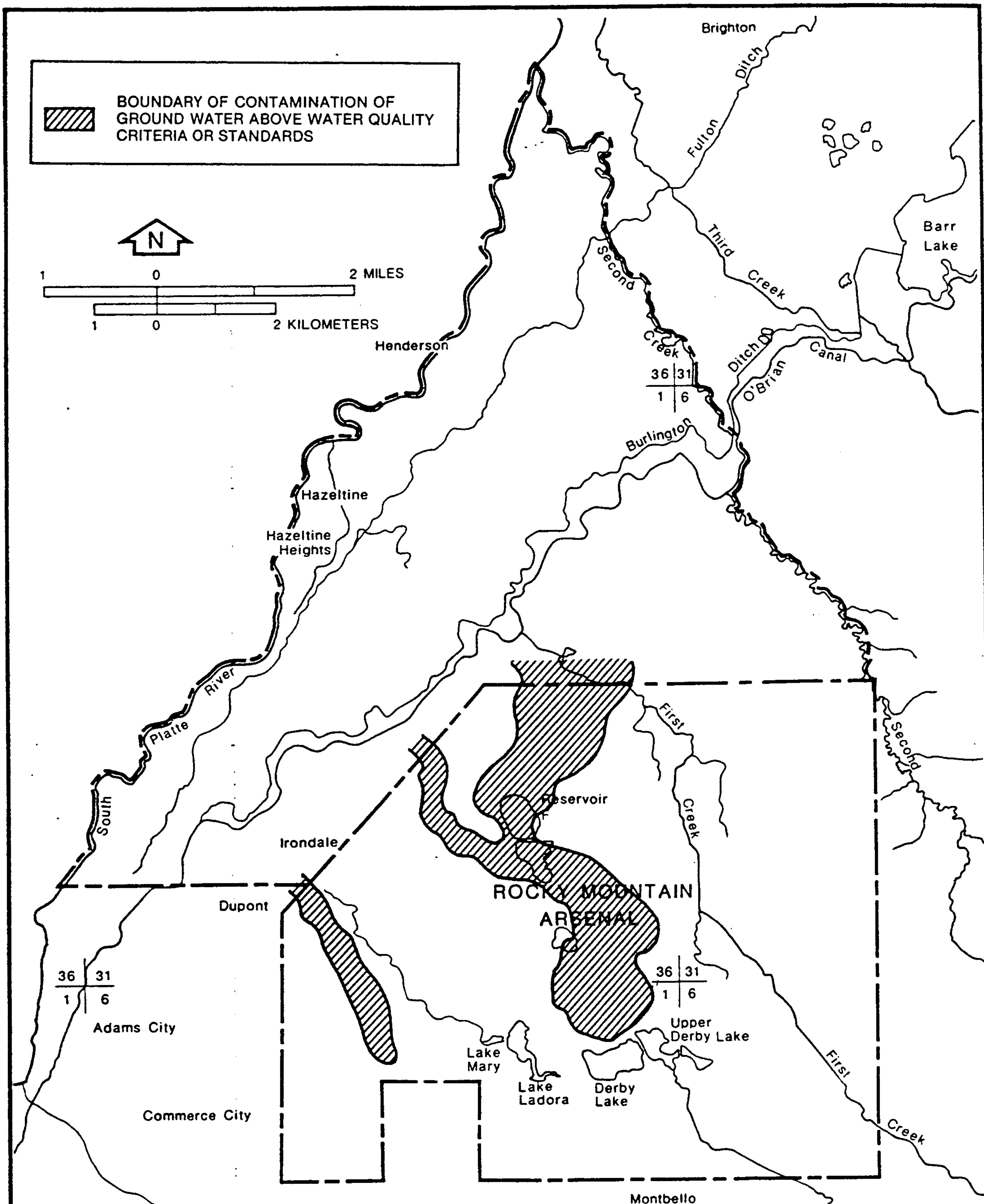

Figure 1.2-8
CHEMICAL CONTAMINATION PLUME ABOVE ACCEPTABLE LIMITS

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Aberdeen Proving Ground, Maryland

figure shows the extent of the composite contaminant plume related to organic compounds including DIMP, Dieldrin, DBCP, Endrin, and DBCP. The ground water flow patterns shown in Figure 1.2-5 are confirmed by the shape of the contaminant plumes as shown in Figure 1.2-8. The general northwestern trend of ground water flow is split into a northern and northwestern component by the bedrock (Denver Formation) high in the northwest portion of RMA. Therefore, ground water contaminants originating from the South Plants Area and Basin A, may travel to RMA's north or northwestern boundaries while contaminants from Basin F are primarily migrating toward the RMA north boundary.

Significant contamination appears to be confined to the alluvium. Migration of contaminants into the Denver formation has not been identified except in locations where there is contact between saturated alluvium and Denver sands or where the alluvium in unsaturated and primary flow is in the Denver Formation. In these later instances contaminants are transported back into the alluvium where it again becomes saturated.

Several ground water monitoring programs have been initiated and remain in operation at RMA to accomplish a variety of objectives. These include the 360° Program, the RCRA Program, and secondary sources. In addition, a number of other monitoring programs have been conducted in the past. The regional ground water monitor programs currently in operation at RMA, specifically the 360° Program and RCRA Programs, represent regulatory compliance efforts that will be consolidated under Task 4.

1.2.5.1 <u>360° Ground Water Monitoring Program</u>
The Cease and Desist Order (1975) issued by the State of Colorado required a regional surveillance program which monitors both ground water and surface water hydrology and water quality. This program was initiated in 1975 and is currently in operation. The objectives of this program are to satisfy the requirements of the Cease and Desist Order and also provide a basic program for RMA surveillance to support other sampling programs.

The 360° Monitoring Program has varied slightly since 1975 and the number of wells sampled has been altered due to abandonment of selected wells and addition of new ground water monitoring wells. Currently, (1985) the 360° Program samples approximately 100 onpost and offpost ground water wells. Water samples from these wells are analyzed for DIMP, DCPD, DBCP, Cl, F, Mg, Ca, K, Na, Nitrate, Sulfate, alkalinity, specific conductivity and pH on a quarterly basis. The 360° Program also collects water level data from 490 monitoring wells on a quarterly basis.

1.2.5.2 RCRA Monitoring Program

Basin F is a RCRA hazardous waste facility and therefore Basin F must comply with appropriate RCRA regulations. During the first year of ground water monitoring the Basin F RCRA program was in the Detection Monitoring Phase and all ground waters were analyzed for RCRA Detection Monitoring Program parameters. Contaminant migration from Basin F was reconfirmed during this monitoring effort. The Basin F monitoring program has progressed into the Compliance Monitoring Phase, with a specific list of contaminants being monitored in the 3 upgradient and 9 down gradient (12 total) monitoring wells. This list of analytes includes DIMP, DBCP, DCPD, Aldrin, Isodrin, Endrin, Dieldrin, Oxathiane, Dithiane, PCPMS, PCPMSO, $PCPMSO_2$, Chloride, and Fluoride.

1.2.5.3 Second Sources Monitoring Program

As a result of contaminant migration offpost there are three boundary control systems currently operating at RMA. These include the Northwest Boundary Control System (NWBC), the North Boundary Control System (NBC), and the Irondale Containment System (IC). The objective of all three boundary control monitoring systems is to evaluate the performance of their respective boundary control systems.

North Boundary Control System

The North Boundary Control System (NBC) has been in operation for several years and includes a physical barrier (slurry wall) with both ground water extraction and ground water injection wells. Dewatering wells are located upgradient of the slurry wall to intercept contaminated ground water. Extracted ground water is treated by carbon adsorption techniques. Treated water is recharged to the alluvium by use of both ground water injection wells and a recharge lagoon on the downgradient side of the slurry wall.

The NBC Monitoring Program consists of the sampling of 80 onpost and offpost wells in the Alluvial and Denver aquifers. Samples from these wells are collected on a quarterly basis and more frequently if problems with the system arise or operational parameters are changed. All water samples collected from the monitoring network are analyzed for DIMP, DCPD, DBCP, Endrin, Dieldrin, Isodrin, Aldrin, Oxathiane, Dithiane, PCPMS, PCPMSO, $PCPMSO_2$, chloride and fluoride.

Northwest Boundary Control System

The Northwest Boundary Control System (NWBC) has been in operation for approximately one year. This containment system consists of both a physical barrier (slurry wall) and hydrologic barrier. Ground water extraction wells collect contaminated ground water which is treated by carbon adsorption prior to recharge.

The NWBC system monitoring system is comprised of 45 onpost and offpost monitoring wells which are sampled on at least a quarterly basis. Water samples collected form these wells are analyzed for the following compounds: DIMP, DBCP, Endrin, Dieldrin, Isodrin, Aldrin, chloride, and fluoride.

Irondale Boundary Control System

The hydrologic control system installed at the southern portion of the northwest RMA boundary (Irondale System) does not contain a physical ground water barrier. This system consists of two rows of ground water dewatering wells and a single row of recharge wells downgradient of the extraction wells. Ground water is extracted, treated, and reinjected. The remaining boundary system is the Irondale Contaminant System. The system is operated by Shell who collects and analyzes the water samples associated with its operation.

All of the monitoring programs discussed above are currently in operation. In addition to these programs, there are a number of other programs that have been conducted in the past. These include the North Boundary Study, Pilot Containment System, Northwest Quadrant, and Nemagon Sampling Programs, all precursors to the various boundary control programs. There was also a Basin A Neck Program conducted to examine the feasibility of installing a barrier system in this area. There have also been several discrete investigations of the ground water quality at RMA that were conducted during a short period of time. These programs were conducted by U.S. Army Waterways Experimental Station (WES) or Shell. Other discrete water quality investigations were conduted by the RMA Environmental Division (RMA-ED) under the Basin F Study, Regional Sampling or Source Identification Programs.

As these programs are not currently operated and are not necessary under regulatory requirements they will not be incorporated under the Task 4 sampling effort. However, information from these programs will be utilized during the well selection activities discussed in Section 3.0 of this Technical Plan.

1.2.6 SURFACE WATER QUALITY

Limited information is available on contamination of the surface waters at RMA. Preliminary analysis of water within First Creek indicated the presence of diethyl and dibutyl phthalates and cyclohexanone (RMA-CCPMT, 1983). Since the stream is generally intermittent, the contaminants infiltrate into the ground water before reaching the northern RMA boundary via surface flow. The only possible exception would be during a major flood event.

Within the Irondale Gulch drainage basin, the offpost storm drainages (Highline Lateral, Uvalda and Havana Interceptors) are free of RMA related contaminants (RMA-CCMPT, 1983). Two of the Lower Lakes have been sampled regularly for the past five years. Actual lake water is relatively clean; however, contaminants are found concentrated in lakebed sediments. Sediment contaminants include Dieldrin and mercury.

The Basin A ditch, a minor flow route that conveys storm runoff from the South Plants Area to Basin A, has been found to contain high amounts of various contaminants. These include chloroform, trichloroethylene, tetrachloroethylene, toluene, xylene, ketones, and benzene (RMA-CCPMT, 1983). These contaminants were probably picked up from past spills on surface soils.

Surface water monitoring at RMA has been performed as part of the 360° Monitoring Program. Although not currently operating, a brief description of the program follows.

360° Monitoring Program

Water samples are collected from 30 onpost and 4 offpost sites on a quarterly basis. Samples are analyzed for DIMP, DCPD, DBCP, Cl, F, Ca, K, Mg, Na, Nitrate, Sulfate, hardness, alkalinity, conductivity, and pH. Sampling points include various surface water features and include streams, ditches, lakes, and ponds.

In addition to water quality data, an intergal part of the program is the collection and compilation of water quantity data. Flow and water level data are collected onpost weekly at eleven gauging stations as well as at three lake sites. Additional measurements are recorded at two flow meters. Information is utilized in the preparation of a monthly RMA Surface Water Balance Summary.

1.3 SUMMARY OF TECHNICAL APPROACH

The purpose of this task is to perform a Water Quality/Quantity Survey for the onpost area of RMA. The scope of work includes selection of groundwater monitoring wells to be sampled and selection of surface water sampling locations. Sampling location selection is followed by collection of surface water and ground water samples, measurement of appropriate field parameters, and chemical analysis of water samples. Finally, this data will be evaluated to document the extent of contamination and verify the information in the existing data base.

1.3.1 SCOPE OF WORK

The purpose of the Task 4 Water Quality/Quantity Survey is to execute a one year ground water and surface water surveillance program capable of satisfying the various regulatory requirements, developing a litigation quality data base and verifying the extent and nature of known contamination. In order to achieve these objectives five distinct technical elements are anticipated. These are as follows:

- o Review historical data;
- o Develop a monitoring program to achieve the above objectives;
- o Execute the monitoring program utilizing litigation quality sampling and analysis procedures;
- o Assess data quarterly for possible adjustments in the monitoring program; and
- o Evaluate the accumulated data of the end of the one year program.

Currently there are over 2,000 monitoring wells on RMA. During the review of historical data, these wells will be evaluated with respect to construction detail, sampling history, and location. Criteria for evaluating these wells are described in Sections 3.1.1.1 through 3.1.1.3.

Based on the results of the review of the historical data a montioring program will be designed. The initial monitoring program design will be developed resulting in an extensive effort during the first quarter. Based on an evaluation of the results obtained during the first quarter, the proposed monitoring program for the second, third, and fourth quarters will be re-examined and modified if deemed necessary.

All ground water monitoring wells and surface water sampling sites will be sampled using uniform sampling methodologies. Ground water and surface water samples will be analyzed for a predetermined list of analytes including numerous organic and inorganic parameters. All sampling, sample preservation, sample handling, and sample shipment will be performed in accordance with approved USATHAMA procedures as described in this Technical Plan.

Sample collection, measurement of field parameters, and analysis of samples will be performed in accordance with USATHAMA Quality Control/Quality Assurance procedures. These procedures include collection of field quality control samples and decontamination of all sampling equipment.

Data interpretation will include use of statistical techniques (Section 8.2) in an attempt to validate the quality of the existing data base. Results of quarterly sampling and measurements will be presented in the form of contaminant distribution/plume and potentiometric surface contour maps. Recharge/discharge between surface water and aquifers will be established and ground water/surface water balances for RMA will be determined. Additionally, approximate rates of contaminant migration will be determined and statistical techniques will be utilized to evaluate levels of confidence for plume configurations.

2.0 EVALUATION OF BACKGROUND DATA

2.1 DATA COMPILATION

The project team expects that although a considerable effort has been made to review site specific background information on RMA surface water and ground water hydro-chemistry, that data gathering and review is an ongoing process. Numerous background documents were reviewed prior to preparation of this technical plan. However, during performance of ground water well screening and selection of surface water sampling locations the project team will assimilate a considerable volume of additional information. This data compilation effort will include literature and data review as well as tabulation of data obtained during the field reconnaissance performed prior to task activities.

2.1.1 SITE RECONNAISSANCE/MEETINGS

The initiation meeting for Task 4 was held in Denver on May 22, 1985. The purpose of this meeting was to allow the project team to discuss the scope of work and project objectives with USATHAMA personnel.

As a result of previous task orders the project team was familiar with key RMA personnel and operational procedures. Therefore, initiation meetings were devoted primarily to discussions of technical issues and schedules.

Due to familiarity of the project team with the RMA site a ground water site reconnaissance was deemed unnecessary. This activity will be performed during the ground water monitoring well screening activity. Site reconnaissance will be utilized to verify the existence and location of wells prior to sampling activities. A reconnaissance of surface water monitoring structures was performed on June 25, 1985 to determine the necessary efforts required to recondition and repair existing monitoring facilities and structures.

2.1.2 LITERATURE/DATA BASE REVIEW

During preparation of this technical plan numerous documents detailing RMA hydrogeology, hydrology, and disposal history were reviewed. With respect to Task 4 background data, a considerable portion of this data is contained within the USATHAMA Univac Data Base. The project team will rely primarily on the USATHAMA data base for information, as this data has passed through USATHAMA data acceptance routines and in general contains all computerized data of concern for the performance of this task. However, some data must be obtained from RMA files and the RMA data base.

The USATHAMA data base contains information for each ground water monitoring well such as well number, coordinates, elevation, bedrock depth, total well depth, geologic parameters, and information on chemical concentrations of analytes in ground waters sampled. In order to perform screening of approximately 2,000 RMA ground water monitoring wells this data is necessary. However, additional data, primarily that data concerning ground water monitoring well construction must be obtained. This construction data is not contained in either the RMA or USATHAMA data bases and must be obtained in the form of well completion diagrams from RMA personnel.

3.0 GEOTECHNICAL PROGRAM

The primary purpose of the geotechnical program for Task 4 is to establish a litigation quality data base on the quantity and quality of surface and ground waters at RMA. This goal will be achieved by examining the historical data on water quantity and quality developed by past and current monitoring programs at RMA, and implementing a field sampling program that is designed to verify the quality of the existing data as well as monitor any changes in the migration of contaminants across RMA. The sampling program will fill any data gaps or deficiencies as well as provide additional information regarding any anomalies or unknowns identified during the evaluation of the existing data base. Finally, the sampling program will incorporate the requirements of existing RMA regulatory compliance monitoring programs that are compatible under task objectives defined by this document.

3.1 GROUND WATER

The primary goal of the ground water monitoring program is to confirm the existing understanding of and monitor changes in the nature and extent of ground water contamination at RMA (Section 1.2). To achieve this goal the following priorities have been established:

- Confirmation of the quality of the data base upon which the present definition of the extent of ground water contamination were based;
- Confirmation of the nature of the contaminants associated with previously defined ground water contaminant plumes; and
- Confirmation of the lateral and vertical extent of previously defined ground water contaminant plumes.

In order to achieve these priorities, two major efforts are envisioned under the ground water program. The first of these efforts is the evaluation of existing data and design of a sampling program to verify the quality of this data. The second effort is implementation of the sampling program.

3.1.1 EVALUATION OF EXISTING GROUND WATER MONITORING DATA

Existing information on monitoring well construction, sampling history, monitoring well location relative to plume configuration, and the requirements of existing RMA ground water monitoring programs will be evaluated as the major requirements for sample program design. This information will be used to:

- Identify wells with suitable construction;
- Define wells with documented sampling histories which display uniform results, consistent trends, highly variable results, anomalous results, or insufficient results to define contaminant conditions;
- Identify wells with optimum locations relative to plume boundaries, areas of greatest contaminant concentrations, and areas inferred to be devoid of ground water contamination; and
- Identify wells that are currently being utilized by the compatible RMA ground water monitoring programs.

The above criteria will be utilized to select the appropriate number of ground water monitoring wells and wells for water level measurements to achieve program objectives. The criteria evaluations will be used for comparative purposes and will consider all of the above factors in designing a monitoring well network which will best allow comparison with historical data compliance with regulatory requirements, and definition of contaminant plume locations.

The conceptual design for well selection process is shown as a flow chart in Figure 3.1-1. All onpost wells for which sufficient information exists will be subjected to a construction evaluation. Wells passing this evaluation will be subjected to a sampling history and location evaluations. Results of these evaluations will be integrated to perform the final well selection.

