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(on diskette - enclosed)

APPENDIX C ANALYTICAL DATA COLLECTED DURING FY89
(on diskette - enclosed)

APPENDIX D GEOLOGIC/WELL CONSTRUCTION LOGS FOR WELLS INSTALLED
DURING FY89

LIST OF ACRONYMS

ACRONYMS AND ABBREVIATIONS

Chlordane	1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a-hexahydro-4,7-methano-1H-indene
C ₆ H ₅ Cl	Chlorobenzene
CMP FY88	Comprehensive Monitoring Program Fiscal Year 1988
CO	Carbon Monoxide
DBCP	Dibromochloropropane
DCLE11	1,1-Dichloroethane
DCLE12	1,2-Dichloroethane
DCPD	Dicyclopentadiene
DDD	Dichlorodiphenyldichloroethane
DMB12	Dimethylbenzene
DMDS	Dimethyl Disulfide
EPA	Environmental Protection Agency
ETC ₆ H ₅	Ethylbenzene
GC/MS	Gas Chromatography/Mass Spectrometry
GC/ECD	Gas Chromatography/Electron Capture Detection
ICAP	Inductively Coupled Argon Plasma
Malathion	0,0-dimethyl-s-(1,2-dicarboxyethyl) phosphorodithioate
MIBK	Methyl Isobutyl Ketone
Parathion	Parathion (C ₁₀ H ₁₄ NO ₅ PS)
PMRMA	Program Manager Rocky Mountain Arsenal
PPDDE	Dichlorodiphenylethane
PPDDT	Dichlorodiphenyltrichloroethane
SO ₂	Sulfur Dioxide
Supona	2-chloro-1-(2,4-dichlorophenyl) vinyl diethyl phosphate
TI2DCE	Trans-1,2-Dichloroethene
TCLEE	Tetrachloroethene
TRCLE	Trichloroethene
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
XYLENE	Xylene

EXECUTIVE SUMMARY

The Ground-Water Element of the Comprehensive Monitoring Program (CMP) has been designed to provide continual and long-term monitoring of ground water at the Rocky Mountain Arsenal (RMA) and adjacent off-post areas. Ground-water data collected during Fiscal Year 1989 (FY89) were obtained to verify data and analyses obtained previously as part of the RMA Remedial Investigation and Feasibility Study (RI/FS), to assess changes in the rate and extent of contaminant migration, and to meet various regulatory needs. Although the CMP has been designed primarily as a regional monitoring program, data have been collected on a more detailed basis in selected areas to support ongoing remedial/response actions or other needs.

Program Design for FY89

The FY89 well network consisted of both on-post and off-post wells for monitoring ground-water level fluctuations and water-quality conditions. The networks were designed to provide regional information about the shallow water-table aquifer (referred to as the unconfined flow system) as well as deeper aquifers of the Denver Formation (confined flow system). Wells were selected on the basis of well-construction, historical water-level and water-quality data. The areal distribution of those wells was considered in order to assure that a greater number of wells were measured in areas of confirmed ground-water contamination or where changing hydrogeologic conditions were anticipated. The water-level network included approximately 1,000 wells monitored on a quarterly basis.

The FY89 water-quality network included 488 wells monitored annually, 388 wells monitored semiannually, and 62 wells monitored quarterly. Wells monitored on an annual basis provided information to assess current contaminant distributions and to identify possible changes in the regional distribution of contaminants. Wells monitored on a semiannual basis provided detailed contaminant distribution information in specific areas of concern. These areas included the North Boundary Containment System Area, the Northwest Boundary Containment System Area, the Irondale Containment System Area, the Basin F Area, the North Plants Area, the Basin A Area, and the South Plants Area. Wells monitored on a quarterly basis provided water-quality data to support ongoing IRA projects in the Basin F Area.

FY89 ground-water samples were routinely analyzed for 73 analytes including both organic and inorganic compounds that were known or suspected to be in ground water. In addition, approximately 18 percent of all water samples were analyzed by GC/MS techniques to confirm or

refute the presence of organic chemicals detected by GC techniques and to identify any compounds not included among the 73 target analytes. The target list of chemicals for FY89 was the same as FY88 with the exception of parathion, cyanide, and acid extractable phenols. These exceptions were added to the FY89 target list on the basis of FY88 GC/MS data and discussions with the Organizations and State. The FY89 analytical program also incorporated a quality assurance and quality control plan designed to provide accurate and reproducible analytical results.

Results of FY89 Program

The FY89 water-level data were used to construct potentiometric-surface maps of the unconfined and confined flow systems. Regional water-table maps corresponding to the Fall 1988, Winter 1989, Spring 1989, and Summer 1989 were constructed for the unconfined flow system. Detailed water-table maps also were constructed for the North Boundary Containment System Area, the Northwest Boundary Containment System Area, and the Basin F Area. Regional potentiometric-surface maps were constructed for six stratigraphic zones within the confined flow system.

In general, the water table decreased approximately 210 ft in elevation across RMA and indicated a regional direction of ground-water flow from southeast to northwest. Seasonal fluctuations in the regional water table during FY89 were small. The largest fluctuation, an increase of approximately 4 ft, occurred in the South Plants Area. The water-table maps indicate that the South Platte River, located approximately two miles northwest of the RMA boundary, acts as a major discharge point for the unconfined flow system.

Local variations in flow direction were common in the unconfined flow system and usually corresponded with areas where the water table was in or near bedrock of the Denver Formation. The most pronounced variation from the regional water table pattern at RMA occurred in the South Plants area where the water table formed a mound approximately 25 ft higher than the surrounding regional water table.

Potentiometric-surface maps of the confined flow system showed regional potential for flow from southeast to northwest as well as an overall potential for downward flow. However, local variability in hydraulic conductivity and local variations in the degree of hydraulic interconnection between stratigraphic intervals have resulted in substantial local variations in flow direction from overall regional trends. Because the CMP has been designed primarily to monitor regional trends, the FY89 data do not fully characterize the significance of these local variations in flow direction. Seasonal variations in water levels of the confined flow system generally were small.

Operation of the North and Northwest Boundary Containment Systems has locally influenced ground-water flow. Differences in elevations of the water table across the boundaries indicated hydraulic separation between up and down gradient flow systems. Changes in the rates and areal distribution of ground-water extraction and injection during FY89 resulted in seasonal variations in the water-table elevation near the boundary systems. The most significant variations occurred at the North Boundary Containment System. Installation and operation of recharge trenches has increased the water-table elevation north of the boundary system and resulted in a reversal of the hydraulic gradient along the western part of system.

Results of water-quality samples and analysis have been used to construct contaminant distribution maps for 21 analytes or analyte groups. Contaminant concentrations in the unconfined flow system have been characterized by preparing contour maps of plume configuration during Fall 1988. Contaminant concentrations in the confined flow system have been characterized by preparing point plots of concentration using Fall 1988 data. Contour maps have not been prepared for the confined flow system because regional contaminant plumes have not been detected.

The regional distribution of contaminants was identified more precisely from FY89 data than has been possible with previous CMP data. The improved definition is attributable primarily to the addition of wells to the CMP water-quality network in the Basin A, South Plants, and North Plants Areas. Previous efforts to map RMA contaminant distributions throughout RMA have relied on data collected from several different time periods and analyzed with different procedures. With data from the FY89 CMP, information from a single time period can be utilized.

Regional contaminant distributions identified from FY89 data were generally consistent with distributions provided in previous CMP and Remedial Investigation reports. Major plumes were present as part of the unconfined flow system in the vicinity of South Plants, North Plants, the disposal basins, and the Motor Pool - Railyard Areas. Plumes extended from these areas north and northwest toward the North Boundary, Northwest Boundary, and Irondale Containment Systems. Off-post plumes extended from north of the North Boundary Containment System toward the South Platte River and principally reflect contaminant migration into off-post areas prior to installation of the boundary system. Plumes in the South Plants Area extended radially outward from apparent source areas in response to prevailing directions of ground-water flow.

The extent of contamination in the unconfined flow system varied from compound to compound. Organic contaminants distributed widely in the vicinity of South Plants, the disposal basins, and

on-post and off-post areas to the north and northwest included dieldrin, endrin, chloroform, trichloroethene, tetrachloroethene, and diisopropylmethylphosphonate. Inorganic compounds with wide distributions included fluoride, chloride, and arsenic. Less extensive on-post and off-post plumes were identified for summed organosulfur compounds, dibromochloropropane, and dicyclopentadiene. Trichloroethene, tetrachloroethene and related volatile halogenated compounds were widely distributed in the western part of RMA and appear to have originated partly from source areas south of RMA.

The FY89 unconfined flow system contaminant distributions that differed from FY88 distributions were dieldrin, endrin, and chloroform. Most of the differences result from programmatic changes in the CMP rather than rapid contaminant migration. Changes in the distributions of dieldrin and endrin were the result of an increase in the number of wells sampled in the South Plants, Basin A, and Basin A Neck areas. Changes in the distribution of chloroform were the result of a FY89 decrease in the certified reporting limit.

The contaminant distribution identified from FY89 data in the confined flow system was substantially more irregular and sporadic than the distribution identified in the unconfined flow system. The irregular distribution of contaminants was primarily a reflection of the large amount of local-scale variability in flow directions and flow rates. Areas where contamination was identified in the confined flow system were generally located beneath contaminated areas of the unconfined flow system. Contaminant concentrations in the confined flow system generally were lower than in the overlying unconfined flow system.

Several chemicals not included on the CMP target list of chemicals were detected in multiple samples submitted for GC/MS analysis. Butylbenzylphthalate was the most commonly identified nontarget compound, but was thought to be a product of laboratory contamination. Dichlorobenzene historically has been present in CMP samples and during FY89 was detected in a significant number of samples. In general, nontarget compounds were detected in samples containing elevated levels of target compounds.

Quality Assurance and Quality Control samples were collected and analyzed during FY89 to evaluate the repeatability and accuracy of water-quality data. These samples consisted of trip, field, and rinse blanks as well as duplicate samples. Although results of the blank samples indicated that sample contamination occasionally occurred, it was a minor problem. Results of sample duplicates indicated that differences in concentrations of organic analytes averaged approximately 36 percent of the concentrations reported in the original sample. This percentage

represented an average for all sample pairs and all organic compounds detected. Repeatability of an individual sample or an individual compound can vary significantly from this average. Results for inorganic analytes were significantly less variable, indicating that reported concentrations of inorganic compounds are more repeatable than concentrations of organic compounds. Differences in concentrations of inorganic analytes averaged approximately 17 percent.

Data Assessment

Operation of the North Boundary Containment System was changed significantly during FY89 with the installation of recharge trenches north of the soil-bentonite slurry wall. The trenches were installed to increase downgradient recharge capacity along the western half of the system. By increasing recharge capacity, it had been predicted that water levels in both the unconfined and confined flow systems north of the slurry wall would be greater than water levels south of the slurry wall, and the potential for contaminant migration beneath the system would be eliminated.

FY89 water-level data indicated that operation of the recharge trenches has begun to have the predicted effect. The water-table elevation in the unconfined flow system north of the system has risen above the water-table elevation south of the system and a reverse hydraulic gradient has been established. Water-level data collected as part of the CMP indicate that the gradient reversal has begun to propagate into the shallow stratigraphic zones of the confined flow system. The low hydraulic conductivity of the confined flow system has influenced the rate of propagation. As a result, the reverse hydraulic gradient throughout the confined flow system was not established during FY89. It is anticipated that future monitoring of the confined flow system will confirm the propagation of a reversed gradient.

Water-quality data indicated that operation of the North Boundary Containment System including the recharge trenches has decreased contaminant concentrations dramatically north of the system. Decreased concentrations are most evident in dibromochloropropane, chloroform, and diisopropylmethylphosphonate, those compounds most frequently detected south of the boundary system. Concentration of these compounds north of the boundary system has steadily decreased with time, due to system operation.

Inorganic data have been used to assess background water quality at RMA. Background water samples from the unconfined flow system typically had calcium-sodium ratios between one and two, specific conductance less than 2,000 $\mu\text{mhos/cm}$, percent oxygen saturation less than 60

percent, and were dominated by sulfate and bicarbonate anions. Background water samples from the confined flow system typically had calcium-sodium ratios less than one, specific conductance values less than 2,300 $\mu\text{mhos/cm}$, percent oxygen saturation less than 60 percent, were slightly dominant in sodium and potassium, and dominant in sulfate.

Background inorganic water quality was compared with inorganic water quality of parts of RMA where contaminant plumes have been mapped. Inorganic water quality of the unconfined flow system in the western part of RMA was similar to background water with the exception of higher values of percent oxygen saturation. Inorganic water quality of the unconfined flow system in the central and northern parts of RMA typically had calcium-sodium ratios less than one. Many samples had specific conductance values that ranged from 2,500 to 20,000 $\mu\text{mhos/cm}$. These differences from background water quality can be related to the past disposal of waste water rich in sodium chloride. Water from the confined flow system in the central part of RMA typically had higher specific conductance and were more strongly dominated by chloride and nitrate than background water.

A FY89 pilot study monitored ground water for isotopic signature. This data was used to assess the degree of hydraulic connection between the unconfined and confined flow systems. Samples collected from the unconfined and confined flow systems were analyzed for deuterium, oxygen-18 and tritium. Results were compared with organic water-quality data. Water from the unconfined flow system generally was isotopically distinct from water in the confined flow system. However, a small degree of mixing was indicated by the isotopic data from some wells completed in the confined flow system. Based on the results of the pilot study, isotopic sampling and analysis for tritium appeared to have greater potential than other isotopes for identifying hydraulic connection between flow systems

Conclusions

Ground-water data collected as part of the CMP during FY89, have been beneficial in confirming results of past investigations, monitoring ongoing remedial/response actions, and providing improved descriptions of the regional distribution of ground-water contaminants. Important conclusions obtained on the basis of FY89 data include:

1. Regional contaminant distributions identified from FY89 data generally were consistent with distributions provided in previous CMP and Remedial Investigation reports.

2. The regional distribution of contaminants has been mapped more precisely than previously possible using data from a single time period.
3. Accuracy and repeatability of water-quality results were good, averaging 36 percent of the reported value for organic contaminants and 17 percent of the reported value for inorganic compounds.
4. Concentrations of contaminants north of the North Boundary Containment System have been reduced substantially as a result of system operation.
5. The potential for contaminant migration beneath the North Boundary Containment System has been reduced. Recent changes in operation of the system have begun to establish a reverse hydraulic gradient in both unconfined and confined flow systems.

1.0 INTRODUCTION

1.1 Site Background

Rocky Mountain Arsenal (RMA) occupies approximately 27 square miles (sq mi) and is located within the border of Adams County, Colorado, about 9 miles (mi) northeast of downtown Denver (Figure 1.1-1). RMA was established by the U.S. Army (the Army) in 1942 to produce chemical and incendiary munitions for World War II. Following World War II, the production of munitions decreased, and the Army leased selected portions of RMA to private industry. Several of the lessees produced industrial chemicals, consisting predominantly of herbicides and pesticides, until 1982.

Chemical agents were produced at RMA until 1957. From 1942 to 1950, mustard agent (H) was produced or distilled in the South Plants manufacturing area. This area was also used to fill shells with the chemical agent phosgene or incendiary mixture including napalm, and white phosphorous. Many different types of obsolete World War II ordnance were destroyed by detonation or incineration at RMA during this time. In the early 1950's RMA was selected to produce the chemical nerve agent Sarin (GB). This was produced in the North Plants manufacturing area until 1957. Munitions filling operations continued at RMA until 1969. From 1970 to 1984, Army activities focussed primarily on the demilitarization of chemical warfare materials.

In 1947, portions of RMA were leased to private industry. Early lessees included the Colorado Fuel and Iron Corporation (CF&I) and the Julius Hyman and Company (Hyman). CF&I produced chlorine, fused caustic and chlorinated benzenes, and attempted to manufacture dichlorodiphenyltrichloroethane (DDT). Hyman produced several pesticides. In 1950, Hyman added to its lease a number of facilities formerly operated by CF&I. In 1952, Shell Chemical Company (Shell) acquired Hyman and operated this company as a wholly owned subsidiary until 1954, when Hyman was integrated into the Shell corporate structure. At this point Shell succeeded Hyman as the named lessee. From 1952 until 1982, Hyman/Shell produced a large number of herbicides and pesticides in the South Plants manufacturing complex.

Between 1942 and 1982 numerous specific releases of chemicals to the environment associated with these production activities were documented. As early as 1951 a link was suspected between waterfowl mortality at RMA and insecticide contamination of the lakes located there. In 1954 and 1955, farmers using well water for irrigation northwest of RMA reported severe crop losses. In 1974, two contaminants -- diisopropylmethyl phosphonate (DIMP), a manufacturing by-product of the nerve agent isopropylmethane fluorophosphonate (Sarin, or GB), and dicyclopentadiene

(DCPD), a chemical used in insecticide production -- were detected in off-post surface water. Since 1978, numerous compounds have been detected in off-post ground water.

1.2 Nature and Extent of Problem

Contaminants were introduced to the RMA environment primarily by the burial or surface disposal of solid wastes, discharge of wastewaters to basins, and leakage of wastewaters and industrial fluids from chemical and sanitary sewer systems. Wastewaters generated by the Army and private industry in the South Plants and North Plants area were discharged to a series of unlined evaporation and holding basins (Basins A, B, C, D and E), and to asphalt-lined Basin F at various times throughout the history of RMA operations (Figure 1.2-1). Unintentional spills of raw materials, process intermediates, solvents, cleaners, fuels, lubricants, and end products also occurred within the manufacturing complexes, storage areas, maintenance areas, or along transport routes at RMA.

A number of these contaminant releases have impacted ground water resulting in a series of contaminant plumes. The occurrence and movement of contaminants in ground water at RMA is complicated by:

- a large number of contaminant sources, some areally separated, some overlapping;
- a large variability in release scenarios, including single or repeated spills, continuous or intermittent leaks, discharges to ditches or basins, leaching from trenches, leaching from or direct contact of ground water with buried transport lines;
- a large number of individual contaminants;
- spatial variabilities in aquifer properties;
- complex interactions between water-bearing zones; and
- historical changes in the distribution and quantity of ground-water recharge.

1.3 Summary of Previous Ground-Water Monitoring Efforts

In the summer of 1974, the detection of DIMP and DCPD off-site highlighted the problem of contaminant migration in ground and surface water at RMA. To address this problem, the Army in 1975 initiated a regional sampling and hydrogeologic surveillance program requiring the quarterly collection and analysis of samples from over 100 wells and surface-water stations located both on- and off-post.

This program was carried out under the direction of the RMA Contamination Control Program which had been established in 1974 to ensure compliance with federal and state environmental laws. The objectives of this program were to evaluate the nature and extent of contamination and to develop response actions to control contaminant migration. Both suspected and confirmed contamination sources were assessed, and contaminant migration pathways were evaluated.

To minimize off-post discharge of RMA contaminants via ground water, three boundary containment systems were constructed, one along part of the northern and two along parts of the northwestern boundaries of RMA. All three systems are currently in operation to intercept and treat contaminated ground water and to recharge the treated water.

From 1975 to the present, numerous ground-water monitoring programs have been conducted at RMA. Following issuance of the cease and desist orders, the Army established the 360 Degree Monitoring Program to monitor regional ground and surface water. The Army also designed and implemented monitoring programs to support the operation of the boundary control systems.

In 1984 the Army awarded a multi-year task order contract to initiate a Remedial Investigation/Feasibility Study (RI/FS) at RMA. Two consecutive regional ground-water tasks were awarded under this contract (Tasks 4 and 44). The purpose of these tasks was to investigate the nature and extent of RMA ground-water contamination and to continue long-term ground-water monitoring initiated under the 360 Degree Program. In addition, Task 25 (Boundary Control Systems Monitoring) was awarded to continue ground-water monitoring in the vicinity of the boundary control systems. In 1987 the Army separated both the long-term ground-water monitoring and the boundary systems monitoring from the RI/FS program. These activities are now included under the ground-water element of the Comprehensive Monitoring Program (CMP).

1.4 Overview of Current Ground-Water Monitoring

The CMP is designed to provide both continual and long-term monitoring of ground water, surface water, air and biota. Administratively, each environmental medium is being monitored within a separate program element. Each element has detailed objectives, outlined in respective technical plans. Each technical plan presents monitoring guidelines, analytical parameters, and sampling protocol and strategies. All four elements have a common objective to provide a database that meets the standards set by the Program Manager of the Rocky Mountain Arsenal (PMRMA). An annual report for each element discusses the monitoring results for the year.

A transitional round of ground-water monitoring activities, called the Transitional Monitoring Program, was initiated in November 1987. This immediately followed the award of the CMP contract. The purpose of the transitional round was to provide continuity with the previous regional and boundary systems monitoring programs conducted under the RI/FS contract. The Transition Monitoring Program, was initiated prior to completing the design of the long-term monitoring well network. In March, 1988, the design strategy of the long-term CMP ground-water monitoring network was developed after reviewing data generated during previous monitoring programs, including data from RI/FS Tasks 4, 25 and 44. This design strategy is presented in the CMP Technical Plan (Stollar, 1989a).

The objectives of the CMP ground-water element are threefold:

- maintain a regional ground-water monitoring program to verify previously obtained RI/FS data and analyses, and satisfy substantive regulatory requirements.
- maintain project area ground-water monitoring program components to verify previously obtained RI/FS data and analyses, support project area system operations, and satisfy substantive regulatory requirements.
- monitor ground-water quality and hydrology to assess changes in the rate and extent of contaminant migration and the distribution of contaminants in both on- and off-post areas.

The ground-water element of the CMP included water-quality monitoring based on one regional well network and two local well networks which emphasize specific areas. The regional monitoring is conducted annually and includes the largest number of monitoring wells. The first localized network is sampled semiannually. It is based on a midsized well network designed to address specific local areas where further evaluation of contaminant flow patterns is required. The second localized network is sampled quarterly. It is based on the smallest monitoring well network and is designed to support ongoing remedial/response actions and/or substantive compliance with applicable regulatory requirements.

This report presents data collected during Fiscal Year 1989 (FY89). The data includes water level measurements in addition to water quality results. Water levels were measured quarterly at approximately 1,000 wells prior to each sampling round. The annual sampling round (approximately 515 wells) was conducted in fall 1988, from late October 1988 through mid-January 1989. The midsized, semiannual monitoring well network (approximately 376 wells) was sampled in spring 1989, beginning in early May and continuing through mid-June 1989. The smallest,

quarterly well network (approximately 51 wells) was sampled independently in February/March, 1989, and August, 1989.

The monitoring well network was expanded in FY89 due to the installation of additional monitoring wells during the year. As indicated in Section 2.3.4 of the Ground-Water Element Technical Plan, newly installed wells are to be included in the CMP ground-water monitoring network for at least two sampling periods following the initial sampling under their respective programs (Stollar, 1989a). During the fall and winter FY89, 38 new monitoring wells were installed at RMA. The purpose of these wells was to provide additional data needed to complete the Remedial Investigation Study Area Reports (SARs). During the summer of FY89, 13 additional wells were added in the vicinity of the Basin F to support the Interim Response Action (IRA). These wells were installed in Section 26 to provide monitoring points around Ponds A and B, the Basin F liquid storage tanks, the Leachate Collection Pond and the Lined and Capped Basin F Waste Pile (Figure 1.4-1). The newly installed wells were sampled once during the FY89 monitoring year in August, 1989.

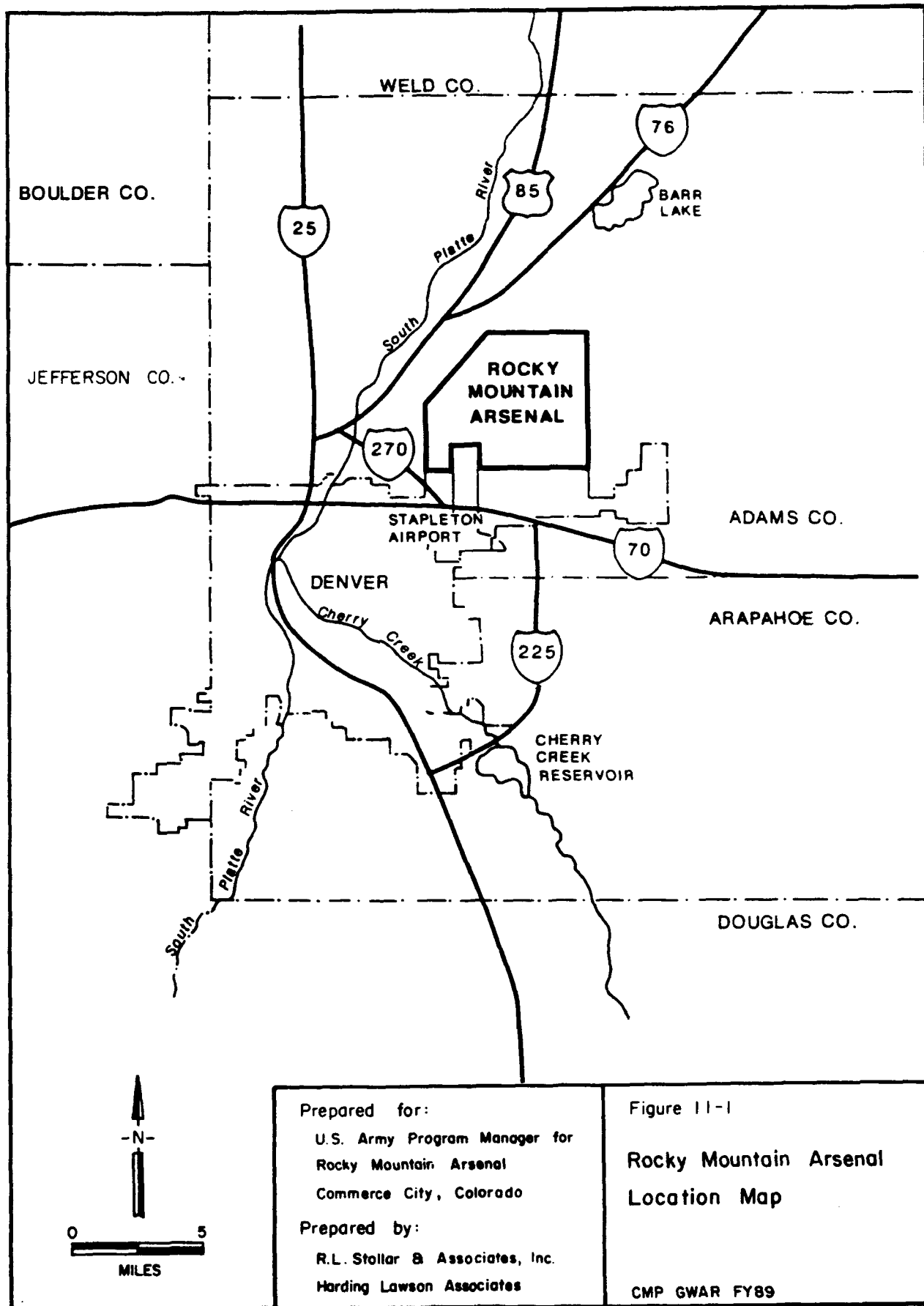
Analytical and hydrogeological data from these new wells are included in this report. Geologic drilling logs, construction specifications, and analytical data in tabular form are in the appendices of the appropriate SARs for the 38 wells installed during the fall and winter of FY89 (Ebasco, 1989 b-h). For the remainder of the new wells installed during FY89, the analytical data and geologic/construction logs are contained in Appendices C and D, respectively, of this report. Additionally, five monitoring wells were installed around the sanitary landfill in Sections 30 and 31 (Figure 1.4-2). These wells were completed and developed after the final sampling event for FY89 and, therefore, data from these wells are not included in this report.

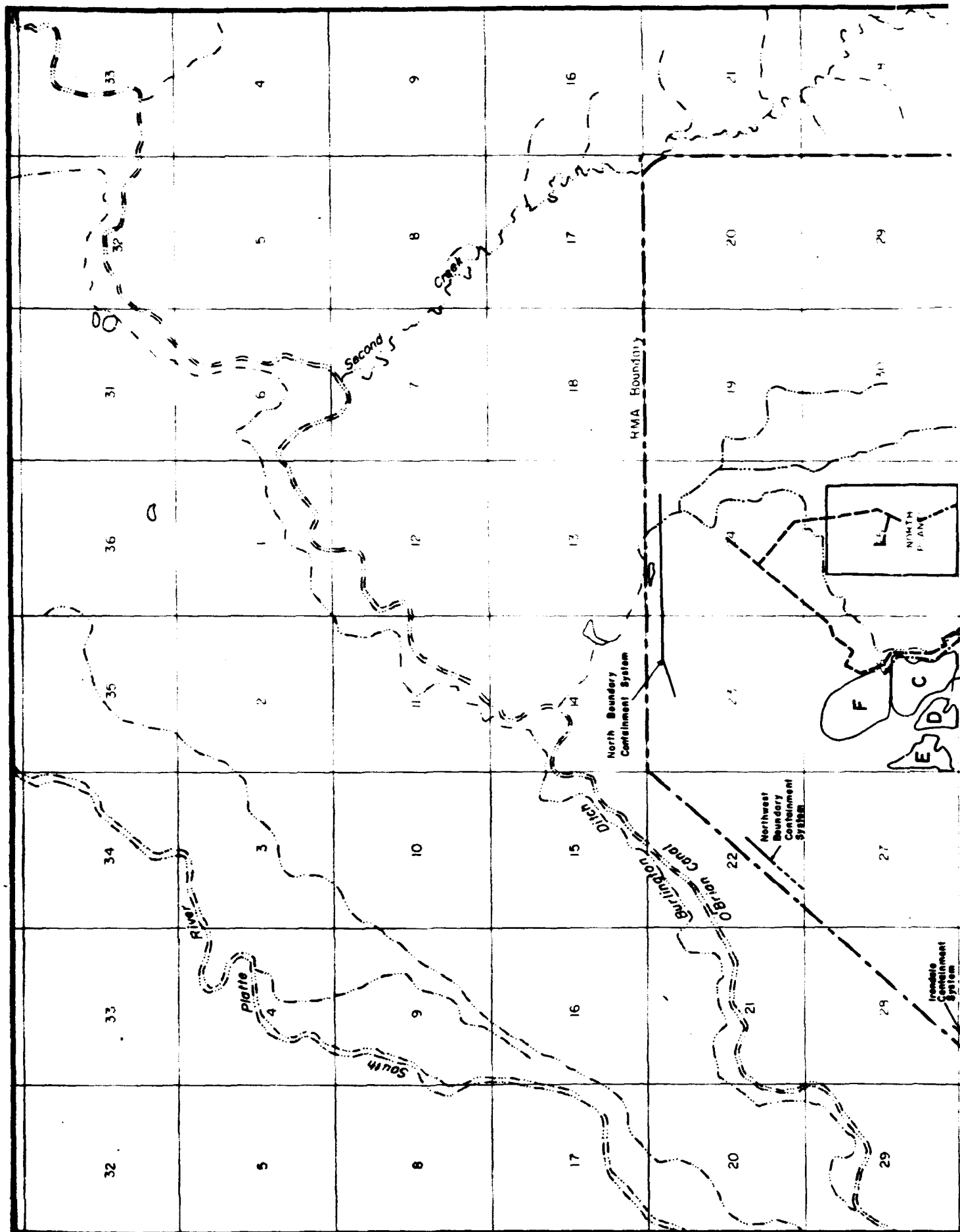
Many sections of this report make frequent references to specific wells. Therefore, it is necessary to understand the well numbering system to help in locating wells spatially. For all wells located on the RMA, the first two digits of a well number refer to the section number in which the well is located. The last three digits indicate the well number within that section. For example, well 01070 is well number 70 in Section 01. All wells installed by Shell are denoted by a 5 as the third digit, for example 01501 is well number 501 in Section 01. (All wells located outside the RMA are identified by "37" in the first two columns of the well number.) Wells are generally installed sequentially within each section, and well numbers are assigned by the RIC Center at RMA.

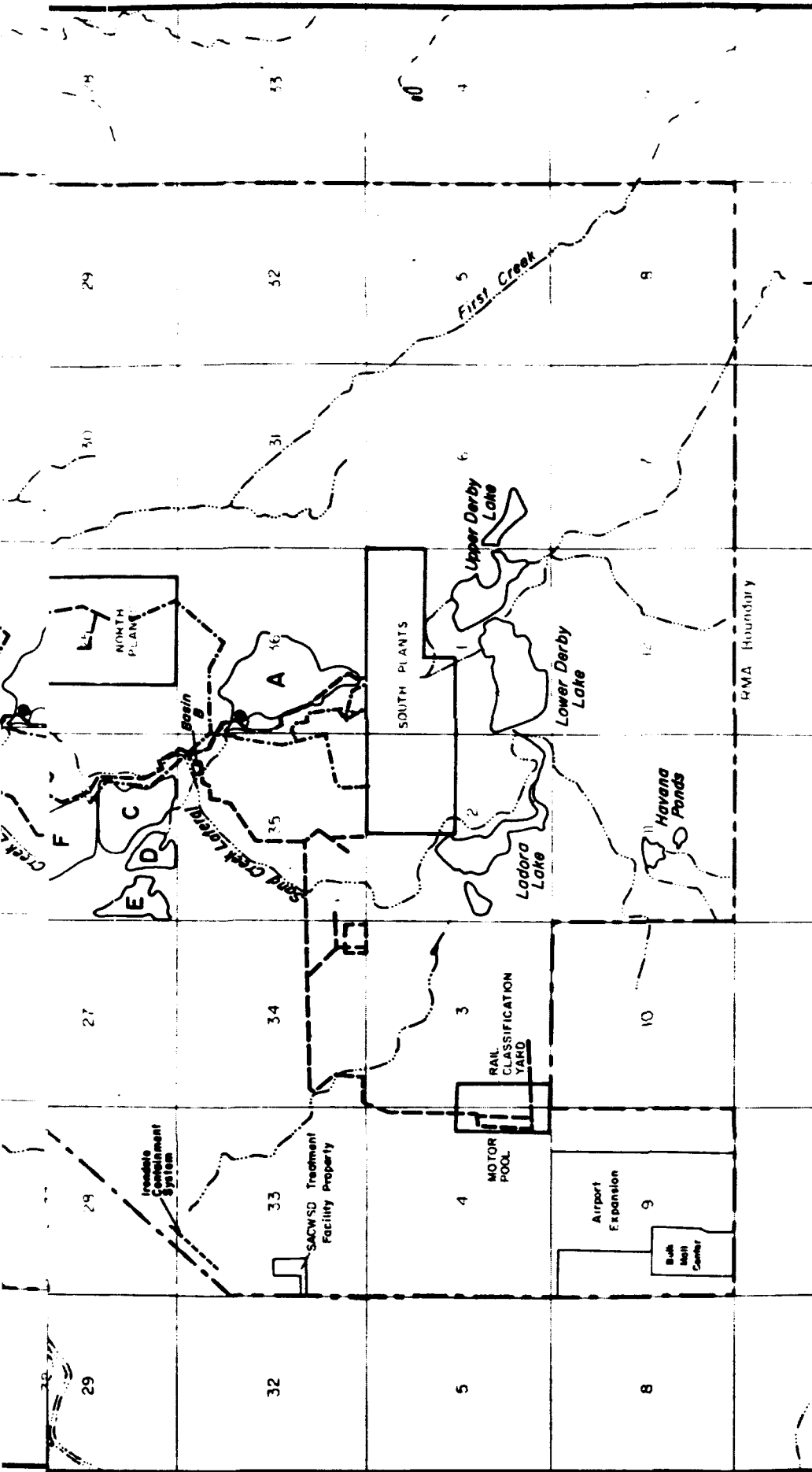
In addition to the newly installed wells, another modification to the monitoring well network was made during FY89. This modification deleted six wells (01069, 01070, 02050, 02052, 04035, 04051) from the semiannual monitoring round. In past years information from wells 01069, 01070, 02050, and 02052 did not significantly add to the understanding of contamination in the South Plants Area.

Water quality data from wells deleted in Section 4 has not significantly enhanced the understanding of contamination in the Railroad Classification Yard area. None of the deleted wells occur in cluster sites and none were completed in the Denver Formation.

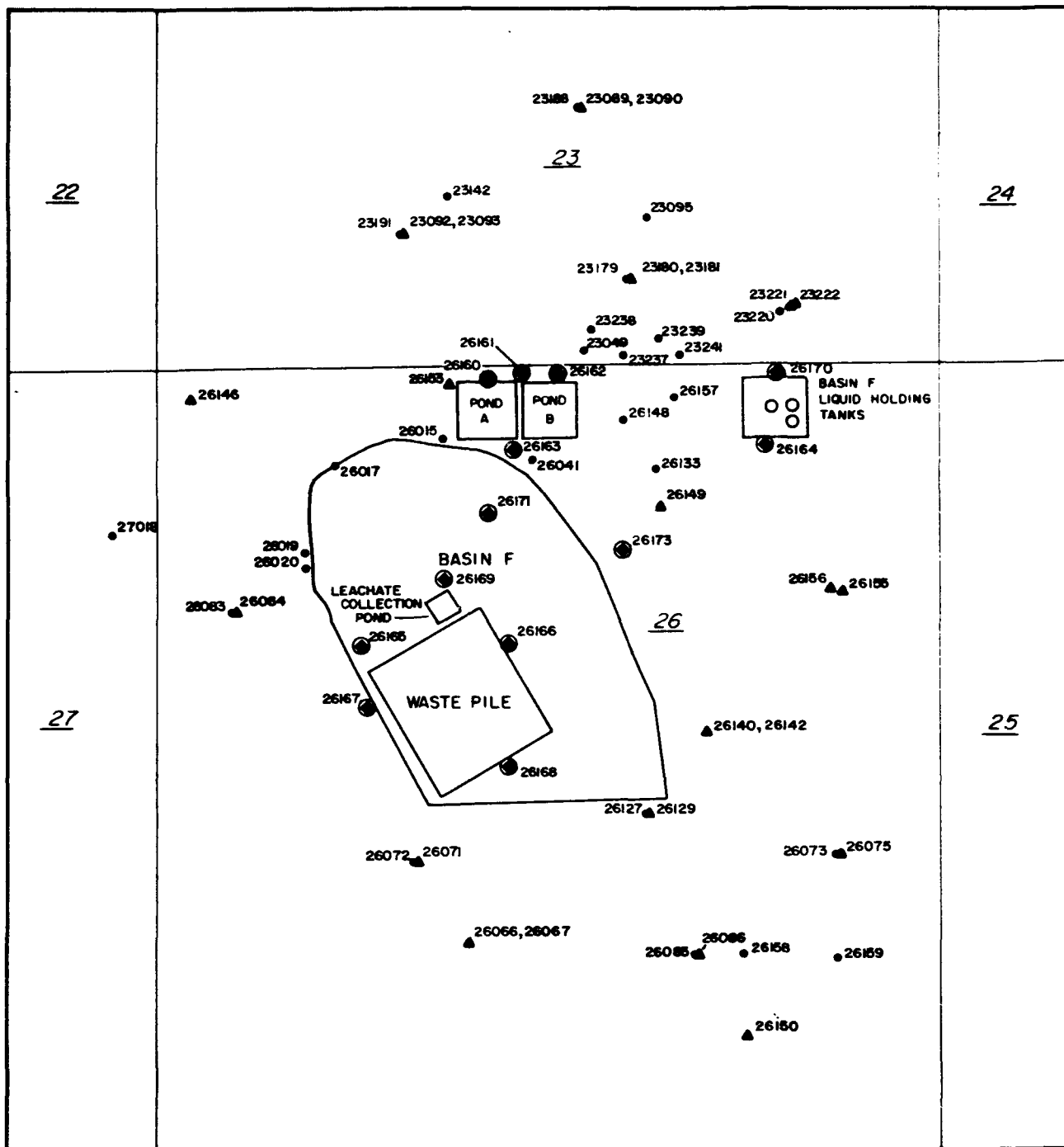
Another program modification included the addition of a new analytical laboratory to the group of contractors within the Stollar team. Hunter Services (formerly ESE) laboratory facilities in Denver replaced Enseco-Cal Lab as the subsidiary CMP analytical laboratory. Analytical parameters remained consistent with those outlined in Table 3.1-1 of the CMP Ground Water Final Technical Plan (Stollar, 1989a), and certified reporting limits (CRLs) are comparable between the primary CMP analytical laboratory, DataChem, Inc., of Salt Lake City, and the ESE-Denver laboratory.







Prepared for : U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by : R.L. Stollar & Associates, Inc. Harding Lawson Associates	Figure 1.2-1 Location of Major Potential Contamination Sites, Lakes and Containment Systems CMP GVAR FY89
Explanation F Former Waste Containment Basin --- Chemical Sewer System --- Sanitary Sewer System Containment System Physical Barrier Hydraulic Barrier	North Arrow Scale: 0 to 8000 Feet / 0 to 2000 Meters



Explanation

- 26188 ● Unconfined Well
- 26084 ▲ Confined (Denver Formation) Well
- 26161 ● Newly Installed Well

27 Section Number



A horizontal scale bar with tick marks at 0, 500, and 1000. The word "FEET" is centered below the bar.

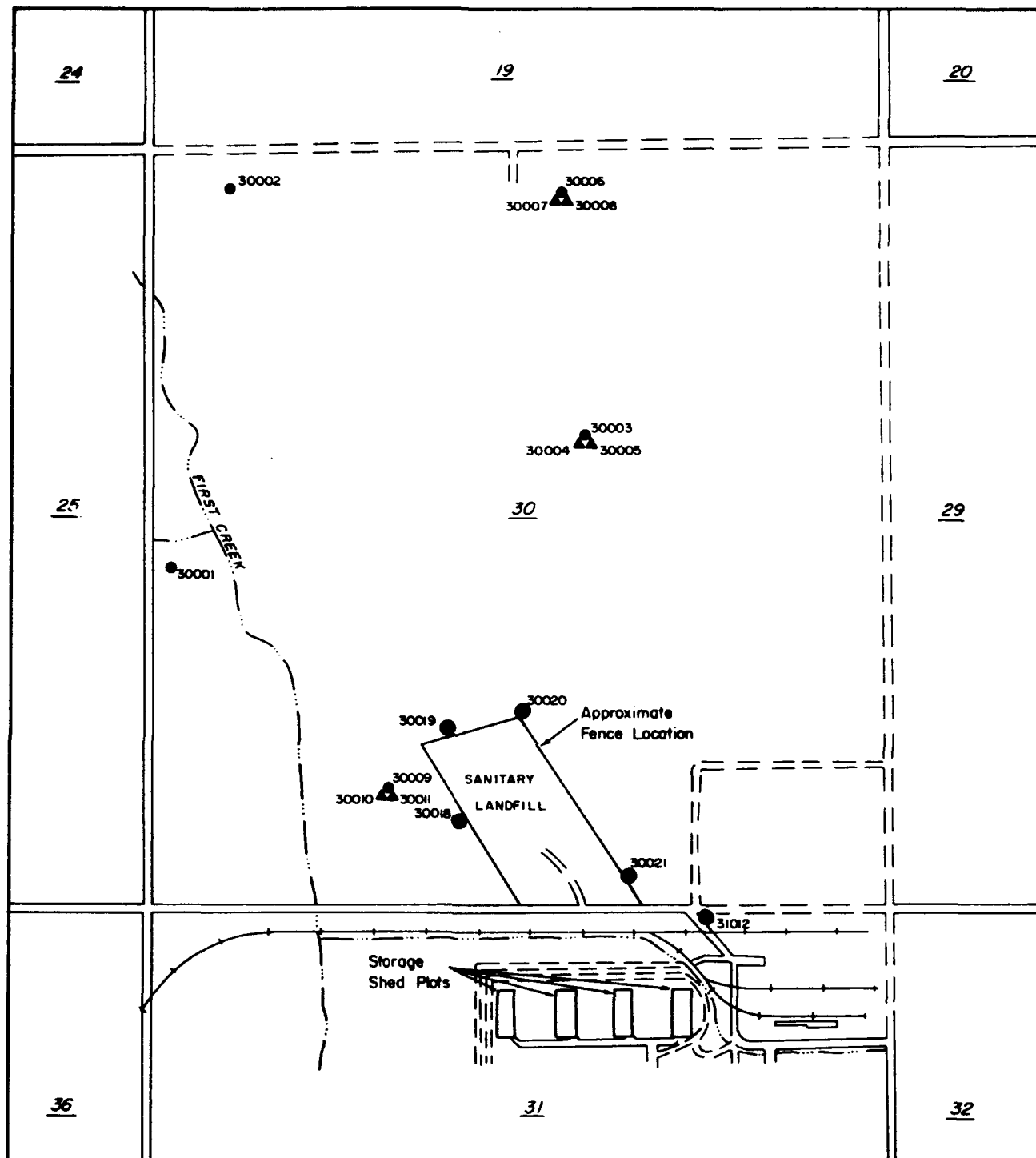
Prepared for
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by :
R L Stollar & Associates, Inc.
Harding Lawson Associates

Figure 1.4-1

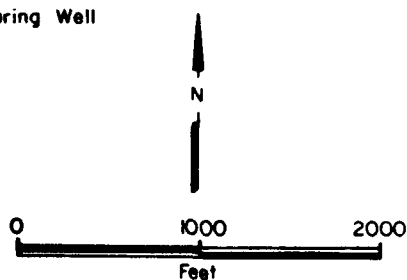
Monitoring Well Locations for Basin F IRA Structures

CMP GWAR FY89



Explanation

- 30001 Unconfined Well
- ▲ 30005 Confined (Denver Formation) Well
- 30018 New Alluvial Monitoring Well
- 30 Section Number



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U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

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Figure 1.4-2

Monitoring Well Locations
in the Vicinity of the
Section 30 Sanitary Landfill
CMP GWAR FY89

2.0 HYDROGEOLOGIC SETTING

This section provides a description of the geologic and hydrogeologic characteristics in the RMA study area. For a more thorough discussion of this subject, refer to the Water Remedial Investigation Report (Ebasco, 1989i), which presents a comprehensive interpretation of hydrologic conditions at RMA.

2.1 Geology

RMA is located within the Denver Basin, a broad structural depression encompassing northeast Colorado and portions of southeast Wyoming and southwest Nebraska. The Denver Basin is a north-south trending asymmetric syncline with a gently dipping eastern flank and a steeply dipping western flank bordering the Colorado front range. RMA is located near the structural axis of the basin and the uppermost sediments beneath RMA dip less than one degree to the southeast.

The Denver Basin was downwarped during the late Cretaceous and early Tertiary periods. Sandstone, siltstone, claystone, and lignite deposited during this period comprise the Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, and Denver Formation (Figure 2.1-1). These strata overlie approximately 7000 feet (ft) of Cretaceous Pierre Shale.

Additional sediments were deposited in the Denver Basin throughout the Tertiary period. Regional uplift and erosion later removed most of these sediments as well as part of the Denver Formation. Quaternary sediments deposited on the late Tertiary erosional surface consist of unconsolidated alluvial gravel, sand, silt, and clay, as well as eolian sand and silt.

The Cretaceous-Tertiary Denver Formation and Quaternary deposits are the two stratigraphic sequences addressed in this report because they contain the principal aquifers in contact with potential contaminant sources in the RMA study area. Quaternary deposits are collectively referred to as the alluvium, although they consist of both alluvial and eolian materials.

2.1.1 Alluvium

Alluvial and eolian sediments in the RMA study area were deposited on an eroded bedrock surface composed of Denver Formation strata (Figure 2.1-2). Locally, alluvial deposits reach a thickness of 130 ft where prominent paleochannels have been carved into the bedrock surface. Typically, the alluvium ranges in thickness from 0 to 50 feet. Alluvium blankets nearly the entire RMA

study area; however, overlying eolian materials are the predominant strata exposed at land surface. Bedrock outcrops of the Denver Formation occur in only a few locations (Figure 2.1-3).

The surficial deposits vary in age, origin of deposition and grain-size distribution. Older alluvial deposits generally are located in areas along the South Platte River and the western tier of RMA and consist of coarse-grained sand and gravel. Coarse-grained deposits were also locally deposited in bedrock paleochannels. Younger eolian and alluvial deposits are finer-grained than the older surficial deposits and commonly form the uppermost deposits throughout much of RMA. A recent investigation by Ebasco (1989i) provides detailed discussions of Quaternary deposits.

2.1.2 Denver Formation

The Denver Formation at RMA consists of a 200 to 500 ft thick sequence of interbedded claystone, siltstone, sandstone, and organic-rich (lignitic) layers (Ebasco, 1989i). The Denver Formation is thickest in the southeastern portion of RMA and thins to the northwest due to erosion. A claystone sequence 50 to 100 ft thick forms the top of the Arapahoe Formation and separates it from the overlying Denver Formation. This clayshale interval, informally called the Buffer Zone, provides hydraulic separation between aquifers in these formations (Romero, 1976).

Most sediments in the Denver Formation were deposited under low-energy continental conditions by fluvial processes in a distal alluvial plain environment (Romero, 1976). This environment gave rise to the accumulation and subsequent lithification of lenticular shaped sandstone and siltstone units within layers of claystone and shale. Sandstone units are up to 50 ft thick. Volcaniclastic material is present in the upper portion of the Denver Formation.

Stratigraphic correlation of units within the Denver Formation is complicated by the discontinuous nature of the sandstone units. Within the South Platte and Basin A area, correlation is aided by the occurrence of a relatively thick, laterally continuous lignitic interval. This lignite layer (Lignite A) has been used as the marker bed from which all other zones in the Denver Formation at RMA have been referenced. Correlations based upon other lignitic layers has resulted in the current interpretation of Denver Formation stratigraphy (Figure 2.1-4).

The Denver Formation dips gently to the southeast and the regional erosional bedrock surface slopes to the northwest. Thus, the stratigraphic units from progressively deeper zones are erosionally truncated to the northwest.

2.2 Hydrogeology

Ground water occurs at RMA under both unconfined (at atmospheric pressure) and confined (under pressures greater than atmospheric) conditions. Water within deeper Denver Formation permeable zones typically is confined, whereas water in unconsolidated surficial deposits typically is unconfined. In this report, ground water is described as being within the unconfined flow system or the confined flow system. Ground water within the confined flow system described in this report is within the Denver Formation. Ground water in confined aquifers beneath the Denver Formation are not addressed in this report.

2.2.1 Unconfined Flow System

At RMA, unconfined conditions may exist in both the alluvium and the Denver Formation. Water in alluvium generally is unconfined. Unconfined conditions may also occur in the Denver Formation where permeable Denver Formation zones are exposed at land surface or where they subcrop beneath saturated or unsaturated surficial (alluvial) deposits. Consequently, the unconfined flow system is interpreted to be a continuous flow system comprising both alluvium and unconfined Denver Formation zones (Ebasco, 1989i). The unconfined flow system includes saturated surficial deposits and subcropping parts of the Denver Formation where lithologic data indicate the presence of sandstone or relatively permeable material. This interpretation is supported by potentiometric data from wells in these Denver Formation units that are comparable to potentiometric data from overlying alluvial wells. In areas where the surficial deposits are unsaturated, the subcropping zones in the Denver Formation that contain water are considered part of the unconfined flow system.

The saturated thickness of the unconfined flow system can range up to 70 ft thick. The thickness is greatest within the alluvium filled bedrock paleochannels in western and northwestern RMA, and south of Ladora Lake. Saturated thickness beneath South Plants and the waste basins typically is 20 ft or less.

From a regional viewpoint, ground water in the unconfined flow system flows northwest across RMA and discharges to the South Platte River. (A detailed discussion of the potentiometric surface for the unconfined flow system is provided in Section 4.1.) Local changes in flow directions may be caused by a number of factors, notably: the configuration of the bedrock surface, spatial variation in hydraulic conductivity of aquifer materials, surface-water impoundments, and man-made features such as the boundary containment systems.

Ground-water flow in the unconfined flow system occurs primarily within saturated alluvium. This is due to the physical properties of alluvial versus bedrock materials. Hydraulic conductivity within the alluvium typically ranges from 2.6×10^3 to 1.7×10^2 ft/day whereas Denver Formation hydraulic conductivity may be on the order of 2.8×10^{-1} ft/day (Ebasco 1989i). Alluvium filled paleochannels incised in the bedrock surface sometimes provide pathways (such as the Basin A Neck and First Creek Off-post Pathways) for contaminant migration in ground water at RMA. Several major contaminant pathways have been identified (Ebasco, 1989i), and have been named to simplify and standardize contaminant distribution discussions (Figure 2.2-1). Pathway names were chosen because of proximity to well-known features and do not imply a source-plume relationship.

Sources of recharge to the unconfined flow system in the study area include infiltration of precipitation and irrigation, seepage from surface-water features such as lakes and streams, inflow from subcropping Denver Formation sandstones, and seepage from man-made structures such as waste basins, canals, ditches, and buried pipelines. The principal discharge location for the unconfined flow system is the South Platte River; however, discharge also occurs at other locations in the RMA study area. Discharge is known to occur at Ladora Lake, Lake Mary, and the Rod and Gun Club Pond (Ebasco, 1989i). Discharge from the unconfined flow system to the Denver Formation may occur in areas where downward vertical gradients exist. A comparison of potentiometric surface data to land surface elevations indicates that unconfined flow system discharge into First Creek occurs near the northern RMA boundary. Discharge by evapotranspiration is likely to occur in areas where the water table is within 5 ft of land surface. Estimated recharge and discharge rates are summarized in the Water Remedial Investigation Report (WRIR) (Ebasco, 1989i).

2.2.2 Confined Flow System

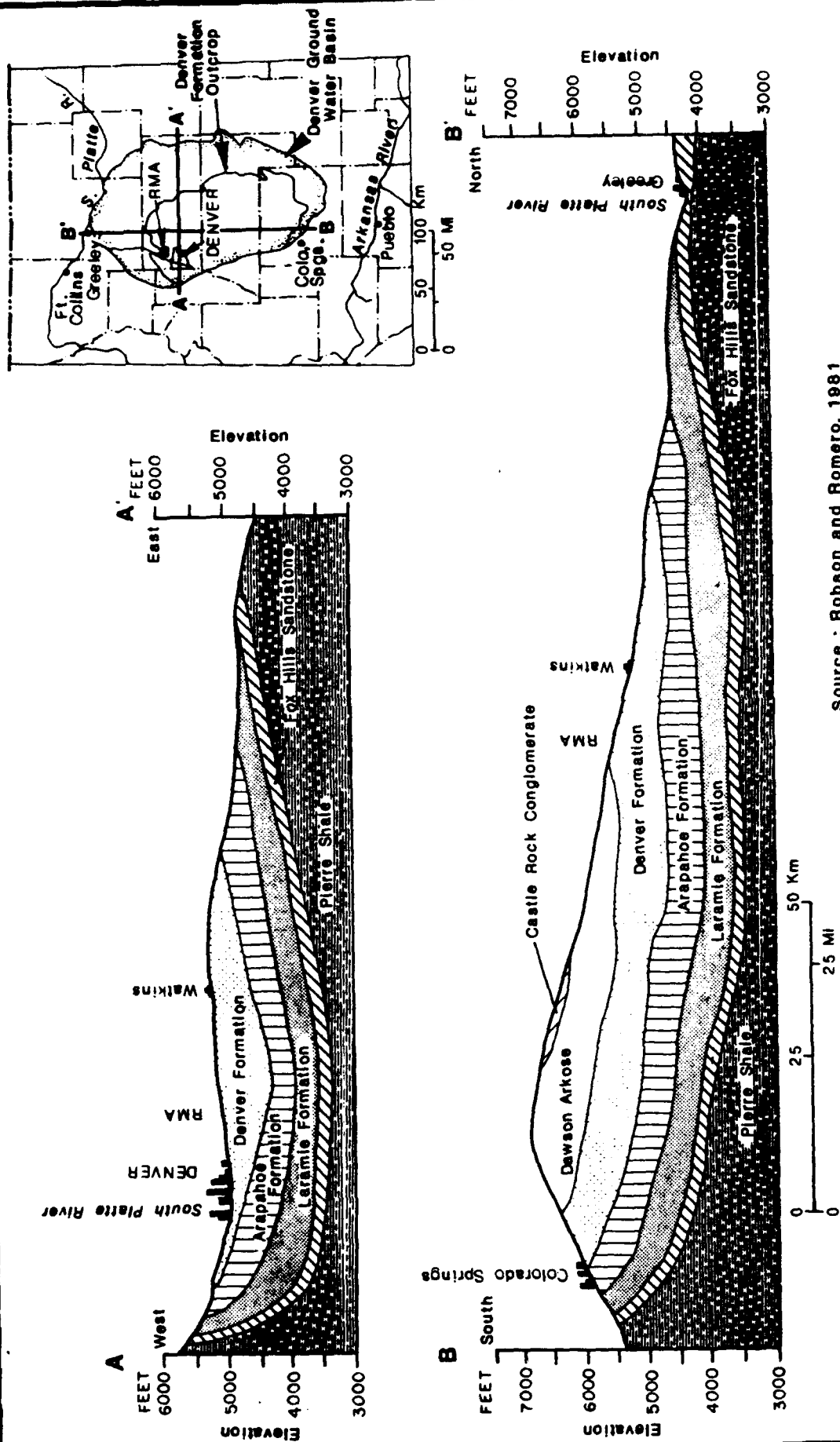
Ground water within strata of the Denver Formation that is under pressure greater than atmospheric is part of the confined flow system. Confined conditions exist within the Denver Formation where relatively impermeable strata separate the unconfined flow system from more permeable horizons deeper in the Denver Formation.

The confined flow system consists of relatively permeable sandstones, siltstones, and lignites interbedded with relatively impermeable claystone. The discontinuous nature of the permeable strata often results in hydraulic separation of individual Denver Formation stratigraphic zones. Confined flow system strata also exhibit a high degree of variability in hydraulic conductivity and storativity from one area to another (Ebasco, 1989i).

Regional ground-water flow in the confined flow system is up dip to the northwest. Ground-water flow direction is the result of greater precipitation and enhanced recharge along streams in upland areas of the Denver Basin (e.g., Castle Rock area), combined with discharge to low points in the Denver Basin (e.g., South Platte River) and areas where pumpage is large.

The hydraulic conductivity of sandstones within the confined flow system range from approximately 2.8×10^0 to 2.8×10^{-2} ft/day based on field testing. Hydraulic conductivity estimates are not available for fractured lignitic beds. However, ground-water flow model analyses indicate that lignitic bed hydraulic conductivities may be an order of magnitude greater than those of sandstones (Ebasco, 1989a).

Hydraulic head in the confined flow system decreases with increasing depth in most locations at RMA. As a result, recharge to the confined flow system is likely to occur by leakage from overlying strata. Recharge also occurs by lateral flow in Denver Formation units from areas south and east of RMA. Discharge from the confined flow system occurs by lateral flow into the unconfined flow system where permeable zones subcrop.



Source : Robeson and Romero, 1981

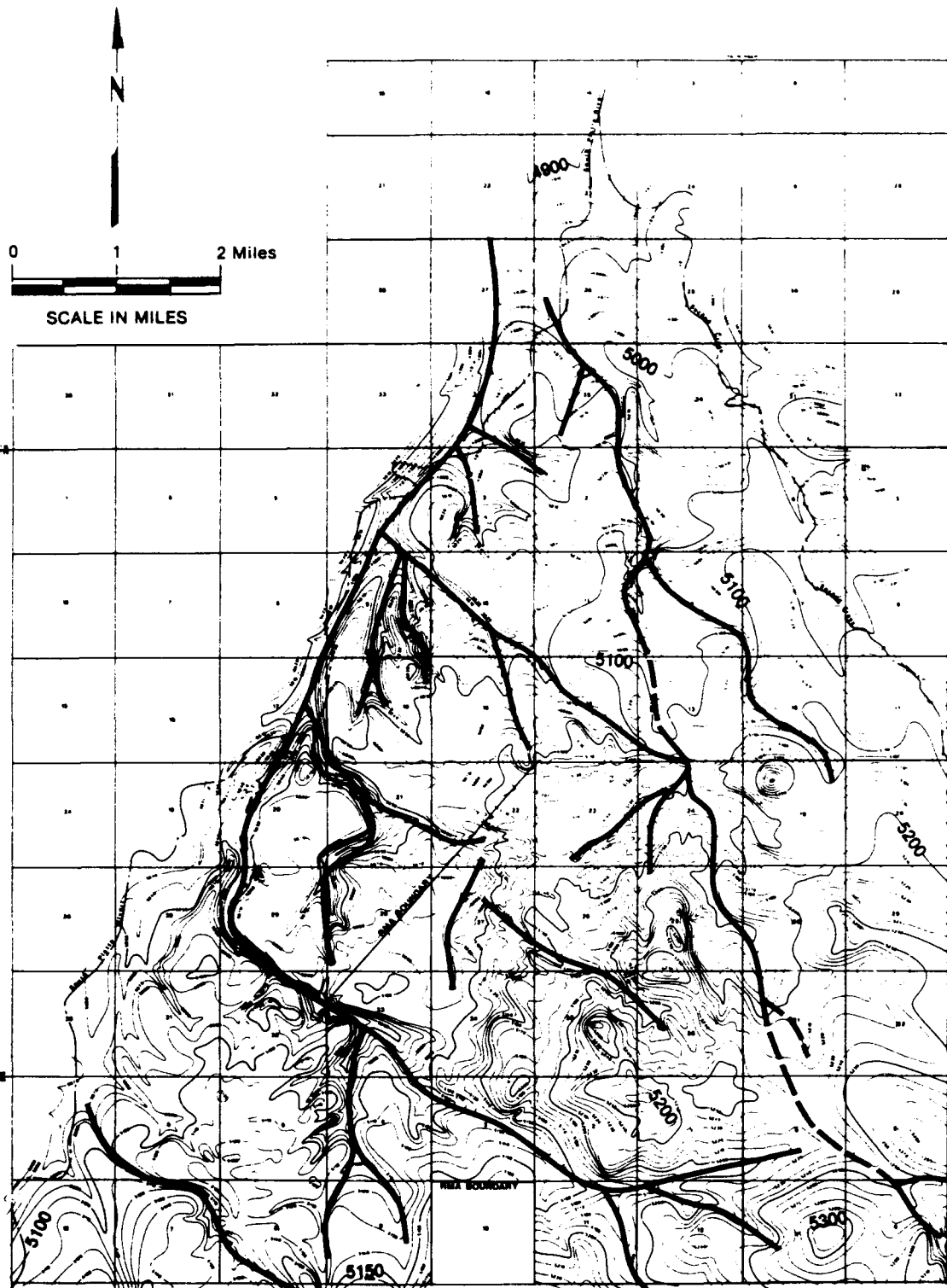
Figure 2.1-1

Upper Stratigraphic Sections of the Denver Basin

Prepared for :
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Harding Lawson Associates

CMP GWAAR FY89



Contour Interval Equals 10 Feet

Source : Modified from Ebasco, 1989i

Prepared for :

U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

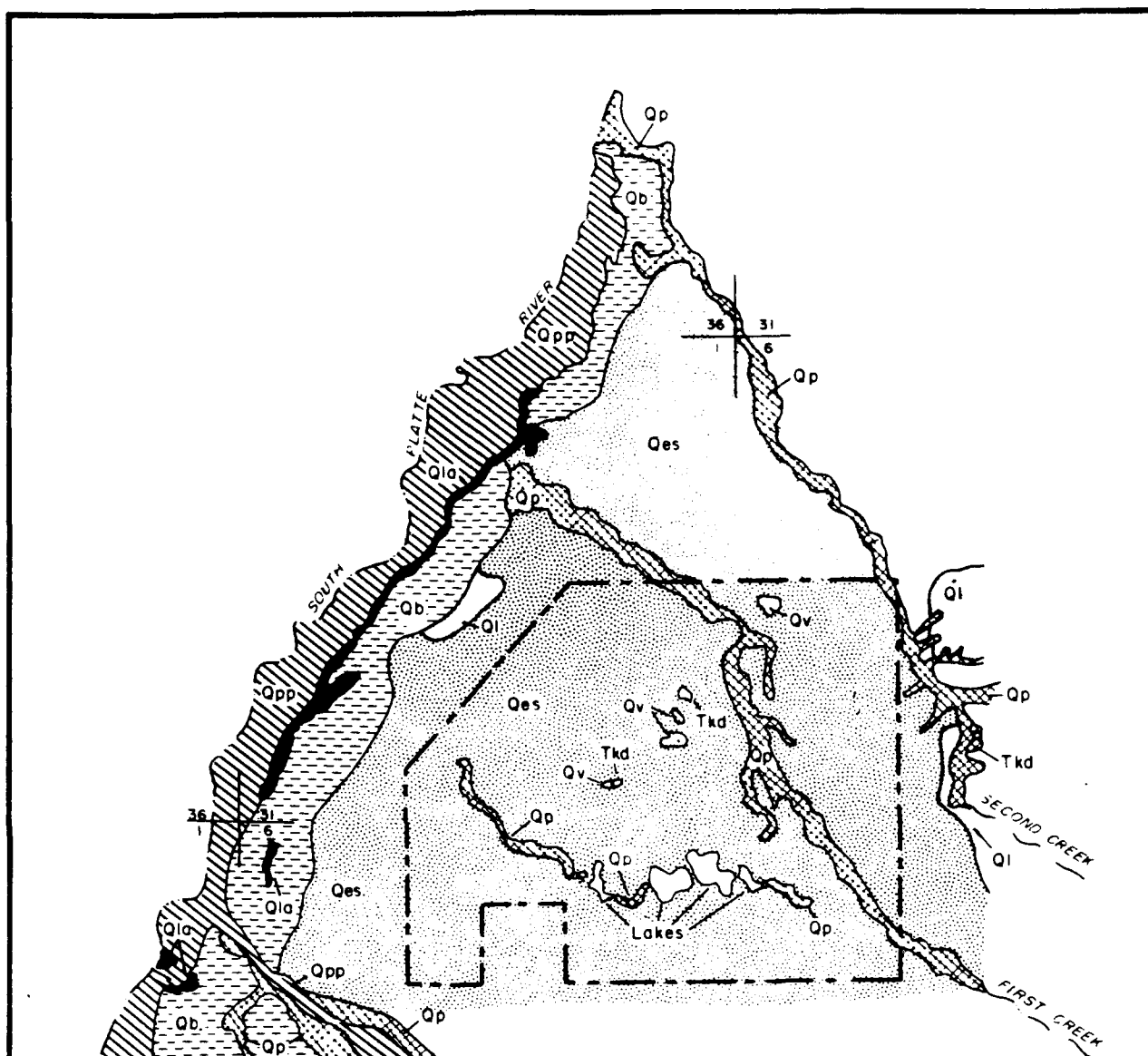
Prepared by :

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Figure 2.1-2

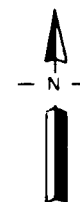
Bedrock Surface at RMA and
Prominent Paleochannels

CMP GVAR FY89



Legend

	Post Piney Creek Alluvium (Quaternary)
	Piney Creek Alluvium (Quaternary)
	Eolian Sand (Quaternary)
	Loess (Quaternary)
	Broadway Alluvium (Quaternary)
	Louviers Alluvium (Quaternary)
	Verdos Alluvium (Quaternary)
	Denver Formation (Upper Cretaceous & Tertiary)



0 1 2
Miles

Source : Lindvall, 1980

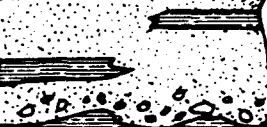
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U.S. Army Program Manager for
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Figure 2.1-3

Surficial Geologic Map of
Rocky Mountain Arsenal Area

CMP GWAR FY89

SYSTEM	ZONE & THICKNESS		LITHOLOGIC DESCRIPTION	
QUATERNARY CRETACEOUS - TERTIARY DENVER FORMATION	Alluvium	0-120'		Gravels, silty sands, sandy silts, and clays; laterally variable
	B	0-25' (0-19')		B Sand, sandstone and claystone
	Volcaniclastic	0-50'		Volcaniclastic material and laterally equivalent claystone and sandstone
	A	0-75'		A Upper (AU) (0-13') A Middle (AM) (0-20') A Lower (AL) (0-20') A Sand (0-46') Sandstone, claystone, and Lignite
	Lignite A	0-11'		
	IU	0-40' (0-36')		
	Lignite B	0-12'		
	1	0-60' (0-54')		
	Lignite C	0-13'		
	2	0-55' (0-41')		
	Lignite D	0-13'		
	3	0-45' (0-33')		
	4	0-50' (0-36')		
	5	0-25' (0-19')		
	6	0-30' (0-23')		
	7	0-30' (0-20')		
	8	0-40' (0-27')		
	9	0-20' (0-6')		

Source : ESE, 1988

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

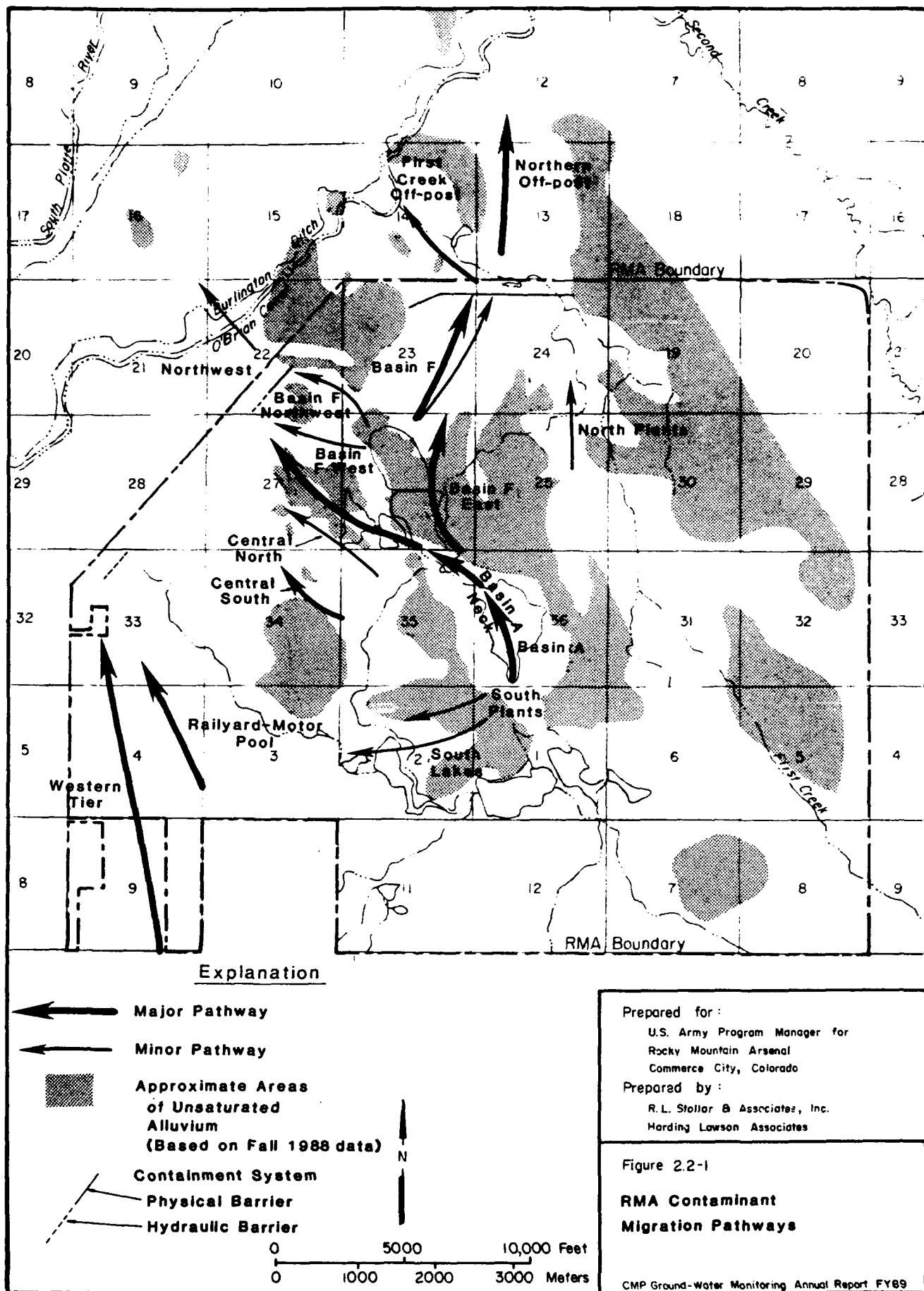
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Figure 2.1-4

RMA Denver Formation
Stratigraphic Column

CMP GWAR FY89



3.0 PROGRAM METHODS AND STRATEGY

The ground-water monitoring well networks of the Comprehensive Monitoring Program at RMA consist of both on- and off-post wells for monitoring water-level fluctuations and water-quality conditions. The water-level network is made up of 1,013 wells monitored on a quarterly basis. The FY89 water-quality network includes 515 wells monitored on an annual, semiannual, or quarterly basis. The monitoring frequency depends on data obtained in many previous investigations in the well area, remedial activities being undertaken in several areas, and other factors that are discussed below.

The well network was designed to meet program objectives efficiently by using an optimal combination of monitoring wells, monitoring frequency and analytical suite. This section of the Annual Report discusses the strategy and criteria for the monitoring network design and the methods for using data generated from the water-quality and water-level monitoring networks. Additionally, the CMP network is compared to previous monitoring networks. The water-level monitoring network is described in Section 3.1; the water-quality monitoring network is covered in Section 3.2; and the CMP analytical program is discussed in Section 3.3.

3.1 Water-Level Monitoring Network

3.1.1 Well Selection Criteria for the Water-Level Monitoring Network

The network of wells used to monitor potentiometric surfaces at RMA was selected after reviewing well construction data and historical water-level data. The areal distribution of wells was also evaluated. Historic water-level data from the spring 1987 monitoring period (RI/FS Tasks 25 and 44) were used as the primary basis for selecting wells for the CMP water-level network because these data represented the most recent comprehensive set of measurements throughout RMA. The quality and reliability of data from each well were assessed by comparison with data from nearby wells.

If a well's construction was not considered adequate for water-quality sampling but the well was located in a critical area, it was retained in the water-level network. A low construction ranking is tolerated for water-level data if the construction problem does not impact the representativeness of the measurements. For example, if a well is partially obstructed such that a bailer cannot be lowered to the water, it may still provide adequate water-table measurements.

Wells in the water-level monitoring network are monitored on a quarterly basis prior to each sampling event. The current network consists of 1,013 wells. This includes 655 unconfined wells and 358 confined wells (Table 3.1-1).

3.1.2 Well Selection Criteria for the Unconfined Flow System

The general philosophy for selecting wells in the unconfined flow system was to retain all wells that had been measured previously unless a specific situation warranted deleting a well from the program. Important vertical hydraulic data were provided by well clusters representing water levels at several depth intervals; therefore, no cluster of this kind was deleted from the program. Consequently, the CMP water-level network includes all wells previously measured during RI/FS Tasks 44 and 25, with the following exceptions:

1. Wells with construction data that indicate they are unacceptable for water-level monitoring;
2. Wells that have been formally abandoned under IRA-3, the Abandoned Well Closure Program; and
3. Wells that have been destroyed, obstructed since CMP startup, or that can no longer be located.