3.1.1.1 Well Construction Evaluation

Current information on file with USATHAMA and RMA indicates that there are 1568 onpost monitor wells (Figure 3.1-2) at RMA (DP Associates, 1985). Initial screening to select wells for water sampling will begin

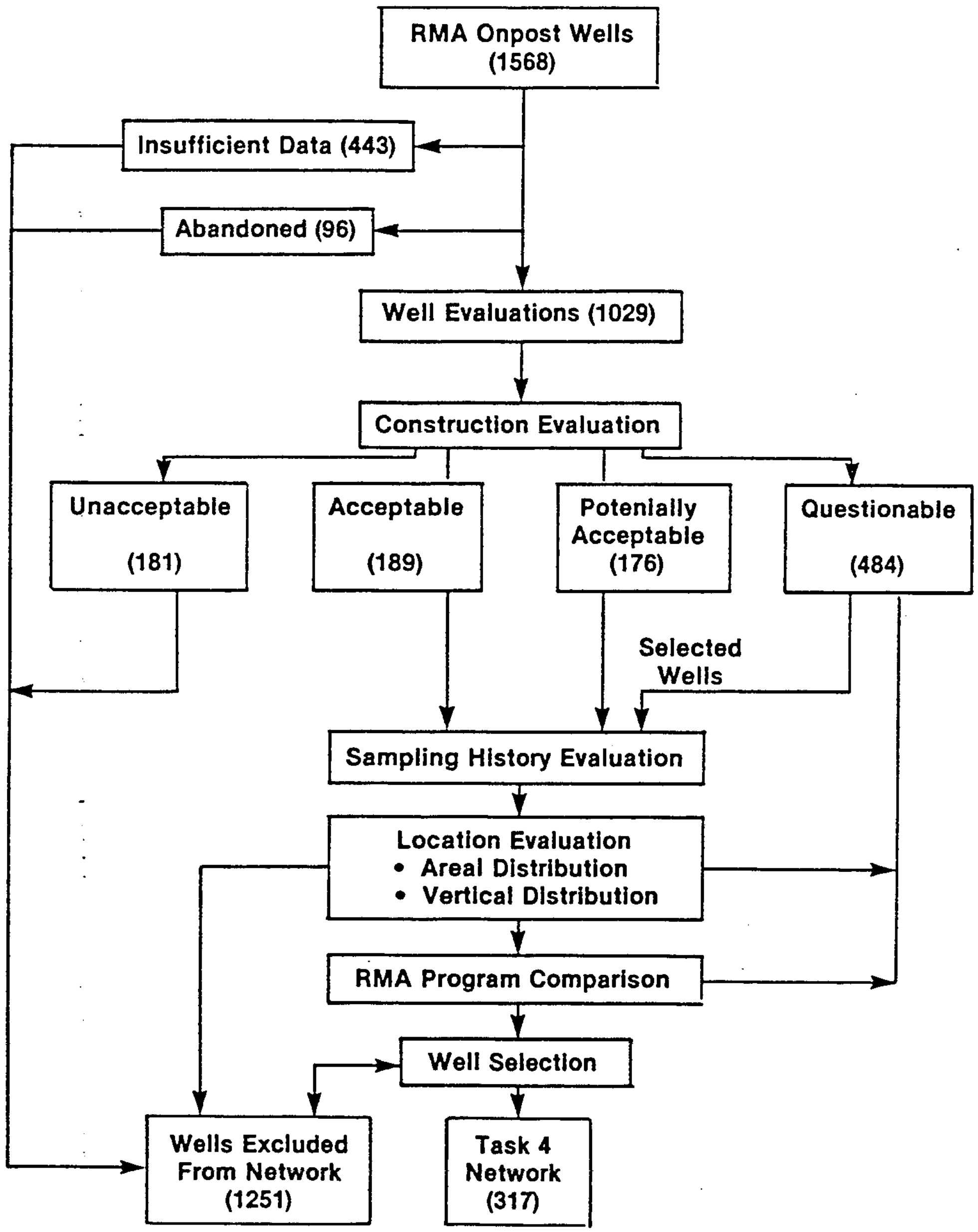

Figure 3.1-1
WELL SELECTION AND EVALUATION PROCESS

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

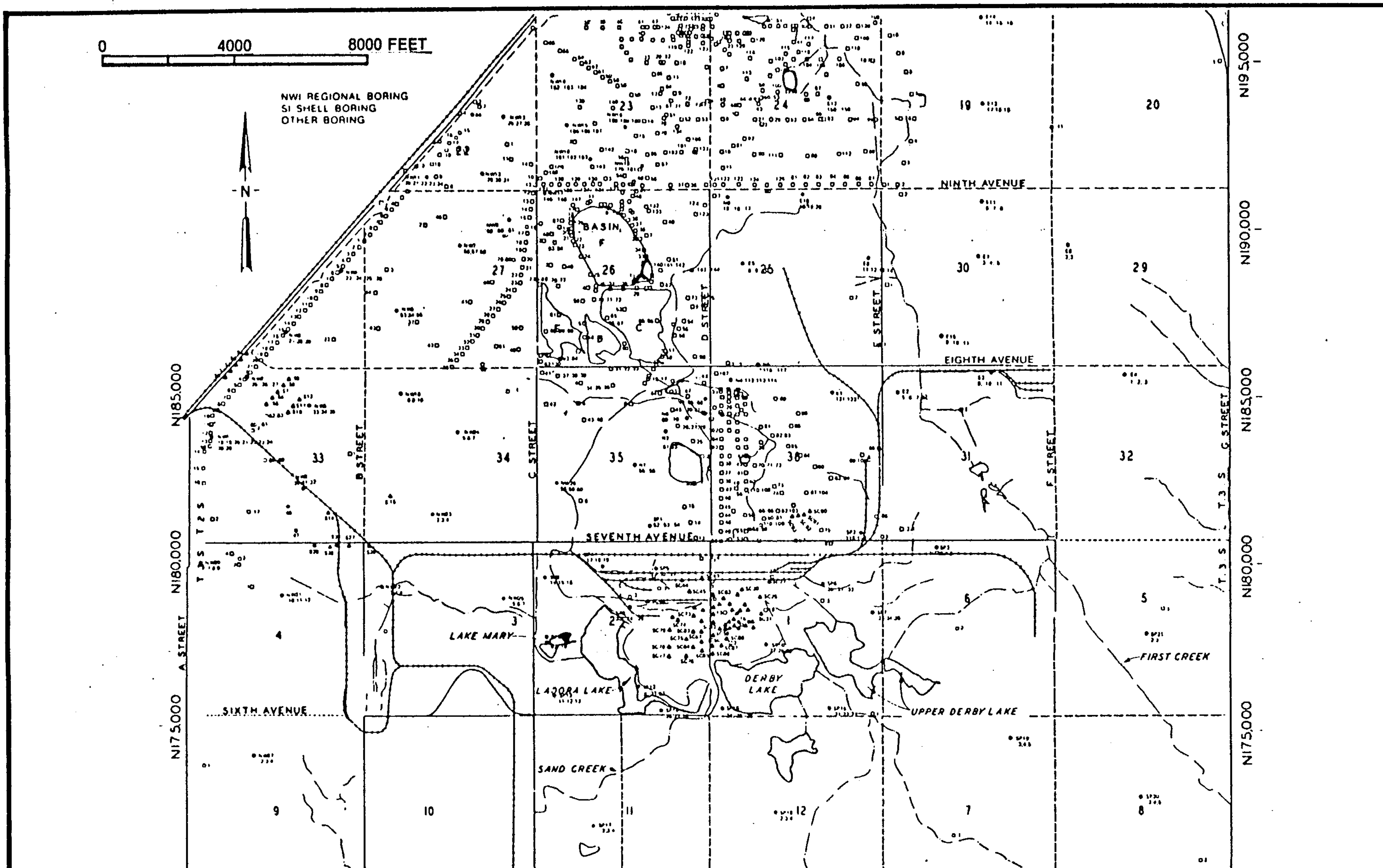

Figure 3.1-2
CASED WELL LOCATION MAP
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

by evaluating information in the USATHAMA/RMA computerized data base, borehole and well completion logs, and the monitoring network proposed by ERTEC (1982). To achieve program objectives, monitoring wells which may not conform with all well selection criteria must remain in the program. However, under certain circumstances wells may be dropped from consideration due to construction. All wells that are located offpost, wells previously abandoned, wells that were completed only to the top of a saturated horizon and are currently dry, or wells with casings that do not extend above the ground surface will be eliminated from consideration. In addition, wells with unclear locations or unknown screened intervals will also be eliminated from further consideration. A tabulation will be prepared summarizing the wells that are eliminated during this stage. It is anticipated that numerous wells may be eliminated from further consideration during this initial screening.

Following the initial screening, the construction records of the remaining wells will be evaluated in detail to determine the following:

- Drilling and completion procedures;
- Location and collar elevation accuracy;
- Casing cap and locking cap detail;
- Surface seal type and interval;
- Casing type and size;
- Blank interval backfill material;
- Screen type and length;
- Aquifer within the screen interval;
- Relation of the screen interval to water levels;
- Relation of the screen interval to aquifer thickness;
- Sand pack type and interval;
- Type and thickness of seal above sandpack;
- Relation of seal to aquifer limits;
- End plug and siltrap detail; and
- Documentation of construction data.

Information will be obtained from the USATHAMA and RMA data bases and from boring and well completion logs on file at the RMA Environmental

Division. To expedite this evaluation and provide consistent results a standardized evaluation sheet will be used for each well (Table 3.1-1). During the review of individual well constructions, appropriate descriptions for each well construction factor will be denoted on these sheets. These sheets will be used for comparative purposes only and are not intended for use in ranking well constructions or eliminating individual wells.

The primary construction factor influencing the suitability of a well for either water sampling or water level measurements is the nature and the placement of the various seals. Lower confined aquifer wells without the minimum 10 ft thick bentonite or grout seal between the upper water table and lower confined aquifers, as required by the Colorado Division of Water Resources, will be eliminated from further consideration. Denver Formation wells without a surface seal or with seals installed partially within the screened interval may be eliminated. Finally, wells without seals above the sandpack may be eliminated from consideration for water sampling. Such wells may continue to be considered potentially useful as piezometers for water level measurements.

The second major factor affecting the suitability of a well for water sampling is casing type. Stainless steel or teflon well construction are preferable to all other materials. Threaded PVC casing will also be considered for water sampling but could be less desirable due to the potential for chemical interactions between certain ground water contaminants and the plasticizers in the casing. Glued joint PVC casing is the least desirable of all casing types and will be primarily considered for water level measurements only. In cases where no other wells for water quality sampling exist the glued PVC wells will recieve consideration.

The next factor influencing well selection is screen placement. As stated previously, wells with screens that intersect more than one aquifer may be eliminated from further consideration. This decision will be made on a case by case basis depending on the nature of the water bearing units involved (i.e., confined or unconfined). Wells with

Table 3.1-1. Well Construction Factors (Page 1 of 2)

Section No.__________ Well No.__________

Construction Factors				
Aquifer	Upper (Alluvial)	Lower (Denver)	Both	Unknown
Location	Surveyed	Approximated From Map	Approximated In Field	Unknown
Collar Elevation	Surveyed	Approximated From Map	Approximated In Field	Unknown
Locking Cap	Yes	Secured Area	No	Unknown
Surface Seal Type	Grout	Bentonite	Soil	Unknown
Surface Seal Interval	≥10 ft	<10 ft	None	Unknown
Blank Interval Backfill	Grout	Soil	Sand	Unknown
Casing Type	Teflon/Stainless	Threaded PVC	Glued PVC	Unknown
Casing Size	≥6 in	4 inch	2-2.5 in	Unknown
Screen Type	Well Screen	Factory Slotted	Field Slotted	Unknown
Screen Length	>20 ft	10-20 ft	<10 ft	Unknown
Screen Interval	Sand	Sand/Clay	Clay	Unknown
Screened Zone	Full Penetration	Partial Penetration	Multiple Aquifer	Unknown
Relation to Water Level	Within Screened Interval	Above Screen	Below Screen	Unknown
Sand Pack Type	Industrial Sand	Pea Gravel	Natural	Unknown
Sand Pack Interval	Above Screen	At Top of Screen	Below Screen	Unknown
Seal Above Sand Pack	Grout	Bentonite	Soil	Unknown
Seal Above Sand Pack Interval	≥10 ft	<10 ft	None	Unknown
End Plug	Threaded	Glued	None	Unknown
Silt Trap	≥1 ft	<1 ft	None	Unknown
Construction Data	Detailed as Built Data	Approximate as Built Data	Work Plan	Unknown
Drilling Method	Auger	Rotary	Conductor Casing	Unknown

Table 3.1-1. Well Construction Factors (Continued, Page 2 of 2)

Section No.__________ Well No.__________

Evaluation

Data Reliability	Excellent	Good	Fair	Poor
Data Accuracy	$\leq$ 1 ft	1-5 ft	>5 ft	Unknown
Recommendation for Monitoring	Acceptable	Possibly Acceptable	Questionable	Abandon
Usefulness for Specific Contaminants	Organic Monitoring	Inorganic Monitoring	Water Level	None
Recommendation for Water Level Measurement	Acceptable	Possibly Acceptable	Questionable	Abandon

Remarks:

Source(s) of Data:

Summary Prepared By:
Date Prepared:

Summary Checked By:
Date Checked:

in = inch
ft = feet

screens that only partially penetrate an aquifer, or that do not intersect the water table for unconfined zones are less desirable as sampling locations. In general this will entail most wells with screen lengths less than 10 ft long. However, the screen lengths will have to be compared to the saturated thickness at each location. In addition, partially penetrating wells or wells with screens below the water table that are completed in a cluster configuration with other similar wells will be retained due to their potential use in evaluating vertical stratification of, or within, a contaminant plume. Finally, wells with screens placed in low permeability horizons may be eliminated unless they are part of a cluster configuration. These wells will be difficult to sample due to their low yield and adjacent wells with higher yields may satisfy program objectives. Wells within the more transmissive portion of the aquifers have a greater probability of producing water representative of the immediate area.

The final major factor affecting selection is the well cap. Only those wells with caps will be considered for water quality sampling. Wells with locking caps or those located in a secured area are preferred due to their relative freedom from potential tampering.

In addition to the above selection criteria, a number of other factors affect the suitability of an individual well for water sampling. These include the nature of the well screen (i.e., wrapped screen, factory slotted, field slotted, or perforated casing), type of sandpack (graded industrial sand, pea-gravel, caved material, etc.), drilling method, and presence of silttrap and end plug. These factors control the sediment content, yield of the well, and its ability to produce samples with stable chemical conditions (i.e., pH, conductance, etc.). These factors along with others previously discussed also control the amount of time required to obtain a sample and a well's ability to produce the required number of casing volumes during evacuation prior to sampling. Sampling procedures for wells with low yields necessitate that the well be pumped dry if less than 5 casing volumes can be evacuated. First water collected may be partially stripped of volatile organics due to time necessary for well recovery.

Finally, a qualitative estimate of the reliability of the construction details based on the available documentation along with a summary of the accuracy of the data will be completed.

Based on the summaries of the construction details, recommendations will be formulated as to the acceptability of each well for water quality sampling and/or water level measurements. Tabulations will be prepared summarizing those wells with constructions suitable, or potentially suitable, for water sampling and/or water level measurements. All wells determined unsuitable, or with constructions or documentation of construction details such that they are determined to be of questionable use, will also be tabulated along with the reasons for these determinations.

Finally, summaries will be prepared on a section by section basis documenting the number of total wells, the number of wells suitable or potentially suitable for water quality sampling and/or water level measurements, the number of wells of questionable construction and the number of wells determined to be unsuitable for water quality sampling or water level measurements. These tabulations will be evaluated to determine that a suitable number of wells remain in each section to continue with the screening process. Any section where no wells with suitable or potentially suitable construction are determined, a re-evaluation will be performed to determine the most suitable well(s), if any, of those available.

3.1.1.2 Sampling History Evaluation

The wells that have not been eliminated from consideration due to unacceptable construction will be evaluated based on their sampling history. Current information provided by the RMA Environmental Division indicated that over 100 onpost wells are currently being monitored by existing programs. These programs include the 360° Water Monitoring Program (75 wells), the RCRA Monitoring Program for Basin F (12 wells) and the Irondale, North Boundary Containment and Northwest Boundary Containment Programs. In addition to these, a number of other programs have been conducted in the recent past including those related to the sanitary landfill, secondary source, etc. Much of the chemical data developed by these programs is currently being stored on the Harris Data Base operated by RMA.

The second step in selecting monitoring wells for inclusion in the Task 4 monitoring efforts is to review the chemical data developed by these programs. The purpose of this review will be to identify wells with long term sampling histories, regularly sampled wells, wells that have displayed consistent results, key wells that have displayed highly variable results, wells with anomalous results, contaminated wells which have not been evaluated for all possible contaminants, wells where the sampling technique may have affected contaminant detection, and wells that must be sampled to meet regulatory requirements at RMA.

Major factors to be evaluated during the review of the chemical data include:

- Sampling history;
- The program under which the well was sampled;
- Past sampling frequency;
- Period of record;
- Analytical program;
- Analytical laboratory;
- Contaminants detected; and
- Contaminant trends.

The first six factors will be used to determine whether a meaningful sampling history, exists for a given well. If a significant sampling record exists, information on the contaminants that have been detected and the temporal trends associated with these contaminants will be evaluated. The goal of this evaluation will be to define wells that display consistently high or low levels of contamination as well as those that have never displayed any contamination.

In addition to those wells displaying consistent trends, wells displaying increasing or decreasing levels of contamination will also be identified. Selected wells from these groups will be included in the first quarter and very probably the second through fourth quarters sampling efforts to evaluate the validity of these trends.

Finally, wells that have previously displayed highly variable results whether on a seasonal or an undefined basis, will be identified. Many of these wells may be included in the first quarter effort to attempt to define representative water quality and contaminant levels for these wells and possibly explain the source of the variability. In addition, wells with inadequate sampling histories that have displayed elevated concentrations of contaminants will also be evaluated for inclusion in the first quarter effort.

In addition to the chemical data available for each well, the sampling procedures employed will also be evaluated. Included in this evaluation will be the well evacuation procedure, evacuation equipment, sampling equipment, field parameter stabilization, and well yield. This information will be used to determine if past sampling procedures may have introduced variability in the chemical data base. It will also be used in planning the first quarter sampling effort. Although wells with moderate to high yields are the most desirable due to their ability to produce the required five casing volumes during evacuation, and therefore presumably representative formation waters, attempts will be made to ensure that wells with a wide variety of yields are sampled. This will allow for an evaluation of the impact of well yield on the analytical results. Methods for sampling low yield wells are discussed in Section 3.1.2.1.2.

The final step in the evaluation of the sampling history will be to evaluate water level data that may have been obtained for each well. Information on the 360° Monitoring Program indicates that water levels in 490 wells are currently measured on a quarterly basis. Similar to the evaluation of the analytical data, the goal of this evaluation is to identify those wells that display consistent water levels, those displaying rising or falling trends and those that display seasonal variations or irregular results. To support this evaluation, information will be obtained on the period or record, frequency of past measurements and relation to current water level measuring programs.

To support all of the above evaluations, an evaluation sheet will be prepared for each well (Table 3.1-2). For ease of tabulation during the review of the analytical data, appropriate descriptions for each factor will be denoted on these sheets. These sheets will be used to document the results of this evaluation and to provide input to the summary evaluation and well selection process to be performed at the end of the data evaluation. It should be noted that unlike the well construction evaluation previously discussed, no screening will occur during the sampling history evaluation. Wells with no sampling history, no detected contaminants, high levels of contaminants, etc. may be included in the first quarter sampling effort. The overall goal of the sampling history program is not to eliminate wells from consideration, but to identify key wells and wells with anomalous or questionable results and to provide a basis to select between wells with similar well constructions and locations.

3.1.1.3 <u>Location Evaluation</u>

Significant previous information has been developed on the saturated thickness, gradients, flow paths and the known extent of individual contaminants within the upper water table aquifer, and the potentiometric surface, and flow paths of the deeper bedrock aquifer. The final step in the evaluation of existing data is to determine the relative merits of each well location with respect to this information. The goal of this evaluation is to determine the relation between existing well locations and the inferred areal extent of the various contaminants. This information will be used to select upgradient wells, downgradient wells, wells that define the lateral extent of contamination, wells that define the maximum contaminant concentrations of individual plumes, wells that define the vertical extent of contamination and wells that confirm the lack of contamination in areas inferred to be unaffected.

Table 3.1-2 Sampling History Data Affecting Selection Summary Sheet

Section No.________________ Well No.________________

Sampling History	Currently in Program		In Past Program	Infrequently Sampled	Sampled Once	Never Sampled
Sampling Program	360		NBC	NWBC	RCRA	Other
Sampling Frequency	Quarterly		Semi-Annual	Annual	Infrequent	Unclear
Period of Record	>5 years		1-5 years	<1 year	Once	Variable
Analytical Program	VOA's	PP's	RMA-Organics	RCRA	Drinking Water	Major Ions
Analytical Laboratory	RMA	CDH	TCH	Contract	Unknown	
Contaminants Detected	Cl	Fl	DIMP	DBCP	DCPD	Other Organics
Contaminant Trends (CH, CL, P, D, I, O)	Consistently High	Consistently Low	Contamination Increasing	Contamination Decreasing	Variable Results	No Contamination Detected
Well Evacuation	5 Casing Volumes		3 Casing Volumes	Field Stabilization	Bail Dry	Unknown
Evacuation Equipment	Bailer		Submersible Pump	Gas Driven Pump	Peristaltic Pump	Unknown
Sampling Equipment	Bailer		Submersible Pump	Gas Driven Pump	Peristaltic Pump	Unknown
Stabilization	Always Stabilizes		Generally Stabilizes	Rarely Stabilizes	Never Stabilized	No Data
Well Yield	≥1 gpm		0.5-1.0 gpm	<0.5 gpm	Runs Dry	No Data
Water Level Measurement	Currently Measured			Measured in Past	Continuously Measured	Never Checked
Frequency	Continuously			Quarterly	Infrequent	Once
Period of Record	>5 years			1-5 years	<1 year	Once Variable
Water Level Trends	Consistent			Rising	Falling	Variable Unknown

Remarks:

Source(s) of Data:

Summary Prepared By:
Date Prepared:

Summary Checked By:
Date Checked:

VOA = Volatiles
PP's = Priority Pollutants

Source: HLA, 1985.

- Aquifer the well is completed in, whether upper or lower aquifer;
- The purpose of the well (i.e., inflow area, source evaluation, plume evaluation, boundary control, etc); and
- The relation of each well to specific sources or plumes, whether they are upgradient, downgradient, lateral to or vertically below a contaminant plume.

This evaluation will be performed on a section by section basis using computer developed well location maps currently being completed by the RIC. Maps of each section, or where well densities are high quarter or quarter-quarter sections, that display the location and well identification number of each well will be obtained. From the listing of wells with acceptable or potentially acceptable constructions (Section 3.1.1.1), those wells completed in the upper water table aquifer and those completed in the lower bedrock aquifer will be identified on each map. Using these as base maps, each well that has displayed contamination in the past will also be identified along with the types of contaminants and the relative concentration of each.

Once the basic data on each well has been assembled on the base maps, information developed through previous hydrogeologic interpretive efforts at RMA will be assembled for each section. Specifically, information on aquifer materials and saturated thickness, potentiometric surfaces, and flow paths will be compiled on the well maps for each section. In addition, information from past evaluations of the extent of contaminant plumes and concentrations will also be assembled for each section. The primary sources of this information will be reports on Selection of Contamination Control Strategy (RMACCPMT, 1983), Decontamination Assessment Report (RMACCPMT, 1984), Regional Ground Water Study of Rocky Mountain Arsenal (May, 1982) and various contractor and government reports on the hydrogeology and water quality of individual areas at RMA.

The purpose of this evaluation is to analyze the spatial relations between the monitoring well network, aquifers, the aquifer conditions, and the known extent of contamination on a section by section basis.

During this evaluation, individual well placements will be examined to ensure that the most probable flow paths in and out of an area have been monitored, that the areas with the greatest flux in and out of a section have been monitored, that background and worst case conditions have been evaluated and that a sufficient density of wells exists to define the lateral extent of contamination.

The end result of this evaluation will be the identification of wells that have the optimum locations relative to the hydrogeologic and known contaminant conditions.

3.1.1.4 Selection of Monitoring Wells

Based on the results of the three previous evaluations an overall summary will be prepared to present the results of these examinations along with tabulation summarizing the relevant conclusions drawn from each evaluation. The following factors will be summarized for each well:

- Aquifer - upper or lower;
- Well Construction - good, potentially acceptable, unacceptable or unknown;
- Sampling History - long term record, single sampling event, quarterly, yearly, etc.;
- Current Programs - 360°, RCRA, NBC, NWBC, IC, or not currently monitored;
- Contaminants Detected and Contaminant Trends; and
- Relation of the well to known contamination - upgradient, downgradient, within plume, lateral to plume, at source, etc.

Based on this summary evaluation, a list of wells recommended for sampling during the first quarter under Task 4 will be presented. This list will then be compared to the list(s) of wells currently being monitored by ongoing RMA programs to assess the degree to which each of the ongoing programs can be incorporated into the Task 4 monitoring efforts. Where it appears that the majority of an ongoing program can be incorporated, those wells that are required by the existing RMA program, but were not included in the list of recommended wells for Task 4, will be re-evaluated. Where possible, these additional wells will be included in the Task 4 program or possibly substituted for equivalent wells in the Task 4 list. For those wells currently being monitored under existing programs that cannot be included in the Task 4 list, a summary of the reason(s) for their exclusion will be developed.

The second step of the summary evaluation is to examine the areal and vertical distribution of the proposed monitoring network. Maps will be prepared showing the distribution of the proposed monitoring points for each aquifer. These distributions will then be evaluated for areal density, their relationship to known flow paths, and their relationship to known contaminant plumes and contaminant sources. Areas of insufficient coverage or excessive coverage will be identified through evaluation of these maps and additions or deletions to proposed monitoring network will be made. In addition, recommendations for additional new monitoring wells that may need to be installed to provide adequate areal coverage will also be presented if necessary.

Once an initial monitoring network for the first quarter sampling has been developed, a sensitivity analysis will be performed on various levels of program reduction. Under this evaluation a specific number of wells, a percentage of the total number of wells, a specific group of wells would be tentatively eliminated from the proposed monitoring network. The remaining network would then be evaluated in terms of its ability to meet the Task 4 program objectives. Provided this reduction does not lessen the ability of the program to achieve the objectives, a second reduction sensitivity analysis will be performed with an additional group of wells. This iterative reduction process will continue until the minimum number of wells required to meet the program objectives, have been identified. A summary will be prepared of all of the wells eliminated in this manner.

The next step is to select monitor wells to be used during the second, third and fourth quarters of the Task 4 program. Selection of these wells will be done by evaluating those wells included in the first quarter monitoring effort. Criteria to be used for including wells in the second, third, and fourth quarter monitoring efforts include the following:

- o Wells required by current RMA programs;
- o Wells that have displayed large variations over time;
- o Critical wells with little sampling history;
- o Wells that previously had displayed anomalous or questionable results;
- o Wells that have displayed trends in contaminant levels over time; and
- o Wells that appear essential to the sampling program as a result of interpretation of first-quarter data.

If possible, results of first quarter sampling will be utilized to design the sampling programs for second, third, and fourth quarters.

As before, a table will be prepared summarizing which wells are recommended for inclusion during the second, third, and fourth quarters and why these wells are included. Similarily, justification for why other wells were deleted from the program will also be presented.

3.1.1.5 Selection of Wells for Water Level Measurements

The final step will be to select wells for water level measurements. Beginning with the monitoring wells to be included in the first quarter monitoring effort, additional wells will be selected from the list of those with constructions suitable or potentially suitable for water level measurements. Emphasis will be placed on wells for which water levels are currently being obtained as part of on-going RMA programs.

Currently, the RMA Environmental Division obtains water levels as part of the 360° Program from 491 wells on a quarterly basis. Based on this a total of 500 wells will be used as a target in designing the water level measurement program for litigation support.

In addition to wells currently part of the RMA 360° Program, emphasis will be placed on wells that form a cluster completed at various depths. This will allow for an estimate of the potential vertical migration rates of contaminants at RMA. Emphasis will also be placed on wells that form transects across the major flow paths into, through, or out of RMA.

Water level measurements obtained from these wells can later be used along with existing hydrogeologic data to perform a water balance for the alluvial aquifer at RMA.

Once the initial set of wells are identified using the above criteria, the areal distribution of the wells will be examined using the maps prepared during the location evaluation effort (Section 3.1.1.3). Additional wells will be added to the program to ensure:

- Adequate areal coverage of the alluvial aquifer;
- Adequate areal coverage of both the highly transmissive alluvium and the low transmissivity weathered bedrock portions of the alluvial aquifer;
- All major flow paths within the alluvial aquifer will be covered;
- Adequate coverage to define variations in the saturated thickness of the alluvial aquifer;
- Adequate coverage in the vicinity of all potential sources of ground water mounding (i.e. South Plants area, Basin A, etc.); and
- Best possible coverage of the Denver sands.

As with the design of water sampling program, the merits of deleting and retaining individual wells will be evaluated. The resulting impacts of the proposed reductions will be evaluated in terms of the validity of the overall program, loss of wells from the on-going RMA program, decreased definition of potential or actual flow paths, potential anomalies that may remain unresolved, or other specific impacts to the program.

The final step will be to prepare a table and maps summarizing the wells that were selected for water level monitoring and the anticipated use of the information to be obtained from each.

3.1.1.6 Field Reconnaissance

The last step in the design of the monitoring program will be a field inspection of the wells proposed for water quality sampling and water level measurement. The purpose of this reconnaissance will be to evaluate access for each well, to familiarize the field team with the locations of the proposed wells, to ensure that all of the proposed wells still exist and are undamaged and to perform limited validation of the data used during the selection process. Under this last item, approximately 10 percent of the selected wells will be examined to confirm the validity of the existing data. Specifically, the location, condition of the surface seal, casing diameter, casing cap, total depth, and depth to water level will be examined and compared to the information obtained during the selection process.

As part of field reconnaissance, the locations and collar elevations of 10 percent of the monitoring wells proposed for water sampling will be surveyed. Surveying will be conducted by a Colorado registered surveyor. This information will be used to confirm the validity of the existing survey data. If surveyed elevations do not agree with RMA/USATHAMA data base values recommendations will be made concerning the need for additional surveying. In addition, any key wells included in the water quality sampling or water level measuring efforts for which accurate location and elevation data does not exist, will also be surveyed. Well numbers, coordinates, elevations, survey marker used, and date of measurement will be recorded in the field notebook. These data will be transmitted to USATHAMA upon completion of surveying.

3.1.1.7 Presentation of the Results

Results of the well selection process and associated evaluations can be found in Appendix A. This report presents the following:

- A brief summary of the selection procedures employed emphasizing any modifications to or variations from the procedures documented in this Technical Plan;
- Tabular summaries of the results of the well construction, sampling history, and location evaluations;
- Summary lists of the monitoring wells to be included in the first quarter, sampling efforts and those for which water

levels are to be obtained along with justification for their inclusion;

- Plates showing the locations of these wells;
- Summary of the results of the field reconnaissance/well inspection reports;
- A detailed discussion of the strengths and weaknesses of the proposed program; and
- A discussion of the ability or limitations of the proposed programs for meeting the requirements of the ongoing RMA monitoring programs.

In addition the project team will submit to USATHAMA copies of the following items resulting from the well selection process. The contractor will also retain copies of all work sheets:

- Work sheets used to evaluate the individual well constructions;
- Work sheets used to summarize the sampling history information;
- Section maps prepared during the evaluation of well locations, hydrogeology, and extent of contamination; and
- Copies of available boring and well completion logs for wells included in the Task 4 Monitoring Program.

3.1.2 GROUND WATER MONITORING

To evaluate the quality of the existing monitoring data, selected ground water monitoring wells will be sampled during the first quarter of Task 4 and a portion of these wells during the subsequent three quarters. The exact wells to be sampled will be determined by the procedures outlined in the previous section.

3.1.2.1 Sampling Protocol

Ground water sampling methodology and techniques will adhere to USATHAMA Geotechnical Requirements with respect to sample collection, sample preservation, sample shipment, and chain-of-custody requirements.

3.1.2.1.1 Water Sampling Forms

All pertinent data obtained during ground water sampling will be recorded on water sampling forms and kept in a bound field notebook. The following information for each well sampled will be included:

1. Well number;
2. Date and time (24-hour system);
3. Pertinent observations (e.g. weather);
4. Casing diameter and condition;
5. Static water level and well depth;
6. Number of gallons per casing volume
7. Pump depth, measured pumping rates, total pumping time and total volume of water removed;
8. Characteristics of the water (color, odor, etc.);
9. Measurements of pH, temperature and conductivity;
10. Sample number;
11. Sample bottles (number, type, preservative); and
12. Signature of sampler and date.

Field meters will be calibrated at the beginning, once during, and at the end of each day of sampling. These data will be recorded in a designated portion of the field notebook.

At the conclusion of each day of sampling, the Field Team Leader will review each page of the notebook for errors and omissions and will then date and sign each reviewed page.

3.1.2.1.2 Sampling Procedures

The following is a summary of the sampling procedures to be employed in Task 4:

1. Record well number, date, time, sample number, other pertinent information (e.g. weather conditions);
2. Measure and record depth to water and total well depth, calculate well casing volume;
3. Lower submersible pump to a few feet below the maximum drawdown or to bottom of well. Record depth to pump;
4. Pump 5 well-volumes out of well. Discharge water to ground at least 50 feet from the well head;

5. Measure and record pumping rate, total pumping time, and total volume purged;
6. Remove pump after purging is completed or if well is dewatered.
7. Sample immediately or if well was dewatered, sample when water level has recovered. Sample using bottom filling teflon® or stainless steel bailer;
8. Decant portion of water into sample bottles. Agitate bottles and discard water. Fill rinsed sample bottles directly from bailer;
9. Label bottles and place in ice chest;
10. Measure and record pH, temperature, and conductivity;
11. Complete chain-of-custody forms; and
12. Sign and date well sampling form.

A detailed step by step methodology will be developed and disseminated to the field crew(s) instructed in its proper implementation.

All downhole equipment will be thoroughly cleaned with COR-approved water prior to and between sampling each well. All cleaned equipment will be placed on and covered with clean plastic sheeting when not in use. A sample of this sheeting will be retained for possible future chemical analysis.

When practical, sampling equipment (e.g. ropes, etc.) will be dedicated to each well to reduce potential cross contamination.

The depth at which the pump is set will be determined by the relationship between the elevation of the water level and the elevation of the well screen. If the water level is within the screened interval or if the well is likely to be dewatered, the pump will be set just above the bottom of the well, the exact distance to be determined in accordance with the pump manufacturers recommendations (usually about 1 ft). If the water level during pumping is above the screened interval the pump will be set a few feet below that water level. In this situation the water near the water surface (where the bailed sample will be obtained) will be removed and replaced by ground water from the aquifer.

Prior to sampling, the pump will be removed form the well to provide access for the bailer. the pump should be equipped with a check valve so that water in the pump and pipe will not drain back into the well.

The ground water will be sampled using a clean, bottom filling teflon® or stainless steel bailer in a manner such that aeration and oxidation of the samples is minimized. A portion of the water will be decanted into the sample bottles, agitated then discarded. The water will then be decanted into the sample bottles.

Each sample will be assigned a unique sample number. A sample typically will consist of several sample fractions collected in separate bottles but labeled with a single sample number. The fractions are analyzed for different sets of parameters.

Each sample container will have a preprinted label. The labels will include the project number, sample number, date, time, sampler's initials, preservations (if any). As a further precaution, the bottle itself will be marked with the sample number and date using nonwater-sollubie ink or paint. Samples will be placed in ice chests and will be kept below 4°C.

A portion of the ground water will be collected in a clean, preferably disposable, container so the measurements of pH, temperature, and conductivity can be made. In addition, the color and odor of the ground water and well as other observations will be recorded.

3.1.2.2 Sample Containers and Preservation

Sample containers and preservatives used in the sampling will be in accordance with USATHAMA specifications. These materials will be provided by the project laboratories.

In general, sample fractions for organic analysis will be collected in amber glass bottles with Teflon®-lined caps and those for inorganic analysis will be collected in polyethylene bottles. Bottles for volatile organic analysis (VOA) should be filled to overflow and then tightly capped to avoid the presence of air bubbles. Air space may be left in the other sample bottles to allow for addition of preservatives, where necessary.

3.1.2.3 Chain-of-Custody

Chain-of-custody forms will be completed by the sample collector. Data on these forms will include the sample number, collection date and time, the number and type of bottles, and the types of sample (soil, ground water, etc.). The sampler will sign and date the form. This form is to be transported with the samples at all times and is an inventory of the samples and those persons with access to the samples. The chain-of-custody forms will be reviewed by the Field Team Leader prior to sample shipment.

3.1.2.4 Sample Shipment

At the end of each sampling day the samples will be brought back to the sampling handling trailer for packaging. The Field Team Leader will review the chain of custody forms (as well as the field notebook as previously mentioned) for errors and omissions.

The samples will be repacked into heavy-duty coolers with ice sealed in plastic bags and will be at a temperature of 4°C. The chain-of-custody forms will be placed in a waterproof bag in the corresponding coolers. The coolers will be sealed and wrapped in accordance with individual shipping requirements. The samples will be shipped by air freight on a daily basis to ensure that sample holding times are not exceeded. Sampling will be scheduled as that the samples can be shipped in a timely manner.

3.2 SURFACE WATER

As part of the Task 4 Survey, surface water data will be collected and compiled to determine the surface water mass balance and water quality across RMA. The surface water program will be designed following the technical elements established for the task and consequently satisfy the overall task objectives.

3.2.1 SURFACE WATER MONITORING

Task 4 surface water monitoring activities will be two-fold. Separate efforts will be established as to determine both the surface water mass balance and the water quality goals of the surface water phase of the task.

3.2.1.1 Water Quantity

The water quantity portion of the Task 4 Survey is designed to determine a surface water mass balance for RMA. Efforts will be directed to the collection, reduction, and compilation of stream flow and precipitation data.

3.2.1.1.1 Water Level and Discharge

Water level measurements will be obtained at eleven monitoring stations currently established across RMA (Figure 3.2-1). Data will be produced through the operation of Stevens Type-F continuous water level recorders. The recorders are equipped with battery-operated clocks, horizontal. drum, 1:5 gauge scale, and have a chart precision of 0.10 ft. The recorders have been modified and calibrated for weekly operation.

To protect the floats and dampen the fluctuations caused by wind and turbulence, the recorders are housed in stilling wells. The structures are located on the stream banks except in the case of the Havana Interceptor which has the well located in the center of the canal. The inlets to the wells consist of two horizontal pipes with a lower inlet being located at an elevation below the lowest water elevation and an upper inlet which would be capable of functioning should the lower one become clogged during high flows. The steel housing is contained in a 6 in thick concrete base to prevent ground water infiltration and stream water outflow. To protect the gauges from weather and vandalism, all wells have small instrument shelters attached at the top end.

The datum of the gauges will be arbitrarily located at an elevation below the lowest possible water level. This will avoid the possibility of negative water level values. The datum selected will be referred to a

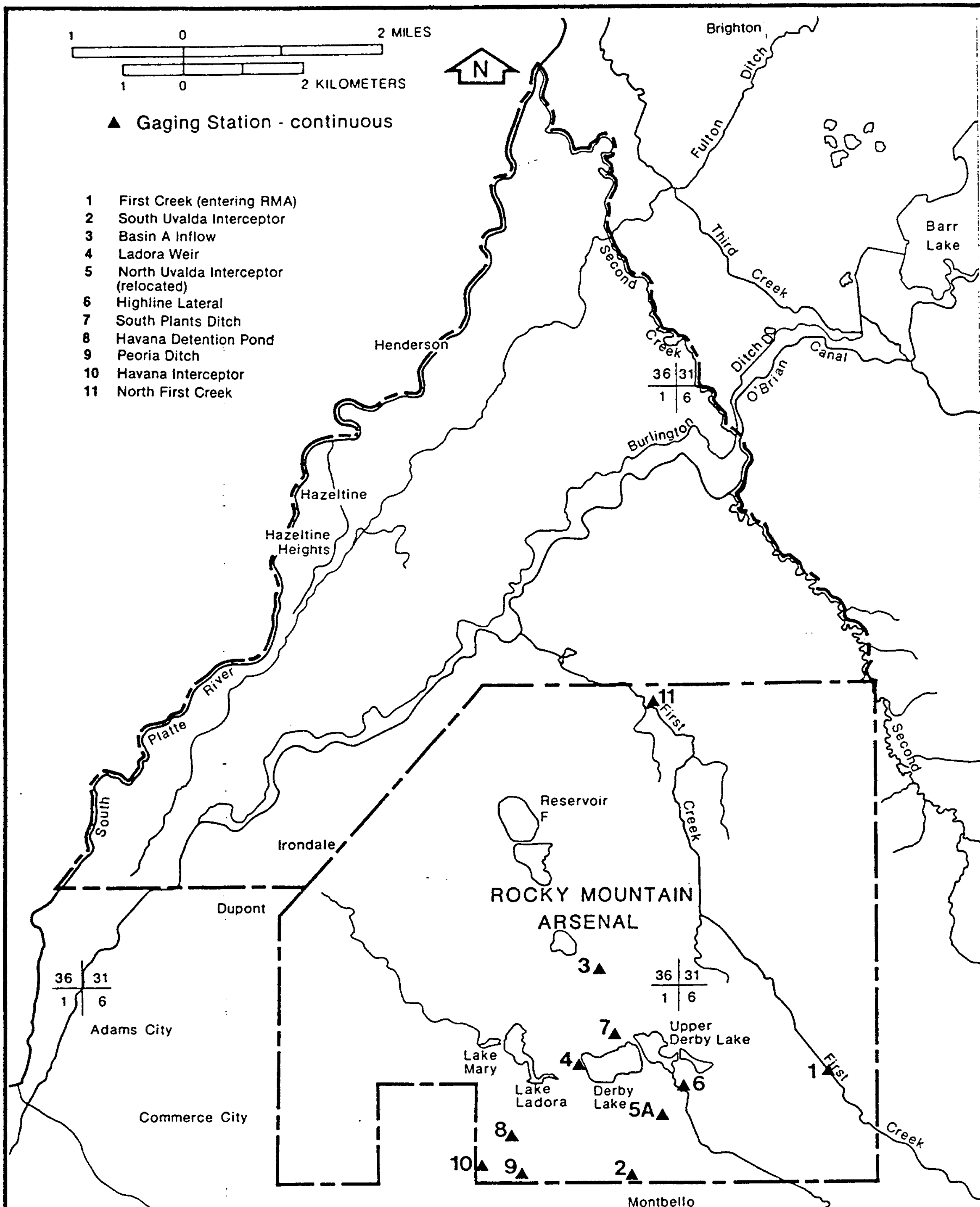

Figure 3.2-1
STREAM FLOW MONITORING STATIONS

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

benchmark of known elevation so the arbitrary datum may be recovered if gauge and reference marks are destroyed.