3.1.3 Well Selection Criteria for the Confined Flow System

The majority of confined flow system wells were included in the water-level monitoring network because ground-water flow patterns in the confined flow system are complex. Conditions under which confined flow system wells were deleted from the program relate to physical problems attributed to each well. These conditions included dry wells and wells that historically provided poor quality water-level measurements and were located near other confined flow system wells. In total, 14 confined flow system wells used in the first year (1987) CMP water-level network

Table 3.1-1 CMP Water-level Monitoring Network, FY89

Section Number	Total Wells	Wells
<u>Unconfined Flow System Wells</u>		
01	41	001, 004, 007, 008, 010, 011, 012, 014, 016, 018, 019, 021, 024, 030, 033, 041, 044, 047, 049, 055, 061, 068, 069, 070, 073, 074, 075, 078, 501, 510, 514, 518, 522, 525, 528, 534, 537, 554, 568, 586, 588
02	28	001, 002, 003, 005, 006, 007, 008, 011, 014, 020, 023, 026, 034, 037, 040, 049, 050, 052, 055, 056, 058, 059, 520, 545, 578, 580, 583, 585
03	5	001, 002, 005, 011, 517
04	39	007, 008, 010, 013, 014, 015, 016, 017, 019, 020, 021, 022, 023, 024, 025, 026, 027, 028, 029, 035, 036, 037, 038, 039, 040, 041, 042, 043, 044, 045, 046, 047, 048, 049, 050, 051, 076, 077, 525
06	2	002, 003
07	2	001, 003
08	2	002, 003
09	10	002, 005, 006, 007, 008, 010, 011, 013, 014, 015
11	4	002, 005, 006, 007
12	6	001, 002, 005, 007, 008, 009
19	3	001, 003, 004
22	17	004, 006, 008, 015, 016, 018, 019, 020, 021, 022, 033, 036, 040, 043, 049, 053, 060
23	83	002, 004, 007, 010, 011, 013, 016, 021, 025, 026, 028, 029, 030, 036, 039, 040, 045, 046, 047, 049, 050, 053, 057, 058, 059, 072, 079, 084, 085, 092, 094, 095, 096, 102, 106, 108, 110, 118, 119, 120, 121, 122, 123, 125, 134, 135, 140, 142, 146, 150, 151, 157, 159, 160, 166, 178, 179, 182, 185, 188, 191, 196, 197, 198, 199, 202, 203, 204, 205, 206, 207, 208, 211, 220, 223, 226, 231, 232, 235, 237, 238, 239, 241

Table 3.1-1

CMP Water-Level Monitoring Network, 1989 (Continued)

Section Number	Total Wells	Wells
24	87	001, 003, 004, 007, 010, 013, 014, 015, 016, 017, 018, 019, 020, 021, 023, 024, 025, 027, 041, 046, 049, 051, 052, 055, 056, 057, 058, 062, 063, 064, 081, 085, 086, 092, 093, 094, 095, 096, 097, 098, 101, 102, 103, 104, 105, 106, 107, 108, 111, 112, 113, 114, 117, 121, 122, 123, 124, 127, 128, 130, 135, 149, 150, 151, 152, 158, 161, 162, 163, 164, 165, 166, 173, 178, 179, 180, 181, 183, 184, 185, 187, 188, 191, 196, 199, 200, 201
25	19	001, 003, 011, 015, 018, 022, 028, 035, 038, 041, 042, 043, 044, 046, 047, 048, 052, 054, 055
26	49	006, 010, 015, 016, 017, 019, 020, 040, 041, 046, 048, 049, 050, 062, 063, 065, 068, 071, 073, 076, 081, 083, 085, 088, 091, 093, 124, 127, 133, 143, 145, 148, 154, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 173
27	43	002, 003, 004, 005, 006, 007, 009, 010, 011, 015, 016, 018, 025, 031, 037, 040, 041, 042, 043, 044, 045, 049, 051, 053, 057, 062, 063, 064, 066, 068, 070, 071, 072, 074, 075, 077, 080, 081, 082, 083, 084, 085, 086
28	14	003, 006, 008, 012, 014, 018, 020, 021, 022, 023, 024, 027, 503, 513
30	3	001, 002, 009
31	5	002, 003, 005, 009, 016
32	2	001, 004
33	53	001, 002, 014, 018, 019, 020, 021, 022, 023, 024, 025, 030, 033, 048, 049, 050, 053, 054, 060, 061, 062, 063, 064, 065, 066, 067, 068, 069, 070, 071, 072, 073, 074, 075, 076, 077, 078, 079, 500, 501, 502, 505, 507, 509, 510, 512, 576, 577, 579, 580, 581, 582, 583
34	5	002, 005, 008, 009, 515
35	22	007, 013, 014, 023, 025, 030, 040, 047, 048, 052, 053, 058, 061, 065, 069, 077, 079, 087, 088, 090, 091, 092
36	43	013, 017, 056, 060, 062, 063, 065, 067, 068, 069, 073, 075, 076, 077, 081, 082, 084, 085, 086, 087, 089, 090, 093, 109, 112, 137, 139, 141, 142, 145, 146, 163, 164, 165, 166, 167, 168, 169, 177, 180, 181, 184, 185

Table 3.1-1 CMP Water-Level Monitoring Network, 1989 (Continued)

Section Number	Total Wells	Wells
Off-Post	68	37304, 37306, 37307, 37308, 37309, 37310, 37312, 37313, 37320, 37323, 37327, 37330, 37331, 37332, 37333, 37334, 37335, 37336, 37337, 37338, 37339, 37340, 37341, 37342, 37343, 37344, 37345, 37346, 37347, 37348, 37349, 37350, 37351, 37352, 37353, 37354, 37355, 37356, 37358, 37359, 37360, 37361, 37362, 37363, 37364, 37366, 37367, 37368, 37369, 37370, 37371, 37373, 37374, 37377, 37378, 37381, 37382, 37383, 37385, 37386, 37389, 37391, 37392, 37395, 37396, 37397, 37398, 37399
Total Unconfined Flow System Wells = 655		
<u>Confined Flow System Wells</u>		
01	29	015, 022, 023, 025, 028, 029, 031, 032, 034, 035, 036, 037, 039, 040, 042, 043, 045, 046, 048, 050, 067, 071, 072, 076, 077, 079, 080, 081, 082
02	33	004, 009, 010, 012, 013, 015, 016, 018, 019, 021, 022, 024, 025, 027, 028, 030, 031, 032, 033, 035, 036, 038, 039, 041, 042, 043, 044, 045, 046, 047, 048, 057, 060
03	5	003, 004, 006, 007, 012
04	3	009, 011, 012
05	3	001, 002, 003
06	2	004, 005
07	2	004, 005
08	1	004
09	2	003, 004
11	2	003, 004
12	2	003, 004
19	10	002, 005, 006, 007, 011, 015, 016, 017, 018, 019
22	8	023, 024, 027, 028, 030, 031, 079, 080

Table 3.1-1 CMP Water-Level Monitoring Network, 1989 (Continued)

Section Number	Total Wells	Wells
23	31	055, 144, 161, 176, 177, 180, 181, 183, 184, 186, 187, 189, 190, 192, 193, 200, 201, 209, 218, 219, 221, 222, 224, 225, 227, 228, 229, 230, 233, 234, 236
24	19	080, 082, 083, 087, 089, 109, 125, 126, 136, 137, 159, 167, 168, 171, 172, 174, 175, 197, 198
25	26	004, 007, 008, 009, 010, 012, 013, 014, 016, 017, 019, 020, 021, 023, 024, 026, 029, 031, 033, 034, 037, 039, 040, 049, 050, 051
26	54	023, 024, 025, 026, 027, 028, 029, 047, 051, 055, 056, 057, 058, 060, 061, 064, 066, 067, 069, 072, 074, 075, 077, 079, 080, 082, 084, 086, 089, 090, 092, 094, 096, 097, 123, 128, 129, 130, 134, 135, 136, 140, 141, 142, 144, 146, 147, 149, 150, 151, 152, 153, 155, 156
27	3	054, 055, 058
28	4	025, 026, 028, 029
29	2	002, 003
30	7	004, 005, 006, 007, 008, 010, 011
31	5	006, 007, 008, 010, 011
32	2	002, 003
33	9	015, 026, 027, 028, 029, 031, 032, 034, 035
34	8	003, 004, 006, 007, 010, 011, 012, 013
35	37	005, 008, 009, 012, 015, 016, 017, 027, 028, 032, 033, 036, 038, 039, 041, 050, 051, 054, 055, 056, 059, 062, 063, 066, 067, 068, 070, 071, 073, 074, 078, 080, 081, 082, 083, 084, 089
36	35	010, 024, 029, 036, 043, 057, 061, 066, 072, 078, 079, 083, 092, 099, 104, 105, 110, 113, 114, 117, 118, 119, 121, 122, 138, 140, 147, 158, 170, 171, 178, 179, 182, 183, 186
Off-Post	14	37316, 37317, 37318, 37319, 37321, 37322, 37365, 37372, 37376, 37379, 37380, 37387, 37388, 37390

Total Confined Flow System Wells = 358

were deleted from the second year (1988) CMP water-level network. The current well network does not include wells that have been abandoned, broken, destroyed, or obstructed.

3.2 Water-Quality Monitoring Network

The on-post water-quality monitoring network was designed to address two objectives through annual, semiannual and quarterly monitoring rounds. The first objective was to confirm presently understood contaminant distributions in general areas and to record possible distribution changes. The second objective was to provide detailed descriptions of contaminant distributions in specific project areas of concern. The project areas are shown in Figure 3.2-1. General areas are all areas outside of designated project area boundaries, and include known areas of ground-water contamination, as well as background areas where contamination has not been detected. In general areas where contamination is present, contaminant distributions are sufficiently well understood, spatially and temporally, to justify a more widely spaced network. In background areas, or downgradient of known plumes, wells are monitored to ascertain whether or not contamination is moving into these areas.

Project areas are those for which additional data, more frequent data collection, and more closely spaced wells are needed to improve the understanding of site conditions. Project areas have also been designated where additional and more frequent data are needed to support ongoing Interim Response Actions (IRAs).

The annual monitoring network incorporates wells from general and project areas. General area wells are only sampled annually. The semiannual monitoring network includes the project areas only. The quarterly monitoring network is designed to support ongoing remedial support and/or substantive regulatory compliance.

The Transitional Monitoring Program (TMP) was the first annual sampling round (winter 1987/88) conducted under the CMP. The TMP was conducted as soon as practical following contract award to ensure temporal continuity between previous Remedial Investigation ground-water investigations (Tasks 25 and 44) and the CMP. The TMP well network was designed as a transition plan and was sampled before the Final CMP Ground-Water Technical Plan was completed (Stollar, 1989a).

The TMP annual sampling network served as the basis for developing the annual network presented in the Final Technical Plan (Stollar, 1989a). The annual network shown in the Technical Plan was first sampled in the fall of 1988, a year after the TMP (winter 1987/88) network had been sampled.

3.2.1 FY89 Water-Quality Monitoring

CMP water-quality monitoring was conducted during FY89 with three monitoring networks: annual, semiannual, and quarterly. The annual FY89 sampling round is referred to as the fall 1988 round. The fall 1988 round results are presented to illustrate regional contaminant distributions in this Annual Report in much the same way that the winter 1987/88 round results illustrated regional contaminant distributions in the FY88 Annual Report. The annual round was used for this purpose because it was the most extensive data set collected during the year; thus, it allowed the most detailed regional contamination assessment.

The FY89 semiannual sampling round was conducted in the spring of 1989. The semiannual network was also sampled as a subset of the fall 1988 annual sampling round. The semiannual network was designed to provide more focused data in 11 specific on-post areas and throughout the off-post area in order to maintain or improve the understanding of site conditions in those areas. All previously monitored off-post wells were included in the semiannual network to allow continued assessment of off-post contaminant distributions.

The monitoring network in the Basin F area was sampled quarterly. This network was designed to provide data to support ongoing IRA projects in that area. The quarterly network was sampled twice (winter and summer 1989) in FY89 as a stand-alone monitoring event, and was also included in the larger semiannual and annual networks.

For clarity, sampling rounds will be referred to as the fall 1988, winter 1989, spring 1989 and summer 1989 sampling rounds. Figure 3.2-2 illustrates how the annual, semiannual, and quarterly sampling networks relate to the fall 1988, winter 1989, spring 1989, and summer 1989 sampling rounds. It also lists the actual number of water levels measured during each round, as this differs from the number proposed.

Not all the wells proposed for sampling were actually sampled in FY89. The fall 1988 well network, as proposed, originally consisted of 515 wells (CMP Ground Water Final Technical Plan, Table 2.4-1; Stollar, 1989a). Of the 515 wells, 488 wells were actually sampled and 27 wells were dry, destroyed, obstructed, or abandoned (Table 3.2-1 and Figures 3.2-3 and 3.2-4). Unusable wells were replaced by alternate wells if two criteria were fulfilled:

- 1) alternate wells are screened in the hydrogeologic zone of interest; and
- 2) alternate wells are located areally to provide the desired coverage.

Table 3.2-1

Fall 1988 Annual Water Quality Monitoring Network

Section Number	Total Wells	Wells Sampled
<u>Unconfined Flow System Wells</u>		
01	17	007, 008, 014*, 017, 020, 047, 055, 061, 068, 069, 070, 510*, 511, 516, 517, 524, 525*
02	11	005*, 007, 008, 014, 020, 023, 034, 037, 050, 052, 545
03	6	002*, 005*, 008, 011, 517, 523*
04	28	007, 008, 010, 014*, 016, 019, 020, 024, 026*, 029, 030, 035, 036, 037, 038, 039, 040, 041, 042, 043, 044, 045, 046, 047, 048, 049, 050, 051
06	2	002, 003
07	1	001
08	1	003
09	9	002, 005, 006, 008, 010*, 011, 013, 014, 015
11	3	002, 005, 007
12	1	002
19	1	001
22	11	006*, 008, 011, 015, 016, 018, 019, 021*, 043, 051, 053
23	31	047, 049, 050, 052, 053, 058, 095*, 096, 108, 118, 142, 150, 151, 179*, 182*, 188*, 191, 197, 198, 202, 204*, 205, 220, 223, 226, 231*, 232, 235, 237, 239, 241
24	26	013, 027, 081, 086*, 092*, 094, 101, 106, 107, 111, 124, 127, 135*, 161, 163, 164, 181, 183, 184, 185, 188*, 191, 196, 199, 200, 201
25	9	011, 018, 041, 042, 043, 044, 046, 047, 048
26	17	006, 015, 017, 019*, 020, 041*, 063, 068, 071*, 073, 083, 085, 088, 127*, 133*, 148, 157
27	25	003, 007, 016, 025, 028*, 031, 040, 042, 044, 049, 053, 056, 057*, 062, 064, 071, 072, 073, 074, 076, 079, 083, 084, 085, 086

Table 3.2-1

Fall 1988 Annual Water Quality Monitoring Network (continued)

Section Number	Total Wells	Wells Sampled
28	4	002, 018, 023*, 027
30	1	009
31	1	005
33	20	001, 002, 025, 030, 033, 048, 063, 064, 066*, 068, 074, 075, 076, 077, 078, 079, 509, 514, 578, 581
34	6	002, 005*, 008*, 009*, 507, 508
35	13	013, 018*, 020, 023, 037, 052, 058, 061, 065*, 077, 079, 087, 088
36	18	001*, 056, 065, 069*, 075, 076*, 084, 090, 094, 123, 137, 139*, 146, 168, 169, 177, 180*, 181
Off-Post	60	37308, 37309, 37312*, 37313, 37320, 37323*, 37327, 37331*, 37332, 37333, 37334, 37335, 37336*, 37337, 37338, 37339, 37341*, 37342, 37343, 37344, 37345*, 37346, 37347, 37348, 37349*, 37350, 37351, 37352, 37353, 37354*, 37355, 37356, 37357, 37358, 37359*, 37360, 37361, 37362, 37363*, 37364, 37366, 37367, 37368*, 37369, 37370, 37371, 37373, 37374, 37377, 37378*, 37381, 37383, 37385, 37386, 37389, 37391*, 37392, 37395, 37396, 37397

Total Unconfined Flow System Wells = 322

Confined Flow System Wells

01	11	015*, 022, 025, 031*, 032*, 036, 037, 048, 067, 071*, 072
02	14	018, 021*, 024, 025, 030, 031*, 035, 036, 038, 039*, 043, 044, 047, 048*
03	4	003*, 004, 006, 012
04	2	011, 012
05	1	001
06	2	004*, 005
08	1	005

Table 3.2-1

Fall 1988 Annual Water Quality Monitoring Network (continued)

Section Number	Total Wells	Wells Sampled
09	1	003*
11	1	004
12	2	003*, 004
19	3	015, 016, 017
22	7	023, 027*, 028, 030, 031, 079, 080*
23	22	177, 180, 181, 183, 184, 186, 187, 189*, 190, 192, 218, 219, 221, 222*, 224, 225, 227, 228*, 230, 233, 234, 236*
24	5	089, 172, 175, 197, 198*
25	6	009, 013*, 014, 016*, 017, 039
26	23	055, 061, 066*, 067, 069, 072, 075, 084, 086, 089, 090, 096, 129, 140, 142*, 146, 149, 150, 151, 152, 153*, 155, 156
27	2	055, 060
28	2	025*, 028
30	1	011
32	1	002
33	4	026, 031, 032*, 034
34	5	003, 006*, 011, 012, 013
35	19	016, 017, 021, 036, 038, 039, 054, 062, 066*, 067, 068, 071, 078, 080, 081, 082, 083, 084, 089
36	15	066, 083, 110*, 114, 117, 119, 122, 148, 149, 170, 171, 178, 179, 182, 183*
Off-Post	12	37316, 37317*, 37318, 37321, 37322, 37365, 37372, 37376, 37379, 37380, 37387, 37388*

Total Confined Flow System Wells = 166

* Indicates wells for which GC/MS analyses were conducted

Table 3.2-1 Fall 1988 Annual Water Quality Monitoring Network (continued)

Wells Not Sampled	Reason
04009, 07004, 09001, 22007, 22029, 22049, 23193, 37340	Insufficient recharge.
23229, 23238, 25022, 26145, 27059, 33028, 35034, 36145, 37304, 35307	Dry.
25004, 33016, 35085, 37058, 37082	Destroyed, abandoned, or not installed.
26065, 35008, 35035	Constricted or in need of development.
Boller tap	In process of drilling new well.

Twenty-seven of the unusable wells were not replaced because alternate wells fulfilling these criteria did not exist. Information on unusable wells is used to modify subsequent monitoring networks.

The Final Technical Plan (Stollar, 1989a; Table 2.4-2) purposes a network of 376 wells in the spring 1989 round. An addendum to the Technical Plan added 38 monitoring wells to the network that were installed in FY89 and deleted six wells that did not significantly add to the current level of understanding of contamination in the South Plants area. Thus, 408 wells were to be sampled in spring 1989; 388 wells were actually sampled and 20 wells were dry, destroyed, obstructed, or abandoned (Table 3.2-2).

The quarterly monitoring network was sampled four times in FY89; twice as a stand-alone effort, once with the semiannual network, and once with the annual network. Fifty-one wells were proposed for the winter 1989 round and 46 were actually sampled (Table 3.2-3). Five wells were not sampled; three unconfined wells (23238, 26065, and 26145) that were dry, and two confined wells (23180 and 23193) that were bailed dry and well recharge was insufficient for sampling.

The quarterly well network sampled in the summer 1989 (Table 3.2-3, Figure 3.2-5) was larger than the network proposed in the Final Technical Plan (Stollar, 1989a). This was because 13 newly installed monitoring wells were added. The 13 wells (26160 through 26171, and 26173) were installed under the CMP ground-water element geotechnical program for the purpose of monitoring newly constructed IRA facilities (two ponds, a tank farm, and a wastepile) in the Basin F area. Thus, 64 wells were proposed for sampling during summer 1989. However, 55 wells were actually sampled, as five (23238, 26065, 26145, 26164, 26167) were dry, three (23180, 23193, 26165) had insufficient recharge, and one (23108) was destroyed.

3.2.1.1 Comparison with Previous RMA Networks. The CMP monitoring well network has evolved from several previous regional RMA monitoring networks. These precursor networks included the Initial Screening Program (ISP), the Final Screening Program (FSP), the Off-Post Contamination Assessment and the Composite Well Program. The immediate precursor to the CMP network was the Task 44 sampling program presented in the Water Remedial Investigation Report (Ebasco, 1989i). The Task 44 sampling program temporally overlapped with the startup of the CMP; which was called the Transitional Monitoring Program (TMP). Due to this overlap, the winter 1987/88 round comprised 255 TMP wells, 67 Task 44 wells located off-post and an additional 145 Task 25 wells located near RMA boundary containment systems. The analytical results from the various programs were presented in the FY88 CMP Ground-Water Annual Report.

Table 3.2-2

Spring 1989 Semiannual Water Quality Monitoring Network

Section Number	Total Wells	Wells Sampled
<u>Unconfined Flow System Wells</u>		
01	14	007, 014, 017, 020, 047, 055, 061, 068, 073, 074, 075, 078, 510, 525
02	9	005, 007, 023, 034, 037, 055, 056, 058, 059
03	4	002, 011, 517, 523
04	27	007, 010, 014, 016, 019, 020, 024, 026, 029, 030, 036, 037, 038, 039, 040, 041, 042, 043, 044, 045, 046, 047, 048, 049, 050, 076, 077
09	7	002, 005, 008, 010, 013, 014, 015
22	4	008, 015, 021, 053
23	21	049, 095, 108, 142, 150, 151, 179, 188, 191, 198, 202, 204, 220, 223, 226, 231, 232, 235, 237, 239, 241
24	13	013, 092, 106, 135, 161, 183, 185, 188, 191, 196, 199, 200, 201
25	11	022, 041, 042, 043, 044, 046, 047, 048, 052, 054, 055
26	18	015, 017, 019, 020, 041, 063, 071, 073, 083, 085, 088, 127, 133, 148, 154, 157, 158, 159
27	17	007, 016, 025, 028, 031, 042, 044, 053, 056, 057, 059, 071, 072, 074, 084, 085, 086
28	4	002, 018, 023, 027
31	3	014, 015, 016
32	1	004
33	18	001, 025, 033, 048, 063, 064, 066, 068, 074, 075, 076, 077, 078, 079, 509, 514, 578, 581
35	12	013, 018, 020, 061, 065, 077, 079, 087, 088, 090, 091, 092
36	14	001, 075, 094, 123, 137, 139, 146, 168, 169, 177, 180, 181, 184, 185

Table 3.2-2

Spring 1989 Semiannual Water Quality Monitoring Network (continued)

Section Number	Total Wells	Wells Sampled
Off-Post	61	37307, 37308, 37309, 37312, 37313, 37320, 37323, 37327, 37331, 37332, 37333, 37334, 37335, 37336, 37337, 37338, 37339, 37341, 37342, 37343, 37344, 37345, 37346, 37347, 37348, 37349, 37350, 37351, 37352, 37353, 37354, 37355, 37356, 37357, 37358, 37359, 37360, 37361, 37362, 37363, 37364, 37366, 37367, 37368, 37369, 37370, 37371, 37373, 37374, 37377, 37378, 37381, 37383, 37385, 37386, 37389, 37391, 37392, 37395, 37396, 37397
Total Unconfined Flow System Wells = 258		
<u>Confined Flow System Wells</u>		
01	12	015, 031, 032, 067, 071, 072, 076, 077, 079, 080, 081, 082
02	14	024, 025, 030, 031, 035, 036, 038, 039, 043, 044, 047, 048, 057, 060
03	3	003, 004, 012
04	2	011, 012
22	6	023, 027, 028, 030, 079, 080
23	17	177, 181, 189, 190, 192, 218, 219, 221, 222, 224, 225, 227, 228, 230, 233, 234, 236
24	4	136, 175, 197, 198
25	4	004, 049, 050, 051
26	22	055, 066, 067, 069, 072, 075, 084, 086, 089, 090, 096, 129, 140, 142, 146, 149, 150, 151, 152, 153, 155, 156
27	2	055, 060
28	2	025, 028
33	4	026, 031, 032, 034
34	3	011, 012, 013
35	14	008, 017, 021, 036, 062, 066, 071, 078, 080, 081, 082, 083, 084, 089

Table 3.2-2 Spring 1989 Semiannual Water Quality Monitoring Network (continued)

Section Number	Total Wells	Wells Sampled
36	9	114, 158, 170, 171, 178, 179, 182, 183, 186
37	12	37316, 37317, 37318, 37321, 37322, 37365, 37372, 37376, 37379, 37380, 37387, 37388

Total Confined Flow System Wells = 130

Wells Not Sampled	Reason
09001, 23180, 23193, 26065, 26145, 37340	Insufficient recharge.
22007, 22029, 23238, 23229, 33028, 35034, 35035, 36145, 37304	Dry.
35016, 35085, 37058, 37082	Destroyed, abandoned, or not installed.
Boller tap	In process or drilling new well.

Table 3.2-3 Wells Sampled During the Winter 1989 and Summer 1989
Quarterly Water Quality Monitoring Programs

Winter 1989

Section Number	Total Wells	Wells Sampled

Unconfined Flow System Wells

23	11	049, 095, 108, 142, 179, 188, 191, 220*, 237, 239, 241
26	13	015, 017, 019, 020, 041, 071, 073, 083, 085, 127, 133*, 148, 157
27	1	016

Total Unconfined Flow System Wells = 25

Confined Flow System Wells

23	6	181, 189, 190, 192, 221, 222*
26	15	066, 067, 072, 075, 084, 086, 129, 140, 142, 146, 149*, 150, 153, 155, 156*

Total Confined Flow System Wells = 21

Summer 1989

Section Number	Total Wells	Wells Sampled

Unconfined Flow System Wells

23	10	049, 095, 142, 179, 188, 191, 220, 237, 239, 241
26	23	015, 017, 019, 020, 041, 071, 073, 083, 085, 127, 133, 148, 157, 160, 161, 162, 163, 166, 168, 169, 170, 171, 173
27	1	016

Total Unconfined Flow System Wells = 34

Confined Flow System Wells

23	6	181, 189, 190, 192, 221, 222
26	15	066, 067, 072, 075, 084, 086, 129, 140, 142, 146, 149, 150, 153, 155, 156

Total Confined Flow System Wells = 21

* Indicates wells for which GC/MS analyses were conducted.

Several other RI/FS well networks designed to monitor specific RMA areas also preceded the CMP program. Components of many of these former networks (including wells installed under these various programs) have been included with modifications in the CMP network design. These former, more localized monitoring well networks include: the Boundary Systems Assessment (Task 25), the North Boundary Containment System Component Assessment (Task 36), the RMA Western Tier Contamination Assessment (Task 38), and the RMA Off-post Remedial Investigation (Task 39). Many of the wells that were sampled under these various RI/FS programs were sampled under the CMP during FY89 for the purposes of database verification and monitoring continuity.

3.2.2 FY89 Water-Quality Data Presentation and Use

Analytical data collected as part of the CMP during FY89 are discussed in Section 4.3 and are presented graphically in Section 4.3 and Appendix A. FY89 results are presented graphically for 21 analytes or analyte groups (Table 3.2-4). Contaminant plume maps for the unconfined flow system are presented in Section 4.3. Analyte detections in the confined flow system are presented as point plots in Appendix A. Many of these point plots combine analyte detections in more than one stratigraphic zone of the Denver Formation. Due to the complex flow pathways in the Denver Formation, plume maps were not prepared for the confined flow system. This strategy for data presentation is consistent with that used in preparing the FY88 Annual Report.

Fall 1988 data were selected for presentation of regional contaminant distributions for FY89 because they are from the annual network and, thus, are the most comprehensive. In contrast, the spring 1989 semiannual round provided data to assess contaminant distributions in the 11 project areas (Figure 3.2-1). The quarterly (winter and summer 1989) rounds provided the data necessary to support ongoing IRAs and to comply with substantive regulatory requirements for the Basin F area.

Temporal variations in regional water quality were assessed for FY89 by comparing fall 1988 analytical results with those presented in the FY88 Annual Report (winter 1987/88). In instances where analytical results of the two annual events differed, results from other FY89 CMP sampling rounds or the Water Remedial Investigation Report were consulted to clarify interpretation. Temporal variations in water quality in specific areas were evaluated by comparing data from the fall 1988 and spring 1989 rounds of the FY89 CMP program.

Table 3.2-4 Analytes Presented Graphically in this Report

-
1. Dieldrin
 2. Endrin
 3. Dithiane/Oxathiane (summed on one map)
 4. Benzothiazole
 5. Organosulfur Compounds (OSCs); includes summed concentrations of:
 - CPMS
 - CPMSO
 - CPMSO₂
 6. Volatile Organic Aromatics (VOAs); includes the following analytes summed on one map:
 - Benzene
 - Chlorobenzene
 - Ethylbenzene
 - Toluene
 - Xylenes
 7. Benzene
 8. Chlorobenzene
 9. Volatile Organohalogens (VOHs) includes concentrations of the following eleven analytes summed on one map:
 - 1,1-Dichloroethane
 - 1,2-Dichloroethane
 - 1,1-Dichloroethene
 - 1,2-Dichloroethene
 - Methylene Chloride
 - Chloroform
 - Carbon Tetrachloride
 - 1,1,1-Trichloroethane
 - 1,1,2-Trichloroethane
 - Trichloroethene
 - Tetrachloroethene
 10. Chloroform
 11. Trichloroethene
 12. Tetrachloroethene
 13. Dibromochloropropane (DBCP)
 14. Dicyclopentadiene (DCPD)
 15. Diisopropylmethylphosphonate (DIMP)
 16. Phenols
 17. Parathion
 18. Cyanide
 19. Fluoride
 20. Chloride
 21. Arsenic
-

3.2.3 Well Selection for Gas Chromatography/Mass Spectrometry Analysis

Gas chromatography and mass spectroscopy (GC/MS) analysis was planned for a maximum of 20 percent of the samples collected from the fall 1988 sampling round. A total of 89 wells were selected for analysis by GC/MS during FY89 (Table 3.2-5). The purpose of these analyses was to provide confirmation of target analytes detected by gas chromatography (GC). In addition, the GC/MS analysis was conducted to tentatively identify non-target compounds. Wells were selected on the basis of:

- range of contaminants based on historical chemical data;
- use of wells for previous GC/MS analyses (approximately half of the selected wells); and
- well construction data.

Although 89 wells were proposed for GC/MS analysis, only 86 were actually sampled. Well 04009 had insufficient recharge for the GC/MS suite. Well 35035 was not sampled because it still needed redevelopment after obstructions had been removed from it. Well 37307 was originally proposed for GC/MS analysis, but in fall 1988 it was dry. The 86 wells analyzed for GC/MS represent nearly 18 percent of the 488 wells sampled in fall 1988.

In selecting wells for GC/MS analysis for the FY89 GC/MS network, historical analytical data were reviewed to ensure that candidate wells contained multiple analytes and wide ranges of those analytes. Wells with diverse analytical results were preferentially selected for GC/MS analysis for comparative purposes. Approximately half of the wells selected for GC/MS analysis in FY89 had previously been included in the FY88 GC/MS network. This 50 percent overlap was used where possible to ensure continuity between the multiple sampling years of the CMP.

Well construction was another selection factor. Well construction was evaluated with respect to stratigraphy in order to associate the well with a specific geologic zone.

3.2.4 CMP Procedures for Water-Quality Monitoring

Several guidance documents in addition to the CMP Ground-Water Technical Plan give detailed information on methods and procedures used to monitor ground-water quality. For example, ground-water sampling and monitoring procedures are discussed in the CMP "Field Procedures

Table 3.2-5

FY89 Wells Sampled for Gas Chromatography and Mass Spectrometry Analysis*

Section No.	Total Wells	Wells Sampled
1	7	014, 015, 031, 032, 071, 510, 525
2	5	005, 021, 031, 039, 048
3	4	002, 003, 005, 523
4	2	014, 026
6	1	004
9	2	003, 010
12	1	003
22	4	006, 021, 027, 080
23	11	095, 179, 182, 188, 189, 204, 220**, 222***, 228, 231, 236
24	5	086, 092, 135, 188, 198
25	2	013, 016
26	10	019, 041, 066, 071, 127, 133***, 142, 149**, 153, 156**
27	2	028, 057
28	2	023, 025
33	2	032, 066
34	4	005, 006, 008, 009
35	3	018, 065, 066
36	7	001, 069, 076, 110, 139, 180, 183
Off-post	15	37312, 37317, 37323, 37331, 37336, 37341, 37345, 37349, 37354, 37359, 37363, 37368, 37378, 37388, 37391

Total Number of Wells = 89

*Samples collected during Fall 1988 Monitoring Program unless noted otherwise. GC/MS results were also obtained for approximately 20 percent of the QA/QC samples.

**Samples collected during Winter 1989 Monitoring Program

***Samples collected during both Fall 1988 and Winter 1989 Monitoring Programs

Manual," laboratory procedures are described in the CMP "Analytical Methods Manual," and the CMP "Quality Assurance/Quality Control Plan" discusses sample handling and chain-of-custody. The "Data Management Plan" addresses data management procedures applicable to all phases of the CMP. The "Health and Safety Plan" for the CMP describes how to conduct CMP ground-water monitoring safely to prevent chemical exposures and personal injuries.

3.3 Analytical Program

The ground-water samples collected during the FY89 sampling rounds were tested for the analytes listed in Table 3.3-1. DataChem, Inc. and Hunter Services Inc. analyzed all of the FY89 water-quality samples. The CMP Final Technical Plan (Stollar, 1989a) incorporates the analytes parathion, cyanide, and acid extractables (phenols) in the CMP FY89 analytical suite. These analytes had not previously been included in any regional sampling program at RMA.

As discussed in Section 3.2.3 of this report, the CMP analytical program included analysis of approximately 18 percent of all ground-water samples by the GC/MS analytical technique. GC/MS analytical results were reviewed to confirm the presence of target analytes detected in investigative samples by gas chromatography. Additionally, GC/MS analyses were used to detect nontarget analytes not included in the CMP analytical parameters list (nontarget analytes). The CMP evaluates nontarget analytes to identify potential additions to the target analyte list. The results of the GC/MS analyses are discussed in Section 4.4 of this report.

The analytical program also incorporated a quality assurance and quality control plan (QA/QC plan). The CMP QA/QC plan discusses quality assurance review processes and specifics such as monitoring analytical controls, control samples, and sample lot controls. In the CMP field program, control samples comprise 25 percent of the total number of samples obtained. The results of the quality assurance and quality control program are discussed in Section 4.5 of this report.