Water surface elevation of Upper Derby, Lower Derby, Ladora, and Mary lakes will further be monitored. Levels will be obtained through observation of staff gauges installed at the lakes. Stage-volume curves will then be utilized to convert measurements to lake stage.

Discharge will be calculated for the 10 open channel monitoring stations and obtained directly for the Ladora and STP flowmeters. To determine monitoring station discharge values, stage will be recorded on a strip chart recorder producing a continuous graphic record on the rise and fall of the water surface with respect to time. In order to convert stage into discharge, the average velocity of the stream will be calculated and multiplied by the channel cross sectional area.

All open channels have been modified by the installation of artifical control structures. These control structures have caused some eroison of the banks and downstream channels. These will be stabilized by using rock gabions and riprap. To the extent possible, without rebuilding the entire structures, the following conditions will be met or nearly approximated within the constraints of practicality.

- The shape of the structure should permit the passage of water without creating undesirable disturbances in the channel above or below the control;
- The structure must be of sufficient height to eliminate the effects of variable downstream conditions;
- The profile of the crest of the control should be designed so that a small change in discharge at low flows will cause a measurable change in stage; and
- The control should have structural stability and should be permanent.

The installation of such artifical controls tend to stabilize the stage-discharge relation and thereby simplify the procedure of obtaining accurate records of discharge. Specifically, of the 10 channels, 5 are natural channels equipped with concrete controls somewhat higher than the downstream channel bottom elevation. In most cases, the controls are lower at the center of the channel than at either bank and form a slightly V-shaped cross section. The stream gauge stations which are equipped with these concrete controls are North and South First Creek, North and South Uvalda Ditch, and Peoria Interceptor.

The five remaining channels are Ladora Weir, Havana Interceptor, South Plants Ditch, Highline Lateral, and Basin A. The Ladora Weir location is equipped with a sharp crested weir, and Havana Interceptor is a large concrete-lined trapezoidal-shaped canal. The South Plants Ditch and Highline Lateral sites are located just upstream from the concrete-lined diversion structures. The Basin A structure is a Vee Notch Weir located in a small channel.

Measurements of flow and the corresponding simultaneous stage recording will be utilized to construct stage-discharge rating curves. In order to determine the discharge corresponding to different stage heights, the velocity and area of each stream must be determined. The velocity will be measured at a number of points across the stream at six-tenths depth. Using this datum, as well as the depth at each point, the mid-section method of calculating the discharge for partial sections will be used.

In the event the streamflows are too swift, as to permit wading into the stream, a "slope area" approach will be used. In conjunction with this, a float method will be used to determine velocities. The method involves measuring the amount of time required for a floating object to travel a known length of straight channel. A coefficient of 0.85 is commonly used to convert surface velocity to mean velocity. This value will be calculated on days of high flow when both methods can be used. Measurements made utilizing this method should result with an accuracy of 10 percent.

The curves will be revised each time channel conditions are altered. Since the rating curves will not be completed until near the end of the project, a Manning's equation approach will be used to estimate flows and flood discharges. The cross-sectional area will be determined from surveys. The roughness coefficient will be solved for using data from direct measurements where discharge and cross-sectional area are known.

3.2.1.1.2 Precipitation

Two precipitation gauges will be installed at RMA. These will be used in conjunction with precipitation measurements obtained at NWS stations at Stapleton Airport and Brighton, Colorado to determine the precipitation input to the RMA surface water mass balance. The gauges are of the tipping bucket variety and are attached by cable to event recorders.

3.2.1.1.3 Suspended Sediment

Surface water flows serve as the meeting place of water from surface runoff, ground water, and municipal and industrial discharges. An important process other than thorough mixing of these sources is their interaction with the sediment load of the stream. The carrying capacity of the stream for sediment increases with increased velocity and turbulence. Since sediment adsorbs anions and cations, the concentration of the particles is directly related to the ability of the stream to maintain sediment in suspension. Collection of suspended sediment samples will therefore aid in the evaluation of the surface water regime by generating data which can be used to determine whether the streams are aggrading or degrading and the resulting amount of sediment in suspension which may impact water quality.

Suspended sediment for the five natural channel locations at RMA will be sampled once a quarter assuming adequate flow conditions exist. This will be accomplished by using a USDHS9, depth-integrated suspended-sediment sampler. The sampler, which is designed for use in streams less than 15 ft deep, weighs about 24 lb, is streamlined with tail vanes to orient it into the direction of flow and is recessed to accommodate a 1 pt container (470 cc).

The sampling operation, the head is oriented upstream with the nozzle pointing directly into the current, and the sampler is lowered from the water surface to the streambed and then raised to a position above the water surface. It is important to lower and raise the sampler at a constant rate, but the sampler may be lowered at a rate different than it is raised. Prior to sampling, all bottles must be clean, and, after sampling, bottles must be capped to prevent contamination.

If, during sampling, the bottle becomes filled, the sample will not be representative of actual stream conditions and must be discarded. The capacity of the sample bottle is 470 cc., but, because the axis of the bottle is inclined to the vertical, any sample in excess of 440 cc may be in error due to the circulation of the water/sediment mixture. The minimum sample volume to obtain a sample large enough for laboratory analysis is 375 cc. If a sample volume is too low, the sampler may be repeatedly lowered and raised until a sufficient volume of sampler is obtained.

To facilitate more efficient sampling, the sampler is equipped with different sized nylon nozzles; the sizes are 1/4, 3/16, and 1/8 in inside diameter. In addition, a chart showing the relation between stream velocity and corresponding filling time is available for each nozzle size. The filling time is the total time of submergence in seconds and therefore represents both the upward and downward movement of the sampler.

The information necessary for each sample bottle is the date, time, location, gauge height, sample number, and samplers name. This information will be written on each sample bottle at the time of sampling.

3.2.1.1.4 Schedule

Monitoring activities will require personnel onsite as dictated by climatological conditions. As recorders have been calibrated for weekly operation, at a minimum personnel will be onsite once a week to collect water level as well as stream flow data. During this time routine maintenance of apparatus and structures will be performed.

Currently, numerous ESE and subcontractor personnel are involved on a daily basis with ongoing field activities at RMA. The onsite staff will be utilized in a reporting network to notify parties directly involved in surface water monitoring of impending storms and uncontrolled actions effecting the surface water budget (surface water diversion, overflows, etc.).During major storm events surface water personnel will be onsite to continuously monitor conditions as well as make daily measurements and data observations as to maintain current stage-discharge curves.

Water quantity data will be reduced on a daily basis and compiled weekly as well as on a monthly basis.

3.2.2.1 Water Quality

Quarterly sampling of water quality will be performed as part of the surface water portion of the Task 4 Survey. Samples will be collected at approximately 30 locations across RMA (Figure 3.2-2) during the first quarter.

3.2.2.1.1 Sampling Protocol

Data from surface water sampling will be recorded on water sampling forms similar to that utilized in ground water sampling. This data will include an accurate description of the point sampled, the date, the sample number, parameter measurements, (pH, temperature, and specific conductivity), sample bottles and the sampler's name.

The sample will either be collected directly in the sample container or in a bailer from which the water is decanted into the sample bottles. Labels will be attached with the sample number and date. Sample number and date will also be written on the sample bottles as described in Sections 3.9.1 of the Task 1 Technical Plan. Samples will be stored on ice at 4°C.

3.2.2.1.2 Sample Containers and Preservation

Surface water samples will be preserved as required by USATHAMA Geotechnical Requirements. In general, samples for organic analysis will be collected in amber glass bottles with Teflon®-lined caps. Samples for inorganic analysis will be collected in polyethylene bottles.

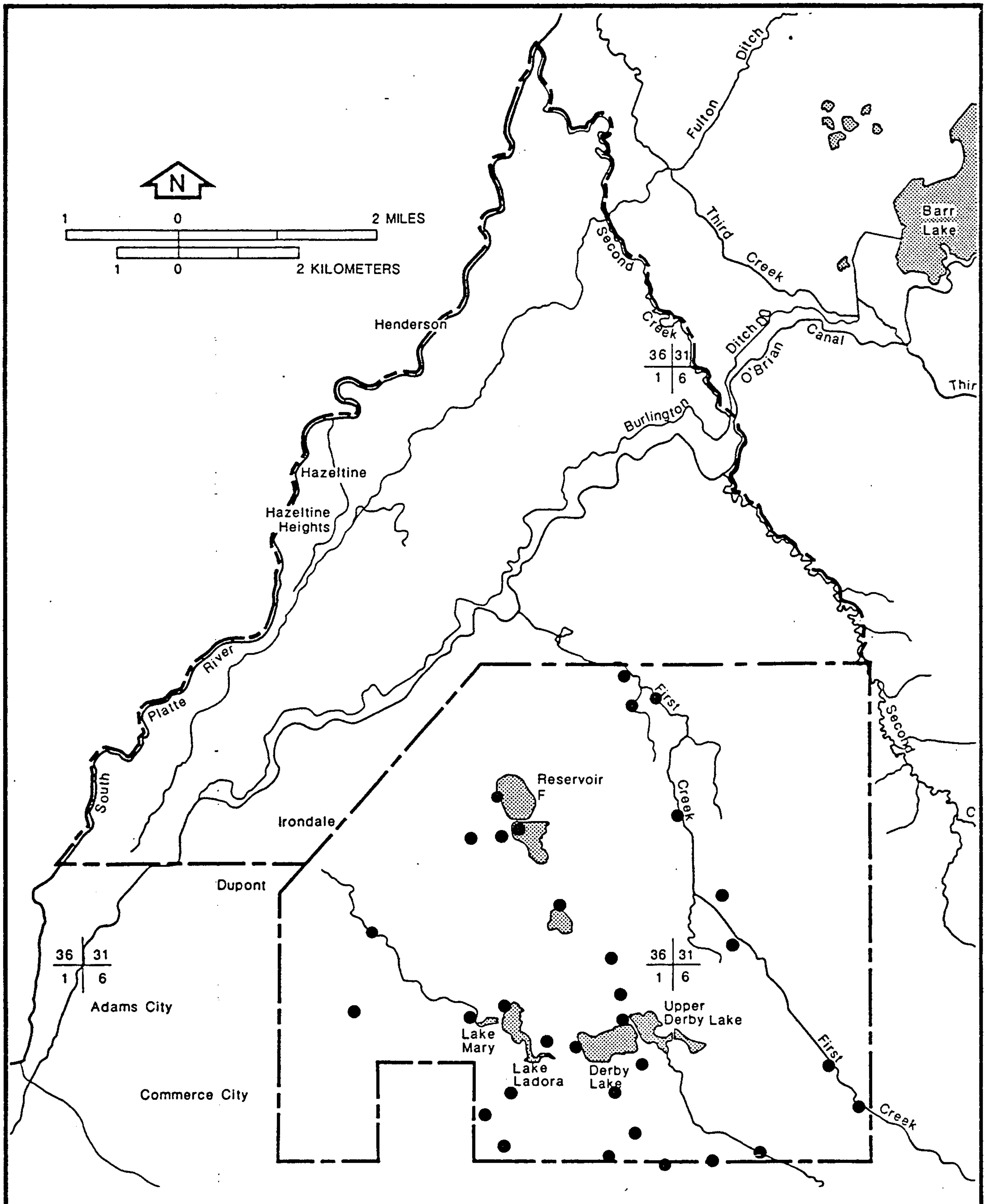

Figure 3.2-2
SURFACE WATER SAMPLING SITES
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

3.2.2.1.3 Chain-of-Custody

Chain-of-custody forms will be completed by the samples and checked by the Field Team Leader according to the procedure described in Section 5.0 of the Task 1 Geotechnical Plan.

3.2.2.1.4 Sample Shipment

Samples will be packaged and shipped according to the procedures described in Section 5.0 of the Task 1 Geotechnical Plan. Chain-of-custody forms will accompany all samples.

3.2.2.1.5 Schedule

As stated, samples will be collected quarterly. In the event that sample collection cannot be performed as a result of dry conditions and no flow, collection will be made during periods of major rainfall when stream flow is renewed.

4.0 CHEMICAL ANALYSIS

The objectives of the chemical analysis program will be to provide USATHAMA with reliable, statistically supportable, and legally defensible chemical data regarding type and level of contamination in surface water and ground water at RMA. As designed the work element will consist of a two phased screening program integrated with surface and ground water sampling efforts. Samples collected during first quarter activity will be analyzed by quantitative techniques with 25 percent of the total samples collected also screened by semi-quantitative methods. Quantitative analyses will be restricted to four pesticides, DCPD, DIMP, five organosulfur compounds, five volatile aromatics, seven volatile organohalogens (including DBCP), and chloride/fluoride. The parameters result from an evaluation of contaminant sources at RMA and the compounds attributable to activities at these sites as well as previously detected chemical substances in the hydrologic regime. The general semi-quantitative screening will be utilized to confirm the analytes identified by quantitative techniques. Analytes to be analyzed for during subsequent quarterly sampling will be determined based on an evaluation first quarter results. If any changes are deemed necessary at that time, the list of chemical parameters will be modified. Tables 4.0-1 and lists the chemical analyses for Task 4.

Defensibility and technical quality of data are assured by requiring documentation of procedures used during the analytical survey. Sample preparation, materials, shipping, handling, chain-of-custody procedures, etc. will be consistent with those required in Task 1.

Chemical analysis costs estimates are based on the assumption that analytical services will be provided by ESE and MRI laboratories. ESE is currently certifying for the necessary methods under other tasks.

There is a possibility that due to scheduling overlap, various tasks may run concurrently. This would result in the number of samples generated

Table 4.0-1. Chemical Analysis - Task 4 (Page 1 of 2)

Analysis/Analytes	Hold Time	Level of Certification	Reference Methods	Method
Organochlorine				
Pesticides		Quantitative	EPA 608	
Aldrin Endrin Dieldrin Isodrin	Extract as quickly as possible. (No more than 7 days). Analyze within 30 days of extraction.			CAP-GC/ECD
Volatile Organohalogens		Quantitative	EPA 601	
Chlorobenzene	14 days			PACK-GC/Hall
Chloroform	14 days			
Carbon Tetrachloride	14 days			
trans-1,2-Dichloroethylene	14 days			
Trichloroethylene (TCE)	14 days			
Tetrachloroethylene	14 days			
Organosulfur Compounds		Quantitative		PACK-GC/FPD-S
P-Chlorophenylmethylsulfone ($PCPMSO_2$) P-Chlorophenylmethylsulfoxide (PCPMSO) P-Chlorophenylmethylsulfide (PCPMS) 1,4-Dithiane 1,4-Oxathiane	Extract as quickly as possible. (No more than 7 days.) Analyze within 30 days of extraction.			

Table 4.0-1. Chemical Analysis - Task 4 (Page 2 of 2)

Analysis/Analytes	Hold Time	Level of Certification	Reference Methods	Method
Volatile Aromatics		Quantitative	EPA 602	PACK-GC/PID
Toluene	14 days			
Benzene	14 days			
Xylene (o-, m-, p-)	14 days			
DCPD		Quantitative	EPA 608	CAP-GC/FID
Dicyclopentadiene	Extract as quickly as possible. (No more than 7 days). Analyze extract within 30 days of extraction.			
DIMP		Qualitative	EPA 622	PACK-GC/FPD-P
Diisopropylmethylphosphonate	Extract as quickly as possible. (No more than 7 days). Analyze within 30 of extraction.			
DBCP				
Dibromochloropropane	14 days	Quantitative		CAP-GC/ECD
Chloride/Fluoride		Quantitative	EPA 300	Ion Chromatograph
Chloride	28 days			
Fluoride	28 days			

Source: ESE, 1985.

by field activities exceeding the processing capacity of the ESE and MRI laboratories. If this overload situation is realized, another laboratory or laboratories would be required to analyze the excess. This would also entail additional certification and management charges.

It should be noted that the proposed analytical techniques may not provide adequate detection limits for water quality criteria. In that event alternate analytical techniques will have to be selected and certified. Costs for this certification process are not included.

Due to the uncertain effect of filtration on samples (i.e. possible removal of analytes of concern), Task 4 samples will not be filtered.

It is anticipated that some 25 percent of the samples analyzed by GC methods will be subjected to a confirmation analysis by a second column GC procedure. Originally, a 10 percent GC/MS confirmation was proposed, however, a review of the chemical data indicates that sufficient GC/MS work has been performed at RMA. To preclude the need for any additional GC/MS work historical records should provide the necessary background data should any unknowns be present. Any unknowns detected during the quantitative screening will be reported using a UNK prefix followed by the retention time expressed in numerical form.

5.0 QUALITY ASSURANCE

Quality Assurance (QA) for Task 4 will be consistent with the Field/Laboratory QA Plan developed for Task 1 activities. The plan is project specific and describes procedures for controlling and monitoring sampling and analysis activities as required under Task 4. As designed, the Field/Laboratory QA Plan will ensure the production of valid and properly formatted data concerning the precision, accuracy, and sensitivity of each method used for USATHAMA sampling and analysis efforts. The plan is based on USATHAMA April, 1982 QA program requirements as modified by U.S. Army AMCCOM Procurement Directorate and ESE as well as certified analytical methods submitted to and approved by USATHAMA. The plan is presented in Appendix B of the Task 1 Technical Plan. Specific RMA QA/QC requirements are detailed in Section 5.0 of the same document.

6.0 DATA MANAGEMENT PLAN

Data for Task 4 will be handled according to the Data Management Plan in Volume I of the Task I Technical Plan, Contract Number DAAK11-84-0016. As outlined in the plan, field data will be entered into the Compaq Plus personnel computer in the ESE Denver office and transmitted to the Compaq in the ESE Gainesville office via telephone. The field data will be transferred to the IR-DMS, put through the Geotest data check routine, validated, and put in Level 2. Sample number assignments, labels, and logsheets will be made in Gainesville and given to the sampling team. Samples shipped to laboratories will follow chain-of-custody procedures described in the Technical Plan. Data from lab analyses will be entered into the ESE Prime 750 computer, incorporated with certification and field data, and formatted into files according to the IR-DMS User's Guide. After validation these files will be sent to the Univac using the Tetronix or the Compaq Plus computer, run through the data-checking routine and elevated to Level 2.

7.0 SAFETY PROGRAM

The purpose of this section is to summarize the safety, accident, and fire protection standards, and to outline standard operating procedures to ensure the safety of all ESE and subcontractor personnel performing Task 4 activities at RMA. Responsibilities, authorities, and reporting procedures as designated for Task 4 are identical to those designed for Task 1 in Section 7.0 of the Task 1 Technical Plan.

The program addresses all of the requirement of DI-A-5239B and fully complies with requirements of the Occupational Safety and Health Administration (OSHA) and U.S. Army Material Command (AMC) Regulation 385-100, Army Regulation (AR) 385-10, and Department of Army Pamphlet (DA PAM) 385-1 for all activities to be conducted. The program also complies with the ESE Analytical Laboratory Safety Plan.

7.1 TASK 4 PROCEDURES

7.1.1 WASTE CHARACTERISTICS

In the 43 year history of RMA, many extremely hazardous chemicals were manufactured, stored, or partially destroyed in demilitarization activities. Key compounds include GB and nerve agents, H and L blister agents, munitions, organophosphorus pesticides and herbicides, phosgene, hydrazine, and toxic metals. A comprehensive list of contaminants of concern is given in Table 7.1-1. It is unlikely that any of these compounds may be encountered during surface and ground water sampling. Detailed information on many of these compounds is given in Agent Fact Sheet, SMCRM Form 357 (RMA, 1984) and Military Chemistry and Chemical Agents, TM 3-215 and AFM 355-7 (Departments of Army and Air Force, 1963). Copies of this information will be available at the support trailer at RMA.

7.1.2 GENERAL PROCEDURES

As Task 4 activities will be RMA wide, the survey will be conducted in both uncontaminated and contaminated areas. In order to develop the most adequate Safety Plan possible an evaluation of each sampling and monitoring station will be made. This will result in each sampling and monitoring location being treated as separate. Overall procedures and methods are outlined in the following sections.

An area of 30 ft will be established around wells and surface monitoring/ sampling sites. This will be considered a "hot zone" and all personnel entering this area will wear the prescribed level of protection. Before entering all personnel protective equipment will be checked for proper fit and operation.

In areas of known or suspected contamination the following decontamination procedures will be followed:

- Equipment decontamination will occur in two phases. Phase I decontamination will occur at the hotline of a particular well or surface water body. Bailers, pumps, and other field equipment will be rinsed at the hotline using an Indian sprayer and wrapped in a plastic bag. The equipment will then be placed in the truck which stays out of the hot zone. The equipment is then driven to the decontamination pad in Section 36 where it will be decontaminated more thoroughly.

- Field team members will also have a two phase decontamination procedure. Outer clothing will be rinsed at the hot line. After this initial decontamination, field personnel will ride in the truck to the decontamination pad. At the pad, all disposable clothing will be removed and discarded into barrels. The field personnel will then ride into the support area south of Section 36, enter the field wash trailer, shower, and change into street clothes.

To avoid contaminating the vehicle, the seats and floors will be lined with plastic at the beginning of each day and after lunch. When field personnel decontaminate at the decontamination pad, this plastic will be removed and discarded. The truck will then be considered clean.

When sampling wells and surface water in Section 36 and 26, the truck will be considered contaminated. The vehicle will then be decontaminated at the decontamination pads in each of the sections.

7.1.3 SURFACE WATER SAMPLING

Surface water within the boundaries of RMA will be sampled during Task 4. The major hazards during this activity are skin and eye contact with contaminated water, and falling into the contaminated body of water. As all surface water sampling will be done from the edge of the water body and not from a boat, the falling hazards should be minimal.

Levels of protection for the surface water sampling/monitoring portion of Task 4 are based on an evaluation of the respective locations by the Subtask Supervisor.

- Section 36--Field personnel will wear full Level C protection while performing surface water sampling/monitoring in Section 36. Respirators will be equipped with Scott 642 OV-H cartridges Saranex®-coated Tyvek® coveralls will be worn prior to conducting operations. Personnel will monitor the area with the HNU to determine airborne contaminant concentration.
- Section 26 and South Plants--Field personnel will wear modified Level D protection. This will include Saranex® suit, inner and outer gloves, boots and boot covers. A respirator will be readily available.
- Other areas--Field personnel will wear Level D protection at all other sampling monitoring sites. Protection will consist of inner and outer rubber gloves, steel toe and shank rubber boots, goggles for the eye protection, and cotton overalls. Respirators will be readily available.

Samplers will avoid submerging their hands in the water deep enough so water drains into the top of the gloves.

Levels of protection will be upgraded if the Safety Officer deems it necessary.

All sampling and monitoring efforts will be performed in pairs. Before commencing activities field personnel will check in at the safety trailer.

7.1.4 GROUND WATER SAMPLING

Ground water from existing wells on RMA will be sampled by field team members. As with surface water sampling, skin and eye contact with contaminated water is a major hazard. Inhalation hazards are increased when the well is first uncapped due to a possible build-up in the well of hazardous vapors, and during well pumping. During pumping activities, volatiles may be stripped from the water and become airborne.

Continuous monitoring with the HNU will take place during well uncapping and purging activities. Respirators will be worn during uncapping activities. If an above background reading is detected during opening, team members will retreat to at least 30 ft away from the well for 10 minutes. This will allow the vapors to disperse. After 10 minutes, team members will again test the well with the HNU.

If organic vapor concentrations are detected above background during well pumping, respirators will be worn at all times or until the safety officer states that respirators may be removed. During both uncapping and pumping activities, if organic vapors are detected above 5 ppm in the breathing zone, work activities will cease immediately.

Levels of protection for the ground water sampling portion of Task 4 will be based on an evaluation of the respective sampling sites by the Subtask Supervisor or his representative. In general, a modified Level D will be required in the uncontaminated areas and full Level C in contaminated areas. Levels will be adjusted if the Safety Officer deems it necessary. During both ground and surface water sampling, field teams will consist of at least two persons. A first aid kit and fire extinguisher will be available at all times. Sampling teams will check-in at the safety trailer prior to commencing activities.

7.2 CONTINGENCY PLANS

7.2.1 CHEMICAL AGENTS AND ORDNANCE

It is possible that during Task 4 activities field teams will encounter surety materials in ground and surface water. The most likely areas to encounter these materials are Section 36 and South Plants.

7.2.1.1 Monitoring Procedures for Surety

In the event that chemical agents are detected, field personnel will follow the procedures as outlined in Section 7 of the Task 1 Technical Plan. Additional safety procedures regarding UXO, chemical agent incidents, emergency services, fire/spills, and accident reporting are also detailed in Section 7 of the Task 1 Technical Plan.

8.0 CONTAMINATION ASSESSMENT

Evaluation of the data generated by the Water Quantity/Quality Survey will center around five primary objectives:

1. Evaluation of the water quality and quantity data obtained during the first quarter sampling effort to determine the adequacy of the sampling program proposed of the second, third, and fourth quarters;
2. Verification of the quality and representativeness of the historical data base;
3. Estimation of a combined surface water and ground water balance for RMA;
4. Definition of the nature, extent, as well as temporal and spatial variations of surface water and ground water contamination at RMA; and
5. Evaluation of the degree of uncertainity associated with each of the above evaluations.

To accomplish these objectives, the contamination assessment consists of several subtasks:

- o Data reduction and presentation;
- o Validation of historical data;
- o Interpretation of water quantity and quality data for RMA; and
- o Evaluation of the adequacy of the Task 4 monitoring activities and the degree of uncertainity associated with the interpretive efforts.

8.1 DATA REDUCTION

Under this subtask, field data and laboratory data obtained during the monitoring efforts will be compiled. Base maps will be prepared showing all of the wells and surface water stations that were sampled or from which water levels or flow values were obtained. Those wells that are completed in the alluvial aquifer and those completed in the Denver Formation will be identified. Principal features of RMA (i.e., major structures, surface water features, disposal basins, etc.) will also be compiled on these maps.

As part of this subtask water level measurements obtained in the field, will be converted to ground water elevations relative to mean sea level. Stream gauge data will be converted to flow rates. Stage discharge rating curves will be developed for the various lakes. Staff gauge data obtained from these lakes will subsequently be converted to water surface elevations using these relationships.

Data obtained during the field and laboratory efforts conducted under this task, as well as limited data obtained during previous investigations at RMA, will be assembled and compiled in tabular format and on the base maps. Maps will include contour plots of ground water elevations, saturated thicknesses, and contaminant concentrations. DAta reduction will also include development of trend plots of water level elevations and contaminant concentrations versus time. Changes in water levels and contaminant concentrations can then be examined.

The final step in data reduction will be to develop cross sections through RMA depicting the hydrogeologic conditions and surface water gradients. Cross section development will rely heavily on information obtained during the design of the monitoring programs; that is boring log data and information from previous geologic evaluations.

8.2 VALIDATION OF HISTORICAL DATA

Under this subtask, statistical techniques will be used to evaluate the quality and the representativeness of the existing data base. This evaluation will be performed by comparing the historical data to the data obtained under the Task 4 efforts. Comparisons will be made using rigorous statistical techniques possibly including, but not limited to, the following methods:

- o Simple statistics (i.e., means, standard deviations, ranges, correlations coefficients, etc.);
- o T-tests, F-tests, and Chi-square tests to determine the difference between mean values, population variance, and population distributions;
- o Linear regression to evaluate temporal variations in water levels and contaminant concentrations; and

- o Analysis of variance if necessary to define the potential sources of variation between the two sets of data.

Based on the statistical testing, those portions of the historical data base (i.e., individual contaminants, individual wells, specific sampling events, etc.) that cannot be validated will be identified. Limitations on the quality of these data will be identified and its usefulness, if any, towards qualitative efforts will be discussed.

Historical data which show no statistically significant variations from the Task 4 data will be identified. The assumptions implicit to the statistical testing will be evaluated in terms of their impact on the validity and usefulness of the historical data. Finally, a summary will be prepared that identifies those types or groups of data that appear to be of a quality acceptable for use in determining water qualities and quantities at RMA.

8.3 DATA INTERPRETATION

Two main efforts are envisioned as necessary components of the Task 4 data interpretation: estimation of water quantities, at and moving through RMA, and definition of the quality of waters on and beneath RMA.

8.3.1 WATER QUANTITY

The overall goal of this effort is to perform a water balance for the RMA which identifies the major components of flow through the site. Water balances will be performed independently for the surface water and ground water systems. These water balances will then be compared. Inconsistencies that may occur will be defined and resolved.

This information will be integrated into an overall water balance for RMA. This overall water balance will identify locations and rates of surface water recharge to the ground water system. Similarly, the locations and rates of any ground water dishcarge areas will also be identifed. Recharge/discharge relationships will be established for both alluvial and Denver aqufiers. Finally, rates of ground water and surface water recharge/discharge for RMA will be estimated.

8.3.1.1 Surface Water Balance

The surface water balance approach will follow the guideline furnished by RMA personnel (Table 8.3-1). Calculation of the surface water balance will include evaporation and transpiration. Total volumes of all surface water bodies will be calculated and losses or gains from these bodies estimated. All components of inflow and outflow for the lakes, and their relationship to surface water drainages will be quantified.

8.3.1.2 Ground Water Balance

Estimation of ground water volumes and flux rates beneath RMA will be performed using a simple analytical model based on Darcy's Law. Input to this model will be derived from the saturated thickness and potentiometric surface maps developed during the data reduction activities along with historical information on aquifer properties.

This evaluation will include definitions of aquifer heterogenity, flow paths, and representative aquifer properties for each unit and area. This information will then be combined with information on the recharge and discharge relationships between the alluvium and surface water, various units within the alluvium, and the alluvium and the underlying Denver Formation. This effort will further subdivide RMA into representative hydrogeologic volumes.

Using hydraulic gradients defined from the potentiometric surface maps, the representative aquifer properties, and the recharge/discharge relations, the flow of ground water through each individual hydrogeologic volume previously defined, will be calculated using an analytical model based on Darcy's Law. By summation, the total ground water flow within the alluvial aquifer beneath RMA will be estimated. Inflow and outflow rates along with recharge and discharge relationships will be compared for mass-balance. If significant variations are found, potential sources of variation will be identified and input into the analytical model.

8.3.2 WATER QUALITY

The evaluation of water quality at RMA will be separated into surface water quality and ground water quality components. However, the final

Table 8.3-1. Water Balance Computations

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1. Havana Pond Water Balance
   - A. Total measured volume of pond at the beginning of the month or study period (see Note 1) ________
   - B. Volume gains over the month or study period
     - Havana Interceptor ________
     - Peoria Interceptor ________
     - Direct Precipitation (see Note 2) ________
   - C. Volume losses over the month or study period
     - Evaporation (see Note 3) ________
     - Transpiration (see Note 4) ________
   - D. Calculated volume of pond at the end of the month or study period ________
   - E. Measured volume of pond at the end of the month or study period ________
   - F. Measured gain or loss in volume over the month or study period ________

2. Lakes Water Balance
   - A. Total measured volume of Upper and Lower Derby Lakes and the beginning of the month or study period (see Note 1) ________
   - B. Volume gains over the month or study period
     - Highline Lateral ________
     - Uvalda Ditch ________
     - South Plants Ditch ________
     - Direct Precipitation (see Note 2) ________
   - C. Volume losses over the month or study period
     - Evaporation (see Note 3) ________
     - Transpiration (see Note 4) ________
   - D. Calculated volume of Upper and Lower Derby Lakes at the end of the month or study period ________
   - E. Measured volume of Upper and Lower Derby Lakes at the end of the month or study period ________
   - F. Measured gain or loss in volume over the month or study period ________
   - G. Total measured volume of Ladora Lake at the beginning of the month of study period (see Note 1) ________
   - H. Volume gains over the month or study period
     - Inflow through Ladora Weir ________
     - Direct Precipitation (see Note 2) ________
   - I. Volume losses over the month or study period
     - Evaporation (see Note 3) ________
     - Transpiration (see Note 4) ________
     - Outflow through Ladora Pump House ________
   - J. Calculated volume of Ladora Lake at the end of the month of study period ________
   - K. Measured volume of Ladora Lake at the end of the month or study period ________
   - I. Measured gain or loss in volume over the month or study period ________

Table 8.3-1. Water Balance Computations (Continued, Page 2 of 2)

3. First Creek Water Balance	
A. Total measured flow onto RMA over the month or study period	________
B. Direct Precipitation (see Note 2)	________
C. Evaporation (see Note 3)	________
D. Transpiration (see Note 4)	________
E. Inflow from Sewage Treatment Plant	________
F. Total measured flow off RMA over the month or study period	________
G. Calculated gain or loss across RMA over the month or study period	________
4. Measured flow into Basin A over the month or study period	________
5. Difference between measured flows at the South Uvalda Ditch monitoring station and the North Uvalda Ditch monitoring over the month or study period	________
6. Lake Mary Water Balance	
A. Total measured volume of pond at the beginning of month or study period (see Note 1)	________
B. Direct Precipitation (see Note 2)	________
C. Evaporation (see Note 3)	________
D. Transpiration (see Note 4)	________
E. Calculated volume of pond at the end of the month or study period	________
F. Measured volume of pond at the end of the month or study period	________
G. Measured gain or loss in volume over the month or study period	________

Note 1: Volume shall be calculated using measured water surface elevation, surface area, and depth data.

Note 2: Precipitation will be obtained from the National Weather Service located at Stapleton International Airport.

Note 3: Evaporation data will be obtained from the U.S. Corps of Engineers Field Office located at Cherry Creek Reservoir. This data available is pan evaporation data which must be converted to lake evaporation using an appropriate constant for the Denver Area. Data is also available from the office of the State Climatologist in Fort Collins, Colorado.

Note 4: Transpiration will be estimated by calculating the acreage of phreatophytes in the respective water balance areas on RMA.

interpretive effort will integrate both surface water and ground water quality to establish the relationship between chemical constituents of all RMA waters.

8.3.2.1 Surface Water Quality

The evaluation of surface water quality will emphasize the areal extent of contamination, the areal distribution of contaminant concentration as a function of position along the channel length, and variations in contaminant concentrations as a function of flow rates. Temporal variations, both short term seasonal variations and long term trends will be examined. Evaluation of these relationships will be performed in both a qualitative manner and through use of rigorous quantitative statistical techniques such as regression analysis.

The areal distribution of surface water contaminants will be presented in graphical form on base maps of RMA surface water features. If possible, surface water chemical contour maps will be constructed. Geochemical properties of surface water will also be presented in graphical form such that the relationship between surface water features and between surface water and ground water features can be examined. Such graphical formats may include Trilinear or Stiff Diagrams.

8.3.2.2 Ground Water Quality

The evaluation of ground water quality beneath RMA will emphasize the areal extent of contamination, and the extent of contamination within each aquifer. Temporal variations in the areal distribution of contamination and the contaminant levels of individual wells will be evaluated.

As with the surface water data, evaluation of these factors will be performed in both a qualitative manner and through the use of rigorous statistical techniques. Qualitative evaluations would include interpretation of contour maps of the distribution of contaminant concentrations, comparison of these maps with previously developed contaminant concentration maps, and interpretation of plots of contaminant concentrations versus time for individual wells or groups of wells. Statistical evaluations might include Z-score plots and contour maps, and cumulative frequency plots. Statistical testing of the difference in contaminant concentrations between various aquifer units may also be conducted with the use of trend surface, regression, and residuals analysis to define data anomalies. Ground water geochemisty may also be examined with the use of Trilinear or Stiff diagrams to establish the interrelationship and degree of mixing between waters within the alluvial and Denver aquifers as well as between the individual hydrogeologic units within these aquifers.

8.3.3 EVALUATION OF TASK 4 DATA

Under this effort, the density and adequacy of the data developed under this task will be evaluated. The goal of this evaluation is to ensure that an adequate amount of data of suitable quality to meet the objectives of Task 4 has been collected. As before, this evaluation will consist of both qualitative and statistical efforts such as kriging or other advanced geostatistical procedures. These efforts will be directed at identifying potential anomalies and assessing the degree of uncertainity associated with the previous evaluations performed for Task 4 data by this subtask.

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APPENDIX A

APPENDIX A

A.0 SELECTION OF RMA GROUND WATER MONITORING NETWORK

Criteria established in Section 3.1.1 of this Technical Plan were utilized to evaluate the condition of existing RMA ground water monitoring wells. Ground water wells were evaluated with respect to construction, sampling history, and location. Well construction evaluations were performed to determine the representativeness of samples taken from a well with respect to the stratigraphic horizon sampled. This evaluation was also performed to establish the level of documented construction detail for litigation support. Sampling history evaluations were performed to determine the length and frequency of sampling history for each well and time trends for contaminant concentrations. Finally a location evaluation was performed to determine the distribution of ground water wells with respect to source boundaries, contaminant plumes, hydrogeologic units, and primary ground water flow paths.

The selected ground water monitoring network consists of 317 wells designated for chemical sampling and 480 wells which have been selected for measurement of static water levels. The procedure used in developing the final network design was performed as illustrated in Figure 3.1-1. The initial evaluation performed was done with respect to well construction and resulted in wells being designated as acceptable, potentially acceptable, questionable, or unacceptable. Wells of acceptable or potentially acceptable construction were further evaluated with respect to sampling history. Wells that are currently, or were formerly sampled under RMA Program were also evaluated. All wells of acceptable and potentially acceptable construction were cartographically plotted in relation to ground water flow directions, aquifer configuration, major sources of contamination, and contaminant plumes. Based on sampling history, areal relationships, and vertical distribution wells were selected for inclusin into the program. Wells of acceptable or potentially acceptable construction were deleted from the program if another acceptable or potentially acceptable well in close proximity was expected to yield similar or repetitive information. Preference was given, when possible, to wells with detailed sampling histories and wells currently in the 360° or RCRA Monitoring Programs.

Table A.1-4. Ground Water Wells of Unacceptable Construction (182)

Section	Well Numbers
5	1
22	1, 9, 10, 32
23	3, 6, 38, 40, 49, 50, 55, 60, 62, 65, 95, 108, 127, 132, 151, 301, 302, 303, 304, 305, 330, 331, 332, 333, 334, 335
24	4, 7, 8, 9, 10, 28, 43, 45, 46, 48, 50, 51, 52, 54, 55, 64, 65, 84, 88, 91, 137, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438
25	1, 2, 27, 28, 33
26	6, 10, 15, 17, 20, 42, 49, 98
27	1, 8, 14, 16, 20, 21, 22, 23, 24, 26, 35, 36
28	10, 16, 17, 19, 21
30	1, 2
31	1, 4
33	3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
34	1
35	1, 4, 10, 19, 24, 42, 43, 44, 45, 46, 49
36	2, 12, 37, 38, 39, 40, 41, 42, 44, 45, 46, 49, 53, 58, 59, 64, 70, 71, 82, 101, 102, 106

Upon completion of the above activities, areas were identified which did not contain wells of acceptable or potentially acceptable construction. Such locations included areas downgradient of known contaminant sources within known contaminant plumes, areas within primary ground water flow paths, and areas thought to be uncontaminated. Ground water wells to be monitored in these locations were selected from the "questionable" category. Sampling histories were then evaluated. Again, preference was given to wells with detailed sampling records and wells currently in RMA programs. Additionally, wells of "questionable" construction which occurred in clusters with wells of acceptable construction were utilized to fully evaluate the vertical distribution of contaminants.

A final screening was performed to assure that adequate numbers of wells were selected in appropriate locations and that the total number of wells in each section was balanced with respect to project objectives and source priority. The following sections described in detail the various steps in development of the proposed ground water monitoring network.

A.1 WELL CONSTRUCTION EVALUATION

Construction evaluation criteria and procedures described in Section 3.1.1.1 of this Technical Plan were utilized to place ground water monitoring wells into acceptable, potentially acceptable, questionable, and unacceptable categories. The RMA Well Summary Report (DP Associates, 1985) contains 1568 individual data records for onpost ground water monitoring wells. Approximately one third of these wells were not evaluated with respect to construction detail as either the Well Summary Report contained insufficient information, no borehole and well completion logs were available, or the well had been previously abandoned. The number of wells falling into these categories are listed below.

Well with insufficient information		= 443
Abandoned Wells		= 96
Total Wells Evaluated		= 1029
	TOTAL	1568

For wells where insufficient information was available, approximately one half (222) were wells which had been constructed by Shell Chemical Company and neither borehole nor well construction logs were made available. Other wells were eliminated from consideration due to unclear or undocumented locations, unknown screened intervals, and undocumented borehole numbers.