Table 3.3-1

Chemicals Analyzed in FY89

Organochlorine Pesticide Method

Aldrin
 Chlordane
 Endrin
 Dieldrin
 Isodrin
 Hexachlorocyclopentadiene
 p,p'-DDE
 p,p'-DDT

Volatile Organohalogen Method

Chlorobenzene
 Chloroform
 Carbon Tetrachloride
 1,2-Dichloroethene
 Trichloroethene
 1,1 Dichloroethene
 1,1 Dichloroethane
 1,2 Dichloroethane
 1,1,1 Trichloroethane
 1,1,2 Trichloroethane
 Methylene Chloride
 Tetrachloroethene

Organosulfur Compound Method

P-Chlorophenylmethylsulfone
 P-Chlorophenylmethylsulfoxide
 P-Chlorophenylmethylsulfide
 1,4-Dithiane
 1,4-Oxithiane
 Dimethyldisulfide
 Benzothiazole

Organophosphorus Compound Method

Atrazine
 Malathion
 Parathion
 Vapona
 Supona

Volatile Aromatic Method

Toluene
 Benzene
 Xylene (m-)
 Ethylbenzene
 Xylene (o,p)

DCPD/MIBK Method

Bicyclo[2,2,1]Hepta-2,5-diene
 Dicyclopentadiene
 Methylisobutyl Ketone

Phosphonate Method

Diisopropylmethylphosphonate (DIMP)
 Dimethylmethylphosphonate (DMMP)

DBCP Method

Dibromochloropropane

Metals

Mercury
 Arsenic
 Cadmium
 Chromium
 Copper
 Lead
 Zinc

Cations

Potassium
 Calcium
 Magnesium
 Sodium

Anions

Chloride
 Fluoride
 Sulfate
 Nitrate+Nitrite
 Alkalinity (as CaCO₃)

Acid Extractables*

Phenols (EPA Method 8270)

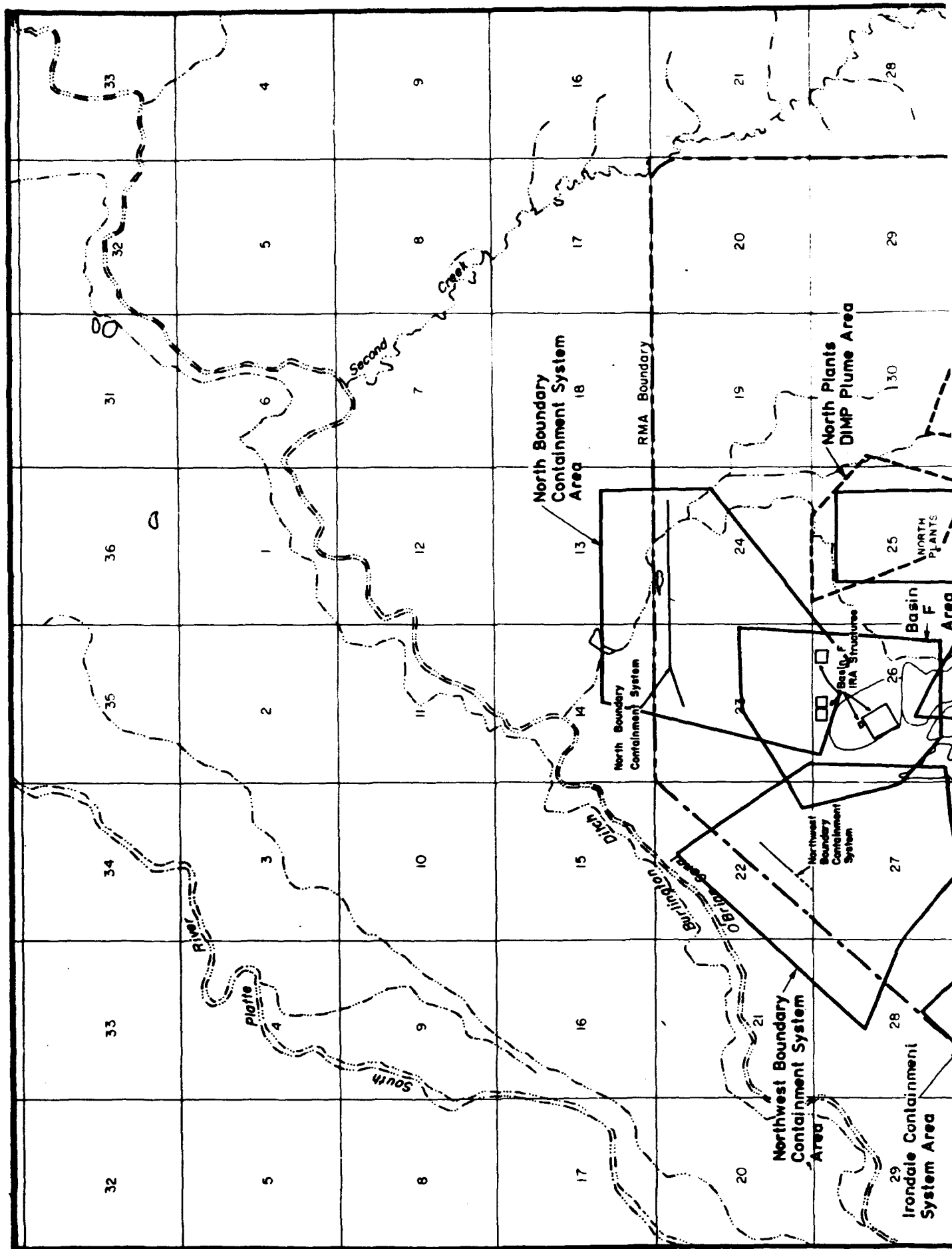
Cyanide Method

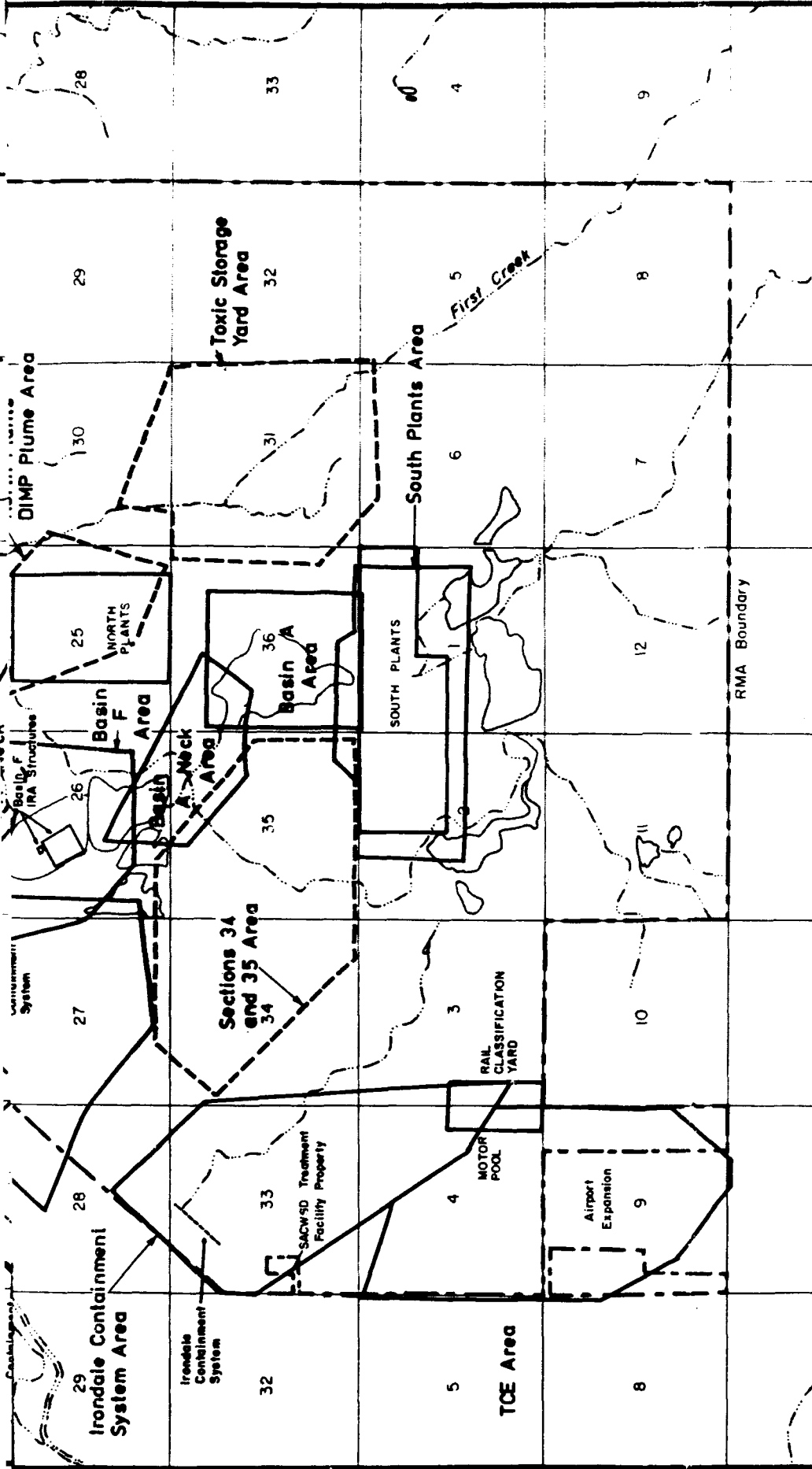
Cyanide

GC/MS (20% of wells sampled annually)

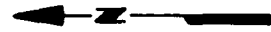
Base
 Neutral
 Acid

* Analyses performed during the fall 1988 and winter 1989 monitoring programs only.





- Explanation
- Designated Project Area
 - - - Tentative Project Area
 - Containment System
 - Physical Barrier
 - Hydraulic Barrier



Prepared for :

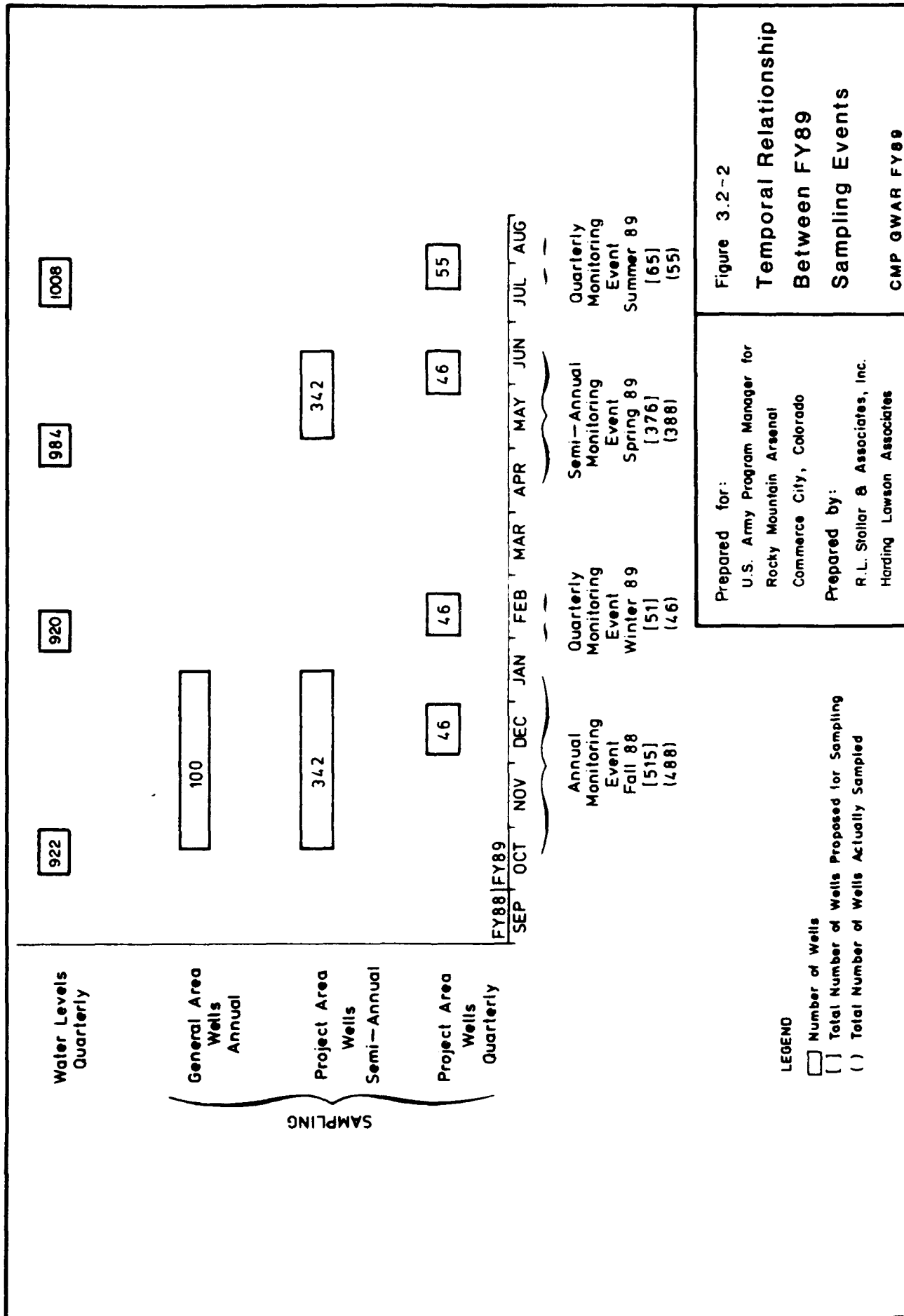
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

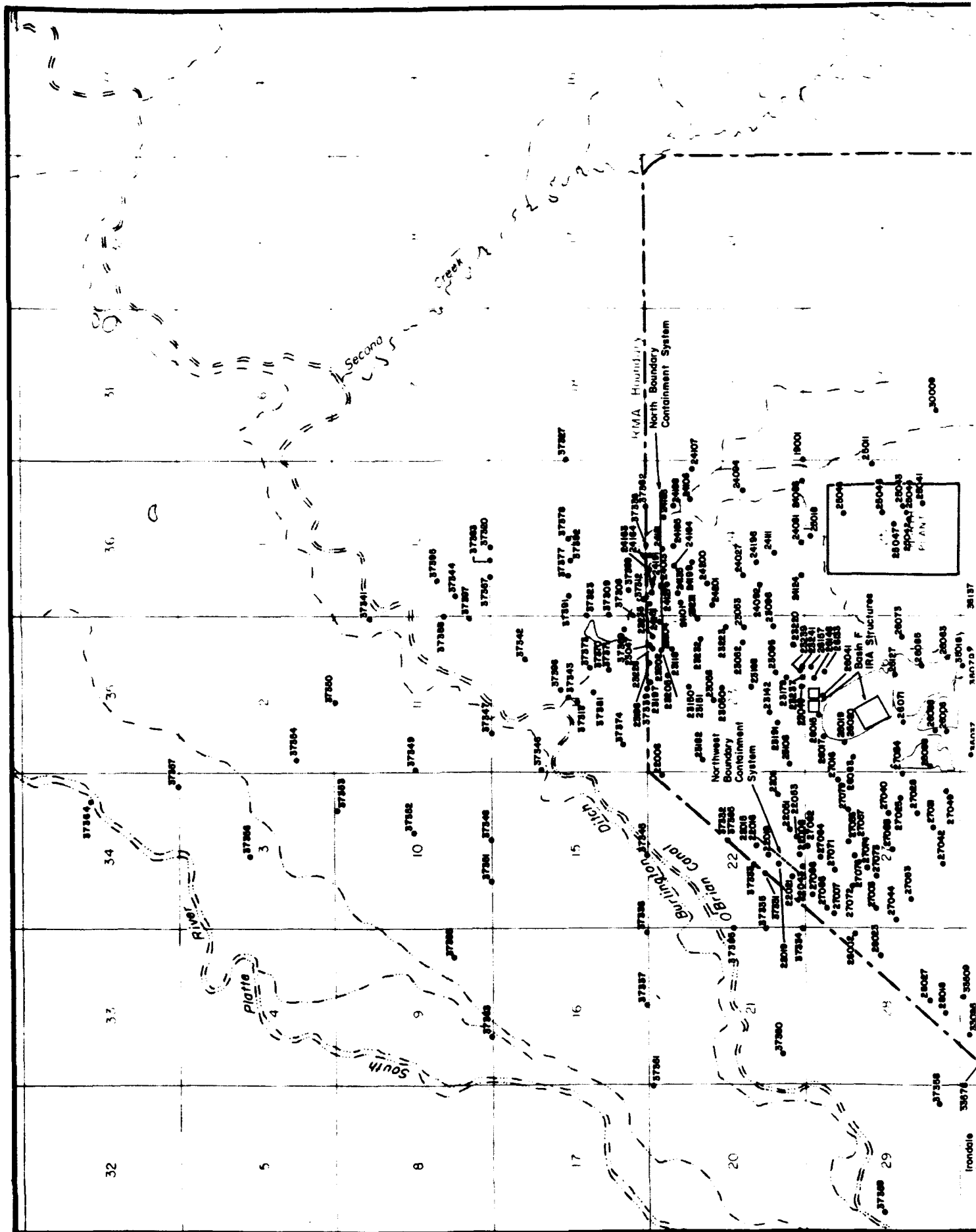
Prepared by :

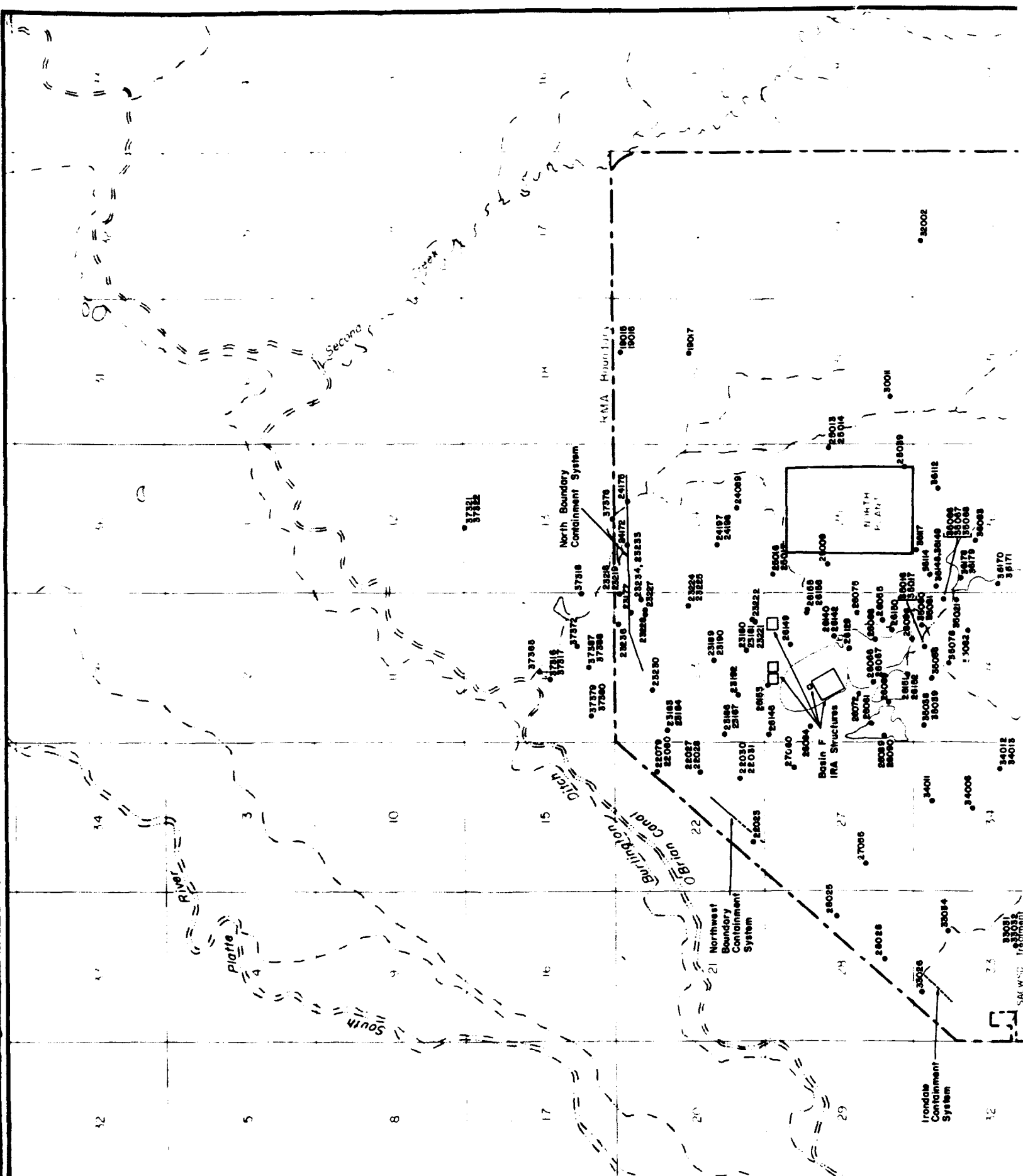
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 3.2-1

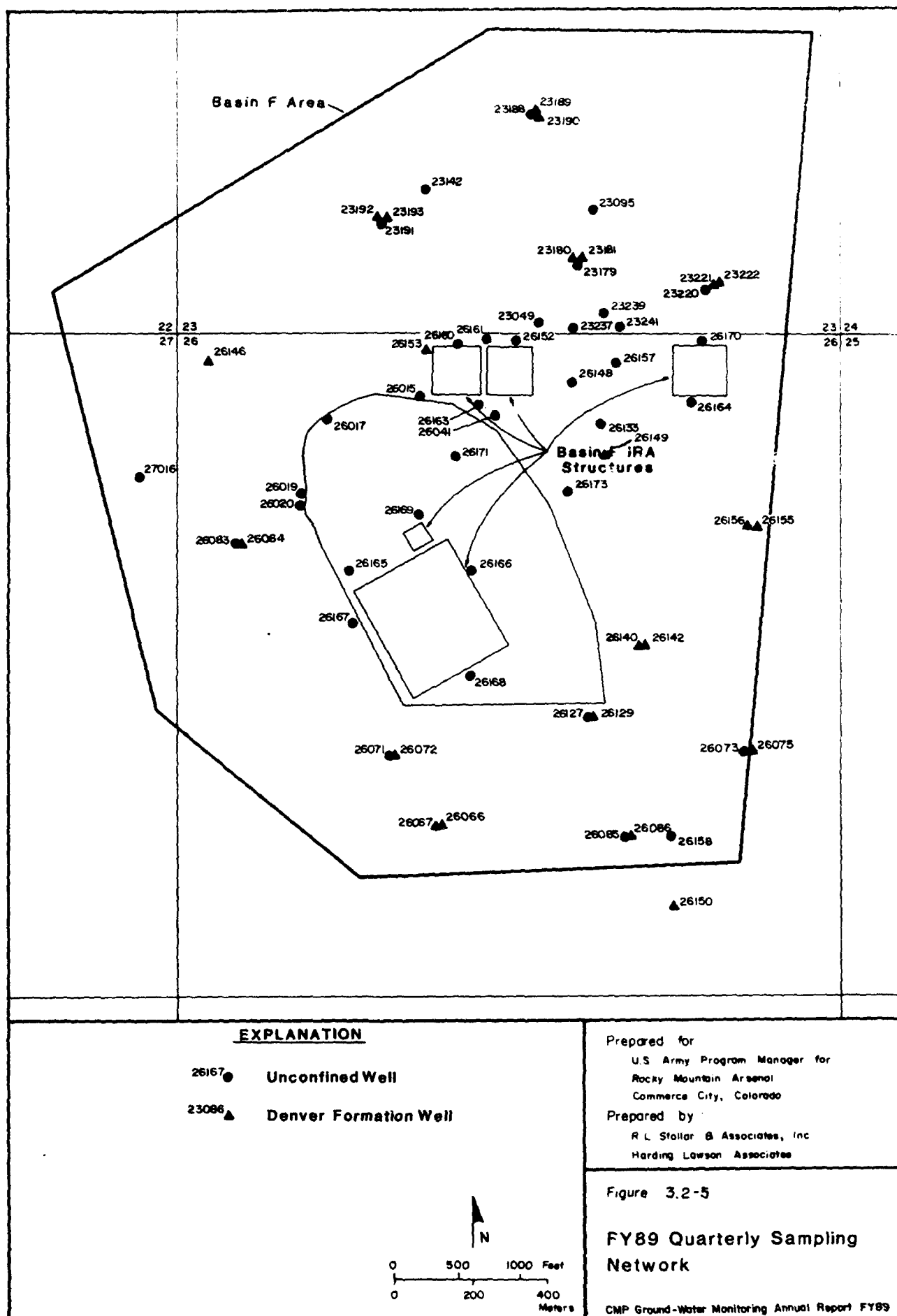
Project Areas in the Comprehensive
Ground-Water Monitoring Program







SAI W-10
T-10-10



4.0 RESULTS OF FY89 PROGRAM

Water-level and water-quality data were collected during four periods of FY89. Table 4.0-1 summarizes the season, the number of wells measured or sampled, and the dates during which the wells were measured or sampled in each quarter.

Table 4.0-1 Summary of Ground-water Data Collection During FY89

Season	No. of Water Level Measurement Wells	Dates of Water-Level Measurements	No. of Water-Quality Wells Proposed	No. of Wells Actually Sampled	Dates of Sampling
Fall 1988	922	10/07/88 to 10/19/88	515	488	10/20/88 to 01/17/89
Winter 1989	920	01/25/89 to 02/09/89	51	46	02/07/89 to 02/16/89
Spring 1989	984	04/21/89 to 05/03/89	376	388	05/03/89 to 06/15/89
Summer 1989	1008	07/24/89 to 08/03/89	65	55	08/03/89 to 08/09/89

The results of the four sampling rounds are discussed in this section, beginning with the potentiometric surfaces of the unconfined and confined flow systems, and continuing with the distribution of contaminants in these systems. Appendix B (on diskette) contains the potentiometric surface data and Appendix C (on diskette) contains the water-quality analytical results for FY89.

4.1 Regional Water-Table Surface

The unconfined flow system represents water-table conditions at RMA. The water table is the uppermost ground-water flow system at RMA. The unconfined flow system consists primarily of saturated alluvial deposits. In certain areas, unconfined conditions also occur within upper portions of the Denver Formation. These areas may exist where sandstone of the Denver Formation subcrops at the alluvial/bedrock contact, or where weathering or fracturing has increased the hydraulic conductivity of upper Denver Formation siltstones and claystones.

Figures 4.1-1, 4.1-2, 4.1-3, and 4.1-4 show the water-table surface at RMA on a regional scale. Each figure presents data from one of the four FY89 monitoring periods.

To construct these water-table elevation maps, water-level data were used from wells completed in the alluvium and upper portions of the Denver Formation. Water-level data from wells screened in the upper portions of the Denver Formation were used only if two conditions were met. The first condition was that the water-level data were consistent with the surrounding water table. The second condition was that the wells' geologic logs indicated potential for direct communication with the unconfined flow system. Data consistent with the surrounding water table were considered to represent unconfined flow if these conditions were met. Alternatively, data not consistent with the surrounding water table were considered to represent confined flow. Discussion of the confined flow system is presented in Section 4.2.

Twenty-nine new wells were completed in the unconfined flow system during FY89, in Sections 1, 2, 4, 25, 26, 30, 32, and 36. The purpose of these new wells was generally to provide additional water-quality data. Water-level data from these new wells generally confirm previous interpretations of the water-table surface in these areas.

Figure 4.1-1 presents the regional water-table surface measured during the fall of 1988. The regional slope of the water table (hydraulic gradient) is from the southeast to the northwest. Across RMA the drop in water-table elevation is approximately 210 feet. This results in regional ground-water flow towards the northwest and an average hydraulic gradient of 0.006 ft/ft across RMA. Approximately two miles northwest of RMA, the water table intersects the Platte River. At this intersection, the Platte River acts as the regional discharge point for the unconfined flow system.

The most pronounced local variation in the configuration of the regional water table surface at RMA is the ground-water mound present beneath the South Plants. This mound is approximately 25 ft higher in elevation than the regional water-table surface, and is coincident with an area of shallow bedrock. To the southeast of the South Plants mound, and along the east and west margins of RMA, the water table has a relatively flat gradient. In these areas, flow in the unconfined system occurs predominantly through alluvial deposits with relatively high hydraulic conductivity. To the northwest of the South Plants, the gradient is generally steeper. In this area, a significant component of unconfined flow occurs through heterogeneous bedrock of the upper Denver Formation. In contrast to alluvium, bedrock generally has relatively low primary hydraulic conductivity. The heterogeneous nature of the bedrock, together with fracturing and weathering of the upper bedrock surface, results in variable hydraulic conductivity. The irregular character of the water table in this area may result from this variability.

Along the north and northwest margins of RMA, the water table is impacted by the boundary containment systems. This impact is discussed in Section 4.1.2.

Downgradient of RMA in the northwest off-post area, the hydraulic gradient flattens. In this area, the unconfined flow system consists predominantly of thick alluvial deposits with relatively high hydraulic conductivity.

4.1.1 Seasonal Fluctuations of the Regional Water Table

Seasonal fluctuations in the configuration of the regional water-table surface are generally small. The general configuration of the regional water table was similar during all FY89 monitoring periods (Figures 4.1-1 through 4.1-4, respectively). A general shift of contour lines in the downgradient direction can be noted on the spring 1989 (Figure 4.1-3) and summer 1989 (Figure 4.1-4) maps. This reflects rising water levels during these seasons. The largest seasonal variation in water-table elevations occurred in the South Plants area where the water table rose approximately 4 feet.

Pronounced water-table variations occurred in the vicinity of the boundary containment systems in FY89. These variations are largely attributable to the operations of the boundary containment systems.

4.1.2 Water-Table Surface in the Boundary Containment Systems Area

Water-level data characterizing the water table were obtained in four separate monitoring events in FY89. These data are principally compiled for assessing water-table fluctuations from a regional perspective. One of the objectives of the CMP, however, is to monitor the hydrologic impact of boundary containment system operation. Where possible, the quarterly water-level data sets have been used to evaluate more local fluctuations associated with systems operations. The information provided here characterizes the NBCS and NWBCS operations. For more detailed information based on weekly water levels obtained from densely-spaced monitoring well networks, the reader is directed to the FY88 Operational Assessment Reports of the NBCS and the NWBCS (PMRMA, 1989b and PMRMA 1989c, respectively).

Figures 4.1-5 through 4.1-8 show the water-table surface elevations in the vicinity of the North Boundary Containment System (NBCS) and the Northwest Boundary Containment System (NWBCS) as measured during the fall 1988, winter, spring, and summer 1989, respectively. These maps are based on a 2-foot contour interval, in order to show local variations in the water-table surface that

are not evident on the regional maps. The effects of the boundary systems on the water-table elevations include:

- Deflected contour lines indicating deviation from regional flow conditions
- Differences in elevations across the boundaries which indicate hydraulic separation between upgradient and downgradient flow systems
- Localized troughs or mounds which reflect extraction or injection of ground water

During the fall of 1988 (Figure 4.1-5), the effects of the NBCS on the water table were apparent in several areas. Upgradient of the system, a large area with a relatively flat gradient coincided with flow through alluvium. Downgradient of the system, the gradient was considerably steeper. Across the barrier, discontinuous contour lines indicate an abrupt change in water-table elevations on either side of the barrier. During the fall of 1988, the maximum head difference (6 ft) across the barrier occurred along its central portion. As shown in Figure 4.1-5, the water levels on the upgradient side of the barrier were higher than water levels on the downgradient side. Near the ends of the containment system, the head differences diminished. For approximately 650 ft along, the western end of the NBCS, there was a reverse gradient, with elevations on the north side of the barrier higher than elevations on the south side.

Fall 1988 water-level data (Figure 4.1-5) were collected prior to the initial startup and operation of the ground-water recharge trenches at the NBCS. The impact of the recharge trenches is discussed for monitoring conducting during and following winter 1989.

The NWBCS (Figure 4.1-5) during the fall of 1988 also impacted the surrounding water table. Based on an interpretation of relatively few data points, an arcuate trough was inferred to exist immediately upgradient of the NWBCS. To the east of the trough, the hydraulic gradient abruptly steepened. The low hydraulic conductivity of the aquifer materials in this area (southeast Section 22) probably accounts for the steepened gradient. Downgradient of the NWBCS, a shallow hydrologic trough with a southeast-northwest axis was inferred to exist in the water-table surface. It should be noted that the inferred existence of this trough was similarly based on relatively few data points.

During the winter 1989 monitoring periods two ground-water mounds were present north of the NBCS as a result of the operation of newly-installed recharge trenches (Figure 4.1-6). Recharge

trench operations began in October 1988 along the northern portion of the NBCS. A reverse hydraulic gradient across the barrier is apparent in Figure 4.1-6 for the western half of the NBCS.

The winter 1989 water-table surface at the NWBCS (Figure 4.1-6) exhibits a flattened gradient in the immediate vicinity of the barrier. The steepened gradient east of the barrier is still present (as it was in fall 1988) but the troughs noted upgradient and downgradient of the NWBCS in the fall of 1988 are not apparent in the winter of 1989.

The spring 1989 water-table map (Figure 4.1-7) indicates that extensive ground-water mounding persisted downgradient of the NBCS, but that the localized, uppermost portions of the mound (enclosed by the 5140-foot contour in Figure 4.1-6) had diminished somewhat. The position of the 5138-foot contour south of the NBCS indicated that the water table had risen slightly in the spring of 1989 relative to the winter of 1989.

The spring 1989 water-table surface at the NWBCS (Figure 4.1-7) is very similar to the previous winter 1989 (Figure 4.1-6) water-table surface. The 5090-foot and 5092-foot contours northwest of the barrier have migrated slightly, indicating a subtle lowering of the downgradient water-table surface.

The steepened water-table surface in the southeast portion of Section 22 east of the NWBCS has become less steep (decreased the hydraulic gradient) due to an overall lowering of the water table. This change in hydraulic gradient has exposed a larger area of unsaturated alluvium in Sections 22 and 27 upgradient of the NWBCS.

The summer 1989 water-table surface (Figure 4.1-8) in the vicinity of the NBCS is very similar to the previous spring 1989 surface. The 5142-foot contour has migrated farther south in Section 23, indicating further flattening of the hydraulic gradient across all of Section 23. Mounding of the water table downgradient of the NBCS is still present, as it was in the previous quarter.

The summer 1989 water-table surface at the NWBCS (Figure 4.1-8) is very similar to the spring 1989 surface. The relative location of the 5092-foot contour has shifted, indicating a slight rise in the water-table elevation downgradient of the system.

4.1.3 Water Table in the Basin F IRA Area

Figure 4.1-9 presents the water-table surface in the Basin F IRA area during the fall of 1988. The contour lines indicate that ground-water flow beneath the IRA structures is to the north. Near the southwest portion of historical Basin F, the gradient is towards the northwest.

The water-table surface in the Basin F area is relatively planar, except for a local westward-trending hydraulic divide located in west-central Section 26. Within the map area, the hydraulic gradient is generally steeper in areas of unsaturated alluvium where unconfined flow occurs through less permeable bedrock of the Denver Formation. Downgradient of the IRA structures, the hydraulic gradient flattens, probably due to both a flat bedrock surface and a relatively thicker interval of saturated alluvium.

Figure 4.1-10 presents the water-table surface of the Basin F IRA area during the winter of 1989. The water-table surface in this area was generally similar to the fall 1988 surface, both in the extent of unsaturated alluvium and the direction and rates of ground-water flow.

The spring 1989 water-table surface (Figure 4.1-11) has several variations from the fall 1988 and winter 1989 surfaces. Contours in the southeast portion of the area have shifted slightly to the north, indicating higher water levels. In contrast, contour lines in the northwest portion of the area have shifted south, indicating a lower water table in that area. In the central portion of the area, the contour lines are more closely spaced, reflecting a steeper hydraulic gradient. The predominately east-west trending local ground-water divide located west of historical Basin F has shifted to trend somewhat southeast-northwest. Additional areas of unsaturated alluvium exist on the spring 1989 map near the common corner of Sections 22, 23, 26, and 27. These additional areas of unsaturated alluvium are attributable to lowered in water levels.

The potentiometric surface of the unconfined flow system in the Basin F IRA area during the summer of 1989 is presented on Figure 4.1-12. This potentiometric surface was generally similar to the spring 1989 surface, except for a general southward shift of contour lines. This southward shift indicates water levels are approximately 1 to 2 ft lower than those measured during the spring of 1989. These lower water levels increased the extent of unsaturated alluvium beneath the western portion of historical Basin F, and north and west of the northern IRA structures.

4.2 Regional Potentiometric Surfaces of the Confined Flow System

Beneath the unconfined flow system, ground water movement occurs through strata of the Denver Formation. These strata consist of irregular, semi-permeable, sandstone and siltstone beds that are dispersed within thick sequences of relatively impermeable claystone. Overall, hydraulic conductivity values for the Denver Formation are lower than the overlying alluvium. Except in locations where permeable units subcrop, ground water in these strata exists at pressures higher than atmospheric. Hence, ground water movement through these strata is considered to be confined.

The Denver Formation has been divided into 17 stratigraphic units, as presented in Section 2.1-1 and on Figure 2.1-4. The potentiometric surface of ground water has been mapped for six of these units: A, 1U, 1, 2, 3 and 4 (Figures 4.2-1 to 4.2-6, respectively). Figures 4.2-1 through 4.2-6 are based on water-level data obtained during the fall of 1988. Maps representing the other three seasons are not presented because the potentiometric surfaces do not vary significantly. Thus, the fall 1988 water-level data provide a reasonable representation of the potentiometric surfaces in the confined flow system for the entire FY89 monitoring period.

The form of the potentiometric surfaces shown for each zone of the Denver Formation generally is similar, with gradients principally toward the northwest. The elevations of the potentiometric surfaces, however, are generally different. Commonly, the potentiometric surface elevations in deeper zones are lower than the potentiometric surface elevations in shallower zones. Also, the ground-water gradient within each zone is in the opposite direction to the dip of the zones. This suggests that flow between zones can occur, and that it has a potential for a downward direction. In certain locations between the potentiometric surface elevations of adjacent zones becomes equal. This suggests that the gradients in these areas are horizontal and communication between zones does would not occur if adjacent zones are separated by a confining layer. If the zones are not separated by an aquitard, the potentiometric relationships suggest that adjacent zones may act as a single hydrostratigraphic unit in these locations. Examples include: southern Basin A - between zones 1U and 1; Basin A Neck - between zones 1 and 2; and the Basin F area between zones 2 and 3. Zones 3 and 4 exhibit nearly identical potentiometric elevations throughout the mapped area, which indicates that these zones may be part of the same hydrostratigraphic unit.

4.3 Contaminant Distribution

Assessment of contaminant distributions in ground water at RMA is based on: (1) chemical analysis of samples collected during the fall of 1988, and the winter, spring, and summer of 1989;

(2) current understanding of stratigraphic correlations of various geologic units at RMA; and (3) current understanding of ground-water flow conditions at RMA. Plume maps were constructed using data from the fall 1988 sampling round, as it was the most comprehensive sampling round during FY89.

4.3.1 Analytical Data Presentation

Twenty-one selected analytes or analyte groups are presented in this section. Contaminant distributions in the unconfined and confined flow systems are described, and comparisons are made between FY89, FY88 and historical analytical results. Plume maps based on fall 1988 analytical results are presented for each analyte or group. Tables are also presented summarizing analytical results of the samples collected in both the unconfined and confined flow systems. These tables present all of the FY89 analytical results as well as the winter 1987/88 results for each analyte discussed.

4.3.2 Dieldrin

A total of 487 samples collected from the unconfined and confined flow systems were analyzed for dieldrin during the fall of 1988. Dieldrin was reported above the CRL (0.0500 $\mu\text{g/l}$) in 141 samples with concentrations ranging from 0.0512 $\mu\text{g/l}$ to 86.0 $\mu\text{g/l}$. Dieldrin was detected in the confined flow system within zones A, 1U, 1, 2, 3, and 5. Table 4.3.2-1 summarizes the detections reported in the unconfined and confined flow systems for FY89.

4.3.2.1 Unconfined Flow System. Among the 321 wells sampled from the unconfined flow system, dieldrin was detected in 124 samples. Concentrations ranged from 0.0512 $\mu\text{g/l}$ to 86.0 $\mu\text{g/l}$. The distribution of dieldrin contamination in the unconfined flow system at RMA for the fall 1988 monitoring event is shown in Figure 4.3.2-1.