Following elimination of the 539 wells with inadequate documentation or that had been abandoned, a total of 1029 ground water monitoring wells underwent detailed well construction screening as described in Section 3.1.1.1. Well construction screening forms for these 1029 wells will be submitted to USATHAMA and copies will also be retained by the project contractors. Results of the construction evaluation are summarized below.

Wells of acceptable construction	= 189
Wells of potentially acceptable construction	= 175

Wells of questionable construction		= 484
Wells of unacceptable construction		= 181
	TOTAL	1029

A large percentage (47%) of monitoring wells examined were of questionable construction. Wells were placed in this designation for one or more of the following reasons:

- o Completions cross hydrogeologic units possibly allowing for cross-contamination or unreliable water level measurements;
- o Discrepancies between the well summary report (DP Associates, 1985) and well completion data on the field boring logs; or
- o Incomplete information on well construction detail.

Wells were defined to be of unacceptable construction for several reasons including the following:

- o No supporting data could be found to verify the information contained in the well summary report (DP Associates, 1985);
- o No information on screened intervals existed on borehole or well completion logs;
- o Bentonite seals were improperly located within the screened interval; and
- o Confined bedrock aquifer wells that were not sealed or otherwise properly isolated from the overlying water table aquifer.

Ground water monitoring wells found to be of acceptable construction are listed by section in Table A.1-1. In general, the information for these wells is complete with minor exceptions. Wells were placed in this category if all or nearly all pertinent data was located and well construction detail was such that the screened interval will provide a ground water sample representative of the adjacent aquifer materials. Many of these wells were installed in later years (1978 to present) during programs associated with the 1100 and 1200 series borings. In general, these wells possessed few data gaps with respect to construction details and these gaps were considered to be insignificant with respect

Table A.1-1. Ground Water Wells of Acceptable Construction (189)

Section	Well Numbers
1	21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 34, 35
2	9, 10, 11, 12, 13, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31
3	2, 3, 4, 5, 6, 7
4	7, 8, 9, 10, 11, 12
5	2, 3
6	3, 4, 5
7	4, 5
8	3, 4, 5
9	2, 3, 4
11	2, 4
12	2, 3, 4
19	14, 15, 16, 17, 18, 19
22	23, 24, 27, 28, 30, 31, 49, 60
23	177, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193
24	159
25	8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20
26	145, 146, 147
27	53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 73, 74, 76, 77, 78, 83
28	25, 28, 29
29	2, 3
30	3, 4, 5, 6, 7, 8, 9, 10, 11
31	5, 6, 7, 8, 9, 10, 11
32	2, 3
33	26, 27, 28, 29, 30, 31, 32, 33, 34, 35
34	2, 3, 4, 5, 6, 7, 8, 9, 10
35	52, 53, 54, 55, 56, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70
36	1, 116, 118, 121

to the objectives of the construction evaluation (e.g., possession of a locking cap).

Wells found to be of potentially acceptable construction are listed by section in Table A.1-2. Wells that fell into this category lacked several pieces of information necessary to be considered acceptable. However, the data obtained suggested that the well was of adequate construction and the screened interval would produce a representative ground water sample. At a minimum, the location of the screened interval with respect to the alluvial bedrock contact, saturated interval, and water table was appropriate. The placement and thickness of seals was considered adequate and well construction materials were of acceptable quality. As the number and placement of wells with acceptable construction was inadequate to achieve project objectives, all wells of potentially acceptable construction were considered for inclusion into the monitoring network.

In summary, a total of 189 acceptable and 175 potentially acceptable wells were considered for inclusion into the proposed network. In order to fill gaps in the areal distribution of the acceptable and potentially acceptable wells, or to include wells with detailed sampling histories, wells of questionable construction (484) were considered for inclusion into the network as necessary. All wells of questionable construction are listed in Table A.1-3.

Ground water wells found to be unacceptable are listed in Table A.1-4. These wells were either of unacceptable construction or contained incomplete well completion documentation for litigation purposes. For wells in this category boring logs or well completion diagrams were located in contrast to the 443 wells for which no information could be found.

Table A.1-2. Ground Water Wells of Potentially Acceptable Construction (176)

Section	Well Numbers
1	30, 33, 36, 37, 38, 39, 40, 41, 42, 43, 47, 48, 49, 50
2	14, 17, 32, 33, 34, 35, 36, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49
7	3
11	3
22	20, 21, 22, 25, 26, 29, 33, 34, 36, 37, 38, 39, 40, 41, 42, 43, 45, 53, 56, 58, 59
23	7, 28, 161, 166, 176, 196, 197, 198, 200, 201, 203, 204, 205, 211, 336, 337, 338, 339, 340, 341, 342
24	1, 2, 136, 49, 150, 158, 161, 162, 163, 164, 170, 171, 172, 173, 174, 175, 176, 178, 179, 183, 184, 185, 188, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354
25	4, 21, 22, 23, 24, 25, 26, 29, 35, 36, 37, 38, 39, 40
26	135, 140, 141, 142
27	64, 66, 68, 69 70, 71, 72
28	26
33	48, 49, 50, 51, 52, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69
35	71, 72
36	112, 113, 114, 117, 119, 122, 136, 137, 138, 139, 140, 141, 142, 146, 147

Table A.1-3. Ground Water Wells of Questionable Construction (483)

Section	Well Numbers
1	1, 2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17, 18, 19, 20
2	1, 2, 3, 4, 5, 6, 7, 8, 37
3	1
6	1, 2
7	1
8	2
11	1
12	1
19	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
20	1
22	2, 3, 4, 6, 8, 12, 13, 14, 15, 16, 17, 18, 19, 44, 51, 52, 54, 55, 57
23	2, 4, 8, 9, 10, 11, 13, 14, 15, 29, 32, 34, 35, 36, 39, 41, 42, 48, 47, 49, 52, 53, 54, 56, 57, 58, 59, 61, 63, 64, 66, 67, 96, 109, 110, 111, 118, 119, 120, 121, 122, 123, 128, 136, 137, 139, 140, 141, 142, 143, 144, 145, 146, 148, 149, 150, 151, 157, 158, 159, 160, 178, 199, 202, 206, 207, 209, 210
24	3, 6, 13, 25, 27, 47, 49, 53, 57, 58, 63, 80, 81, 83, 85, 86, 87, 89, 90, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 121, 122, 123, 124, 126, 127, 128, 129, 130, 135, 151, 165, 166, 167, 168, 169, 171, 177, 180, 181, 182, 186, 187
25	3, 5, 6, 7, 30, 31, 34
26	1, 2, 4, 5, 9, 11, 13, 14, 16, 18, 19, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 40, 41, 42, 43, 44, 45, 46, 47, 48, 50, 51, 52, 53, 54, 55, 56, 57, 58, 60, 61, 62, 63, 64, 65, 66, 67, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 96, 97, 119, 123, 124, 126, 127, 128, 129, 131, 132, 133, 136, 138, 139, 143, 144

Table A.1-3. Ground Water Wells of Questionable Construction (483)

Section	Well Numbers
27	2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, 15, 17, 18, 19, 25, 27, 28, 29, 30, 31, 32, 33, 34, 37, 40, 41, 42, 43, 44, 45, 49, 50, 51, 52, 63, 65, 75, 79, 80, 81, 82
28	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 14, 15, 16, 18, 20, 22, 23, 24, 27
31	2, 3
32	1
33	1, 2, 16, 18, 19, 20, 21, 22, 23, 24, 25, 53, 54
35	2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 47, 48, 50, 51, 73, 74, 76
36	3, 6, 7, 8, 9, 10, 11, 13, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 43, 48, 50, 55, 56, 57, 60, 61, 62, 63, 65, 66, 67, 68, 69, 72, 73, 74, 75, 76, 77, 78, 79, 81, 83, 84, 85, 86, 87, 88, 80, 90, 91, 103, 105, 107, 108, 109, 110, 145

A.2 SAMPLING HISTORY EVALUATION

All ground water monitoring wells which were considered of acceptable or potentially acceptable construction were subjected to a sampling history evaluation. In addition to those wells of preferred construction, sampling history evaluations were performed for all wells of questionable construction that are part of the current 360 Degree and RCRA Monitoring Programs. Sampling history evaluation was also performed for other wells of questionable construction that were considered for inclusion into the program resulting from the location evaluation and final selection process.

The purpose of this evaluation was not to eliminate wells from sampling but to identify monitoring wells that exhibit;

- Long term sampling histories;
- Elevated contaminant concentrations;
- Consistent contaminant concentrations;
- Trends in contaminant concentrations; and
- Erratic or anomalous chemistry.

This information was used to select between adjacent wells that were expected to provide similar results.

Criteria evaluated are described in Section 3.1.1.2 of this Technical Plan. Factors examined and documented for each well include the frequency of sampling, the period of record, and the analytes measured and well status with respect to current RMA Programs. Evaluation of chemical data included the identification of contaminants detected, frequency and magnitude of this detection, and chemical trends. Contaminant trends were described as eratic (variable), increasing or decreasing, and consistently high or low. Contaminant trends were noted for all organic compounds and inorganics ions of significant or detectable concentrations.

Section 3.1.1.2 of the Technical Plan indicates that sampling procedures were also to be evaluated fore each sampling event. However, upon consultation with RMA and USATHAMA personnel it was concluded that insufficient information was available to evaluate sampling methodology.

RMA programs currently have generalized sampling procedures and RMA programs from prior years do not have documented program sampling procedures nor were sampling records maintained for each well. Therefore, insufficient information was available to determine well evacuation volumes, evacuation equipment, sampling equipment, well yield, or methods used to ensure well stabilization such as measurement of key chemical parameters. For these reasons appropriate portions of the sampling history evaluation sheet (Table 3.1-2) were deleted. Copies of all evaluation sheets will be submitted to USATHAMA and originals will be retained by the contractor.

Based on the evaluation of prior sampling results, a number of general observations were identified. First, most wells exhibited consistent trends (increasing, decreasing, or constant) with respect to inorganic contaminants (Cl, F, SO_4) and organic contaminants of high solubility and low volatility. However, these same wells had a high tendency to exhibit variable concentrations for organic contaminants present at concentrations near the method detection limit and for organics with moderate volatility.

Variations in concentrations of organic contaminants near the method detection limits most likely result from inherent variability in the analytical techniques at low concentrations. Additionally, variations in the method detection limits achieved by each of the laboratories analyzing samples (RMA, CDH, TCH, and SCC) may have obscured definition of contaminant trends.

Erratic results for volatile and semi-volatile organic compounds is assumed to be at least partially a result of incomplete or inconsistent well purging techniques. Volatile organics will be air stripped from ground water by certain sampling procedures and also during atmospheric contact in the well bore. Sample handling and preservation techniques may also affect the quality of volatile and semi-volatile analytical results, however, there was no documentation available to evaluate this impact.

Ground water monitoring wells present in the current 360° and RCRA Programs have a long and detailed sampling history. However, less than one half of these wells were considered acceptable or potentially acceptable with respect to well construction. In some cases no well construction data was available for these wells. Many of the wells installed in the early 1980's were found to have acceptable construction but as these wells (1100 series) were relatively new only a short period of record was available for evaluation.

Many of the wells do not possess regular detailed sampling history over a long period of record. For example, many wells were sampled on a semi-annual, quarterly or even more frequent basis for a period of one to two years. However, their remaining sampling history displays numerous gaps where these same wells were not sampled for several years. In many cases they were sampled with a different frequency (i.e., annually) several years later. Much of this variation in sampling history apparently results from budgetary and manpower restrictions at RMA. However, these variations in sampling history, along with those previously noted, prevented a straight forward interpretation of contaminant trends.

A final factor affecting definition of contaminant trends was the variation in analytes employed for successive sampling event. For example, in one year, major ions were evaluated, several years later RMA organics were evaluated, and subsequently only pesticides were evaluated. In other cases, pesticides would be detected during a specific sampling event or sequence of events (i.e., four quarters in one year) but were not included in the analytical program for subsequent years. Again, these variations presumably resulted from budgetary and manpower restrictions at RMA.

In summary, there were many factors that obscured definition of contaminant trends. As a result, much of the benefits of the sampling history evaluation were reduced to merely identifying wells with long sampling records and those that had never, or only infrequently been sampled, and also identifying wells containing ground water with elevated concentrations of contaminants.

A.3 LOCATION EVALUATION

The final screening performed prior to selection of the ground water monitoring network was to evaluate the areal and vertical distribution of the wells. The purpose of this exercise was to select monitoring wells which are in critical locations with respect to aquifer configuration, ground water flow paths, contaminant sources and contaminant plumes.

The initial effort in evaluating the location factors was to examine the distribution of wells with acceptable or potentially acceptable construction with respect to aquifer distributions and ground water flow paths. The distribution of alluvial and upper Denver wells was overlaid on the map of primary flow components at RMA (Figure 1.2-4). Areas of insufficient coverage, incomplete transects across or along major flow paths or areas with dense coverage outside of major flow paths (i.e. bedrock highs) were identified. For areas of insufficient coverage wells with questionable construction details were used to fill out the network. For areas of dense coverage, duplicate wells were identified. Selection between these wells was then based on sampling history, requirements of current RMA programs, or other factors as discussed in the next section.

In addition to evaluating the areal distribution of wells with respect to aquifer configuration and ground water flow paths, vertical distribution was also examined. This was performed primarily by identifying selected wells that were part of well clusters and including additional members of the clusters from the list of wells with questionable constructions. In addition, major clusters composed entirely of wells with questionable constructions were identified and the merits of including these clusters were evaluated. Finally, the overall distribution of clusters was evaluated to identify areas of dense coverage or duplication of clusters. Reductions in the density of clusters was based on sampling history, requirements of current RMA programs or other factors as discussed in the next section.

The second step in evaluating the location factors was to compare the distribution of acceptable, and potentially acceptable wells, and the questionable wells selected during the hydrogeologic evaluation, with the map of major contaminant sources (Figure 1.2-8). The distribution of wells was then examined with respect to its ability to define the impacts arising from each of these major sources. Where insufficient coverage, relative to upgradient, lateral and downgradient water quality in the vicinity of the individual sources, was identified, additional wells were included from the list of those with questionable constructions.

Efforts were next directed to a comparison of the areal distribution of wells against the extent of the known contaminant plumes (Figure 1.2-9). Areas with insufficient longitudinal or tranverse coverage relative to plume limits were identified and additional wells of questionable construction were selected. In general, comparison of the well distribution to the plume limits did not significantly affect the network. This is due to the fact that the distribution had already been evaluated against the major ground water flow paths and these flow paths strongly control the extent of the plumes.

The final step in the location evaluation was to evaluate the vertical distribution of sampling points. Existing clusters or portions of clusters already selected for the program during the evaluation of the areal distribution, were identified. The density of these clusters was then examined to assure an adequate distribution. Additional wells were included from the list of questionable wells to complete clusters.

A.4 FINAL GROUND WATER SAMPLING NETWORK

Upon completion of the construction, sampling history, and location evaluations a final ground water monitoring network was selected. These 317 wells, designated for sampling, are shown in Figure A.4-1 and listed in Table A.4-1. A significant number of these wells were of acceptable (176) and potentially acceptable (57) construction. However, as a result of the addition of other wells in critical locations or with long term sampling histories, 80 wells of questionable construction were included in this program. A single well of unacceptable construction (5-001) has also been included in the program. This well was added as it is currently in the 360° Program, the only alluvial well in Section 5, and part of a well cluster designated for sampling. The well was considered unacceptable due to the lack of well construction detail. Three wells for which no boring logs were located were also added to the network. These wells 3-008, 3-009, and 3-010 are located near the rail classification yard. They were installed in the 1200 series boring program and thus were probably of adequate construction. No other wells are present in the alluvium in this area so these wells have been included in the network. An effort will be made to locate boring logs or well construction information prior to sampling.

Following completion of the well construction evaluation for all 1029 wells for which sufficient data was available, wells considered to be acceptable and potentially acceptable construction were plotted on the RMA map. As discussed under location evaluation (A.3), wells of questionable construction that are currently sampled under the 360° or RCRA Programs and wells of questionable construction in areas where insufficient well density was achieved were also plotted. These wells were then examined with respect to source boundaries, contaminant plumes, and ground water flow patterns. Strategy for exclusion of wells from the program is described below.

In locations where contaminant plumes or contaminated sources were not in close proximity, individual wells or well clusters that are adjacent to other wells or clusters were examined. Deletions from the network for adjacent wells or well clusters were made based on sampling history and well construction. Sampling history factors included frequency of sample

Table A.4-1. Proposed Ground Water Monitoring Network

Section	Total Wells	Well Numbers
1	21	8, 12, 14, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35
2	23	8, 9, 10, 11, 12, 13, 17, 18, 19, 20, 21, 22, 23, 24, 25, 30, 31, 34, 35, 36, 37, 38, 39
3	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
4	6	7, 8, 9, 10, 11, 12
5	3	1, 2, 3
6	4	2, 3, 4, 5
7	4	1, 3, 4, 5
8	4	2, 3, 4, 5
9	3	2, 3, 4
11	3	2, 3, 4
12	3	2, 3, 4
19	6	14, 15, 16, 17, 18, 19
20	0	NONE
22	14	20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31, 49, 59, 60
23	24	7, 29, 39, 49, 142, 166, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193
24	10	1, 150, 158, 159, 170, 178, 179, 184, 185, 188
25	19	8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 38, 39, 40
26	31	11, 41, 65, 66, 67, 70, 71, 72, 73, 74, 75, 76, 83, 84, 85, 86, 91, 92, 93, 94, 127, 128, 129, 132, 133, 140, 141, 142, 145, 146, 147
27	17	3, 40, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 74, 75, 76, 77, 78

Table A.4-1. Proposed Ground Water Monitoring Network

Section	Total Wells	Well Numbers
28	6	23, 25, 26, 27, 28, 29
29	2	2, 3,
30	6	3, 4, 5, 9, 10, 11
31	4	5, 6, 7, 8
32	3	1, 2, 3
33	23	2, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 60, 61, 62, 63,
34	9	2, 3, 4, 5, 6, 7, 8, 9, 10
35	30	5, 12, 13, 16, 17, 34, 35, 36, 37, 38, 39, 52, 53, 54, 55, 56, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71, 72
36	29	1, 65, 66, 69, 75, 76, 82, 83, 84, 90, 91, 109, 110, 112, 113, 114, 116, 117, 118, 119, 121, 122, 136, 137, 138, 139, 140, 141, 142

collection, contaminants detected, contaminant concentrations, and inclusion in current RMA programs. Well construction considerations included depth of the screened interval (formation), screen length, and casing diameter. Preference was always given to the use of well clusters when feasible to obtain information on vertical stratification.

In areas adjacent to contaminant sources or within contaminant plumes, deletions from the program were made as necessary to provide best plume cross sections and vertical stratification. Rationale is essentially identical to that discussed above but emphasis was placed on retaining all wells presently in the current 360° Program. Preference was also given to wells with screened intervals greater than 5 ft oriented such that information can be obtained perpendicular to the direction of contaminant transport. Such lines of wells will provide control on contaminant migration.

In areas where contaminants have been detected over large depth increments preference was for inclusion of well clusters. In many cases alluvial wells associated with a cluster were rated as having questionable construction yet other cluster wells completed in the lower Denver Formation were of acceptable or potentially acceptable construction. In such cases the alluvial well has been included in the program to provide information on vertical distribution of contaminants. Wells which occur in clusters but do not have associated alluvial wells and individual wells located in the Denver Formation, were generally deleted from the network. Wells in clusters that have overlapping screened intervals were examined and appropriate reductions in the cluster made. In several instances clusters containing 5 to 8 wells contained overlapping or continuous screened intervals. In general reductions were made to include an alluvial, upper Denver, intermediate Denver, and lower Denver Formation well in the network. For the purposes of this evaluation the upper Denver wells were defined to be those wells with screens within 10 ft of the bedrock contact. Intermediate wells possessed screens between 10 and 50 ft and lower wells had screens set at depths greater than 50 ft below the contact. The majority of well clusters selected consisted of three monitoring wells. When possible well clusters in sections considered uncontaminated were retained in the network to provide both background ground water chemistry data and water quality information for interpretation of ground water flow.

Following these activities, a final review of the ground water monitoring network was performed. This review included tabulation of wells by section to achieve program balancing. This review also included the plotting of wells in various stratigraphic horizons to ensure adequate coverage for the alluvium and various levels within the Denver Formation. Network wells shown in Figure A.4-1 are listed by section in Table A.4-2. This table shows total wells per section and the associated distribution of these wells in various stratigraphic horizons. Of the 317 wells, 249 are associated with the 85 cluster configurations included in the program.

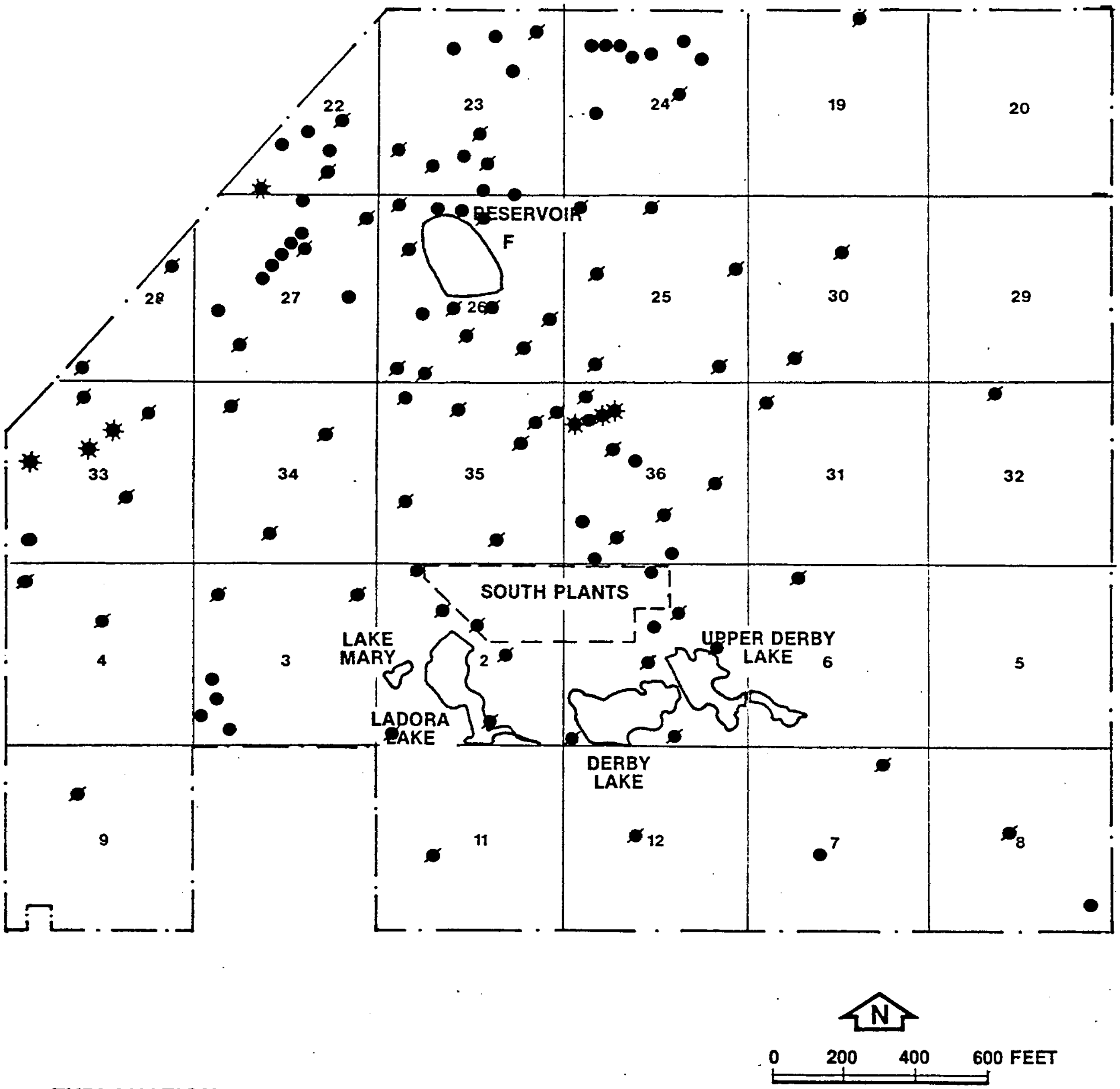
Areal distribution of wells in each of the stratigraphic horizons of Table A.4-1 are shown in Figures A.4-2 through A.4-5 for alluvium, upper Denver, intermediate Denver, and lower Denver respectively. Figure A.4-2 shows a widespread distribution of alluvial wells with highest well densities adjacent and downgradient of known contaminant sources. Locations of upper Denver wells are shown in Figure A.4-3. Distribution of these wells is sparse but this upper Denver is probably highly weathered and functions as part of the alluvial aquifer system.

Figure A.4-4 shows areal distribution of wells in the intermediate Denver Formation. These wells are probably semi-confined in that they have the potential to be continuous with the alluvial aquifer through connection along whether horizons or sand lenses. Figure A.4-5 shows distribution of wells in the lower Denver Formation. Highest well densities are for sections containing contaminant sources to evaluate the potential for contamination of lower aquifer systems.

Figure A.4-6 shows the distribution of alluvial and upper Denver wells with respect to the configuration of aquifer units and the major ground water flow paths beneath RMA. As can be seen from this figure, all major ground water flow paths have been covered.

Table A.4-2 Summary of Proposed Monitoring Well Description by Section

Section	Total	Number of Clusters	Alluvium	Upper Denver[1]	Middle Denver[2]	Lower Denver[3]
1	21	5	7	3	5	6
2	23	8	7	1	7	8
3	10	2	6	0	1	3
4	6	2	2	0	1	3
5	3	1	0	0	2	1
6	4	1	2	0	1	1
7	4	1	2	0	1	1
8	4	1	2	0	1	1
9	3	1	1	0	1	1
11	3	1	1	1	1	0
12	3	1	1	0	1	1
19	6	2	1	0	2	3
20	0	-	-	-	-	-
22	14	3	8	0	3	3
23	24	5	11	3	5	5
24	10	1	9	0	1	0
25	19	6	6	0	9	4
26	31	10	13	2	12	4
27	17	3	11	0	3	3
28	6	2	2	1	2	1
29	2	1	0	0	1	1
30	6	2	2	1	2	1
31	4	1	1	1	1	1
32	3	1	1	0	0	2
33	23	6	15	0	5	3
34	9	3	3	0	5	1
35	30	8	7	3	12	8
36	29	7	16	1	7	5
TOTALS	317	85	137 (43%)	17 (5%)	92 (29%)	71 (22%)



EXPLANATION

- ● Single Alluvial Well
- Alluvial Well Paired With Bedrock Well(s)
- ✱ Multiple Alluvial Wells in Vertical Cluster

Figure A.4-2
ALLUVIAL WELLS
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

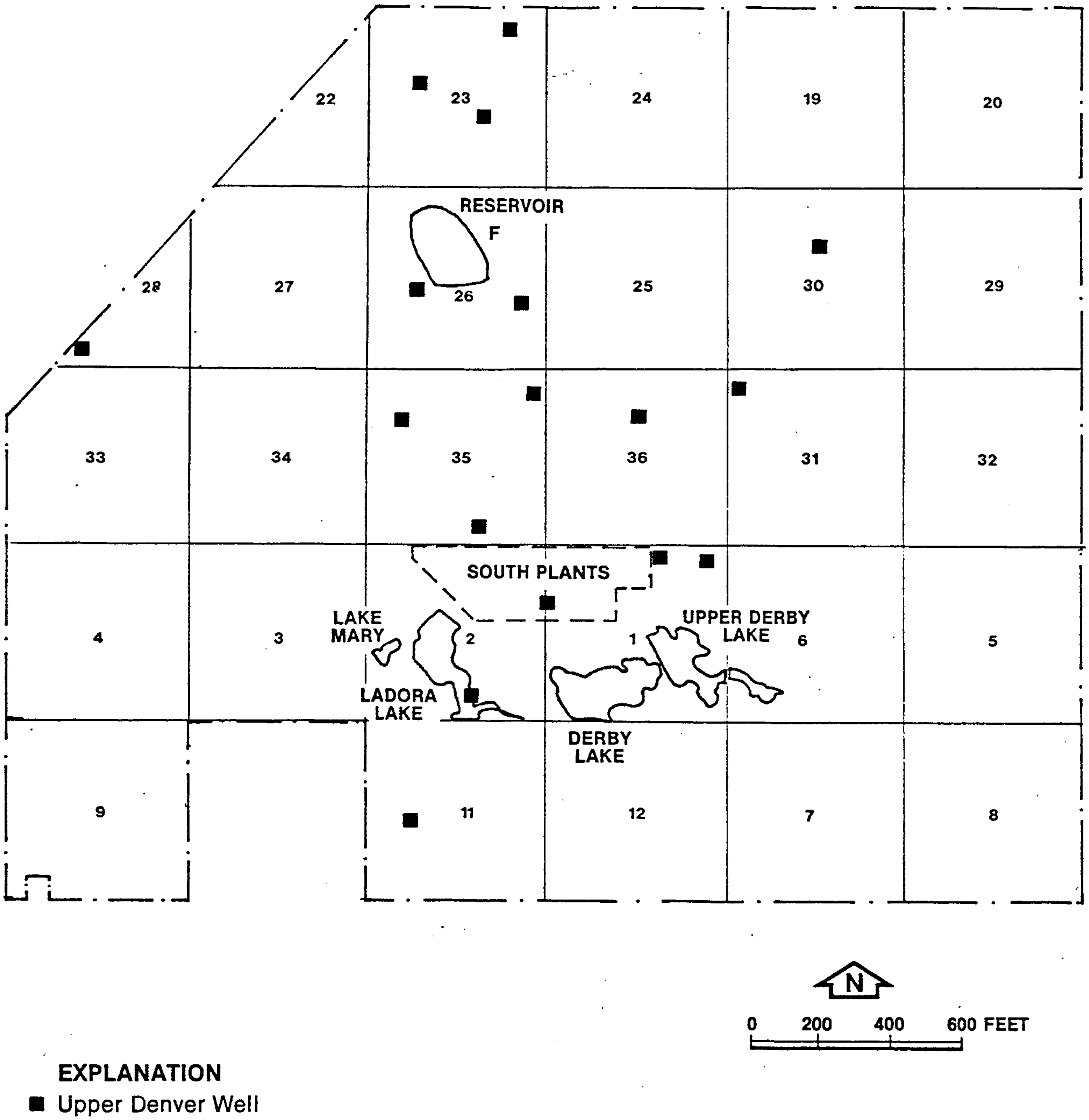


Figure A.4-3
UPPER DENVER WELLS
(WITHIN 10 FEET OF CONTACT)
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

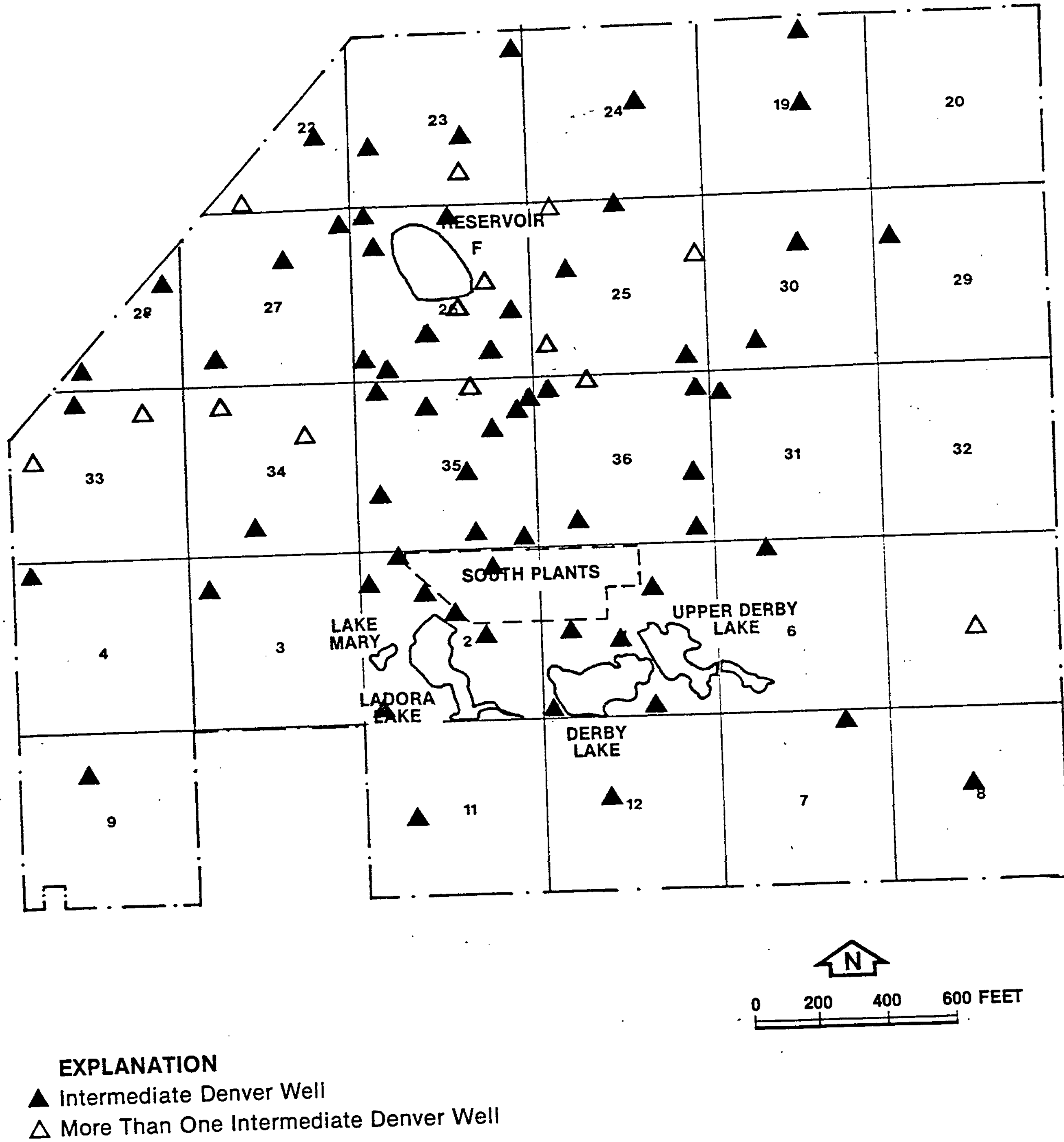


Figure A.4-4
INTERMEDIATE DENVER WELLS
(10-50 FEET BELOW CONTACT)
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

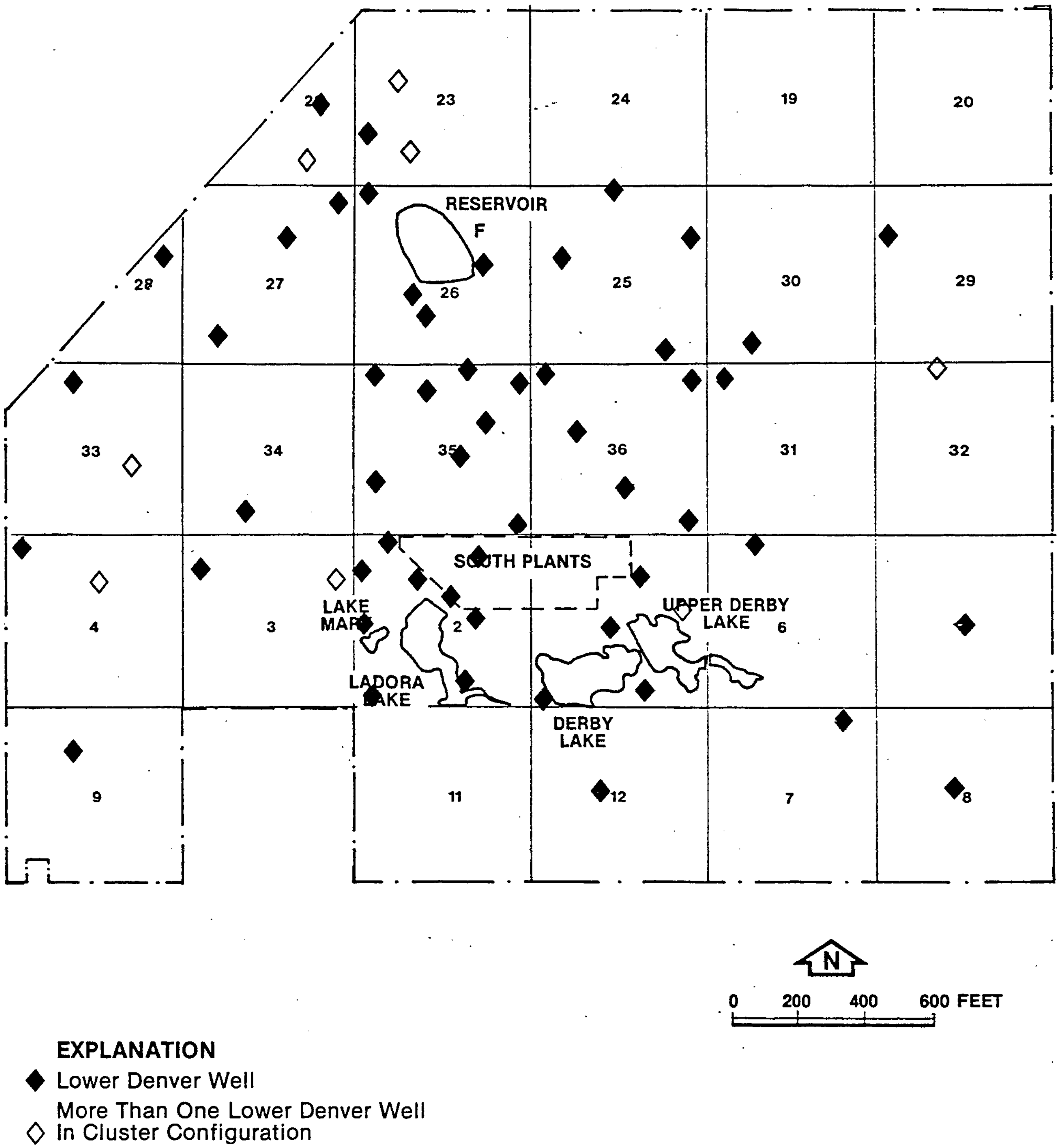
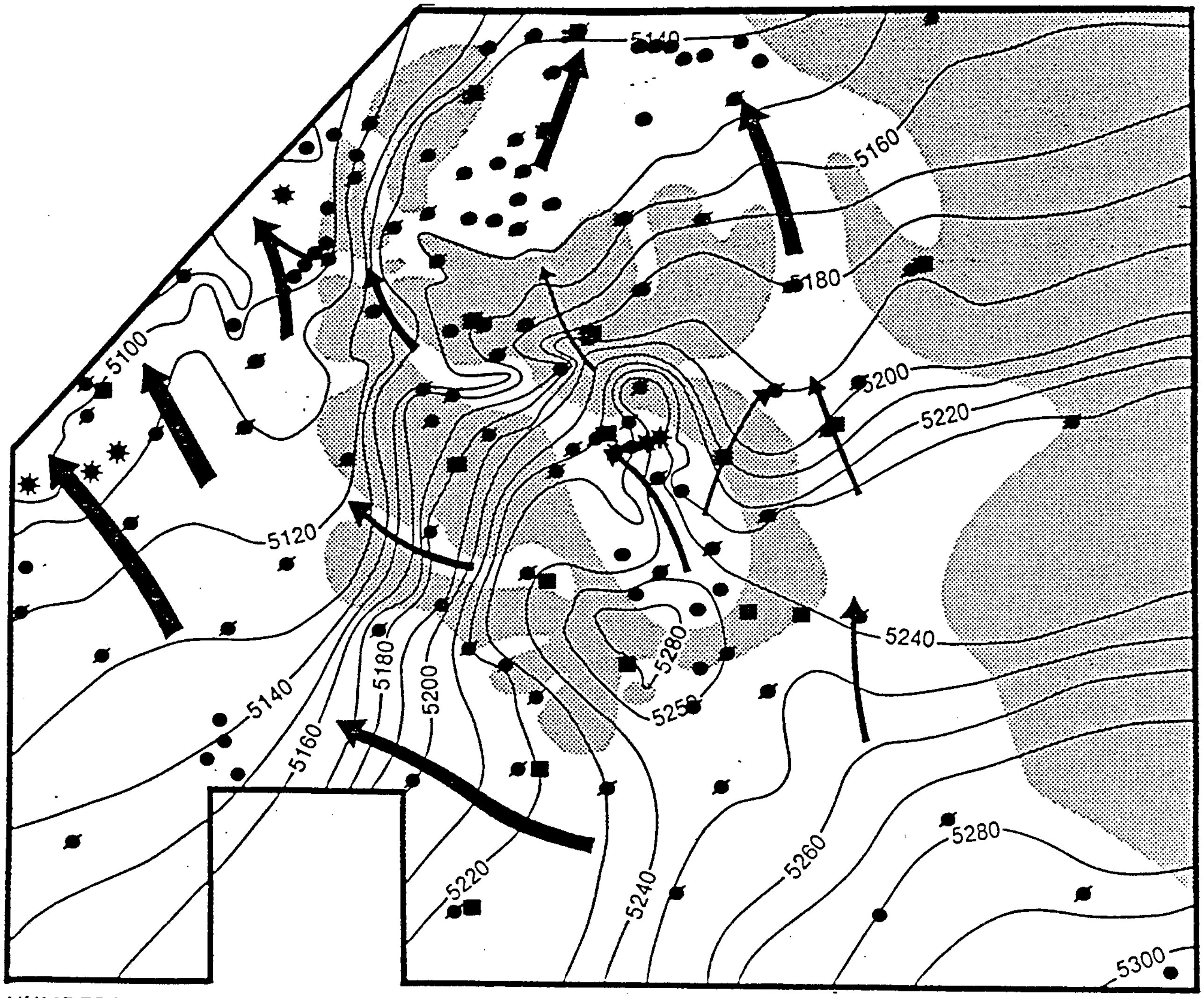