A continuous plume of dieldrin extended from the South Plants and Basin A to the NBCS and the NWBCS. The affected pathways within this plume included the South Plants-Basin A, South Lakes, Basin A Neck, Central North, Basin F East, Basin F West, Basin F Northwest, and Basin F Pathways. An isolated dieldrin plume existed in the Central South Pathway. Off-post, dieldrin plumes were inferred in the First Creek Off-Post, Northern Off-Post, and Northwest Pathways.

The dieldrin plume extended from a small concentration high in the South Plants, north into Basin A and southeast along the South Lakes Pathway. A lobe of the plume extended east into Section 3, where Well 03005 yielded a dieldrin concentration of 5.00 $\mu\text{g/l}$, the highest in the South

Table 4.3.2-1

Dieldrin Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	321	124	0.0512 - 86.0
	Winter 89	25	23	0.121 - 2.30
	Spring 89	257	88	0.0527 - 9.60
	Summer 89	34	31	0.0864 - 2.50
	Winter 87/88	325	136	0.052 - 150
<u>Confined Flow System</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	5	0.0631 - 0.633
	Winter 89	0	0	
	Spring 89	29	4	0.0810 - 22.0
	Summer 89	0	0	
	Winter 87/88	28	4	0.0800 - 0.844
IU	Fall 88	20	3	0.0535 - 0.173
	Winter 89	0	0	
	Spring 89	18	5	0.0637 - 0.291
	Summer 89	0	0	
	Winter 87/88	12	1	0.281
1	Fall 88	22	3	0.0535 - 0.0608
	Winter 89	6	3	0.0778 - 0.121
	Spring 89	16	2	0.0644 - 0.0799
	Summer 89	6	1	0.0512
	Winter 87/88	16	3	0.0660 - 0.142
2	Fall 88	37	4	0.0549 - 0.175
	Winter 89	11	4	0.154 - 0.533
	Spring 89	24	2	0.0615 - 0.126
	Summer 89	11	1	0.130
	Winter 87/88	26	4	0.056 - 0.091
3	Fall 88	19	1	7.10
	Winter 89	3	2	0.0682 - 0.517
	Spring 89	17	2	0.0841 - 0.563
	Summer 89	3	1	0.291
	Winter 87/88	18	3	0.077 - 0.571

Table 4.3.2-1

Dieldrin Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	0	0.452
	Winter 89	1	1	
	Spring 89	16	0	
	Summer 89	1	0	0.069
	Winter 87/88	18	1	
5	Fall 88	9	1	0.0635
	Winter 89	0	0	0.077
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	10	1	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
<u>Total Confined Flow System</u>				
	Fall 88	166	17	0.0535 - 7.10
	Winter 89	21	10	0.0682 - 0.533
	Spring 89	130	15	0.0615 - 22.0
	Summer 89	21	3	0.0512 - 0.291
	Winter 87/88	135	19	0.051 - 0.844
Explanation:			Certified Reporting Limits (µg/l)	
Fall 88	(Fall 1988 annual sampling event)		0.0500	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		0.0500	
Spring 89	(Spring 1989 semi-annual sampling event)		0.0500/0.0539	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		0.0500	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		0.050/0.054/0.060	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

Lakes area. Within Basin A, a concentration high was centered around Well 36056, which yielded 65.0 µg/l of dieldrin.

From Basin A, dieldrin contamination extended northeast into the Basin A Neck and Basin F East Pathways. Dieldrin contamination within the Basin A Neck Pathway merged with contamination in the Central North, Basin F West and Basin F Northwest Pathways as the plume approached the NWBCS. Along the northwest RMA boundary, dieldrin extended off-post a short distance beyond the NWBCS and south of the NWBCS.

Dieldrin contamination in the Basin F East Pathway merged with the Basin F Pathway plume in north-central Section 26. Dieldrin concentration highs occurred in the Basin F Pathway plume downgradient of Basin F. The highest fall 1988 detection in the Basin F Pathway plume was 7.60 µg/l at Well 23241. Dieldrin contamination extended along the Basin F Pathway to the NBCS. Downgradient of the NBCS, dieldrin plumes extended for approximately one mile along the First Creek and Northern Off-Post Pathways. The highest off-post dieldrin detection within these pathways was 0.840 µg/l at Well 37312.

Isolated dieldrin detections were reported on-post in Sections 1, 2, 23, 24, 25, 27, and 35. Off-post isolated detections were reported at Wells 37355 and 37377.

4.3.2.2 Confined Flow System. Dieldrin analyses were performed on 166 samples collected from the confined flow system during the fall of 1988. Dieldrin was detected in 17 samples from zones A, 1U, 1, 2, 3, and 5. Concentrations ranged from 0.0535 to 7.10 µg/l. Table 4.3.2-1 summarizes these results for each zone of the confined flow system. Figures A-1 through A-3 are point plots showing the distribution of dieldrin in the confined flow system.

Dieldrin contamination in the confined flow system occurred predominantly beneath areas of unconfined flow system contamination. The highest fall 1988 detection was 7.40 µg/l at Well 26142 (zone 3). This well is located in east-central Section 26, where unconfined flow system contamination existed in the Basin F East Pathway. The deepest fall 1988 dieldrin detection occurred at Well 36148 (zone 1). This well yielded 0.0535 µg/l of dieldrin from a screened interval 93 to 163 feet below ground surface. The well is located in northwest Section 36.

4.3.2.3 Winter 87/88 and FY89 Comparisons. Dieldrin was detected in 136 of 325 samples from the unconfined flow system in winter 1987/88, compared to 124 of 321 samples analyzed during the fall of 1988. Data from FY89 provide a more complete understanding of the distribution of dieldrin in the unconfined flow system than was available in the FY88 Annual

Report. In particular, the extent of dieldrin in the South Plants, Basin A, and Sections 34 and 35 are better defined due to an increased sampling density in these areas during FY89. Plume configurations are similar in the areas of the NBCS and NWBCS. Wells where dieldrin concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Dieldrin was detected in the confined flow system in 19 of 135 samples collected during the winter of 1987/88 compared to 17 of 166 samples collected during fall 1988. Table 4.3.2-1 summarizes the winter 1987/88 and fall 1988 results for each zone of the confined flow system. Areas in which the presence of dieldrin was further substantiated include the Basin A Neck, Basin C, and Basin F areas where dieldrin was detected in both winter 1987/88 and fall 1988. Dieldrin was detected more frequently in fall 1988 in the South Plants and less frequently at the NBCS than in winter 1987/88. Due to the general low hydraulic conductivity and large heterogeneity of the Denver aquifer, substantial data variability is likely to occur in any single sample period. Data interpretation based on a single sample period may not be effective in recognizing anomalous data, therefore, variations such as those noted in the South Plants should be considered appropriately.

4.3.3 Endrin

Analyses for endrin were performed on 455 ground-water samples collected during the fall of 1988. Concentrations ranging from 0.0510 to 14.0 $\mu\text{g/l}$ were detected in 78 of the 455 samples analyzed. The CRL for the fall of 1988 was 0.0500 $\mu\text{g/l}$. The distribution of endrin in the unconfined flow system is illustrated in Figure 4.3.3-1. Endrin was detected in the confined flow system within zones A, 1, 2, 3, and 5 during the fall of 1988. Endrin detections for FY89 are summarized in Table 4.3.3-1.

4.3.3.1 Unconfined Flow System. Ground-water samples from 298 wells completed in the unconfined flow system were analyzed for endrin during the fall of 1988. Endrin concentrations ranging from 0.0515 to 14.0 $\mu\text{g/l}$ were detected in 68 of these samples. Figure 4.3.3-1 illustrates unconfined flow system plumes interpreted from the fall 1988 data. Endrin plumes were present in the South Plants - Basin A-Basin A Neck Pathways, and the Basin F and Basin F West Pathways. Endrin also was present along the First Creek Off-Post Pathway and downgradient of the NWBCS.

The fall 1988 data indicated that endrin formed a continuous plume originating in the South Plants and extending along the Basin A and Basin A Neck Pathways. The plume appeared to end upgradient of the NWBCS in northern Section 27. Endrin concentrations within the South Plants-

Table 4.3.2-2 Wells with Considerable Variation in Analyte Concentrations Between Sampling Periods

Dieldrin

01517, 23053, 24201, 26083, 26142*, 27016, 37355

Endrin

01516, 23049, 23053, 23095, 23108, 23223, 23237, 24201, 26015, 26019, 26041, 26083, 26142*, 35018, 36110*, 36182*, 37313, 37343, 37396

Dithiane/Oxathiane

01014, 23223, 26069*, 26085, 26096*, 26127, 26157, 35016*, 35065, 36168

Benzothiazole

01014, 01517, 26041, 26066*, 26085, 26127, 35065, 36001, 36094, 36168

Organosulfur Compounds

01014, 01517, 02047*, 19015*, 23180*, 26015, 26066*, 26127, 35016*, 35065, 36181, 37365*

Volatile Aromatics

01511, 01516, 03002, 03012*, 09002, 09014, 23095, 23179, 24101, 26148, 27003, 33030, 33075, 35078*, 36110*, 36169, 36170*, 36171*, 37316*

Benzene

01007, 01071*, 02031*, 23151, 23196, 25016*, 26020, 33032*, 36076, 36171*, 37317*

Chlorobenzene

01071*, 03523, 04010, 04038, 04039, 04046, 09006, 09011, 23049, 23053, 23106, 23197, 24181, 24200, 26150*, 26155*, 27003, 27064, 27086, 33032*, 33077, 35065, 35079, 35081*, 36075, 36170*, 36179*, 36180, 36183*, 37317*, 37318*, 37322*, 37331, 37334, 37335, 37397

Volatile Organohalogens

01048*, 02044*, 26041, 27055*, 36182*

Chloroform

01517, 01525, 02039*, 02044*, 02050, 03004*, 03011, 09005, 22033, 23095, 23180*, 23188, 23191, 23204, 23239, 24018, 24081, 24101, 26017, 26019, 26020, 26089*, 26142, 27016, 27055*, 27064, 27072, 33032*, 33030, 35089*, 36117*, 36169, 36170*, 36177, 36182*, 37378, 37389, 37391

Trichloroethene (TRCLE)

04048, 09002, 36001, 37317*

Tetrachloroethene (TCLEE)

26148, 28027, 33509, 37378, 37391

Dibromochloropropane (DBCP)

01510, 01517, 01525, 25047, 25048, 26113*, 26133, 36001, 37367, 37391

Dicyclopentadiene (DCPD)

01070, 01525, 23024, 24043, 25013*, 28025*, 35084*, 37317*, 37365*, 37381

* Confined flow system well.

Table 4.3.2-2 Wells with Considerable Variation in Analyte Concentrations Between Sampling Periods (continued)

Diisopropylmethyl phosphonate (DIMP)

23239, 23241, 26015, 26041, 26148, 26066*, 26090*, 26129*, 26157, 35020, 36084, 37312, 37318*, 37339, 37371, 37381

Parathion

01525, 04020, 23220, 23239, 26072*, 26083, 26133, 26146*, 26148, 26157, 36001, 36181

Cyanide

01071*, 26028, 28002, 35078*, 36171*, 36179*, 36182*

Fluoride

26067*

Arsenic

03003*, 23142, 23191, 23192*, 23239, 23241, 26017, 26041, 26066*, 26073, 26129*, 26149*, 28028*, 36114*, 36177, 36180

Trace Metals

35087

* Confined flow system well.

Table 4.3.3-1 Endrin Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	298	68	0.0515 - 14.0
	Winter 89	25	21	0.0519 - 1.10
	Spring 89	257	43	0.0544 - 9.40
	Summer 89	34	28	0.0551 - 3.80
	Winter 87/88	325	75	0.057 - 63.0
<u>Confined Flow System Zone</u>				
B	Fall 88	1	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	30	3	0.0579 - 4.20
	Winter 89	0	0	
	Spring 89	29	4	0.0508 - 22.0
	Summer 89	0	0	
	Winter 87/88	28	1	0.068
IU	Fall 88	20	0	
	Winter 89	0	0	
	Spring 89	18	3	0.102 - 0.192
	Summer 89	0	0	
	Winter 87/88	12	2	0.078 - 0.101
1	Fall 88	22	2	0.216 - 0.403
	Winter 89	6	1	0.0606
	Spring 89	16	0	
	Summer 89	6	1	0.0624
	Winter 87/88	16	0	
2	Fall 88	37	3	0.0684 - 0.470
	Winter 89	11	1	0.0519
	Spring 89	24	2	0.0553 - 0.0902
	Summer 89	11	1	0.0525
	Winter 87/88	26	1	0.066
3	Fall 88	18	1	1.20
	Winter 89	3	1	0.0634
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	18	1	0.080

Table 4.3.3-1

Endrin Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	17	0	
	Winter 89	0	0	
	Spring 89	16	1	0.125
	Summer 89	1	0	
	Winter 87/88	18	1	0.070
5	Fall 88	8	1	0.0510
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	10	0	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	

Total Confined Flow System

Fall 88	157	10	0.051 - 4.20
Winter 89	21	3	0.0519 - 0.0634
Spring 89	130	10	0.0508 - 22.0
Summer 89	21	2	0.0525 - 0.0624
Winter 87/88	135	6	0.066 - 0.080

Explanation:	Certified Reporting Limits (µg/l)
Fall 88 (Fall 1988 annual sampling event)	0.0500
Winter 89 (Winter 1989 quarterly Basin F sampling event)	0.0500
Spring 89 (Spring 1989 semi-annual sampling event)	0.0500/0.0600
Summer 89 (Summer 1989 quarterly Basin F sampling event)	0.0500
Winter 87/88 (Annual event including the TMP/Task 25/Task 44)	0.050/0.060/0.052

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

Basin A-Basin A Neck plume ranged from 0.0755 to 14.0 $\mu\text{g/l}$, with the highest concentration occurring at Well 36001. Concentrations in excess of 1.00 $\mu\text{g/l}$ within the plume occupied a rather restricted area within the South Plants and downgradient of the lime settling ponds in southwest Section 36. Endrin was not detected in Well 35018, located in the Basin A Neck Pathway. Because endrin was detected in both spring 1988 and spring 1989 at concentrations of 4.20 and 0.130 $\mu\text{g/l}$, respectively, the fall 1988 data may be anomalous.

Endrin detected in the Basin F Pathway ranged in concentration from 0.333 to 4.10 $\mu\text{g/l}$. Endrin formed a continuous plume originating in the Basin F area and extending downgradient to the NBCS. Endrin also occupied the Basin F West Pathway from about 1000 feet west of Basin F to the NWBCS.

Downgradient of the NBCS, endrin was detected in seven wells within a plume that extended a short distance along the First Creek Off-Post Pathway. The greatest endrin concentration in this plume was 0.880 $\mu\text{g/l}$ at Well 37312. Isolated endrin detections occurred on-post in Sections 1, 3, 23, 24, 25, 27, and 34, and off-post along the Northwest and Northern Off-post Pathways.

4.3.3.2 Confined Flow System. Endrin was detected in 10 of 157 confined flow system samples analyzed during the fall of 1988. Concentrations ranging from 0.0510 to 4.20 $\mu\text{g/l}$ were reported for samples from wells completed in zones A, 1, 2, 3, and 5. Analytical results from individual zones of the confined flow system for FY89 are summarized in Table 4.3.3-1. Point plots of the fall 1988 results are presented in Figures A-4 through A-6.

The greatest depth at which endrin was detected during the fall of 1988 was in Well 36148 (zone 1). An endrin concentration of 0.403 $\mu\text{g/l}$ was obtained from the well screened from 93 to 163 feet below ground surface. The lowest stratigraphic zone containing endrin was zone 5 at Well 22031. An endrin concentration of 0.0510 $\mu\text{g/l}$ was measured at this well located up-gradient of the NWBCS and screened from 124 to 134 feet below ground surface. Endrin contamination in the confined flow system occurred, for the most part, beneath areas of unconfined flow system contamination.

4.3.3.3 Winter 87/88 and FY89 Comparison. Endrin was detected in the unconfined flow system in 75 of 325 samples for the winter of 1987/88 and in 68 of 298 samples for the fall of 1988. Comparison of data from winter 1987/88 and FY89 shows some differences in the extent of endrin. Endrin distribution during the fall of 1988 appeared to be more extensive along the Basin A and Basin A Neck pathways than during the winter of 1987/88. An increased sampling density for FY89 and endrin detections in several wells for the fall of 1988, but not the winter of

1987/88, were the reasons for this change. In general, endrin distribution was similar downgradient of the NBCS and NWBCS for the two sampling programs. Wells where endrin concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

During the winter of 1987/88 sampling, endrin was detected in 6 of 135 samples in the confined flow system compared to 10 of 157 samples for fall 1988. Table 4.3.3-1 summarizes the winter 1987/88 and fall 1988 results for each zone of the confined flow system. Endrin was detected in Section 26 and the Basin A Neck area in both sampling rounds. Detections of endrin were noted in the South Plants area during fall 1988 only. The Denver aquifer generally has low hydraulic conductivity and is very heterogeneous. This yields substantial data variability in any single sampling period and so differences should be appropriately considered.

4.3.4 Dithiane and Oxathiane

Dithiane and oxathiane analyses were performed on 487 ground-water samples collected during the fall of 1988. The dithiane and oxathiane CRLs were 1.34 and 2.38 $\mu\text{g/l}$, respectively. Detections of dithiane and oxathiane are presented by summing the concentration of each and presenting the composite data. Dithiane and oxathiane are mustard-agent degradation products and have similar properties that influence their transport; therefore, they are grouped together. Composite detections ranged from 1.75 to 5,650 $\mu\text{g/l}$ in 54 of the samples analyzed. Dithiane and oxathiane were not detected in the remaining 433 samples. Dithiane/oxathiane was above CRLs in confined flow system zones 1U, 1 and 2. Dithiane/oxathiane analytical results for FY89 are summarized in Table 4.3.4-1.

4.3.4.1 Unconfined Flow System. During the fall of 1988, 321 ground-water samples from the unconfined flow system were analyzed for dithiane/oxathiane. In 48 samples, dithiane/oxathiane concentrations ranged from 1.75 to 5,650 $\mu\text{g/l}$. The highest CRL for the samples analyzed (2.38 $\mu\text{g/l}$) was used as the lowest contour value in constructing the contaminant plume map shown in Figure 4.3.4-1.

A continuous dithiane/oxathiane plume is interpreted to extend from northwestern Section 1 via the South Plants-Basin A, Basin A Neck, and Basin F Pathways to just south of the NBCS. The continuity of the plume from the Basin A area to Basin F was previously interpreted from historical data; however, wells added to the sampling network in the Basin A Neck area in the fall of 1988 confirm the continuity of the plume. Fall 1988 data also indicated the presence of

Table 4.3.4-1

Dithiane/Oxathiane Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
<u>Unconfined Flow System</u>				
	Fall 88	321	48	1.75 - 5650
	Winter 89	25	17	3.34 - 185
	Spring 89	258	44	1.51 - 1700
	Summer 89	34	26	1.93 - 96.3
	Winter 87/88	290	63	1.90 - 4320
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	0	
	Winter 89	0	0	
	Spring 89	29	0	
	Summer 89	0	0	
	Winter 87/88	28	3	1.34 - 341
IU	Fall 88	20	2	96.0 - 191
	Winter 89	0	0	
	Spring 89	18	2	9.38 - 42.7
	Summer 89	0	0	
	Winter 87/88	12	2	88.0 - 338
1	Fall 88	22	2	26.3 - 289
	Winter 89	6	2	37.0 - 174
	Spring 89	16	2	14.0 - 211
	Summer 89	6	2	29.3 - 105
	Winter 87/88	16	2	20.1 - 141
2	Fall 88	37	2	255 - 590
	Winter 89	11	1	243
	Spring 89	24	2	22.6 - 35.9
	Summer 89	11	1	106
	Winter 87/88	26	2	27.1 - >37.6
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	1	40.7
	Summer 89	3	0	
	Winter 87/88	18	0	

Table 4.3.4-1

Diathiane/Oxathiane Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	0	
	Winter 87/88	17	0	
5	Fall 88	9	0	
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	9	1	4.98
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	

Total Confined Flow System

Fall 88	166	6	26.3 - 590
Winter 89	21	3	37.0 - 243
Spring 89	130	7	9.38 - 211
Summer 89	21	3	29.3 - 106
Winter 87/88	134	10	1.34 - 341

Explanation:		Lowest Certified Reporting Limits of Summed Compounds ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	1.34
Winter 89	(Winter 1989 quarterly Basin F sampling event)	1.34
Spring 89	(Spring 1989 semi-annual sampling event)	1.34/1.35
Summer 89	(Summer 1989 quarterly Basin F sampling event)	1.34
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	1.34/1.35/1.10

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

dithiane/oxathiane in two off-post wells in Section 14 near the convergence of First Creek and the O'Brian Canal.

The farthest upgradient detection of dithiane/oxathiane occurred in the South Plants area. The plume extends northward into the Basin A Neck and northwest into Section 26 and the Basin F Pathway. The highest detected concentration of dithiane/oxathiane was on the north side of Basin A in Well 36177 (5,650 $\mu\text{g/l}$). The highest dithiane/oxathiane concentration in the Basin A Neck Pathway was 913 $\mu\text{g/l}$ in Well 35079, the highest concentration in the Basin F East-Basin F Pathway was 344 $\mu\text{g/l}$ (Well 23053), and the highest concentration in the South Plants Pathway was 140 $\mu\text{g/l}$ in Well 01020. Dithiane/oxathiane was not detected in Well 36168 in the South Plants Pathway and in Well 35065 in the Basin A Neck Pathway in the fall of 1988. However, these results are probably anomalous because previous and subsequent sampling indicated that dithiane/oxathiane concentrations were above the CRL in these wells, and the wells lie within the center of the plume.

Only two detections of dithiane/oxathiane occurred outside of the plume described above. Concentrations of 1.75 $\mu\text{g/l}$ in Well 37343 and 16.4 $\mu\text{g/l}$ in Well 37396 were detected off-post along the First Creek Off-Post Pathway.

4.3.4.2 Confined Flow System. Analyses for dithiane/oxathiane were performed on 166 ground-water samples collected during the fall of 1988 from the confined flow system. Analytical results for the fall 1988 sampling are summarized in Table 4.3.4-1. Point plots of results from the fall 1988 sampling of the confined flow system are presented in Figures A-7 through A-8.

Dithiane/oxathiane concentrations above CRLs ranging from 26.3 to 590 $\mu\text{g/l}$ were detected in 6 samples analyzed from Denver Formation zones 1U, 1 and 2. Wells with elevated concentrations of dithiane/oxathiane were located in Section 26 and Section 35 between Basin A and Basin F. The highest detection occurred in Well 26069 which is completed in zone 2 to a depth of 79.5 feet. The deepest detection (255 $\mu\text{g/l}$) was also in zone 2 (Well 26129), 100 ft below ground level.

Contamination in the confined flow system can be correlated with plumes in the overlying unconfined flow system. For example, the highest concentrations in the unconfined flow system occur in the northern part of Basin A and appear to be associated with confined flow system detections to the northwest in zones 1U, 1, and 2.

4.3.4.3 Winter 87/88 and FY89 Comparison. Detections of dithiane/oxathiane occurred in the unconfined flow system in 63 of 290 wells for winter 1987/88 compared to 48 of 321 wells for fall

1988. Plumes for the two periods were similar in configuration and concentration on RMA. A greater sampling density in fall 1988 in sections 26 and 35 allowed better definition of the plume in the Basin A Neck area. Plume configurations for the two sampling periods differ north of the NBCS. In the winter of 1987/88, the plume extended from the boundary of RMA to the O'Brian Canal. During fall 1988 only detections near O'Brian Canal were reported. Wells where dithiane/oxathiane concentrations varied considerably from previous or subsequent sampling records are listed in Table 4.3.2-2.

During the winter of 1987/88, dithiane/oxathiane was detected in 10 of 134 confined flow samples compared to 6 of 166 for the fall of 1988. Table 4.3.4-1 summarizes the results for each of the confined zones. The fall 1988 data corroborate the detections of dithiane/oxathiane found in Sections 25 and 26 during sampling in winter 1987/88. Dithiane/oxathiane were detected in Basin A and the South Lakes areas only during the winter 1987/88 sampling round. Due to the heterogeneity and low hydraulic conductivity of the Denver aquifer, substantial variability may occur in any single sampling period. This should be realized when interpreting dithiane/oxathiane detections occurring during only one sampling period. The primary difference between the two periods, is related to changes in well the network.

4.3.5 Benzothiazole

Analyses for benzothiazole were conducted on 487 ground-water samples obtained during the fall of 1988. The CRL was 5.00 $\mu\text{g/l}$ for the fall of 1988. Benzothiazole concentrations ranged from 6.62 to 820 $\mu\text{g/l}$ in 14 samples, but was not detected in the remaining 473 samples. Benzothiazole was not detected in any of the 166 samples analyzed from the confined flow system. The distribution of benzothiazole in the unconfined flow system for the fall 1988 sampling quarter is illustrated in Figure 4.3.5-1. Detections in the unconfined flow system for FY89 are summarized in Table 4.3.5-1.

4.3.5.1 Unconfined Flow System. Benzothiazole plumes are located in the South Plants-Basin A and Basin F Pathways. The benzothiazole plume in the South Plants area extends north from the northwest portion of Section 1 to Section 36. Concentrations in the wells near the north end of the plume (Wells 36001 and 36168) were 6.62 and 9.66 $\mu\text{g/l}$ in the fall of 1988; however, benzothiazole was not detected previous or subsequent samples. Therefore, the northern limit of the plume is Well 01525. The highest concentration of benzothiazole was in the South Plants area in Well 01525.

Table 4.3.5-1

Benzothiazole Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
<u>Unconfined Flow System</u>				
	Fall 88	321	14	6.62 - 820
	Winter 89	25	5	5.54 - 9.45
	Spring 89	258	9	1.28 - 15.1
	Summer 89	34	10	5.43 - 21.5
	Winter 87/88	290	27	2.07 - 370
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	0	
	Winter 89	0	0	
	Spring 89	29	0	
	Summer 89	0	0	
	Winter 87/88	28	2	6.49 - 48.4
IU	Fall 88	20	0	
	Winter 89	0	0	
	Spring 89	18	0	
	Summer 89	0	0	
	Winter 87/88	12	1	14.3
1	Fall 88	22	0	
	Winter 89	6	0	
	Spring 89	16	0	
	Summer 89	6	1	10.6
	Winter 87/88	16	1	13.5
2	Fall 88	37	0	
	Winter 89	11	0	
	Spring 89	24	0	
	Summer 89	11	0	
	Winter 87/88	26	4	6.00 - 8.50
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	18	0	

Table 4.3.5-1

Benzothiazole Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	12.4
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	0	
	Winter 87/88	17	1	
5	Fall 88	9	0	1.99
	Winter 89	0	0	
	Spring 89	16	0	
	Summer 89	0	0	
	Winter 87/88	9	1	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	

Total Confined Flow System

Fall 88	166	0	
Winter 89	21	0	
Spring 89	130	0	
Summer 89	21	1	10.6
Winter 87/88	134	10	1.99 - 48.4

Explanation:		Certified Reporting Limits ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	5.00
Winter 89	(Winter 1989 quarterly Basin F sampling event)	5.00
Spring 89	(Spring 1989 semi-annual sampling event)	1.14/5.00
Summer 89	(Summer 1989 quarterly Basin F sampling event)	5.00
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	5.00/1.14

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

The Basin F plume extended from the Basin F area downgradient along the Basin F Pathway about 3,000 ft. Reported concentrations at wells within the plume ranged from 9.05 to 41.9 µg/l. The highest concentration was reported in Well 26041, near the southern or upgradient end of the plume.

Benzothiazole was detected in four isolated wells at concentrations ranging from 7.76 to 430 µg/l. Benzothiazole was also detected along the Basin F East Pathway, on the northeast side of Basin A, and southwest of Basin F.

4.3.5.2 Confined Flow System. During the fall of 1988, 166 ground-water samples were collected from the confined flow system and analyzed for benzothiazole. Of these, no sample had a detectable concentration of benzothiazole.

4.3.5.3 Winter 1987/88 and FY89 Comparison. Benzothiazole was detected in 27 of 290 samples in the unconfined flow system in winter 1987/88, while 14 of 321 samples had detections in the fall of 1988. In both the winter of 1987/88 and fall of 1988 benzothiazole was detected in the South Plants - Basin A, and Basin F pathways. However, the plumes were less extensive in the fall, 1988. Wells where benzothiazole concentrations varied considerably from previous or subsequent sampling periods are listed in Table 4.3.3-2.

Benzothiazole was not detected in any of the 166 samples from the confined flow system in the fall of 1988, including 9 of the 10 wells with detectable concentrations in winter 1987/88. The data are summarized in Table 4.3.5-1. This illustrates the variability of the Denver aquifer system. Thus, data interpretation based on a single sample period may not be effective in recognizing anomalous data. Variations in benzothiazole concentrations should be considered appropriately.

4.3.6 Organosulfur Compounds

Analyses for one or more of the organosulfur compounds *p*-chlorophenylmethyl sulfide, sulfoxide and sulfone were performed on 487 ground-water samples obtained during the fall of 1988. The CRLs for the fall 1988 sampling round ranged from 5.69 to 11.5 µg/l. Organosulfur compound concentrations above CRLs ranging from 7.96 µg/l to 9440 µg/l were detected in 53 of the samples analyzed. The balance of the samples did not contain detectable concentrations of organosulfur compounds. Organosulfur compounds were detected above CRLs in the confined flow system in four samples from zones A, 1U, 1 and 2. The distribution of organosulfur compounds in the unconfined flow system for the fall 1988 sampling is presented in Figure 4.3.6-1. Detections of

Table 4.3.6-1

Summed Organosulfur Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	321	49	7.96 - 9440
	Winter 89	25	16	11.4 - 1300
	Spring 89	258	44	2.87 - 13,700
	Summer 89	34	27	7.07 - 2470
	Winter 87/88	290	100	2.54 - 6320
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	1	21.5
A	Fall 88	35	1	30.3
	Winter 89	0	0	
	Spring 89	29	2	3.44 - 6.30
	Summer 89	0	0	
	Winter 87/88	28	3	6.39 - 79.6
IU	Fall 88	20	1	84.3
	Winter 89	0	0	
	Spring 89	18	1	33.9
	Summer 89	0	0	
	Winter 87/88	12	1	46.9
1	Fall 88	22	1	84.7
	Winter 89	6	0	
	Spring 89	16	0	
	Summer 89	6	1	19.0
	Winter 87/88	16	0	
2	Fall 88	37	1	42.8
	Winter 89	11	0	
	Spring 89	24	1	13.7
	Summer 89	11	0	
	Winter 87/88	26	2	11.5 - 32.8
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	18	3	7.93 - 10.3

Table 4.3.6-1

Summed Organosulfur Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	1	52.5
	Summer 89	1	0	
	Winter 87/88	17	1	62.9
5	Fall 88	9	0	
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	9	1	3.73
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	8.88
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	6.80

Total Confined Flow System

Fall 88	166	4	30.3 - 84.7
Winter 89	21	0	
Spring 89	130	5	3.44 - 52.5
Summer 89	21	1	19.0
Winter 87/88	134	15	3.73 - 79.6

Explanation:		Lowest Certified Reporting Limits of Summed Compounds ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	5.69
Winter 89	(Winter 1989 quarterly Basin F sampling event)	5.69
Spring 89	(Spring 1989 semi-annual sampling event)	1.08/5.69
Summer 89	(Summer 1989 quarterly Basin F sampling event)	5.69
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	5.69/1.08

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

the organosulfur compounds in both the unconfined and confined flow systems for FY89 are summarized in Table 4.3.6-1.

In summing the organosulfur compounds, the resulting distribution maps include compounds that may have originated from different sources. Consequently, the analyte-specific plume maps of constituents within this group are considered more accurate than the summed organosulfur maps for depicting and interpreting ground-water quality degradation.

4.3.6.1 Unconfined Flow System. Ground-water samples from 321 unconfined wells were analyzed for organosulfur compounds. Of these, 49 contained concentrations of organosulfur compounds above CRLs, with concentrations ranging from 7.96 to 9440 $\mu\text{g/l}$. The highest CRL for the organosulfur compounds (11.5 $\mu\text{g/l}$ for p-chlorophenylmethyl sulfoxide) was used as the lowest contour value in constructing the contaminant distribution map shown in Figure 4.3.6-1.

Organosulfur compounds were detected in the South Plants-Basin A - A Neck Pathway, the Basin F Pathway, and the Northern Off-Post Pathway. One isolated detection was reported in Section 26, along the Basin F East Pathway.

The plume in the South Plants-Basin A - A Neck Pathway trends primarily north from an area of high concentration located in northwestern Section 1. The area of high concentration coincides with the South Plants ground-water mound. The plume trends northwest through the Basin A Neck pathway to the southcentral portion of Section 26. Summed concentrations detected at wells within the plume ranged from 14.3 to 9440 $\mu\text{g/l}$, with the highest detection reported in Well 01525 located in northwestern Section 1. A discrepancy in reported values within the plume was observed in Wells 36001 and 36181 located adjacent to each other in the southwest corner of Section 36. The concentration in Well 36001 was 171 $\mu\text{g/l}$ and below CRL in Well 36181. GC/MS data indicated the presence of organosulfur compounds in Well 36181, which suggests that organosulfur compounds are indeed present and the reported value in Well 36181 is probably not representative of the actual distribution of organosulfur compounds in this area.

The Basin F plume trends north-northeast along the Basin F Pathway to the NBCS. Total organosulfur concentrations reported within this plume ranged from 14.8 to 2160 $\mu\text{g/l}$. The highest concentration was in Well 23053 located near the eastern edge of Section 23. A second area of high concentration within the plume is located just northeast of Basin F, where a concentration of 1470 $\mu\text{g/l}$ was reported in Well 26133.

A plume downgradient of the NBCS extends along the Northern Off-Post Pathway. Total organosulfur compounds detected in wells within this plume ranged from 34.6 to 100 µg/l. The highest concentration was detected in Well 37344 in Section 12, near the leading edge of the plume.

4.3.6.2 Confined Flow System. Analyses for the organosulfur compounds, p-chlorophenylmethyl sulfide, sulfoxide and sulfone, were performed on 166 ground-water samples obtained from the confined flow system during the fall of 1988. Concentrations ranging from 30.3 µg/l to 84.7 µg/l were detected in four of the samples analyzed. Zones A, 1U, 1, and 2 each had one detection above CRLs. Point plots of the data are shown in Figures A-9 through A-11. Fall 1988 analytical results are summarized in Table 4.3.6-1.

The maximum concentration and the deepest detection was in zone 1 at a depth of 163 ft in Well 36148. A similar concentration (84.3 µg/l) was detected in zone 1U at a depth of 52.7 ft in Well 26096. Both of these wells are located in the vicinity of the Basin A Neck. Two other detections occurred northeast of Basin F, directly below the Basin F plume in the unconfined flow system, and in Section 2, west of organosulfur detections in the South Plants area in the unconfined flow system.

4.3.6.3 Winter 1987/88 and FY89 Comparison. Organosulfur compounds were detected in 100 of 290 wells sampled in the unconfined flow system during winter 1987/88 compared to 49 of 321 samples in fall 1988. The distribution of organosulfur compounds was generally similar during both sampling periods; however, contamination in the South Lakes Pathway was only identified in the winter of 1987/88. Within the Basin A Neck the extent of organosulfur compounds are better defined due to increased sampling density. Organosulfur compounds downgradient of the NBCS were detected during both sampling periods however, detections in the First Creek Off-Post Pathway occurred only during winter 1987/88. Wells with variable concentrations of organosulfurs are listed in Table 4.3.2-2.

During the winter of 1987/88, organosulfur compounds were detected in 14 of 132 samples in confined flow zones. This compares to 4 detections in 166 samples in the fall of 1988. Table 4.3.6-1 summarizes the results for each of the confined zones. Detections in the confined flow system in the winter of 1987/88 were more widespread laterally and vertically than in the fall of 1988. As previously stated, the Denver aquifer is very heterogeneous and substantial data variability is likely to occur in any single sampling period. Therefore, variations such as those noted in winter 1987/88 should be considered appropriately.

4.3.7 Volatile Aromatics

The volatile aromatics group includes benzene, chlorobenzene, toluene, ethylbenzene and the xylene isomers. Chlorobenzene is also an organohalogen, but because of its aromatic structure it is included in this section. Chlorobenzene and benzene are discussed individually later in this section. Summed volatile aromatics were obtained by adding the concentrations of compounds in this group.

Volatile aromatics analyses were performed on 487 ground-water samples obtained during the fall 1988 annual monitoring. The CRLs for the fall 1988 CMP ranged from 0.820 to 1.47 $\mu\text{g/l}$. Concentrations of summed volatile aromatic compounds above CRLs, ranged from 0.991 to 240,000 $\mu\text{g/l}$ in 104 of these samples. Volatile aromatics were not detected in the balance of the samples. Detections were reported in the unconfined flow system and confined flow system (zones A, 1U, 1, 2, 3 and 5). The distribution of total volatile aromatic compounds in RMA ground water for FY89 is summarized in Table 4.3.7-1.

In summing the volatile aromatics, the resulting distribution maps include compounds that may have originated from different sources. Consequently, the analyte-specific plume maps of constituents within this group are considered more accurate than the summed volatile aromatic maps for depicting and interpreting ground-water quality degradation.

4.3.7.1 Unconfined Flow System. A total of 322 ground-water samples from the unconfined flow system were analyzed for volatile aromatics. Of these, 71 had concentrations above the CRL ranging from 0.991 to 240,000 $\mu\text{g/l}$.

The highest CRL (1.47 $\mu\text{g/l}$) was used as the lowest contour interval to construct the plume map shown in Figure 4.3.7-1. Plumes of volatile aromatics with concentrations above CRLs were present in the South Plants-Basin A-Basin A Neck Pathway, near the NWBCS, and in the Basin F and Northern Off-post Pathways.

There were two areas of high concentration within the South Plants-Basin A-Basin A Neck plume which extend north and southwest from the ground-water mound in Section 1. Ground water flows radially away from the ground-water mound, to the north beneath Basin A, and south and west in Sections 1 and 2. Reported concentrations ranged from 0.991 to 240,000 $\mu\text{g/l}$, with the highest concentration occurring in Well 01014. The plume extended north through the Basin A Pathway and terminated near the southwest corner of Section 26.

Table 4.3.7-1

Summed Volatile Aromatic Compounds Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	71	0.991 - 240,000
	Winter 89	25	13	2.47 - 394
	Spring 89	257	112	0.698 - 227,000
	Summer 89	34	16	1.22 - 1525
	Winter 87/88	325	126	0.622 - 680,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	12	1.39 - 158,000
	Winter 89	0	0	
	Spring 89	29	6	1.70 - 241,000
	Summer 89	0	0	
	Winter 87/88	28	11	1.58 - >450
IU	Fall 88	20	6	1.78 - 178
	Winter 89	0	0	
	Spring 89	16	9	1.79 - 191
	Summer 89	0	0	
	Winter 87/88	12	4	3.32 - 90.8
1	Fall 88	22	6	2.24 - 168
	Winter 89	6	3	5.44 - 146
	Spring 89	16	8	1.06 - 234
	Summer 89	6	2	3.81 - 10.7
	Winter 87/88	16	5	1.11 - 11.6
2	Fall 88	36	6	1.15 - 20.0
	Winter 89	11	3	6.93 - 23.5
	Spring 89	24	13	1.90 - 20.9
	Summer 89	11	3	1.23 - 9.89
	Winter 87/88	27	8	1.65 - 207
3	Fall 88	19	1	3.85
	Winter 89	3	0	
	Spring 89	17	8	1.47 - 13.0
	Summer 89	3	0	
	Winter 87/88	18	8	2.21 - >93.9

Table 4.3.7-1

Summed Volatile Aromatic Compounds Analytical Results Summary
(Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	9	1.35 - 13.0
	Summer 89	1	0	
	Winter 87/88	19	9	1.11 - >q41
5	Fall 88	9	2	10.4 - 66.0
	Winter 89	0	0	
	Spring 89	6	3	4.32 - 51.5
	Summer 89	0	0	
	Winter 87/88	10	6	5.46 - 50.5
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	1	1.51
	Summer 89	0	0	
	Winter 87/88	2	1	12.0
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	323

Total Confined Flow System

Fall 88	165	33	1.15 - 158,000
Winter 89	21	6	5.44 - 146
Spring 89	130	57	1.06 - 241,000
Summer 89	21	5	1.23 - 10.7
Winter 87/88	138	54	1.11 - >450

Explanation:		Lowest Certified Reporting Limits of Summed Compounds ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	0.820
Winter 89	(Winter 1989 quarterly Basin F sampling event)	0.820
Spring 89	(Spring 1989 semi-annual sampling event)	0.620/0.820
Summer 89	(Summer 1989 quarterly Basin F sampling event)	0.8280
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	0.820/0.620/0.580

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

Volatile aromatics also have been detected near the NWBCS. Two small plumes were present northwest of the Basin F Northwest, and Basin A Neck Pathways in Sections 22 and 27, respectively. Detected concentrations ranged from 1.69 to 2.52 $\mu\text{g/l}$ in Section 22 and from 1.77 to 257 $\mu\text{g/l}$ in Section 27.

The Basin F plume extended from the Basin F area northeast along the Basin F Pathway to the NBCS where it extended laterally along the boundary system. Volatile aromatic compounds have also been detected in the southern portion of Section 13. Detected concentrations within the on-post plume range from 1.93 to 219 $\mu\text{g/l}$ (Well 26148). The maximum concentration was detected near the northeast corner of Basin F.

Isolated detections ranged in concentration from 2.05 to 2.14 $\mu\text{g/l}$ in two off-post wells and from 1.05 to 142 $\mu\text{g/l}$ in 15 on-post wells. The two highest concentrations, 74.8 and 142 $\mu\text{g/l}$, were detected in Section 9 in the Western Tier area.

4.3.7.2 Confined Flow System. Total volatile aromatic analyses were performed on 165 samples, with 33 detections ranging from 1.15 to 158,000 $\mu\text{g/l}$. Benzene and chlorobenzene are the most frequently detected compounds in the total volatile aromatic group. The majority of above-CRL reports were in samples from Denver Formation zones A, 1U, 1 and 2. Zone 5 had two above-CRL detections, zone 3 had only one above-CRL detection, and zones B, 4, 6 and 7 had no detections. Analytical results for the confined flow system from fall 1988, winter 1989, spring 1989, and summer 1989 sampling periods are summarized in Table 4.3.7-1. Point plots from the fall 1988 sampling period are presented in Figures A-12 through A-14.

In general, volatile organics in the confined flow system can be associated with contamination in the overlying unconfined flow system. In several cases, concentrations in the confined flow system were similar to those in the unconfined flow system directly above it. The most notable example of increasing concentration in deeper zones occurred in the South Plants-Basin A-Basin A Neck area. A concentration of 158,000 $\mu\text{g/l}$ was detected near the southwest corner of Section 36 in Well 36182. This well is completed in zone A, directly below water in the unconfined flow system with a concentration of 108,000 $\mu\text{g/l}$. In zones 1U, 1 and 2, detections primarily occurred in the area northwest of Basin A to the southwest end of the Basin F plume. Detections in zones 3 and 5 were on-post near the northern and northwest boundaries of RMA. Toward the northwest boundary of RMA, the lower stratigraphic zones are progressively closer to the surface as higher (or younger) zones subcrop in a northwest direction and the wells typically are completed in the lower zones. Therefore, the distribution of some of these detections was due to the well network. The deepest detection of volatile aromatics during the fall of 1988 occurred in Well 36171 at a

concentration of 2.93 $\mu\text{g/l}$. This well is completed 173 ft below ground level in zone 1 and is located along the western edge of Basin A.

4.3.7.3 Winter 1987/88 and FY89 Comparison. Volatile aromatics were detected in 126 of 325 winter 1987/88 samples from the unconfined flow system compared to 71 of 323 samples in the fall of 1988. Although concentrations varied slightly, plume configurations in the South Plants - Basin A and Basin F areas are similar in fall 1988 and winter 1987/88. However, fall 1988 data show an extended plume through the Basin A Neck area due to the addition of new wells in the fall 1988 sampling period. Plume configurations at the boundary systems have changed between the two sampling periods. The winter 1987/88 data show a plume south of the NWBCS which extends off post through the Northwest Pathway. The fall 1988 data indicate that the plume is not present off-post. The winter 1987/88 data show plumes, at the eastern and western ends of the NBCS, both on- and off-post. The fall 1989 data show isolated detections of volatile aromatic compounds in these areas. In general, the extent of volatile aromatic compounds north of the NBCS is reduced relative to last year. Winter 1987/88 volatile aromatic plume in the RMA Western Tier is not supported by fall 1988 data. Wells where volatile aromatic concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Volatile aromatic compounds were detected in 54 of 138 confined flow system samples in the winter of 1987/88 while 33 of 165 samples recorded detections in the fall of 1988. Table 4.3.7-1 summarizes the results for each of the confined zones. The distribution of summed volatile aromatic compounds in the confined flow system was generally similar during both sampling periods. However, there were more detections of volatile aromatics in the northern portion of RMA and off-post of the NBCS in winter 1987/88. No volatile aromatic compounds were detected in the confined flow system off-post in fall 1988. Interpretations of the data based on a single sampling period may not be effective in recognizing anomalous data, due to the variability of the Denver aquifer.

4.3.8 Benzene

Benzene analyses were conducted on 487 samples collected during the fall of 1988. The CRL value was 1.05 $\mu\text{g/l}$. Concentrations which exceeded the CRL ranged from 1.25 $\mu\text{g/l}$ to 240,000 $\mu\text{g/l}$ in 72 of these samples. Benzene was detected in zones A, 1U, 1, 2, 3 and 5 of the Denver Formation. Detections in both unconfined and confined flow systems in the fall of 1988 are summarized in Table 4.3.8-1.

Table 4.3.8-1

Benzene Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	49	1.25 - 240,000
	Winter 89	25	9	1.77 - 220
	Spring 89	257	51	1.41 - 220,000
	Summer 89	34	12	1.22 - 140
	Winter 87/88	301	48	2.00 - 680,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	10	1.39 - 47,000
	Winter 89	0	0	
	Spring 89	29	6	1.65 - 100,000
	Summer 89	0	0	
	Winter 87/88	26	3	1.79 - 250
IU	Fall 88	20	5	1.33 - 29.1
	Winter 89	0	0	
	Spring 89	18	5	1.97 - 17.6
	Summer 89	0	0	
	Winter 87/88	11	1	40.0
1	Fall 88	22	3	1.44 - 11.3
	Winter 89	6	1	9.50
	Spring 89	16	7	1.56 - 10.5
	Summer 89	6	0	
	Winter 87/88	15	1	11.6
2	Fall 88	36	2	1.71 - 20.0
	Winter 89	11	2	1.53 - 5.76
	Spring 89	24	8	1.90 - 6.41
	Summer 89	11	2	1.23 - 4.41
	Winter 87/88	24	5	2.21 - 37.5
3	Fall 88	19	1	3.85
	Winter 89	3	0	
	Spring 89	17	5	1.33 - 13.0
	Summer 89	3	0	
	Winter 87/88	18	4	2.21 - 13.7

Table 4.3.8-1

Benzene Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	3	1.35 - 3.80
	Summer 89	1	0	
	Winter 87/88	18	4	2.29 - 42.8
5	Fall 88	9	2	2.62 - 10.4
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	10	2	6.03 - 9.44
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	1	1.51
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	250

Total Confined Flow System

Fall 88	165	23	1.33 - 47,000
Winter 89	21	3	1.53 - 9.50
Spring 89	130	95	1.33 - 100,000
Summer 89	21	2	1.23 - 4.41
Winter 87/88	130	22	1.79 - 250

Explanation:

Certified Reporting Limits
($\mu\text{g/l}$)

Fall 88	(Fall 1988 annual sampling event)	1.05
Winter 89	(Winter 1989 quarterly Basin F sampling event)	1.05
Spring 89	(Spring 1989 semi-annual sampling event)	1.05/1.92
Summer 89	(Summer 1989 quarterly Basin F sampling event)	1.05
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	1.70/1.92/1.10

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

4.3.8.1 Unconfined Flow System. During the fall of 1988, 322 ground-water samples were collected from wells completed in the unconfined flow system and analyzed for benzene. Concentrations ranging from 1.25 $\mu\text{g/l}$ to 240,000 $\mu\text{g/l}$ were detected in 49 of the samples. The CRL (1.05 $\mu\text{g/l}$) was used as the lowest contour value in constructing the contaminant plume map shown in Figure 4.3.8-1.

Benzene occurs primarily in two areas: South Plants-South Lakes - Basin A, and in the Basin F Pathway from Basin F toward the NBCS. In addition, a small plume of benzene is present in Sections 26 and 35 in the Basin A Neck.

Benzene in the South Plants-South Lakes - Basin A area had a concentration of 240,000 $\mu\text{g/l}$ (Well 01014). Two plumes with elevated concentrations of benzene (greater than 10,000 $\mu\text{g/l}$) extend to the north and to the southwest from the ground-water mound in the South Plants area of Section 1.

Benzene was detected between 1.36 $\mu\text{g/l}$ and 3.84 $\mu\text{g/l}$ in three wells along the Basin A Neck Pathway. This plume is not interpreted to be continuous with the South Plants - South Lakes - Basin A plume.

The southern edge of the Basin F plume originated in the Basin F area and extended through the Basin F pathway to the NBCS. The highest concentration in this plume was 140 $\mu\text{g/l}$ (Well 26148), detected approximately 1,000 ft northeast of Basin F. The benzene plume extended laterally to the east along the NBCS. Benzene also was detected in three wells north of the boundary system, along the northern RMA border, at concentrations ranging from 2.11 to 8.49 $\mu\text{g/l}$.

In addition to the occurrences of benzene discussed above, benzene was detected in ten isolated locations on RMA. Concentrations in these wells ranged from 1.69 to 11.6 $\mu\text{g/l}$. The highest was detected in Well 27003 which is located to the south of the NWBCS.

4.3.8.2 Confined Flow System. Of 165 samples collected from confined flow system wells, 23 had detections ranging from 1.33 to 47,000 $\mu\text{g/l}$. Analytical results for the fall of 1988 are summarized in Table 4.3.8-1. Point plots of fall 1988 analytical results are presented in Figures A-15 through A-17.

The majority of detections occur in zones A and 1U of the Denver Formation in the area directly below and adjacent to the South Plants-Basin A plume in the unconfined flow system. Other detections in the confined flow system occur in the Basin A Neck and along the northern and

northwestern RMA boundaries. Although several of the detections in the confined flow system beneath South Plants-Basin A correlate with detections in the unconfined flow system, detections along the northwest RMA boundary do not generally correspond to the benzene distribution in the overlying unconfined flow system.

The highest detection in the confined flow system was in Well 36182 at a depth of 75.0 ft (zone A). This well is located near the southwest corner of Section 36 where some of the highest concentrations in the unconfined flow system occur. Benzene concentrations in other wells were significantly lower and ranged from 1.33 to 20.0 $\mu\text{g/l}$ with one detection $>40.2 \mu\text{g/l}$. This occurred in Well 02030, located west of the South Plants-Basin A unconfined flow system plume. The deepest benzene contamination in the confined flow system occurred at 173 ft in Well 36171 (2.93 $\mu\text{g/l}$), completed in Denver zone 1. Well 36171 is located along the western edge of Basin A.

4.3.8.3 Winter 1987/88 and FY89 Comparison. Benzene was detected in 48 of 301 winter 1987/88 samples from the unconfined flow system and in 49 of 322 samples in fall 1988. Benzene was present in the South Plants - South Lakes - Basin A Pathway and the Basin F Pathway in both annual sampling programs. A northeast Basin A extension of the plume is indicated by fall 1988 data. Differences between the fall 1988 and winter 1987/88 distribution of benzene occurred in the RMA Western Tier. A plume was mapped in this area for winter 1987/88, but fall 1988 data did not substantiate the presence of benzene. Wells where benzene concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Benzene was detected in 22 of 130 samples from the confined flow system during winter 1987/88. Of the 165 samples collected in fall 1988, 23 had detections. Table 4.3.8-1 summarizes the results for each of the confined zones. During both sampling periods, benzene occurred in South Plants, Basin A Neck, NBCS and NWBCS areas. Due to the nature of the Denver aquifer, data interpretation based on a single sampling period may not be effective in recognizing anomalous data.

4.3.9 Chlorobenzene

Chlorobenzene analyses were performed on 488 ground-water samples collected during the fall of 1988. The CRL for the fall of 1988 was 0.820 $\mu\text{g/l}$. Chlorobenzene concentrations ranging from 0.991 to 110,000 $\mu\text{g/l}$ were reported in 49 samples. Chlorobenzene was reported in zones A, 1U, 1, 2 and 5 of the unconfined flow system. Detections in both the unconfined and confined flow systems during the fall of 1988 are summarized in Table 4.3.9-1.

Table 4.3.9-1

Chlorobenzene Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	36	0.991 - 66,000
	Winter 89	25	8	1.20 - 23.0
	Spring 89	258	78	0.943 - 110,000
	Summer 89	34	6	0.941 - 40.7
	Winter 87/88	317	108	0.620 - 41,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	3	1.52 - 110,000
	Winter 89	0	0	
	Spring 89	29	4	19.2 - 140,000
	Summer 89	0	0	
	Winter 87/88	28	11	1.06 - >200
IU	Fall 88	20	3	2.15 - 167
	Winter 89	0	0	
	Spring 89	18	7	1.76 - 165
	Summer 89	0	0	
	Winter 87/88	12	4	3.32 - 55.5
1	Fall 88	22	4	2.24 - 155
	Winter 89	6	3	5.44 - 135
	Spring 89	16	6	1.06 - 220
	Summer 89	6	2	3.81 - 10.7
	Winter 87/88	16	4	1.11 - 10.7
2	Fall 88	37	2	1.15 - 6.65
	Winter 89	11	3	1.17 - 19.7
	Spring 89	24	5	4.34 - 20.9
	Summer 89	11	2	1.08 - 9.89
	Winter 87/88	26	3	1.65 - 170
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	4	3.89 - 6.14
	Summer 89	3	0	
	Winter 87/88	18	6	3.50 - 81.4

Table 4.3.9-1

Chlorobenzene Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	6	3.09 - 13.0
	Summer 89	1	0	
	Winter 87/88	18	9	1.11 - >98.0
5	Fall 88	9	1	63.4
	Winter 89	0	0	
	Spring 89	6	3	4.32 - 51.5
	Summer 89	0	0	
	Winter 87/88	10	5	1.41 - 39.8
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	12.0
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	40.3

Total Confined Flow System

Fall 88	166	13	1.15 - 110,000
Winter 89	21	6	1.17 - 135
Spring 89	130	35	1.06 - 140,000
Summer 89	21	4	1.08 - 10.7
Winter 87/88	136	45	1.06 - >200

Explanation:		Certified Reporting Limits ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	0.820
Winter 89	(Winter 1989 quarterly Basin F sampling event)	0.820
Spring 89	(Spring 1989 semi-annual sampling event)	0.820/1.36
Summer 89	(Summer 1989 quarterly Basin F sampling event)	0.820
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	0.820/1.36/0.580

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

4.3.9.1 Unconfined Flow System. Chlorobenzene was detected in 36 of 322 ground-water samples from the unconfined flow system. Concentrations ranged from 0.991 to 66,000 $\mu\text{g/l}$. The CRL of 0.820 $\mu\text{g/l}$ was used as the lowest contour line in constructing the contaminant distribution map shown in Figure 4.3.9-1 of this report.

Chlorobenzene was detected in the South Plants-Basin A Pathway, Basin A Neck, Basin F and Northern Off-Post Pathways. The South Plants-Basin A plume originates in the South Plants area and extended both north across Basin A and southwest across northwestern Section 1 into Section 2. Reported concentrations in this plume ranged from 0.991 to 66,000 $\mu\text{g/l}$. The area of highest concentration was located in southwest Section 36, just downgradient from South Plants. An area of elevated concentration (1,400 $\mu\text{g/l}$) in the northeast corner of Section 36 was indicated by fall 1988 sampling results from Well 36180. The southwest extension of the plume in Section 2 is a preliminary interpretation indicated by data from Well 02545 (340 $\mu\text{g/l}$).

In the Basin F Pathway, a small, two-lobed plume was present immediately south of the NBCS. Detections in Wells 23231 and 24184 within the plume were 1.14 and 32.3 $\mu\text{g/l}$, respectively. Previous sampling results indicated chlorobenzene also was present near the northeast corner of Basin F (Wells 23049, 23096, 23106, 23239, 26133); however, chlorobenzene was not detected in this area in the fall of 1988. The latter two CRLs were elevated due to dilutions during laboratory analysis. Results from subsequent events confirmed the detections in Wells 23239 and 26133, but not in Wells 23106 or 23049. Well 23096 was not sampled.

The plume in the Northern Off-Post Pathway extended north of the NBCS. Concentrations in wells within the plume were 63.4 and 120 $\mu\text{g/l}$.

Isolated detections ranging from 1.11 to 240 $\mu\text{g/l}$ occurred in seven on-post wells and one off-post well. Four of the detections occurred in the vicinity of Basin F and the area to the northwest, one was detected near North Plants and two were present in Section 9 in the Western Tier area. The off-post detection was in Section 14 near the northern RMA boundary.

4.3.9.2 Confined Flow System. Chlorobenzene analyses were performed on 166 ground-water samples from the confined flow system, resulting in 13 sample concentrations above the CRL during the fall of 1988. Concentration ranged from 1.15 to 110,000 $\mu\text{g/l}$, with detections reported in zones A, 1U, 1, 2 and 5. Analytical results for the Denver Formation are summarized in Table 4.3.9-1, and point plots of chlorobenzene detections from fall 1988 analytical results are shown in Figures A-18 through A-19.

The highest concentration (110,000 $\mu\text{g/l}$) was reported in zone A in southwest Section 36 in Well 36182. The highest detection in the unconfined flow system (66,000 $\mu\text{g/l}$), also occurred in this area, but was at a lower concentration than in the confined flow system. The deepest chlorobenzene detection in the confined flow system was near the northwest end of Basin A in Well 36179 (zone 1). A concentration of 155 $\mu\text{g/l}$ was detected 151 ft below ground level. A concentration of 12.4 $\mu\text{g/l}$ was detected in the overlying unconfined flow system.

In general, chlorobenzene concentrations in the confined flow system were not areally coincident with detections in the unconfined flow system. In addition to the observations described above, concentration in the confined flow system was higher than in the unconfined flow system in the Basin A area, north of Basin A, Basin A Neck area and the vicinity of Basin F. The largest differences occurred in the northern area of Basin A where chlorobenzene was detected at concentrations of 155 and 167 $\mu\text{g/l}$ in zones 1 and 1U, respectively, and at 12.4 and 3.09 $\mu\text{g/l}$ in the overlying unconfined flow system.

4.3.9.3 Winter 1987/88 and FY89 Comparison. Chlorobenzene was detected in 108 of 317 winter 1987/88 samples in the unconfined flow system compared to 36 of 322 samples in fall 1988. The chlorobenzene plume in the South Plants - Basin A areas maintains a similar configuration between the winter 1987/88 and the fall 1988 periods. Differences between these sample periods, however, are evident in other areas. Plumes previously identified in the Western Tier, Basin F, Northwest, and Northern Off-Post Pathways were either not as extensive or not evident in the fall 1988 data. The Western Tier, Basin F, and NWBCS areas showed only isolated detections in the fall 1988 sampling period. In the winter of 1987/88, the Northern Off-Post plume extended approximately 4000 ft north of the NBCS in comparison to 1000 ft in the fall of 1988. Wells where concentrations of chlorobenzene varied considerably are listed in Table 4.3.2-2.

In the winter of 1987/88, chlorobenzene was detected in 46 of 166 samples in comparison to 13 of 136 in the fall of 1988. Table 4.3.9-1 summarizes the results for each of the confined zones. Detections occurred in both sampling rounds in Basin A, Basin A Neck, and Basin C areas. Chlorobenzene was detected more frequently in the NBCS area during the winter 1987/88 sampling program than in the fall 1988 program. No chlorobenzene was detected in the confined flow system off-post in fall 1988. As previously stated, the heterogeneity of the Denver aquifer is likely to produce data variability. Interpretations based on one sampling period should be considered appropriately.

4.3.10 Volatile Organohalogens

The compounds included in the volatile organohalogen (VOH) group are:

- 1,1-Dichloroethene
- 1,2-Dichloroethene
- 1,1-Dichloroethane
- 1,2-Dichloroethane
- 1,1,1-Trichloroethane
- 1,1,2-Trichloroethane
- Carbon Tetrachloride
- Chloroform (CHCL3)
- Methylene Chloride
- Tetrachloroethene (TCLEE)
- Trichloroethene (TRCLE)

The summed concentrations of these 11 analytes are reported collectively as the total VOH concentration. Three analytes within this group: chloroform (CHCL3), tetrachloroethene (TCLEE), and trichloroethene (TRCLE) are discussed separately later in this report.

VOH analyses were performed on 488 samples collected from the unconfined and confined flow systems during the fall of 1988. A detection was recorded if one or more of the individual VOH compounds was identified. In the fall of 1988 there were 267 VOH detections ranging from 0.567 to 2,900,000 $\mu\text{g/l}$. VOH detections were reported in the confined flow system within zones B, A, 1U, 1, 2, 3, 4, and 5. Table 4.3.10-1 summarizes VOH detections in the unconfined and confined flow systems.

4.3.10.1 Unconfined Flow System. A total of 217 VOH detections were reported among the 322 unconfined flow system samples collected during the fall of 1988. Concentrations ranged from 0.570 to 2,900,000 $\mu\text{g/l}$. The highest CRL of the 11 VOH compounds (7.40 $\mu\text{g/l}$ for methylene chloride) was used as the lowest isoconcentration contour for preparing the VOH plume map (Figure 4.3.10-1). On-post, VOH plumes were present in the South Plants-Basin A and South Lakes Pathways, the Basin A Neck and Central Pathways, the Basin F West, Basin F East, and Basin F Pathways, the Tier and Railyard-Motorpool Pathways, and the North Plants Pathway. Off-post, plumes were identified in the Northwest, First Creek, and Northern Off-Post Pathways.

Table 4.3.10-1

Summed Volatile Organohalogen Compounds Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	217	0.570 - 2,900,000
	Winter 89	25	24	1.25 - 68,400
	Spring 89	258	160	0.580 - 2,500,000
	Summer 89	34	25	0.665 - 36,000
	Winter 87/88	322	223	0.568 - 463,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	5.68
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	1	2.86
A	Fall 88	37	17	0.851 - 2420
	Winter 89	0	0	
	Spring 89	29	12	1.59 - 2820
	Summer 89	0	0	
	Winter 87/88	28	19	0.745 - >q660
IU	Fall 88	20	6	2.01 - 61.3
	Winter 89	0	0	
	Spring 89	13	6	2.43 - 153
	Summer 89	0	0	
	Winter 87/88	12	7	0.840 - 26.1
1	Fall 88	22	11	0.807 - 107
	Winter 89	6	3	6.23 - 61.7
	Spring 89	16	7	0.788 - 70.0
	Summer 89	6	3	1.44 - 83.3
	Winter 87/88	16	2	10.7 - 40.1
2	Fall 88	37	9	0.567 - 43.9
	Winter 89	11	7	0.857 - 21.1
	Spring 89	24	6	0.780 - 26.8
	Summer 89	10	1	0.612
	Winter 87/88	26	10	0.626 - 12.8
3	Fall 88	19	4	0.757 - 23.3
	Winter 89	3	1	4.52
	Spring 89	17	3	1.30 - 20.5
	Summer 89	0	0	
	Winter 87/88	18	5	0.759 - 5.45

Table 4.3.10-1 Summed Volatile Organohalogen Compounds Analytical Results Summary
(Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	1	0.999
	Winter 89	1	0	
	Spring 89	16	6	0.782 - 3.59
	Summer 89	1	0	
	Winter 87/88	19	4	1.00 - 15.7
5	Fall 88	9	1	1.32
	Winter 89	0	0	
	Spring 89	6	2	1.25 - 1.85
	Summer 89	0	0	
	Winter 87/88	10	3	2.31 - 127
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	10.6
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	484
<u>Total Confined Flow System</u>				
	Fall 88	166	50	0.567 - 2420
	Winter 89	21	11	0.857 - 61.7
	Spring 89	130	42	0.780 - 2820
	Summer 89	20	5	0.612 - 83.3
	Winter 87/88	137	55	0.626 - >q660
Explanation:			Lowest Certified Reporting Limits of Summed Compounds (µg/l)	
Fall 88	(Fall 1988 annual sampling event)		0.500	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		0.500	
Spring 89	(Spring 1989 semi-annual sampling event)		0.500/1.09	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		0.500	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		0.500/1.09/0.610	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

The most extensive VOH plume originated in the South Plants and Basin A (Figure 4.3.10-1). The highest fall 1988 VOH detection of 2,900,000 $\mu\text{g/l}$ (predominately chloroform) occurred in this area at Well 36198, located in the southwestern portion of the section, south of the lime settling ponds. The VOH plume spread radially from the South Plants, however the predominant contaminant flux was north into Basin A. VOH contamination also extended southwest from the South Plant into southern Section 2 along the South Lakes Pathway.

From Basin A, the VOH plume extended northwest into the Basin A Neck and Basin F East Pathways. The plume extended northwest along the Basin A Neck Pathway into Section 27 where it merged with VOH contamination within the Central Pathways and extended north towards the NWBCS. VOH contamination in the Basin F West Pathway merged with the plume in northern Section 27. VOH contamination was identified offpost to the northwest of the NWBCS along the Northwest Pathway. VOH composite concentrations within the Basin A Neck, Basin F East, Central, Basin F West, and Northwest Pathways were generally less than 50 $\mu\text{g/l}$.

VOH contamination in the Basin F East Pathway merged with contamination in the Basin F Pathway. The contaminant mass in the Basin F Pathway was substantially larger than the contaminant mass along the Basin F East Pathway. The highest fall 1988 VOH detection in the Basin F Pathway was 80,600 $\mu\text{g/l}$ at Well 26133. VOH contamination in the Basin F Pathway extended north to the NBCS.

Downgradient of the NBCS, remnants of a VOH plume extended north and northwest along the First Creek and Northern Off-Post Pathways. As shown in Figure 4.3.10-1, this plume is interpreted as not being continuous with the on-post plume. The highest fall 1988 VOH detection in this off-post plume occurred at Well 37344. A composite concentration of 1100 $\mu\text{g/l}$ was measured at this well, located approximately 6500 feet north of RMA along the Northern Off-post Pathway.

In the southwestern part of RMA, VOH plumes occurred along the Western Tier and Railyard-Motorpool Pathways. The Western Tier plume migrated onto the RMA Section 9 from an unknown source south or southeast of RMA. The highest fall 1988 VOH concentration in this plume was 235 $\mu\text{g/l}$ at Well 09014, located in southeast Section 9, near the southern RMA boundary. The Railyard-Motorpool plume extended northwest from a source in the Rail Classification Yard or Motorpool areas. The highest fall 1988 VOH concentration in this plume was 146 $\mu\text{g/l}$ at Well 04030. The leading edge of the Railyard-Motorpool plume shown on Figure 4.3.10-1 was in northeastern Section 4, however, it is likely that the plume extended

northwest at concentrations less than the lowest isoconcentration contour of 7.40 µg/l and merged with the Western Tier plume.

A VOH plume, originating at the North Plants, extended north along the North Plants Pathway. The highest fall 1988 composite VOH concentration measured in this plume was 347 µg/l at Well 25042.

A majority of the isolated detections shown in Figure 4.3.10-1 were concentrations that were below the lower contour value and occurred in close proximity to the plume areas. Isolated fall 1988 VOH detections above 7.40 µg/l occurred in Sections 2, 33, 35, and off-post.

4.3.10.2 Confined Flow System. VOH detections were reported in 50 of the 166 samples analyzed from the confined flow system during the fall of 1988. Denver Formation zones B, A, 1U, 1, 2, 3, 4, and 5 yielded detections ranging from 0.567 µg/l to 2,420 µg/l. Table 4.3.10-1 summarizes these results and point plots illustrating VOH detections in the confined flow system are shown in Figures A-20 through A-22.

The highest fall 1988 VOH composite concentration of 2420 µg/l was measured at Well 36182, which is completed in zone A. This well is proximal to the highest unconfined flow system VOH contamination in southwest Section 36. The greatest depth at which VOH compounds were detected during the fall of 1988 was 210 feet at Well 01048 (zone 2). At this well, 4.90 µg/l of chloroform was detected. The second deepest VOH detection occurred at Well 36171 (zone 1). A concentration of 3.71 µg/l of trichloroethene was measured at this well which is located in Basin A and completed to a depth of 173 feet below ground surface. Volatile organic halogen contamination in the confined flow system occurred, for the most part, beneath areas of unconfined flow system contamination.

4.3.10.3 Winter 87/88 and FY89 Comparisons. In the unconfined flow system, volatile organic halogens were detected in 233 of 322 winter 1987/88 samples compared to 217 of 322 fall 1988 samples. Data from fall 1988 substantiate winter 1987/88 VOH plume configurations throughout the study area. In addition, new wells installed in Section 25 and sampled during fall 1988 indicate a VOH plume extending from North Plants. In the Basin A Neck area, additional wells sampled during fall 1988 resulted in better plume definition. During fall 1988, VOH contamination was more continuous along the Basin A Neck and central pathways. Finally, the VOH plume off-post north of the NBCS was determined to be discontinuous with the on-post plume. Wells where VOH concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Composite VOH compounds were detected in the confined flow system in 55 of 137 samples analyzed during the winter of 1987/88 compared to 50 of 160 samples analyzed during the fall of 1988 (Table 4.3.10-1). Areas where VOH contamination was detected during both sampling periods include the South Lakes, South Plants, Basin A and Basin A Neck, Section 26 and the NBCS. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single period.

4.3.11 Chloroform

Analyses for chloroform were performed on 488 ground-water samples collected during the fall of 1988. Chloroform concentrations ranging from 0.567 to 2,900,000 $\mu\text{g/l}$ were detected in 215 samples. The CRL for the fall 1988 monitoring program was 0.500 $\mu\text{g/l}$. Chloroform was detected in the confined flow system in zones B, A, 1U, 1, 2, and 3. The distribution of chloroform in the unconfined flow system is illustrated in Figure 4.3.11-1. Unconfined and confined flow system chloroform detections for FY89 are summarized in Table 4.3.11-1.

4.3.11.1 Unconfined Flow System. Ground-water samples collected from 322 wells completed in the unconfined flow system were analyzed for chloroform during the fall of 1988. Concentrations of chloroform ranging from 0.570 to 2,900,000 $\mu\text{g/l}$ were measured in 173 of these samples.

Based on the fall 1988 data, chloroform formed an areally extensive plume occupying the South Plants-Basin A-Basin A Neck Pathways, the South Lakes and Central Pathways, and the Basin F and Basin F East Pathways to the NBCS (Figure 4.3.11-1). Chloroform contamination off-post was identified along the Northern Off-Post and Northwest Pathways. As illustrated in Figure 4.3.11-1 however, continuity of the chloroform plumes across the NBCS is interrupted by boundary system operations. Plumes of chloroform also were identified along the North Plants and Railyard-Motorpool Pathways.

The highest chloroform concentrations occurred along the South Plants-Basin A and Basin F Pathways. The highest concentration of chloroform measured during the fall of 1988 was 2,900,000 $\mu\text{g/l}$ at Well 36168, located adjacent to the South Plants. From the South Plants, the chloroform plume migrated radially as a result of the South Plants ground-water mound.

From the South Plants and Basin A, the chloroform plume extended west and northwest along the Basin A Neck, Central North, and Central South Pathways, and north along the Basin F East Pathway. The highest fall 1988 chloroform concentration along pathways to the west and

Table 4.3.11-1

Chloroform Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	173	0.570 - 2,900,000
	Winter 89	25	23	0.580 - 66,000
	Spring 89	258	122	0.570 - 2,500,000
	Summer 89	34	19	0.620 - 35,000
	Winter 87/88	319	171	0.570 - 460,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	3.78
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	1	2.86
A	Fall 88	35	16	0.851 - 198
	Winter 89	0	0	
	Spring 89	29	9	1.59 - 730
	Summer 89	0	0	
	Winter 87/88	28	15	0.710 - 1000
IU	Fall 88	20	4	0.874 - 50.5
	Winter 89	0	0	
	Spring 89	18	5	1.77 - 18.5
	Summer 89	0	0	
	Winter 87/88	12	5	0.800 - 26.1
1	Fall 88	22	9	0.791 - 106
	Winter 89	6	2	1.31 - 61.7
	Spring 89	16	5	0.585 - 70.0
	Summer 89	6	3	1.44 - 83.3
	Winter 87/88	16	2	0.570 - 40.1
2	Fall 88	37	8	0.567 - 43.9
	Winter 89	11	6	0.857 - 10.9
	Spring 89	24	6	0.780 - 26.6
	Summer 89	11	2	0.612 - 14.2
	Winter 87/88	25	6	0.630 - 12.8
3	Fall 88	19	4	0.757 - 23.3
	Winter 89	3	0	
	Spring 89	17	3	1.30 - 20.5
	Summer 89	3	0	
	Winter 87/88	18	1	1.05 - 16.8

Table 4.3.11-1 Chloroform Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	5	0.782 - 3.59
	Summer 89	1	1	1.34
	Winter 87/88	19	1	2.21
5	Fall 88	9	0	
	Winter 89	0	0	
	Spring 89	6	2	0.795 - 1.25
	Summer 89	0	0	
	Winter 87/88	10	1	2.05
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	2.85
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	480
<u>Total Confined Flow System</u>				
	Fall 88	166	42	0.567 - 198
	Winter 89	21	8	0.857 - 61.7
	Spring 89	130	35	0.585 - 730
	Summer 89	21	6	0.612 - 83.3
	Winter 87/88	136	36	0.570 - 460,000
Explanation:			Certified Reporting Limits (µg/l)	
Fall 88	(Fall 1988 annual sampling event)		0.500	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		0.500	
Spring 89	(Spring 1989 semi-annual sampling event)		0.500/1.88	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		0.500	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		0.500/1.88/1.40	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

northwest was 51.0 µg/l at Well 22043, located just upgradient of the NWBCS. Chloroform extending from the Central and Basin A Neck Pathways are not intercepted by the NWBCS.

The Basin F East Pathway plume merged with the Basin F Pathway plume downgradient of the Basin F area, where chloroform concentrations increase substantially. The highest fall 1988 chloroform detection within the Basin F Pathway was 70,000 µg/l at Well 26133. Detected chloroform concentrations decreased along the Basin F Pathway towards the NBCS. Potentiometric data indicate that the isolated plume of chloroform in north-central Section 23 upgradient of the NBCS probably is related to contamination along the Basin F pathway.

Chloroform was detected downgradient of the NBCS during the fall of 1988 along the Northern Off-Post Pathway and in several wells along the length of the containment system. The highest detected concentration along the Northern Off-Post Pathway of 1000 µg/l occurred at Well 37344 more than one mile north of the NBCS.