Figure A.4-5
LOWER DENVER WELLS
(>50 FEET BELOW CONTACT)
ROCKY MOUNTAIN ARSENAL

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland



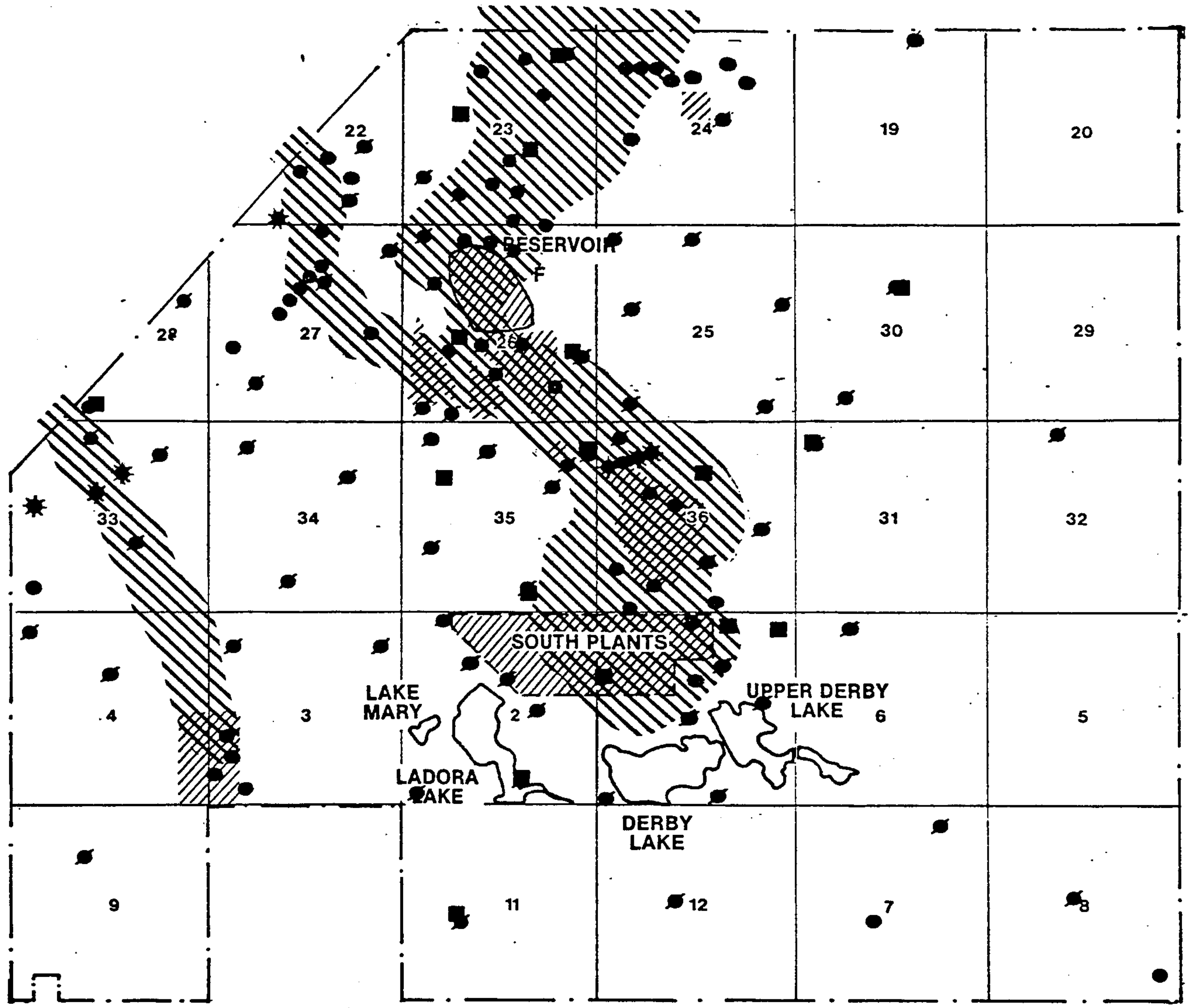
NUMBERS ON THIS FIGURE ARE
IN FEET ABOVE MSL TAKEN IN
3RD QUARTER 1981.

EXPLANATION

- Water Table is Below the Alluvial-Denver Contact
- Flow Components
- Alluvial Wells
- Upper Denver Wells

Figure A.4-6 RELATIONSHIP OF ALLUVIAL AND UPPER DENVER GROUND WATER WELLS TO WATER TABLE AND FLOW COMPONENTS AT ROCKY MOUNTAIN ARSENAL SOURCE: HARDING LAWSON ASSOCIATES, 1985	**Prepared for:** **U.S. Army Toxic and Hazardous Materials Agency** **Aberdeen Proving Ground, Maryland**

Prior to finalization of the program the well distribution was examined with respect to the source area and contaminant plumes. Table A.4-2 shows highest well densities in Section 26, 35, 36, 23, 33, 1 and 2. These sections contain either known source areas or are located adjacent to RMA boundaries where contaminant plumes are migrating. Table A.4-2 shows that approximately one half of the wells are located in the alluvium or shallow Denver Formation. Remaining wells are split between the middle and lower levels of the Denver Formation beneath RMA. Figure A.4-7 displays the distribution of alluvial and shallow Denver wells with respect to the primary contaminant sources and contaminant plumes at RMA. All of the primary contaminant sources are surrounded by both upgradient and downgradient wells. In addition, both wells transects across each known contaminant plume and vertical clusters completed within each plume have also been included.



EXPLANATION

Contaimination of Ground Water Above Water Quality Criteria or Standards

Areas Where Major Contributions to Ground Water Contamination May Have Occurred

- Single Alluviaı Well
- Alluvial Well Paired with One or More Bedrock Wells
- Cluster of Alluvial Wells Completed at Differenl Depths
- Upper Denver Wells

Figure A.4-7
RELATIONSHIP OF ALLUVIAL AND UPPER DENVER GROUND WATER WELLS TO WATER TABLE AND FLOW COMPONENTS AT ROCKY MOUNTAIN ARSENAL

SOURCE: HARDING LAWSON ASSOCIATES, 1985

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

A.5 FINAL WATER LEVEL MEASUREMENT NETWORK

A process similar to that utilized for well selection was repeated to define the well network for water level measurements. Beginning with the 317 wells proposed for water quality sampling, additional wells were selected for inclusion in the Task 4 program from the 360° Program. These wells were selected to fill gaps in the proposed Task 4 program. The next step was to select additional wells of questionable construction detail to fill gaps in the areal distribution. The final step was to compare the proposed distribution to the aquifer configuration and the ground water flow paths.

Table A.5-1 summarizes all of the wells included in the water level measurement network. Figure A.5-1 shows the distribution of alluvial and upper bedrock wells relative to the aquifer units and ground water flow paths.

A total number of wells to be used for water level measurements is at least 480. Following field reconnaissance efforts the number of well designated for water level measurements may be increased.

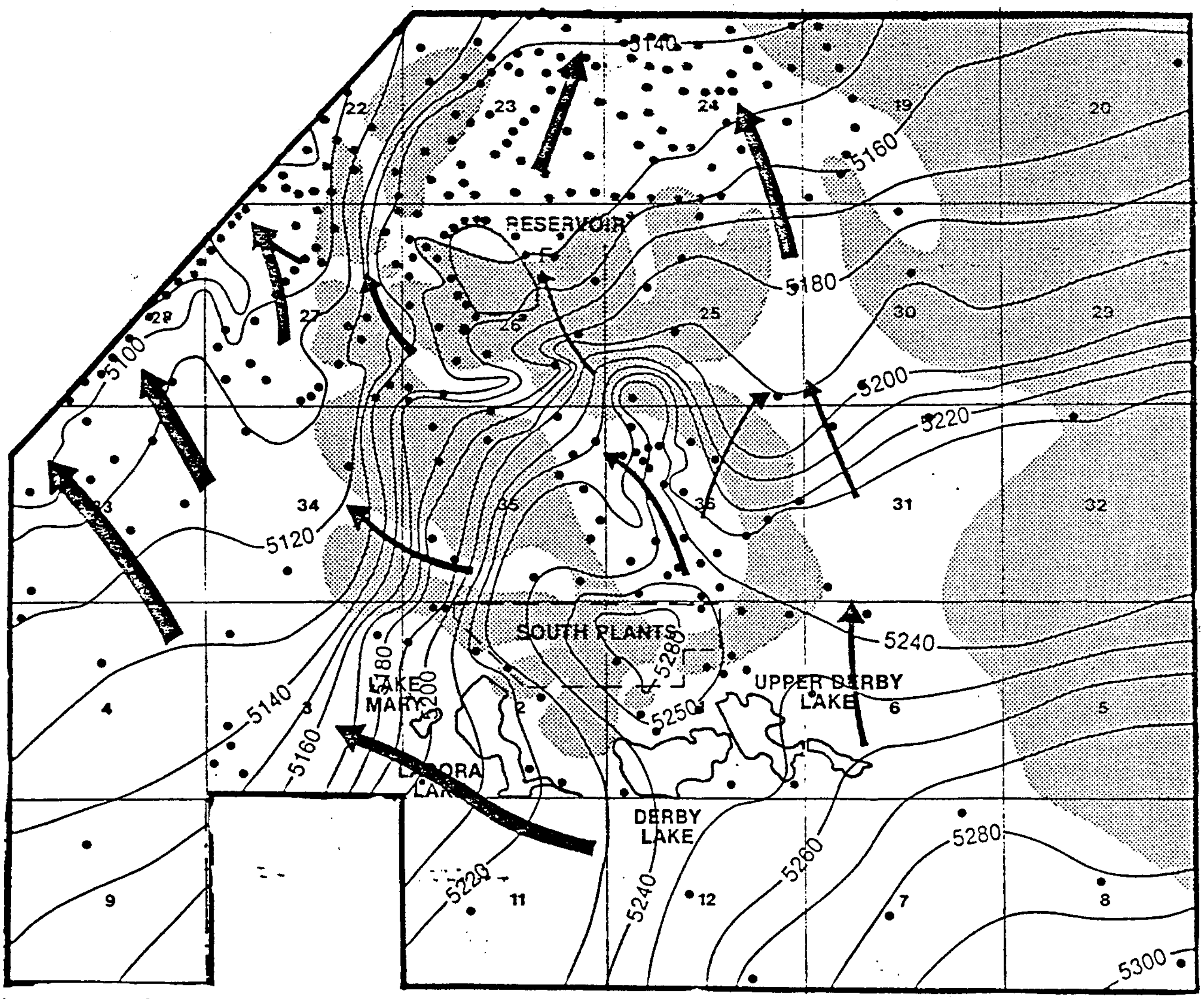
Table A.5-1. Proposed Well Network for Water Level Measurements (Page 1 of 2)

Section	Total Wells	Well Numbers
1	23	1, 2, 8, 12, 14, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35
2	24	8, 9, 10, 11, 12, 13, 14, 17, 18, 19, 20, 21, 22, 23, 24, 25, 30, 31, 34, 35, 36, 37, 38, 39
3	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
4	6	7, 8, 9, 10, 11, 12
5	3	1, 2, 3
6	4	2, 3, 4, 5
7	4	1, 3, 4, 5
8	4	2, 3, 4, 5
9	3	2, 3, 4
11	3	2, 3, 4
12	4	1, 2, 3, 4
19	11	1, 4, 8, 9, 10, 14, 15, 16, 17, 18, 19
20	0	NONE
22	21	20, 21, 22, 23, 24, 25, 27, 28, 29, 30, 31, 49, 59, 60, 2, 3, 6, 8, 13, 12, 14
23	59	7, 29, 39, 49, 142, 166, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 2, 4, 8, 10, 11, 13, 15, 36, 47, 59, 61, 63, 66, 67, 109, 110, 111, 118, 119, 120, 123, 128, 137, 139, 140, 141, 143, 146, 148, 149, 150, 52, 57, 96,14
24	45	1, 150, 158 159, 170, 178, 179, 184, 185, 188, 3, 6, 81, 92, 93, 94, 95, 96, 97, 98, 100, 101, 103, 106, 107, 111, 112, 113, 114, 115, 121, 123, 90, 92

Table A.5-1. Proposed Well Network for Water Level Measurements (Continued, Page 2 of 2)

Section	Total Wells	Well Numbers
25	21	8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 38, 39, 40, 30, 31
26	57	11, 41, 65, 66, 67, 70, 71, 72, 73, 74, 75, 76, 83, 84, 85, 86, 91, 92, 93, 2, 4, 9, 18, 48, 50, 94, 127, 128, 129, 132, 133, 140, 141, 142 145, 146, 147, 62, 78, 81, 88, 13, 19, 27, 28, 40, 51 60, 69, 143, 144, 54, 55, 56, 1, 5, 40
27	36	3, 40, 54 55, 56, 57, 58, 59, 60, 61 62, 74, 75 76, 77, 78, 2, 10, 28, 32, 37, 41, 43, 44, 45, 50, 51, 2, 4, 5, 6, 9, 63, 53, 60, 53
28	15	23, 25, 26, 27, 28, 29, 5, 12, 18, 22, 24, 2, 8, 15, 20
29	2	2, 3
30	7	3, 4, 5, 6, 9, 10, 11
31	6	3, 5, 6, 7, 8, 9
32	3	1, 2, 3
33	24	1, 2, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 60, 61, 62, 63
34	9	2, 3, 4, 5, 6, 7, 8, 9, 10
35	38	5, 12, 13, 16, 17, 34, 35, 36, 37, 38, 39, 52, 53, 54, 55 56, 58, 59, 60, 61, 62, 63, 65 66, 67, 68, 69, 70, 71, 72, 6, 23, 25, 31, 7, 8, 14, 15
36	38	1, 65, 66, 69, 75, 76, 82, 83, 84, 90, 91, 109, 110, 112, 113, 114, 116, 117, 118, 119 121, 122, 136, 137, 138, 139, 140, 141, 142, 13, 60, 63, 67, 73, 81, 85, 87, 89

TOTAL WELLS = 480



NUMBERS ON THIS FIGURE ARE IN FEET ABOVE MSL TAKEN IN 3RD QUARTER 1981.

N

0 400 600 FEET

EXPLANATION

- Alluvial or Upper Denver Wells

Figure A.5-1
ALLUVIAL WELLS AND UPPER DENVER WELLS (WATER LEVEL MEASUREMENTS)

SOURCE: HARDING LAWSON ASSOCIATES, 1985

Prepared for:
U.S. Army Toxic and Hazardous Materials Agency
Aberdeen Proving Ground, Maryland

A.6 COMPARISON WITH CURRENT RMA GROUND WATER PROGRAMS

As described in this Technical Plan the objectives of the Task 4 network are not compatible with objectives of the programs designed for operation of boundary control systems. Therefore, monitoring efforts for these wells, which may take place on a frequent basis depending on system conditions, will be performed by RMA personnel. The objectives of this Task 4 program are however, compatible with the objectives of the 360° and RCRA Ground Water Monitoring Programs. The well evaluation procedure was designed to give high priority to the inclusion in the Task 4 network of wells currently sampled under RMA programs.

Table A.6-1 lists all ground water monitoring wells currently designated for sampling under the 360° and RCRA programs. This table also lists which wells from these RMA programs have been included in the network and which wells could not be included in the Task 4 network. Of the 75 wells to be sampled under the current 360° Program a total of 41 (55%) have been included in the Task 4 program. Of the 12 monitoring wells designated for monitoring under the RMA 1985-1986 RCRA Program, 6 wells have been included in this network. Therefore, over one half of the RMA Program wells could be included in the Task 4 network. A total of 394 (80%) of the 490 wells scheduled for water level measurements under the 360° Program have been included in the Task 4 Program.

With respect to the RCRA Program all wells currently in the program that were of questionable construction or better were included in the Task 4 network. Wells 23-095, 23-108, 26-015, 26-017, 26-020, and 27-016 were found to be of inadequate or undocumented construction and placed in the unacceptable construction category. Although these wells for the most part had excellent sampling histories and good location, inclusion into the Task 4 network was not possible due to the lack of well construction data. As these wells are not in the Task 4 network, the selection of Task 4 wells was performed to substitute Task 4 wells of adequate construction for RCRA wells not included in the network.

RCRA wells 26-015, 26-017, and 26-020 are located along the northern edge of Basin F. These downgradient wells have been replaced by wells 26-011,

Table A.6-1. Current RMA Onpost 360° and RCRA Ground Water Monitoring Programs

Section	Well Numbers: Included in Task 4 Network	Well Numbers: Not in Task 4 Network
1	14, 21, 27, 30	--
2	20, 23	--
3	1, 5	--
4	10	--
5	1	--
6	2, 3	--
7	1	--
8	2	--
9	2	--
11	2	--
12	2	1
19	--	1, 4
22	--	1, 3, 4, 5, 6, 8, 17
23	7, 29, 49*, 142*	2, 3, 6, 72, 95*, 108*
24	1	3, 6, 57
25	11	--
26	41*, 73*, 85*, 127*, 133	5, 6, 8, 15*, 17**, 20**, 48
27	3, 40	2, 11, 16*, 24, 35
28	23, 27	10
30	9	1
31	5	1
33	2, 18, 25, 30	1
34	5, 8	--
35	5, 12, 61	1,2
36	1, 116, 118, 121	93

* = RCRA Program

** = Both Programs

cluster 26-145/26-146/26-147, and cluster 26-083/26-084. Downgradient RCRA wells 23-095 and 23-108 have been replaced by several downgradient clusters including 23-191/23-192/23-193, 23-185/23-186/23-187, as well as single wells 23-049, and 23-142. The single downgradient RCRA well in Section 27 (27-016) was of unacceptable construction and was replaced by well cluster 27-059/27-060/27-061.

As stated previously 41 of the 75 360° wells have been included in the Task 4 network. Wells that could not be included in this network generally exhibited inadequate, questionable, or undocumented construction placing them in the questionable and unacceptable categories. Of the 34 wells not included in the Task 4 network 18 were of questionable construction, 12 were of unacceptable construction, and for the remaining 4 wells no borehole logs or construction detail were available. Replacement wells for those 360° wells not included in the Task 4 network were not assigned but adequate coverage in the vicinities of these wells ensures generation of similar water quality data. In many cases well clusters near the unacceptable 360° well should provide sufficient information on water quality and water levels.

Table A.6-2 presents a comparison of the ground water level measurement currently conducted under the 360° Program with those envisioned under Task 4. As can be seen from this table, 80 percent of the water level measurements collected under the 360° Program will be collected under Task 4. The remaining 20 percent represent wells that were rejected from the Task 4 program due to well construction factors, wells for which boring/completion logs could not be located, and wells which were considered to provide duplicate information to that being obtained from other wells.

Table A.6-2. Comparison of Current RMA Onpost 360° Program Water Level Measurements with the Task 4 Program

Section	360°	Task 4	Rejects	No Logs	Duplicates
1	22	21	—	1	—
2	20	15	—	3	2
3	8	8	—	—	—
4	9	6	—	3	—
5	3	3	—	—	—
6	4	4	—	—	—
7	4	4	—	—	—
8	4	4	—	—	—
9	4	3	—	1	—
11	3	3	—	—	—
12	4	4	—	—	—
19	15	15	—	—	—
20	0	1	—	—	—
22	20	16	2	1	1
23	66	50	8	8	—
24	47	32	12	3	—
25	16	13	2	0	1
26	56	45	3	5	3
27	39	28	11	—	—
28	12	11	1	—	—
29	2	2	—	—	—
30	11	9	2	—	—
31	10	8	2	—	—
32	3	3	—	—	—
33	22	14	4	4	—
34	11	9	1	1	—
35	43	36	6	1	—
36	32	27	2	3	—
TOTALS	490	394	56	33	7