Isolated plumes of chloroform were identified from fall 1988 data along the North Plants Pathway and along the Railyard-Motorpool Pathway. Isolated detections of chloroform occurred in Sections 1, 2, 9, 23, 24, 28, 33, 36, and in five off-post wells.

4.3.11.2 Confined Flow System. Chloroform was detected in 42 of 166 confined flow system samples analyzed during the fall of 1988. Chloroform detections ranging from 0.567 to 198 µg/l were measured from wells completed in zones B, A, 1U, 1, 2, and 3. FY89 analytical results for individual zones of the confined flow system are summarized in Table 4.3.11-1. Point plots of these results are presented in Figures A-23 through A-25.

Fall 1988 chloroform detections in the confined flow system occurred predominately beneath areas of unconfined flow system chloroform contamination. The greatest depth at which chloroform was detected during the fall of 1988 was 210 feet in Well 01048 (zone 2). A chloroform concentration of 4.90 µg/l was measured. Because this well is located upgradient of all RMA sources of chloroform, connection with contamination by RMA sources is unlikely. Denver Formation zone 3, at a depth of 145 feet in Well 19016, was the lowest stratigraphic unit in which chloroform (0.773 µg/l) was detected. The highest chloroform concentrations detected in the fall of 1988 occurred in zone A Wells 02030, 02035, and 36117. Chloroform concentrations of 198, 197, and 180 µg/l, respectively, were measured at these wells.

4.3.11.3 Winter 1987/88 and FY89 Comparison. In the unconfined flow system, chloroform was detected in 171 of 319 winter 1987/88 samples and in 173 of 322 fall 1988 samples.

Chloroform distribution was generally similar during both sampling periods, however, because of a lower fall 1988 CRL chloroform appears to be more extensive. The addition of fall 1988 monitoring wells in the North Plants led to the identification of a chloroform plume extending north from the North Plants. The addition of wells in the Basin A Neck to the fall 1988 program has resulted in more continuous plume definition. Wells where chloroform concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Chloroform was detected in 36 of 136 confined flow system samples during the winter of 1987/88 compared to 42 of 166 samples for the fall 1988 sampling period (Table 4.3.11-1). The presence of chloroform in the confined flow system was confirmed in the South Plants, South Lakes, Basin A Neck, Basin A areas, and Sections 23 and 26. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single sampling period.

4.3.12 Trichloroethene

Analyses for trichloroethene were performed on 488 ground-water samples collected during the fall 1988 monitoring period. The CRL for the fall of 1988 was 0.560 $\mu\text{g/l}$. Trichloroethene concentrations ranged from 0.625 to 4800 $\mu\text{g/l}$ in 146 of the samples analyzed. Trichloroethene was detected in the confined flow system in 19 out of 166 samples from zones A, 1U, 1, 2, 3 and 5. Trichloroethene in both the unconfined and confined flow systems for the FY89 monitoring program is summarized in Table 4.3.12-1.

4.3.12.1 Unconfined Flow System. Trichloroethene was detected in 127 of 322 ground-water samples collected during the fall of 1988 from wells completed in the unconfined flow system. Concentrations ranged from 0.625 $\mu\text{g/l}$ to 4800 $\mu\text{g/l}$. The CRL value of 0.560 $\mu\text{g/l}$ was used as the lowest contour line in constructing the contaminant plume map shown in Figure 4.3.12-1.

Based on fall 1988 data, trichloroethene extended in a continuous plume through the South Plants, Basin A, Basin A Neck, Basin F East, and Basin F Pathways to the NBCS. Plumes of trichloroethene also were detected in the Basin A Neck Pathway to the Northwest Boundary Containment System, in the Northern and First Creek Off-Post Pathways, and the Railyard-Motor Pool and Western Tier Pathways.

The highest concentration of trichloroethene at RMA during the fall of 1988 (4800 $\mu\text{g/l}$ in Well 36181) was detected in the South Plants-Basin A Pathway in southwest Section 36. Elevated trichloroethene concentrations were also detected in nearby Wells 36001 (2,500 $\mu\text{g/l}$) and 36168

Table 4.3.12-1

Trichloroethene Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	127	0.625 - 4800
	Winter 89	25	14	0.665 - 36.0
	Spring 89	257	90	0.709 - 880
	Summer 89	34	17	0.665 - 280
	Winter 87/88	318	116	0.619 - 2400
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	7	0.754 - 1500
	Winter 89	0	0	
	Spring 89	29	6	0.749 - 1100
	Summer 89	0	0	
	Winter 87/88	28	8	0.645 - 440
IU	Fall 88	20	5	1.00 - 4.84
	Winter 89	0	0	
	Spring 89	18	5	0.659 - 6.56
	Summer 89	0	0	
	Winter 87/88	12	2	1.32 - 2.55
1	Fall 88	22	4	0.649 - 4.77
	Winter 89	6	2	3.90 - 5.13
	Spring 89	16	4	0.788 - 5.40
	Summer 89	6	1	6.03
	Winter 87/88	16	1	5.46
2	Fall 88	37	1	0.835
	Winter 89	11	0	
	Spring 89	24	0	
	Summer 89	10	0	
	Winter 87/88	26	4	0.615 - 10.8
3	Fall 88	19	1	2.34
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	18	4	0.759 - 5.45

Table 4.3.12-1

Trichloroethene Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	1	1.62
	Summer 89	1	0	
	Winter 87/88	19	4	1.00 - 13.5
5	Fall 88	9	1	1.32
	Winter 89	0	0	
	Spring 89	6	1	1.05
	Summer 89	0	0	
	Winter 87/88	10	3	1.30 - 2.95
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	1.48
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	2.77
<u>Total Confined Flow System</u>				
	Fall 88	166	19	0.649 - 1500
	Winter 89	21	2	3.90 - 5.13
	Spring 89	130	17	0.659 - 1100
	Summer 89	20	1	6.03
	Winter 87/88	137	30	0.615 - 440

Explanation:		Certified Reporting Limits ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	0.560
Winter 89	(Winter 1989 quarterly Basin F sampling event)	0.560
Spring 89	(Spring 1989 semi-annual sampling event)	0.560/1.31
Summer 89	(Summer 1989 quarterly Basin F sampling event)	0.560
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	0.560/1.31

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

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(2,100 $\mu\text{g/l}$). From the southwest corner of Section 36, the plume extended southwest to the central portion of Section 2 and northwest into the Basin A Neck Pathway, through the Basin F East and Basin F Pathways, to the NBCS. Another area of elevated concentration (greater than 100 $\mu\text{g/l}$) within the plume occurred near the northeast corner of Basin A. The interpreted plume configuration in this area corresponded to historical distributions.

Along the Basin A Neck Pathway, extending northwest to the NWBCS, the continuity of the trichloroethene plume through the southwest corner of Section 26 and the southeast corner of Section 27 has not been confirmed with available data due to the complexity of ground water flow in this area. It is believed that the plume is continuous through the area between Wells 26068 and 27025. Concentrations within the plume ranged from 0.768 to 2.90 $\mu\text{g/l}$.

Along the Western Tier and Railyard-Motor Pool Pathways in Sections 4, 9 and 33, trichloroethene was detected at concentrations ranging from 0.911 to 144 $\mu\text{g/l}$. The plume extended to the western border of Sections 4, 9, and 33. Trichloroethene was not found in two wells within the western edge of the plume thus interpreted, one in the northwest corner of Section 9 (Well 09002) and one in the northwest corner of Section 33 (Well 33076). The historical off-post trichloroethene contamination is indicated by the shaded area (Figure 4.3.12-1) west of RMA. The concentrations from the wells that were sampled by the EPA between December 1985 and March 1987 ranged from 5.00 to 100 $\mu\text{g/l}$.

Trichloroethene contamination was identified in the First Creek and Northern Off-Post Pathways downgradient of the NBCS. At present, the trichloroethene plume is discontinuous across the NBCS. The maximum concentration detected in the Northern Off-Post Pathway was 4.34 $\mu\text{g/l}$, detected in Well 37344, and the maximum concentration in the First Creek Off-Post Pathway was 2.42 $\mu\text{g/l}$ in Well 37396.

In addition to the plumes described above, there were 12 isolated detections of trichloroethene, ranging in concentration from 0.724 to 8.11 $\mu\text{g/l}$. The highest concentration was detected near the center of Section 25 in Well 25042. Most of the detections occurred on-post in the northern areas of RMA.

4.3.12.2 Confined Flow System. Analyses for trichloroethene were performed on 166 ground-water samples collected from the confined flow system during fall 1988 monitoring. Trichloroethene concentrations ranging from 0.649 to 1500 $\mu\text{g/l}$ were detected in 19 of the samples. Analytical results for the fall 1988 sampling are summarized in Table 4.3.12-1. Point plots from the fall 1988 sampling are presented in Figures A-26 through A-28.

Detections were most frequent within zones A, 1U and 1. Single detections occurred in zones 2, 3 and 5. The maximum concentration was detected in the South Plants area in southwest Section 36, underlying the maximum concentration in the unconfined flow system. The deepest detection of trichloroethene occurred at 173 ft on the west side of Basin A in Well 36171 (zone 1). The concentration was 3.71 $\mu\text{g/l}$.

The distribution of trichloroethene in the confined flow system generally could be correlated with the trichloroethene distribution in the unconfined flow system. Detections in zone A primarily occurred in the South Plants-Basin A area, whereas detections in lower stratigraphic zones were more widespread.

4.3.12.3 Winter 1987/88 and FY89 Comparisons. Trichloroethene was detected in the unconfined flow system in 116 of 318 winter 1987/88 samples compared to 127 of 322 fall 1988 samples (Table 4.3.12-1). Fall 1988 data confirmed the presence of trichloroethene in South Plants, Basin A, Basin A Neck, South Lakes, Northern Off-Post, Basin F, the Rail Yard - Motor Pool and Western Tier Pathways. The addition of wells in the Basin A Neck to the fall 1988 program has resulted in more continuous plume definition. Trichloroethene distribution near the NWBCS was less extensive in fall 1988 than winter 1987/88. Wells where trichloroethene concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Trichloroethene was detected in 30 of 137 samples from the confined flow system in the winter 1987/88 compared to 19 of 166 fall 1988 samples (Table 4.3.12-1). Fall 1988 data confirmed the presence of trichloroethene in the South Plants area, Basins A, Section 26, the Basin A Neck, and at the NBCS. Winter 1987/88 trichloroethene detections north of the NBCS were not substantiated by fall 1988 data. Isolated trichloroethene detections in Sections 4, 23, 27, 30, and 33 during the winter of 1987/88 also were not repeated during the fall of 1988 sampling round. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single sampling period. Therefore, variations such as those noted at the NBCS should be considered appropriately.

4.3.13 Tetrachloroethene

Tetrachloroethene was detected in 105 of 488 wells analyzed during the fall 1988 sampling with concentrations ranging from 0.892 to 700 $\mu\text{g/l}$. The CRL for the fall of 1988 was 0.750 $\mu\text{g/l}$. Tetrachloroethene results in both the confined and unconfined flow systems are presented in Table 4.3.13-1.

Table 4.3.13-1

Tetrachloroethene Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	90	0.892 - 700
	Winter 89	25	15	2.03 - 660
	Spring 89	258	71	0.843 - 5700
	Summer 89	34	16	0.962 - 1100
	Winter 87/88	318	92	0.879 - 1700
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	1.90
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
A	Fall 88	35	5	1.23 - 82.0
	Winter 89	0	0	
	Spring 89	29	2	4.02 - 140
	Summer 89	0	0	
	Winter 87/88	28	6	0.829 - 26.0
IU	Fall 88	20	1	2.02
	Winter 89	0	0	
	Spring 89	18	2	1.44 - 1.74
	Summer 89	0	0	
	Winter 87/88	12	2	0.848 - 2.00
1	Fall 88	22	3	1.58 - 3.58
	Winter 89	6	2	1.02 - 3.64
	Spring 89	16	1	5.32
	Summer 89	6	1	5.58
	Winter 87/88	16	1	4.69
2	Fall 88	37	5	0.998 - 3.15
	Winter 89	11	5	0.877 - 9.95
	Spring 89	24	1	1.43
	Summer 89	11	1	0.833
	Winter 87/88	26	2	1.21 - 2.40
3	Fall 88	19	0	
	Winter 89	3	1	4.52
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	18	0	

Table 4.3.13-1

Tetrachloroethene Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	0	5.76
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	1	
	Winter 87/88	19	0	
5	Fall 88	9	0	1.31
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	10	1	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	1.98
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	1	
<u>Total Confined Flow System</u>				
	Fall 88	166	15	0.998 - 82.0
	Winter 89	21	8	0.877 - 9.95
	Spring 89	130	6	1.43 - 140
	Summer 89	21	3	0.833 - 5.76
	Winter 87/88	137	14	0.829 - 65.0
Explanation:			<u>Certified Reporting Limits (µg/l)</u>	
Fall 88	(Fall 1988 annual sampling event)		0.750	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		0.750	
Spring 89	(Spring 1989 semi-annual sampling event)		0.750/2.76	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		0.750	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		0.750/2.76/1.30	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

4.3.13.1 Unconfined Flow System. Of the 322 ground-water samples collected from the unconfined flow system, 90 had detections of tetrachloroethene ranging from 0.892 to 700 $\mu\text{g/l}$. The CRL of 0.750 $\mu\text{g/l}$ was used as the lowest contour value in constructing the plume map shown in Figure 4.3.13-1. Tetrachloroethene plumes were detected in the South Plants-Basin A - A Neck, Basin F, Western Tier, and the First Creek and Northern Off-Post Pathways.

The South Plants-Basin A - A Neck plume originates in the South Plants area and continues north through Basin A and the Basin A Neck. Tetrachloroethene migration to the southwest also occurs as a result of the ground-water mound in the South Plants. Interpretation of data indicated that the plume extended to the central portion of Section 2. Concentrations ranged from 1.11 to 700 $\mu\text{g/l}$, with the highest tetrachloroethene concentration reported in northwest Section 1 (Well 01524).

Tetrachloroethene was detected at the northeastern boundary of Basin F and northeast along the Basin F Pathway to the NBCS. Concentrations in the plume ranged from 0.923 to 680 $\mu\text{g/l}$ (Well 26133).

Tetrachloroethene was detected off-post along the Northern Off-Post and First Creek Off-Post Pathways, in plumes which are slightly discontinuous across the NBCS. Concentrations in these plumes ranged from 1.27 to 102 $\mu\text{g/l}$ (Well 37344).

Detections of tetrachloroethene in the Western Tier trend north-south, parallel to the RMA western border, and were located within Sections 4, 9, and 33. The areal extent of the plume cannot be defined using on-post data alone because the plume extends off-post. The maximum concentration in this area in the fall of 1988 was 2.82 $\mu\text{g/l}$.

A small plume of tetrachloroethene was delineated to the north in Sections 28 and 33 based on data from Wells 28027 and 33509. Fall 1988 detections were 1.75 and 3.60 $\mu\text{g/l}$, respectively.

Outside the plumes described above, concentrations of tetrachloroethene ranging from 1.04 to 54.7 $\mu\text{g/l}$ were reported in 11 wells. Two of these occurred in the Western Tier area near the southern border of RMA in Section 9; six occurred in northwest RMA on-post areas; and three occurred off-post.

4.3.13.2 Confined Flow System. Tetrachloroethene detected in 15 of 166 ground-water samples from the confined flow system. Concentrations ranged from 0.998 to 82.0 $\mu\text{g/l}$. Analytical results for the Denver Formation are summarized in Table 4.3.13-1. Point plots of the data are shown in Figures A-29 through A-31. Detections were from zones A, B, 1U, 1, and 2.

The detections in zones B and A generally occur in the vicinity of South Plants. In other confined zones, the detections are primarily under the Basin A Neck and Basin F East Pathways. Tetrachloroethene in the confined flow system was generally present outside the plumes delineated in the unconfined flow system and not directly below the plumes. The point of highest concentration (82.0 $\mu\text{g/l}$) was reported in Well 36182 which is completed in zone A to a depth of 75.0 ft below ground level. This well is located approximately 400 ft north of Well 01524 which had the highest concentration of tetrachloroethene in the overlying unconfined flow system (700 $\mu\text{g/l}$). The deepest contamination by tetrachloroethene in the confined flow system occurred in Well 26152 (zone 2), screened to a depth of 104.9 feet. The tetrachloroethene concentration in this well was 2.31 $\mu\text{g/l}$, and the well is located in the vicinity of the Basin A Neck.

4.3.13.3 Winter 1987/88 and FY89 Comparisons. Tetrachloroethene was detected in the unconfined flow system in 92 of 318 wells sampled in the winter of 1987/88 compared to 90 of 322 wells sampled in the fall of 1988 (Table 4.1.13-1). Fall 1988 data confirmed tetrachloroethene plumes in the South Plants, South Lakes, Basin A, Basin A Neck, and Basin F, Northern Off-Post and First Creek Off-Post Pathways. The plumes in the South Lakes and Basin A Neck Pathways were extended based on fall 1988 data, as was the plume in the Western Tier Pathway. Wells where tetrachloroethene concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Tetrachloroethene was detected in the confined flow system in 14 of 137 samples in the winter of 1987/88 compared to 15 of 166 samples in the fall of 1988 (Table 4.3.13-1). Tetrachloroethene presence was further substantiated in South Plants, Southern Basin A, and Basin A Neck areas. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single sampling period.

4.3.14 Dibromochloropropane (DBCP)

Analyses for DBCP were performed on 486 ground-water samples collected during the fall of 1988, and DBCP was detected in 57 samples. Dibromochloropropane concentrations ranged from 0.199 to 1,900 $\mu\text{g/l}$. Dibromochloropropane detections for samples collected from the unconfined and confined flow systems for the FY89 monitoring programs are summarized in Table 4.3.14-1.

4.3.14.1 Unconfined Flow System. Dibromochloropropane was identified in 49 of the 320 unconfined samples analyzed during the fall of 1988. Concentrations ranging from 0.199 to 1,900 $\mu\text{g/l}$ were reported. The CRL of 0.195 $\mu\text{g/l}$ was used as the lowest contour value shown on the plume map in Figure 4.3.14-1.

Table 4.3.14-1

Dibromochloropropane Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	320	49	0.199 - 1900
	Winter 89	25	6	0.241 - 17.0
	Spring 89	258	57	0.154 - 270
	Summer 89	34	8	0.349 - 9.75
	Winter 87/88	307	62	0.144 - 57,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	2	0.220 - 310
	Winter 89	0	0	
	Spring 89	29	2	0.351 - 310
	Summer 89	0	0	
	Winter 87/88	22	2	0.496 - 21.0
IU	Fall 88	20	3	1.13 - 9.78
	Winter 89	0	0	
	Spring 89	18	3	0.632 - 1.90
	Summer 89	0	0	
	Winter 87/88	11	0	
1	Fall 88	22	1	8.96
	Winter 89	6	0	
	Spring 89	16	3	0.208 - 0.361
	Summer 89	6	0	
	Winter 87/88	14	0	
2	Fall 88	37	1	0.403
	Winter 89	11	1	2.40
	Spring 89	24	4	0.205 - 1.10
	Summer 89			
	Winter 87/88	23	2	0.234 - 0.330
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	1	0.200
	Summer 89	3	0	
	Winter 87/88	17	1	0.202

Table 4.3.14-1

Dibromochloropropane Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	0	0.784
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	1	
	Winter 87/88	18	0	
5	Fall 88	9	1	0.340 0.393 - 0.548
	Winter 89	0	0	
	Spring 89	6	2	
	Summer 89	0	0	
	Winter 87/88	8	0	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
<u>Total Confined Flow System</u>				
	Fall 88	166	8	0.220 - 310
	Winter 89	21	1	2.40
	Spring 89	130	15	0.200 - 310
	Summer 89	21	1	0.784
	Winter 87/88	119	5	0.202 - 21.0

Explanation:		Certified Reporting Limits ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	0.195
Winter 89	(Winter 1989 quarterly Basin F sampling event)	0.195
Spring 89	(Spring 1989 semi-annual sampling event)	0.130/0.195
Summer 89	(Summer 1989 quarterly Basin F sampling event)	0.195
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	0.190/0.130

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

As shown in Figure 4.3.14-1, three separate DBCP plumes were present on-post and one plume was present off-post. The plumes included the South Plants-Basin A Pathway, Railyard-Motor Pool Pathway, Basin F Pathway, and the Northern Off-Post Pathway.

The largest DBCP plume originates in the South Plants. The highest fall 1988 DBCP concentration (1,900 $\mu\text{g/l}$) was reported in this area from Well 01061. From the South Plants, the plume extends north into Basin A. Concentrations in the plume ranged from 0.217 $\mu\text{g/l}$ (Well 36090) to 1,900 $\mu\text{g/l}$ (Well 01061).

The second largest DBCP plume occupied the Railyard-Motor Pool Pathway in western RMA. This relatively narrow plume originated in the Rail Classification Yard and extends northwest into Section 33 where it is intercepted by the Irondale Containment System. The highest DBCP concentration in this plume was recorded at Well 04026 (100 $\mu\text{g/l}$). Vertical stratification of DBCP in the unconfined flow system is evident at well clusters 04026-04029 and 04014-04016. The wells screened in the shallow portion of the thick saturated alluvium have DBCP concentration one to two orders of magnitude greater than the wells screened in the deeper portion of the alluvium.

A DBCP plume extended northeast from the Basin F area to the NBCS along the Basin F Pathway. Within this plume, DBCP ranged in concentration from 0.206 $\mu\text{g/l}$ (Well 24013) where the plume is intercepted by the NBCS, to 28.0 $\mu\text{g/l}$ (Well 26157) near Basin F.

Downgradient of the NBCS a DBCP plume extends north along the Northern Off-Post Pathway. This DBCP plume has been shown to be associated with the DBCP plume further downgradient (north) along this pathway; however, fall 1988 results do not support this interpretation. The highest fall 1988 DBCP detection within the Northern Off-Post Pathway was 9.62 $\mu\text{g/l}$ at Well 37344.

A small DBCP plume existed along the Basin A Neck Pathway in southwest Section 26. This is based on DBCP detections at Wells 26006 and 26068. Isolated fall 1988 DBCP detections occurred within Sections 1, 2, 9, 22, 24, 25, and 27. Previous and/or subsequent sampling indicates that the two isolated detections in Section 9 and the two isolated detections in Section 25 appear to be spurious. Isolated detections in Sections 1, 2, 22, and 27 appear to be related to current or historical plume areas.

4.3.14.2 Confined Flow System. A total of 166 samples from the confined flow system were analyzed for DBCP during the fall of 1988. Eight detections were reported with a range from

0.220 to 310 $\mu\text{g/l}$. The affected zones included A, 1U, 1, 2, and 5. Table 4.3.14-1 summarizes these detections and Figures A-32 through A-34 are point plots of the results.

Dibromochloropropane contamination in the confined flow system occurred predominately beneath unconfined flow system contamination. The highest fall 1988 DBCP detection in the confined flow system was 310 $\mu\text{g/l}$ within Well 36182 (zone A). This well is located approximately 1,000 feet downgradient from the highest DBCP concentration within the unconfined flow system. The deepest fall 1988 detection of DBCP occurred in Well 36179 (zone 1) at a depth of 151 feet below ground surface. The well contained a DBCP concentration of 8.96 $\mu\text{g/l}$, and is located along the western margin of Basin A.

4.3.14.3 Winter 1987/88 and FY89 Comparisons. Dibromochloropropane was detected in the unconfined flow system in 62 of 307 samples analyzed during the winter of 1987/88 period compared to 49 of 320 samples analyzed during fall of 1988 (Table 4.3.14-1). Fall 1988 data further substantiated the presence of DBCP in the Rail Classification Yard - Motor Pool, the South Plants - Basin A, and the Basin F Pathways. The extent of plumes in the Rail Classification Yard - Motor Pool and the Northern Off-Post Pathway decreased from winter 1987/88 to fall 1988. Dibromochloropropane was detected in two of seven newly installed wells in the North Plants. Wells where DBCP concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Dibromochloropropane was detected in the confined flow system in five of 119 samples in the winter of 1987/88 compared to eight of 166 samples in the fall of 1988 (Table 4.3.2-2). Fall 1988 data indicate the presence of DBCP in the confined flow system in Sections 1, 24, 26, 35, and 36. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single sampling period. Interpretation of variable data should be considered appropriately.

4.3.15 Dicyclopentadiene (DCPD)

During the fall of 1988, dicyclopentadiene analyses were performed on 481 ground-water samples. Dicyclopentadiene concentrations ranging from 9.47 $\mu\text{g/l}$ to 3600 $\mu\text{g/l}$ were reported in 47 of the 481 ground-water samples obtained. The CRL for the samples collected during the fall of 1988 was 5.00 $\mu\text{g/l}$. Dicyclopentadiene was detected in confined flow system zones A, 1, 2, and 4. Dicyclopentadiene detections are summarized in Table 4.3.15-1.

Table 4.3.15-1

Dicyclopentadiene Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	317	42	10.5 - 3600
	Winter 89	25	12	32.4 - 3600
	Spring 89	258	37	10.5 - 12,100
	Summer 89	34	14	12.4 - 1500
	Winter 87/88	280	58	10.6 - 12,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	0	0	
A	Fall 88	35	1	13.6
	Winter 89	0	0	
	Spring 89	29	1	51.8
	Summer 89	0	0	
	Winter 87/88	28	0	
IU	Fall 88	20	0	
	Winter 89	0	0	
	Spring 89	18	1	13.2
	Summer 89	0	0	
	Winter 87/88	12	0	
1	Fall 88	22	1	16.4
	Winter 89	6	0	
	Spring 89	16	0	
	Summer 89	6	0	
	Winter 87/88	14	0	
2	Fall 88	35	1	15.6
	Winter 89	11	1	10.2
	Spring 89	24	1	9.36
	Summer 89	10	0	
	Winter 87/88	24	2	12.3 - 330
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
	Winter 87/88	17	0	

Table 4.3.15-1

Dicyclopentadiene Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	2	9.47 - 21.5
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	0	
	Winter 87/88	16	0	
5	Fall 88	9	0	18.2 - 27.1
	Winter 89	0	0	
	Spring 89	6	2	
	Summer 89	0	0	
	Winter 87/88	7	2	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
<u>Total Confined Flow System</u>				
	Fall 88	164	5	9.47 - 21.5
	Winter 89	21	1	10.2
	Spring 89	130	5	9.36 - 51.8
	Summer 89	20	0	
	Winter 87/88	124	4	12.3 - 330
Explanation:			Certified Reporting Limits (µg/l)	
Fall 88	(Fall 1988 annual sampling event)		5.00	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		5.00	
Spring 89	(Spring 1989 semi-annual sampling event)		5.00/9.31	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		5.00	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		5.00/9.31	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

4.3.15.1 Unconfined Flow System. Ground-water samples from 317 wells completed in the unconfined flow system were analyzed for dicyclopentadiene. Of these, 42 had concentrations that ranged from 10.5 $\mu\text{g/l}$ to 3600 $\mu\text{g/l}$. The CRL (5.00 $\mu\text{g/l}$) was used as the lowest contour value in constructing the plume map shown in Figure 4.3.15-1. Dicyclopentadiene occurs in three main areas: the South Plants-Basin A - Basin A Neck Pathway, the Basin F Pathway, and in the First Creek Off-Post Pathway. Isolated dicyclopentadiene detections were present in Sections 1, 4, 27, 33, and 34.

The South Plants-Basin A plume originated in the South Plants area and extended northward through Basin A. Some dicyclopentadiene migration to the southwest from the South Plants area into Section 2 also was apparent. Concentrations within the South Plants-Basin A plume range from 13.1 $\mu\text{g/l}$ in Well 36056, to 2400 $\mu\text{g/l}$ in Well 01014.

A small plume defined by Wells 35065 and 35018 occurs in the Basin A Neck Pathway. Although the likely source of this plume in the South Plants-Basin A area, fall 1988 data do not permit illustration of this plume as continuous with the South Plants-Basin A plume.

The Basin F Pathway plume extended from the Basin F area north along the Basin F Pathway to the North Boundary Containment System. Concentrations of dicyclopentadiene ranging from 23.3 $\mu\text{g/l}$ (Well 23188) to 3600 $\mu\text{g/l}$ (Well 23049) were reported within this plume.

The First Creek Off-Post, plume which is discontinuous with the on-post plume, was identified downgradient of the North Boundary Containment System in off-post Section 14. Concentrations within this plume ranged from 10.5 $\mu\text{g/l}$ in Well 37343, to 250 $\mu\text{g/l}$ in Well 37373. An isolated dicyclopentadiene detection of 25.1 $\mu\text{g/l}$ was reported in the Northern Off-Post Pathway at Well 37344.

4.3.15.2 Confined Flow System. Dicyclopentadiene was detected in five of 164 ground-water samples from the confined flow system. These detections were from Denver Formation zones A, 1, 2, and 4, with values ranging from 9.47 $\mu\text{g/l}$ to 21.5 $\mu\text{g/l}$. Point plots showing confined flow system dicyclopentadiene detections during the fall 1988 program are shown in Figures A-35 through A-36. Table 4.3.15-1 summarizes the results for each confined flow system zone.

The highest dicyclopentadiene concentration of 21.5 $\mu\text{g/l}$ was reported in Well 37365 (zone 4), located beneath the First Creek Off-post Pathway in Section 14. Other confined flow system detections occurred in areas proximal to unconfined flow system plumes. The deepest fall 1988 dicyclopentadiene detection occurred in Well 35084 (zone 1) at a depth of 174 feet below ground

surface. A dicyclopentadiene concentration of 16.4 $\mu\text{g/l}$ was detected at this well located adjacent to South Plants. This detection has not been confirmed with spring 1988 and spring 1989 samples which were below detection.

4.3.15.3 Winter 1987/88 and FY89 Comparisons. Dicyclopentadiene was detected in the unconfined flow system in 58 of 280 winter 1987/88 samples compared to 42 of 317 fall 1988 samples (Table 4.3.15-1). Fall 1988 data confirmed the existence of dicyclopentadiene plumes in the South Plants, Basin A, Basin A Neck, Basin F, and First Creek Off-Post Pathways. The configuration of the plumes are similar between the two sampling periods, except for the First Creek Off-Post Pathway plume which decreased in size. This reduction occurs at the NBCS, likely reflecting the impact of the newly installed recharge trenches. Monitoring wells, added to the fall 1988 network, in Sections 27 and 34, identified several isolated dicyclopentadiene detections. Wells where dicyclopentadiene concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Dicyclopentadiene was detected in the confined flow system in 5 of 164 samples in the winter of 1987/88 compared to 5 of 124 samples in the fall of 1988. Table 4.3.15-1 summarizes these results for each zone of the confined flow system. There were no detections of dicyclopentadiene in the same wells during both sampling periods. Except for the two detections close together off-post in Section 14 during the fall of 1988, all detections during both sampling periods were areally or vertically isolated. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any sampling period. Therefore variations such as those noted above should be considered appropriately.

4.3.16 Diisopropylmethylphosphonate (DIMP)

Diisopropylmethylphosphonate (DIMP) was detected in 267 of 485 samples analyzed during the fall of 1988. The CRL for the fall period was 0.392 $\mu\text{g/l}$ and the range of reported concentrations was from 0.441 to 34,000 $\mu\text{g/l}$. The distribution of DIMP in the unconfined flow system is illustrated in Figure 4.3.16-1. Diisopropylmethylphosphonate was detected in the confined flow system within zones B, A, 1U, 1, 2, 3, 4, 5, and 6. Diisopropylmethylphosphonate detections for the FY89 monitoring programs are summarized in Table 4.3.16-1.

4.3.16.1 Unconfined Flow System. A total of 321 samples from wells completed in the unconfined flow system were analyzed for DIMP during the fall of 1988. Diisopropylmethylphosphonate was reported in 211 wells, ranging from 0.441 to 34,000 $\mu\text{g/l}$. The CRL (0.392 $\mu\text{g/l}$) was used as the lowest contour value in constructing the plume map shown in Figure 4.3.16-1.

Table 4.3.16-1

Diisopropylmethylphosphonate Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
<u>Unconfined Flow System</u>				
	Fall 88	321	211	0.441 - 34,000
	Winter 89	25	25	1.64 - 2700
	Spring 89	258	144	0.471 - 9300
	Summer 89	34	34	1.91 - 2800
	Winter 87/88	306	125	11.5 - 9000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	0.922
	Winter 89	0	0	
	Spring 8	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	10	0.466 - 2200
	Winter 89	0	0	
	Spring 89	29	6	
	Summer 89	0	0	
	Winter 87/88	26	2	
IU	Fall 88	20	7	0.827 - 3100
	Winter 89	0	0	
	Spring 89	18	5	
	Summer 89	0	0	
	Winter 87/88	12	2	
1	Fall 88	22	13	0.567 - 400
	Winter 89	6	4	
	Spring 89	16	8	
	Summer 89	6	4	
	Winter 87/88	14	3	
2	Fall 88	35	11	0.643 - 2900
	Winter 89	11	2	
	Spring 89	24	7	
	Summer 89	11	3	
	Winter 87/88	23	2	
3	Fall 88	19	5	0.640 - 100
	Winter 89	3	0	
	Spring 89	17	5	
	Summer 89	3	0	
	Winter 87/88	17	1	

Table 4.3.16-1

Diisopropylmethylphosphonate Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
4	Fall 88	18	7	0.648 - 2.28
	Winter 89	1	0	
	Spring 89	16	5	0.483 - 27.3
	Summer 89	1	0	
	Winter 87/88	18	1	11.5
5	Fall 88	9	1	1.23
	Winter 89	0	0	
	Spring 89	6	2	0.871 - 3.33
	Summer 89	0	0	
	Winter 87/88	9	0	
6	Fall 88	2	1	0.458
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	1	0.449
	Summer 89	0	0	
	Winter 87/88	1	0	
<u>Total Confined Flow System</u>				
	Fall 88	164	56	0.458 - 3100
	Winter 89	21	6	0.445 - 1800
	Spring 89	130	39	0.449 - 2500
	Summer 89	21	7	0.629 - 2000
	Winter 87/88	125	11	11.5 - 5900

Explanation:		Certified Reporting Limits (µg/l)
Fall 88	(Fall 1988 annual sampling event)	0.392
Winter 89	(Winter 1989 quarterly Basin F sampling event)	0.392
Spring 89	(Spring 1989 semi-annual sampling event)	0.392/10.1
Summer 89	(Summer 1989 quarterly Basin F sampling event)	0.392
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	18.5/10.1/10.5

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

Diisopropylmethylphosphonate occurs as a widening continuous plume extending predominantly north and northwest from sources within South Plants, North Plants, and Basin A. On post, DIMP occupied all of the following contaminant migration pathways: South Plants-Basin A, South Lakes, Basin A Neck, Central North, Central South, Basin F East, Basin F West, Basin F, North Plants, and Basin F Northwest. Off post, DIMP occupied the Northern Off-Post, First Creek Off-Post, and Northwest Pathways.

The most upgradient detection of DIMP contamination apparent from the fall 1988 analytical data occurred in the South Plants. The highest detection measured in the South Plants during the fall of 1988 was 460 $\mu\text{g/l}$ at Well 01525. From the South Plants, DIMP appeared to migrate in several directions in response to radial flow from the South Plants ground-water mound.

The highest fall 1988 detection of DIMP was 34,000 $\mu\text{g/l}$ at Well 36123 located downgradient of Basin A in northwest Section 36. From Basin A, DIMP concentrations in excess of 1000 $\mu\text{g/l}$ extended continuously through the Basin A Neck northward through Basins C and F and along the Basin F Pathway to the NBCS.

The northwest migration of DIMP along the Basin A Neck Pathway west of Section 26 occurred at concentrations generally less than 10 $\mu\text{g/l}$. This also was true for migration along the Central, Basin F West and Basin F Northwest Pathways. The highest fall 1988 DIMP detection in the vicinity of the NWBCS was 18.2 $\mu\text{g/l}$ at Well 22053.

The plume of DIMP originating in the North Plants extended north and merged with the Basin F plume in west-central Section 24. Concentrations within this plume ranged from 0.693 $\mu\text{g/l}$ in Well 25041 to 340 $\mu\text{g/l}$ in Well 24081. The highest DIMP detection within the North Plants was 250 $\mu\text{g/l}$ at Well 25047.

Diisopropylmethylphosphonate existed off post in a wide plume encompassing the Northern Off-Post, First Creek Off-Post and Northwest Pathways and the areas in between the pathways. This plume may have reached the South Platte River. Contaminant migration has been halted at the NBCS and NWBCS, but DIMP can continue to move off post between the barriers, and a great deal of historical contaminant remains off post. Diisopropylmethylphosphonate detections greater than 1000 $\mu\text{g/l}$ were reported in three wells along the First Creek Off-Post Pathway. The highest off-post fall 1988 DIMP detection was 2600 $\mu\text{g/l}$ at Well 37313.

Isolated DIMP detections occurred on-post in Sections 1, 2, 4, 6, 8, 9, 12, 28, and 30. These detections resulted from the lowering of the CRL from 18.5 to 0.392 $\mu\text{g/l}$.

4.3.16.2 Confined Flow System. Diisopropylmethylphosphonate was detected in 56 of 164 ground-water samples collected from wells screened in the confined flow system. These detections were from zones B, A, 1U, 1, 2, 3, 4, 5, and 6, with values ranging from 0.458 $\mu\text{g/l}$ to 3100 $\mu\text{g/l}$. Table 4.3.16-1 summarizes the results. Figures A-37 through A-40 are point plots showing the fall 1988 distribution of DIMP in the confined flow system.

The occurrence of DIMP in the confined flow system was primarily beneath areas of contamination in the unconfined flow system. The highest fall 1988 DIMP detection was at Well 35016 (zone 1U), located along the Basin A Neck Pathway in Section 35. In general, the greatest extent of confined flow system DIMP contamination appears to be beneath the basins in Section 26 and along the Basin A Neck Pathway in zones 1U and 2, respectively. The deepest detection (187 ft) was in Well 04012, completed in zone 6, at a concentration of 0.458 $\mu\text{g/l}$.

4.3.16.3 Winter 1987/88 and FY89 Comparisons. Diisopropylmethylphosphonate was detected in the unconfined flow system in 125 of 306 samples during the winter of 1987/88 compared to 211 of 321 samples during the fall of 1988 (Table 4.3.16-1). The CRL for DIMP was lowered from 18.5 $\mu\text{g/l}$, during the winter of 1987/88 to 0.392 $\mu\text{g/l}$ during the fall of 1988. Because of this change, DIMP contamination appears more extensive during the fall of 1988.

Additional monitoring wells were installed in the North Plants subsequent to the winter of 1987/88 and prior to the fall of 1988. Samples from these wells resulted in the identification of a DIMP plume originating in the North Plants on the fall 1988 plume map. Wells where DIMP concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Diisopropylmethylphosphonate was detected in the confined flow system in 11 of 125 samples during the winter of 1987/88 compared to 56 of 164 samples during the fall of 1988 (Table 4.3.16-1). The increase in detections during fall 1988 can be attributed, in part, to the lowering of the CRL from 18.5 to 0.392 $\mu\text{g/l}$. Fall 1988 data confirmed the winter 1987/88 DIMP detections in the Basin A Neck, Basin C and First Creek Off-Post area. Additionally, fall 1988 DIMP detections occurred in the confined flow system in the South Plants/Basin A, and Basin F area, and in the Northern Off-Post Pathway. Isolated detections of DIMP also occurred in Sections 4, 11, 12, and 30. Due to the generally low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any single sampling period.

4.3.17 Phenols

In order to discuss the analytical results of the acid extractable fraction, total phenol concentrations are presented as the sum of detected concentrations of the PMRMA certified compounds comprising this group. Phenols were sampled for analysis during the fall 1988 and winter 1989 monitoring periods. The summed compounds included in this group are:

- 2,4,5-Trichlorophenol
- 2,4,6-Trichlorophenol
- 2,4-Dichlorophenol
- 2,4-Dimethylphenol
- 2,4-Dinitrophenol
- 2-Chlorophenol
- 2-Methylphenol / 2-Cresol
- 2-Nitrophenol
- 4-Chloro-3-cresol / 3-Methyl-4-chlorophenol
- 4-Methylphenol / 4-Cresol
- 4-Nitrophenol
- Pentachlorophenol
- Phenol

Ground-water samples from 315 wells were analyzed during the fall of 1988 for compounds in the phenols group. Ground-water samples were collected from an additional 170 wells. However, the laboratory performing the analyses was not PMRMA-certified initially to analyze for all phenolic compounds, so results were not obtained. Composite phenol concentrations ranging from 5.15 to 110 $\mu\text{g/l}$ were detected in 17 of the 315 samples analyzed. Only 7 of the 13 phenolic compounds comprising the group were detected at RMA. These included:

- 2-Chlorophenol
- 2-Methylphenol
- 2-Nitrophenol
- 4-Chloro-3-cresol
- 4-Methylphenol
- Pentachlorophenol
- Phenol

Table 4.3.17-1

Summed Phenols Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	192	8	9.98 - 110
	Winter 89	25	1	13.6
<u>Confined Flow System Zone</u>				
B	Fall 88	0	0	
	Winter 89	0	0	
A	Fall 88	27	1	14.0
	Winter 89	0	0	
IU	Fall 88	20	2	12.9 - 14.7
	Winter 89	0	0	
1	Fall 88	18	2	17.2
	Winter 89	6	0	
2	Fall 88	29	1	5.15
	Winter 89	11	0	
3	Fall 88	14	1	6.97
	Winter 89	3	0	
4	Fall 88	9	1	6.55
	Winter 89	1	0	
5	Fall 88	6	1	5.36
	Winter 89	0	0	
6	Fall 88	2	0	
	Winter 89	0	0	
7	Fall 88	2	0	
	Winter 89	0	0	

Table 4.3.17-1

Summed Phenols Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
<u>Total Confined Flow System</u>				
	Fall 88	127	9	5.15 - 17.2
	Winter 89	21	0	
Explanation:			<u>Lowest Certified Reporting Limits of Summed Compounds (µg/l)</u>	
Fall 88	(Fall 1988 annual sampling event)		2.20	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		2.20	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

The CRLs for the 13 targeted phenol compounds ranged from 2.20 µg/l for Phenol to 176 µg/l for 2,4-Dinitrophenol. Phenol group compounds were detected in the confined flow system in zones A, 1U, 1, 2, 3, 4, and 5. Unconfined and confined flow system phenol detections for the FY89 monitoring events are summarized in Table 4.3.17-1. The distribution of phenols in the unconfined flow system is illustrated in Figure 4.3.17-1. Because analysis for compounds within the phenol group were not undertaken in recent historical monitoring programs, a historical comparison is not presented in this report.

4.3.17.1 Unconfined Flow System. Ground-water samples from 192 monitoring wells completed in the unconfined flow system were analyzed for phenols during the fall of 1988. Phenols were detected in eight samples with composite concentrations ranging from 9.98 to 110 µg/l.

A single, relatively small phenols plume was identified during the fall of 1988 (Figure 4.3.17-1). The plume extended from the South Plants into southern Basin A along the Basin A Pathway. The highest composite phenol detection (110 µg/l) within this plume occurred at Well 36076.

Isolated detections of phenols occurred at Wells 22008, 26041, and 36084. Well 22008, located just upgradient of the NWBCS, yielded 9.98 µg/l of the compound phenol. Well 26041, located within the Basin F Pathway, yielded 74.5 µg/l of the compound 4-chloro-3-cresol. Well 36084, located within Basin A, yielded 29.6 µg/l of the compound 4-methylphenol.

4.3.17.2 Confined Flow System. Compounds within the phenols group were detected in nine of 127 ground-water samples collected from confined flow system zones during the fall of 1988. Composite concentrations ranging from 5.15 to 17.2 µg/l were obtained from wells completed in zones A, 1, 1U, 2, 3, 4, and 5. Of the 13 compounds in the group, only 2-methylphenol and phenol were detected in the confined flow system. Analytical results from individual zones of the confined flow system are summarized in Table 4.3.17-1. Point plots of these results are presented in Figures A-41 through A-43.

During the fall of 1988, phenols were detected in the confined flow system in Sections 1, 23, 35, and 36. The greatest depth at which phenols were detected was 18.3 ft in Well 35078 (zone 1). A concentration of 17.2 µg/l of 2-methylphenol was reported from this well. The lowest stratigraphic unit containing phenols was zone 5 at Well 23225. A sample containing 2-methylphenol at a concentration of 5.36 µg/l was obtained from this well, located in east-central Section 23.

4.3.17.3 FY89 Comparison. Because ground-water samples were not analyzed for phenols prior to fall 1988, only comparisons between fall 1988 and winter 1988/89 (a quarterly sample, network) can be made. Phenols were detected in 8 of 192 unconfined flow system samples in fall 1988 and in 1 of 25 samples in winter 1988/89. One detection occurred in both the fall 1988 and winter 1988/89 sampling rounds at Well 26041. Wells where concentration of phenols varied considerably between sampling rounds are listed in Table 4.3.2-2.

Phenols were detected in 9 of 127 confined flow system wells sampled in fall 1988 and none of the 21 wells sampled in winter 1988/89. Phenols were not detected in the Basin F area during either sampling period. Table 4.3.17-1 summarizes the results.

4.3.18 Parathion

Analyses for parathion were performed on 485 ground-water samples collected during the fall of 1988. Parathion concentrations ranging from 0.838 to 24.0 $\mu\text{g/l}$ were detected in 35 of the 485 samples analyzed. The CRL for parathion for the fall 1988 period was 0.647 $\mu\text{g/l}$. Parathion was detected in only one sample from the confined flow system (zone A). The distribution of parathion in the unconfined flow system is illustrated in Figure 4.3.18-1. Parathion detections for FY89 are summarized in Table 4.3.18-1. Because parathion was not analyzed in recent historical monitoring programs, a historical comparison is not presented in this report.

4.3.18.1 Unconfined Flow System. Ground-water samples collected from 320 wells completed in the unconfined flow system were analyzed for parathion during the fall of 1988. Parathion detections ranging from 0.838 to 24.0 $\mu\text{g/l}$ were measured in 34 of these samples.

Parathion plumes were identified in the South Plants-Basin A, Basin A Neck, and Basin F Pathways during the fall 1988 (Figure 4.3.18-1). The highest concentration of parathion, 24.0 $\mu\text{g/l}$, was obtained from Well 01525, located within South Plants. Parathion was detected both north along the Basin A Pathway and southwest toward the South Lakes Pathway from the South Plants. Fall 1988 data indicated that the South Plants-Basin A parathion plume was separated from the plume in the Basin A Neck Pathway. The Basin A Neck Pathway plume was interpreted from detections of 4.62 and 4.96 $\mu\text{g/l}$ at Wells 26006 and 35018, respectively.

Parathion occurred within the Basin F Pathway in concentrations ranging from 0.954 to 15.4 $\mu\text{g/l}$. The highest detections were located in Section 26 wells northeast of Basin F. The parathion plume appeared to bifurcate into two lobes as it entered Section 23, one to the north and one to the

Table 4.3.18-1

Parathion Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	320	34	0.838 - 24.0
	Winter 89	25	7	1.02 - 11.5
	Spring 89	258	21	0.847 - 16.8
	Summer 89	34	1	1.15
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
A	Fall 88	35	1	1.07
	Winter 89	0	0	
	Spring 89	29	1	1.07
	Summer 89	0	0	
IU	Fall 88	20	0	
	Winter 89	0	0	
	Spring 89	18	1	1.65
	Summer 89	0	0	
1	Fall 88	22	0	
	Winter 89	6	0	
	Spring 89	16	0	
	Summer 89	6	0	
2	Fall 88	36	0	
	Winter 89	11	1	50.0
	Spring 89	24	2	1.62 - 1.91
	Summer 89	11	0	
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
4	Fall 88	18	0	
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	0	

Table 4.3.18-1

Parathion Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
5	Fall 88	9	0	
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
<u>Total Confined Flow System</u>				
	Fall 88	165	1	1.07
	Winter 89	21	1	50.0
	Spring 89	130	4	1.07 - 1.91
	Summer 89	21	0	
Explanation:			Certified Reporting Limits ($\mu\text{g/l}$)	
Fall 88	(Fall 1988 annual sampling event)		0.647	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		0.647	
Spring 89	(Spring 1989 semi-annual sampling event)		0.250/0.647	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		0.647	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

northeast. The leading edges of both lobes appear to terminate south of the NBCS in Sections 23 and 24.

Off-post isolated detections of parathion occurred north of the NBCS at Wells 37309, 37370, and 37371. Concentrations ranged from 0.838 to 2.44 $\mu\text{g/l}$. On-post isolated detections occurred in Sections 2, 3, 4, 23, 26, and 27 and generally were proximal to observed plumes or source areas. Isolated detections at Wells 03005 and 04020 were more distant from known source areas but were downgradient of detections in the South Lakes Pathway.

The deepest fall 1988 detection of parathion occurred in the unconfined flow system at Well 04020. A parathion concentration of 1.32 $\mu\text{g/l}$ was obtained at a depth of 79 feet below ground surface and was not confirmed by subsequent spring 1989 data.

4.3.18.2 Confined Flow System. Parathion was detected in the confined flow system in only one of 165 samples analyzed during the fall of 1988. The sole confined flow system detection occurred within zone A at Well 02035 (Figure A-44) located southwest of South Plants along the South Lakes Pathway. A parathion concentration of 1.07 $\mu\text{g/l}$ was reported for this well which is screened from 31 to 46 feet below ground surface.

4.3.18.3 FY89 Comparison. Because ground-water samples were not analyzed for parathion prior to fall 1988, comparisons can only be made between FY89 sampling events. Parathion was detected in 34 of 340 samples taken in the unconfined flow system during the fall of 1988 compared to detections in 21 of 258 samples taken in spring 1989. Seventeen of the 34 wells showing parathion contamination in fall 1988 did not contain parathion in spring 1989. Conversely, 10 of the 21 wells showing parathion contamination in spring 1989 did not contain parathion during the fall. Wells with variable parathion concentrations are listed in Table 4.3.2-2.

During the fall 1988 sampling round, 1 out of 165 wells detected parathion in the confined flow system compared to 4 of 130 wells in spring 1989 (Table 4.3.18-1). The five total detections occurred as isolated hits and have not been confirmed by subsequent samples. Due to the general low hydraulic conductivity and large heterogeneity of the Denver Formation, substantial data variability is likely to occur in any sampling period. Data interpretation based on a single sample period may not be effective in recognizing anomalous data, therefore, variable data should be considered appropriately.

4.3.19 Cyanide

Analyses for cyanide were performed on 484 ground water samples obtained during the fall of 1988. Cyanide was not analyzed in prior sampling events. The fall 1988 CRL for cyanide was 5.00 $\mu\text{g/l}$. Cyanide concentrations ranging from 5.05 to 100 $\mu\text{g/l}$ were reported in 149 of the samples analyzed. Unconfined and confined flow system cyanide detections for the FY89 monitoring program are summarized in Table 4.3.19-1.

4.3.19.1 Unconfined Flow System. A total of 319 samples from wells completed in the unconfined flow system were analyzed for cyanide during the fall of 1988. Concentrations ranged from 5.19 to 100 $\mu\text{g/l}$ in 94 of these samples. The CRL of 5.00 $\mu\text{g/l}$ was used as the lowest contour value in constructing the cyanide plume map (Figure 4.3.19-1).

Six cyanide plumes were identified in the fall of 1988 data. They were located in the South Lakes-South Plants-Basin A-Basin A Neck Pathway, the Basin F Pathway, the Central North-Basin A Neck Pathway, the Basin F Northwest Pathway, the North Plants Pathway, and the Western Tier Pathway.

The largest plume and the plume with the highest cyanide concentration was in the South Lakes and South Plants area and extended north through Basin A and northwest through the Basin A Neck. There was a northeast extension from South Plants to the east side of Basin A. The highest cyanide concentration detected was 100 $\mu\text{g/l}$ in Well 01020 in northern Section 1.

A second cyanide plume extended from the Basin F area, north to the NBCS. The plume divided near the boundary system. Only two isolated detections were present north of the boundary system. Concentrations within the plume range from 5.00 to 34.8 $\mu\text{g/l}$. The maximum concentration was detected in Well 23223, near the eastern edge of Section 23.

Additional cyanide plumes trended northwest in the vicinity of the Central North-Basin A Neck and Basin F Northwest Pathways. The Basin F Northwest plume did not extend past the NWBCS., and concentrations ranged from 8.01 to 11.1 $\mu\text{g/l}$. Concentrations in the Central North-Basin A Neck plume ranged from 6.45 to 8.86 $\mu\text{g/l}$.

Cyanide in the North Plants Pathway area ranged in concentration from 5.96 to 15.2 $\mu\text{g/l}$. The plume generally trended north.

Table 4.3.19-1

Cyanide Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	319	94	5.19 - 100
	Winter 89	25	6	6.02 - 20.4
	Spring 89	235	16	3.50 - 161
	Summer 89	33	15	9.25 - 26.5
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	12.9
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
A	Fall 88	35	15	5.39 - 31.3
	Winter 89	0	0	
	Spring 89	29	0	
	Summer 89	0	0	
IU	Fall 88	20	11	5.12 - 22.4
	Winter 89	0	0	
	Spring 89	18	0	
	Summer 89	0	0	
1	Fall 88	22	9	5.49 - 33.5
	Winter 89	6	0	
	Spring 89	16	0	
	Summer 89	6	0	
2	Fall 88	36	11	6.34 - 37.2
	Winter 89	11	0	
	Spring 89	24	0	
	Summer 89	11	0	
3	Fall 88	19	3	6.67 - 8.50
	Winter 89	3	0	
	Spring 89	17	0	
	Summer 89	3	0	
4	Fall 88	18	3	5.05 - 9.71
	Winter 89	1	0	
	Spring 89	16	0	
	Summer 89	1	0	

Table 4.3.19-1

Cyanide Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range (µg/l)
5	Fall 88	9	2	5.26 - 14.5
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
<u>Total Confined Flow System</u>				
	Fall 88	165	55	5.05 - 37.2
	Winter 89	21	3	1.53 - 9.50
	Spring 89	130	0	
	Summer 89	21	0	
Explanation:			<u>Certified Reporting Limits (µg/l)</u>	
Fall 88	(Fall 1988 annual sampling event)		5.00	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		5.00	
Spring 89	(Spring 1989 semi-annual sampling event)		2.50/5.00	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		5.00	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

The Western Tier plume trended northwest through Section 9 and into Section 4 at the southern border of RMA. It appears that a source of the plume may have been located to the south of RMA. Concentrations ranged from 6.67 to 13.8 $\mu\text{g/l}$. The highest concentration was detected in Well 09010, along the northern boundary of Section 9.

Isolated detections of cyanide occurred in 15 on-post wells and two off-post wells. On-post concentrations in these wells ranged from 5.33 to 32.0 $\mu\text{g/l}$ (Well 26073). Off-post concentrations were in Sections 29 and 14 at 5.25 and 10.7 $\mu\text{g/l}$, respectively.

4.3.19.2 Confined Flow System. During the fall of 1988, analyses for cyanide were conducted on 165 ground-water samples collected from the confined flow system. Cyanide was detected above CRL in 55 samples at concentrations ranging from 5.05 to 37.2 $\mu\text{g/l}$ in zones B, A, 1U, 1, 2, 3, 4 and 5 of the Denver Formation. Analytical results for the fall of 1988 are summarized in Table 4.3.19-1. Confined system point plots from the fall 1988 analytical results are presented in Figure A-45 through A-48.

Cyanide was detected above CRL in the area surrounding the South Plants, Basin A and Basin F, and near the north and northwest boundaries of RMA. Most detections of cyanide in the confined flow system did not appear to be directly associated with detections in the unconfined flow system.

The highest concentration of cyanide (37.2 $\mu\text{g/l}$) was detected in Well 35039 in the northwest corner of Section 35. Concentrations were below CRL in a well completed in the overlying unconfined flow system within the Central North Pathway.

The deepest detection of cyanide was in zone 2 in Well 01048, completed to a depth of 210 feet. A concentration of 12.2 $\mu\text{g/l}$ was measured in this well which is located near the center of Section 1, south of South Plants. A concentration of 6.14 $\mu\text{g/l}$ (Well 01047), was detected in the overlying plume in the unconfined flow system.

4.3.19.3 FY89 Comparison. Because ground-water samples were not analyzed for cyanide prior to fall 1988, comparisons can only be made between FY89 sampling events. Cyanide was detected in all 4 of the sampling rounds in FY89 (Table 4.3.19-1). Many of the detections in the fall of 1988 were not confirmed by later data, due to both smaller well networks and fewer detections in subsequent sampling events. However, cyanide was detected in the South Plants - Basin A area and within the Basin F area during subsequent FY89 sampling periods. Wells with variable cyanide concentrations are listed in Table 4.3.2-2.

The fall 1988 cyanide concentrations typically were not confirmed by subsequent monitoring data in the confined flow system. Detections occurred in 55 of 165 wells sampled in fall 1988 and 3 of 21 wells sampled in winter 1989. Most detections in the confined flow system occurred beneath areas where cyanide was detected in the unconfined flow system. Table 4.3.4-1 summarizes the results for each of the confined zones. Cyanide was not detected in wells sampled in the spring or summer of 1989.

Due to the heterogeneity of the Denver aquifer, substantial data variability is likely to occur and data interpretation based on a single sample period may not be effective in recognizing anomalous data.

4.3.20 Fluoride

Analyses for fluoride were performed on 488 ground-water samples obtained during the fall of 1988 monitoring. The CRL for the fall of 1988 was 482 $\mu\text{g/l}$; however, the CRLs for FY88 and FY89 monitoring ranged from 482 to 1,220 $\mu\text{g/l}$. Fluoride concentrations ranging from 1,230 to 320,000 $\mu\text{g/l}$, were reported in 411 of the 488 samples analyzed. Fluoride was detected in all zones of the confined flow system that were sampled. Unconfined and confined flow system fluoride detections for the FY89 monitoring program are summarized in Table 4.3.20-1.

Fluoride is a naturally occurring constituent of ground water. The water quality upgradient of RMA contaminant source areas has been monitored for fluoride to determine a background quality; however, levels representing background concentrations for fluoride have not been established for RMA. Thus, the CRL of 1,220 $\mu\text{g/l}$ was used as the lowest contour line for fluoride plume maps described here. Fluoride data for samples collected between 1964 and 1976 from wells upgradient of RMA show fluoride concentrations ranged from 570 to 1,000 $\mu\text{g/l}$; however, fluoride concentrations ranging from 1,230 to 4,850 $\mu\text{g/l}$ were detected along the southern or upgradient border of RMA, indicating that background fluoride concentrations may be higher than the CRL of 1,220 $\mu\text{g/l}$.

4.3.20.1 Unconfined Flow System. Fluoride was analyzed in 322 samples from the unconfined flow system during the fall of 1988. Reported concentrations ranged from 1,230 $\mu\text{g/l}$ to 320,000 $\mu\text{g/l}$ in 260 samples.

The highest CRL value (1,220 $\mu\text{g/l}$) in FY88 and FY89 monitoring events was used as the lowest contour line in constructing the contaminant distribution map shown in Figure 4.3.20-1. As a result, the figure shows a widespread distribution of fluoride. Because the distribution is greater

Table 4.3.20-1

Fluoride Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above 1200 µg/l	Range (µg/l)
<u>Unconfined Flow System</u>				
	Fall 88	322	260	1230 - 320,000
	Winter 89	25	25	2540 - 200,000
	Spring 89	258	175	1230 - 140,000
	Summer 89	34	34	2470 - 500,000
	Winter 87/88	302	245	1230 - 21,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	4670
	Winter 89	11	10	1510 - 2420
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	30	1270 - 14,000
	Winter 89	0	0	
	Spring 89	29	20	1380 - 11,000
	Summer 89	0	0	
	Winter 87/88	27	24	1310 - 16,000
IU	Fall 88	20	20	1320 - 10,000
	Winter 89	0	0	
	Spring 89	18	11	1270 - 6000
	Summer 89	0	0	
	Winter 87/88	11	10	1280 - 4400
1	Fall 88	22	21	1480 - 7300
	Winter 89	6	5	1620 - 9500
	Spring 89	16	15	1400 - 5800
	Summer 89	6	6	1780 - 9400
	Winter 87/88	15	15	1430 - 4430
2	Fall 88	37	35	1260 - 4320
	Winter 89	11	10	1510 - 2420
	Spring 89	24	21	1280 - 4600
	Summer 89	11	11	1430 - 2920
	Winter 87/88	25	21	1280 - 190,000
3	Fall 88	19	17	1290
	Winter 89	3	3	2320 - 2710
	Spring 89	17	13	1240 - 35,000
	Summer 89	3	3	2220 - 2700
	Winter 87/88	18	10	1480 - 5530

Table 4.3.20-1

Fluoride Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above 1200 $\mu\text{g/l}$	Range ($\mu\text{g/l}$)
4	Fall 88	18	14	1580 - 4200
	Winter 89	1	1	2620
	Spring 89	16	12	1330 - 3760
	Summer 89	1	1	2700
	Winter 87/88	18	12	1310 - 4710
5	Fall 88	9	9	1290 - 6900
	Winter 89	0	0	
	Spring 89	6	5	1990 - 7160
	Summer 89	0	0	
	Winter 87/88	8	6	1760 - 7280
6	Fall 88	2	2	4630 - 6100
	Winter 89	0	0	
	Spring 89	2	2	4750 - 6190
	Summer 89	0	0	
	Winter 87/88	2	2	1680 - 3050
7	Fall 88	2	2	1790 - 2210
	Winter 89	0	0	
	Spring 89	2	2	1720 - 1830
	Summer 89	0	0	
	Winter 87/88	2	2	2080 - 2380

Total Confined Flow System

Fall 88	166	151	1260 - 14,000
Winter 89	21	19	1510 - 9500
Spring 89	130	101	1240 - 35,000
Summer 89	21	21	1430 - 9400
Winter 87/88	129	104	1280 - 190,000

Explanation:		Assumed Approximate Background Values ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	1220
Winter 89	(Winter 1989 quarterly Basin F sampling event)	1220
Spring 89	(Spring 1989 semi-annual sampling event)	1220
Summer 89	(Summer 1989 quarterly Basin F sampling event)	1220
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	1220

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

than that indicated by other RMA contaminants, it is likely that a higher concentration should be used to represent RMA contributions of fluoride to ground water. In general, the plumes delineated by the 5,000 $\mu\text{g/l}$ contour lines appear to be associated with known RMA source areas and are similar in extent and configuration to those of other analytes; therefore, for the purposes of this discussion, fluoride concentration is considered elevated if it is in excess of 5,000 $\mu\text{g/l}$. Elevated fluoride concentrations (in excess of 5,000 $\mu\text{g/l}$) are mapped in three primary areas: the South Plants-Basin A-Basin A Neck Pathway, the Basin F- Basin F Northwest Pathways, and the First Creek Off-Post Pathway.

In the South Plants area, elevated fluoride levels occurred in a relatively small area which extended from northwestern Section 1 into southwestern Section 36. The highest fluoride concentration detected in this plume during the fall of 1988 was 64,000 $\mu\text{g/l}$ in Well 01525. Occurrences of fluoride in the Basin A Neck Pathway and along the north edge of Basin A range in concentration from 5,200 to 22,000 $\mu\text{g/l}$. Fluoride concentrations between 1,230 and 5,000 $\mu\text{g/l}$ were detected in a large plume surrounding the South Plants-Basin A - Basin A Neck area, extending to the north off-post and to the south, across the southern RMA border. The eastern as well as southern extent of the plume was poorly defined.

Fluoride concentrations in excess of 5,000 $\mu\text{g/l}$ identified during fall 1988 monitoring extended from northeast of the Basin F area along the Basin F Pathway toward the NBCS. The highest fluoride concentration in this plume and on RMA was 320,000 $\mu\text{g/l}$, on the northeast side of Basin F in Section 26. The plume extended southwest into Section 27 to the south of the NWBCS. The northwest component of the plume extended approximately 800 ft off-post, bypassing the west end of the NBCS. The northeast component terminated at the NBCS. Areas of other fluoride concentrations greater than 5,000 $\mu\text{g/l}$ were detected north of the NBCS and are discussed below.

North of the NBCS, fluoride concentrations greater than 5,000 $\mu\text{g/l}$ were detected in wells along the First Creek Off-Post Pathway. The highest concentration (5,960 $\mu\text{g/l}$) was detected in Well 37309 along the boundary between Section 13 and Section 14. Concentrations approaching 5,000 $\mu\text{g/l}$ were detected in wells in the Northern Off-Post Pathway.

In addition to the fluoride concentrations greater than 5,000 $\mu\text{g/l}$ discussed above, fluoride was detected at 5,500 $\mu\text{g/l}$ and 5,800 $\mu\text{g/l}$ in two wells near the eastern edge of the NBCS and at 7,900 $\mu\text{g/l}$ and 8,410 $\mu\text{g/l}$ in two wells in the Western Tier. Although concentrations in the two wells near the NBCS were consistent with other detections, the fall 1988 concentrations reported in the Western Tier (Wells 04038 and 33066) were anomalously high.

4.3.20.2 Confined Flow System. Fluoride analyses were performed on 166 ground-water samples from the confined flow system obtained during the fall of 1988. Concentrations above 1,220 $\mu\text{g/l}$ were recorded in 151 wells from zones B, A, 1U, 1, 2, 3, 4, 5, 6, and 7, with values ranging from 1,260 to 14,000 $\mu\text{g/l}$. Analytical results for the confined flow system from the fall of 1988, winter of 1987/88, and spring and summer of 1989 are summarized in Table 4.3.20-1. Selected point plots from the sampling programs cited above are presented in Figures A-49 through A-54.

The maximum fluoride concentration of 14,000 $\mu\text{g/l}$ was reported in Well 02030, located in the western portion of South Plants and completed to a depth of 73 ft (Figure A-49). Concentrations in the overlying unconfined flow system in this area were generally between 2,000 and 5,000 $\mu\text{g/l}$.

The deepest well in which fluoride was reported at a concentration above 1,220 $\mu\text{g/l}$ was Well 01048 at a concentration of 2,010 $\mu\text{g/l}$. The well is located near the center of Section 1 and is screened from 160 to 210 ft below ground level, in zone 2. Similar concentrations are present in the overlying unconfined flow system.

Fluoride concentrations greater than 3,000 $\mu\text{g/l}$ within the confined flow system are generally located in the vicinity of fluoride contamination within the unconfined flow system. In general, the highest fluoride concentrations (above 5,000 $\mu\text{g/l}$) in the confined flow system are located beneath Basin A, Basin A Neck, South Plants, and Sections 4 and 33 in the Western Tier. There were eight detections above 5,000 $\mu\text{g/l}$ in the confined flow system but in almost all cases, the fluoride concentration in the overlying unconfined flow system was less than in the underlying confined flow system.

4.3.20.3 Winter 87/88 and FY89 Comparison. Data from FY89 provide a more complete understanding of the distribution of fluoride in the unconfined flow system than was available in the FY88 Annual Report. In particular, the extent of fluoride in the Basin A, Basin A Neck, Basin F, and North Plants is better defined due to a higher sampling density in these areas during FY89. Plume configurations are similar near the NWBCS, in the western tier, and downgradient off-post. Wells where fluoride concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Fluoride was detected in the confined flow system in 104 of 129 samples collected during the winter of 1987/88, compared to 151 of 166 samples collected during fall 1988. Table 4.3.20-1 summarizes the winter 1987/88 and fall 1988 results for each zone of the confined system. Areas in which the presence of fluoride in the confined flow system was further substantiated include

Sections 3, 4, and 27, as well as, Basin A Neck, Basin C, D, E, and Basin F areas. Due to the general low hydraulic conductivity and large heterogeneity of the Denver aquifer, substantial data variability is likely to occur in any single sampling period. Therefore, data interpretation based on a single sample period should consider variable data appropriately.

4.3.21 Chloride

Chloride analyses were performed on 488 samples collected from the unconfined flow system and the confined flow system during the fall of 1988. Chloride, a naturally occurring constituent in ground water, was reported in every sample except one. A chloride concentration of 75,000 $\mu\text{g/l}$ was selected as the lowermost contour value for preparing a chloride plume map of the study area (Figure 4.3.21-1). This value was selected previously for the chloride plume map presented in the 1988 CMP Annual Report based on the uppermost chloride concentration representative of uncontaminated areas at RMA. Fall 1988 chloride data also indicate that 75,000 $\mu\text{g/l}$ is a reasonable value to distinguish upgradient, uncontaminated areas from contaminated areas. Fall 1988 chloride concentrations exceeded 75,000 $\mu\text{g/l}$ in 267 of 488 wells with a range from 76,000 to 19,000,000 $\mu\text{g/l}$. Chloride was detected in the confined flow system above 75,000 $\mu\text{g/l}$ within zones B, A, 1U, 1, 2, 3, 4, and 5. Chloride detections for FY89 are summarized in Table 4.3.21-1.

4.3.21.1 Unconfined Flow System. A total of 322 wells within the unconfined flow system were analyzed for chloride during the fall of 1988. Upgradient concentrations ranged from 20,000 to 72,000 $\mu\text{g/l}$ (except for an isolated detection of 79,000 $\mu\text{g/l}$ at Well 12002). Chloride concentrations within contaminated areas ranged from 76,000 to 19,000,000 $\mu\text{g/l}$ with a total of 205 detections above 75,000 $\mu\text{g/l}$.

A broad, continuous chloride plume during the fall of 1988 encompassed most of the central and north central sections of RMA (Figure 4.3.21-1). This chloride plume continued off-post northwestward toward the South Platte River. The plume expanded laterally from approximately one-half mile wide in the South Plants area to over three miles wide just off-post. Chloride contamination existed in all contaminant pathways identified at RMA except the Railyard-Motor Pool Pathway. Elevated concentrations (500,000 $\mu\text{g/l}$ or greater) occurred in the South Plants-Basin A, Basin A Neck, Basin F East, Basin F, and First Creek Off-post Pathways. Locally, chloride concentrations exceeded 1,000,000 $\mu\text{g/l}$ within these pathways. The highest fall 1988 unconfined flow system chloride concentration was 19,000,000 $\mu\text{g/l}$ at Well 26041. This well is located downgradient of Basin F in the Basin F Pathway.

Table 4.3.21-1

Chloride Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above 75,000 $\mu\text{g/l}$	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	322	205	76,000 - 19,000,000
	Winter 89	25	25	97,000 - 18,000,000
	Spring 89	258	171	76,000 - 21,000,000
	Summer 89	34	33	120,000 - 15,000,000
	Winter 87/88	311	231	77,300 - 7,400,000
<u>Confined Flow System Zone</u>				
B	Fall 88	2	1	160,000
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	14	82,000 - 5,400,000
	Winter 89	0	0	
	Spring 89	29	14	76,000 - 5,500,000
	Summer 89	0	0	
	Winter 87/88	27	5	120,000 - 3,300,000
IU	Fall 88	20	6	76,000 - 1,600,600
	Winter 89	0	0	
	Spring 89	18	5	110,000 - 1,500,000
	Summer 89	0	0	
	Winter 87/88	12	3	83,000 - 1,300,000
1	Fall 88	22	7	170,000 - 2,600,000
	Winter 89	6	3	630,000 - 2,300,000
	Spring 89	16	7	150,000 - 2,300,000
	Summer 89	6	3	660,000 - 2,600,000
	Winter 87/88	15	5	93,000 - 2,800,000
2	Fall 88	37	15	86,000 - 1,300,000
	Winter 89	11	5	81,000 - 660,000
	Spring 89	24	13	80,000 - 1,200,000
	Summer 89	11	4	120,000 - 700,000
	Winter 87/88	25	10	79,000 - 1,400,000
3	Fall 88	19	7	89,000 - 860,000
	Winter 89	3	1	250,000
	Spring 89	17	6	93,000 - 720,000
	Summer 89	3	1	270,000
	Winter 87/88	18	6	84,000 - 427,000

Table 4.3.21-1

Chloride Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above 75,000 $\mu\text{g/l}$	Range ($\mu\text{g/l}$)
4	Fall 88	18	10	76,000 - 880,000
	Winter 89	1	1	200,000
	Spring 89	16	7	190,000 - 830,000
	Summer 89	1	1	190,000
	Winter 87/88	18	5	79,500 - 400,000
5	Fall 88	9	2	370,000 - 440,000
	Winter 89	0	0	
	Spring 89	6	0	
	Summer 89	0	0	
	Winter 87/88	9	3	120,000 - 554,000
6	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	

Total Confined Flow System

Fall 88	166	62	76,000 - 5,400,000
Winter 89	21	10	81,000 - 2,300,000
Spring 89	130	52	76,000 - 5,500,000
Summer 89	21	9	120,000 - 2,600,000
Winter 87/88	131	38	79,000 - 3,300,000

Explanation:		Assumed Approximate Background Value ($\mu\text{g/l}$)
Fall 88	(Fall 1988 annual sampling event)	75,000
Winter 89	(Winter 1989 quarterly Basin F sampling event)	75,000
Spring 89	(Spring 1989 semini-annual sampling event)	75,000
Summer 89	(Summer 1989 quarterly Basin F sampling event)	75,000
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)	75,000

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

A small chloride plume occurred in the RMA Western Tier Pathway. This plume extended from the southern boundary of Section 9 due north through parts of Sections 4 and 33 at a width of approximately 1,000 feet. Chloride concentrations in this plume ranged from 91,000 $\mu\text{g/l}$ (Well 33002) to 170,000 $\mu\text{g/l}$ (Well 04043). This plume probably originated from an off-post source south or southeast of RMA.

The extent of chloride contamination was uncertain along the northeast margin of the plume, east of the North Plants, and along the Northern Off-post Pathways. Chloride concentrations exceeded 150,000 $\mu\text{g/l}$ at Wells 24107 and 37327. These wells define the eastern margin of data control in northeast RMA. These detections indicated that either background chloride concentrations were higher in this area or that unknown chloride contamination sources existed further east or southeast of this area.

Isolated detections of chloride exceeding 75,000 $\mu\text{g/l}$ occurred on-post in Sections 12 and 25. An anomalous below detection value (less than 720 $\mu\text{g/l}$) occurred at Well 27063. This well is located upgradient of the NWBCS in northcentral Section 27.

4.3.21.2 Confined Flow System. Chloride analyses were performed on 166 samples collected from wells in the confined Denver Formation flow system during the fall of 1988. A total of 62 chloride detections (above 75,000 $\mu\text{g/l}$) occurred in Denver Formation zones B through 5 ranging from 76,000 to 5,400,000 $\mu\text{g/l}$. Table 4.3.21-1 summarizes these detections and Figures A-55 through A-58 are point plots showing fall 1988 confined flow system chloride distribution.

As shown on the point plots (Figures A-55 through A-58), chloride contamination in the confined flow system occurred predominately beneath areas of unconfined flow system contamination. The highest fall 1988 chloride concentration (5,400,000 $\mu\text{g/l}$) occurred in Well 02030 screened in Denver Formation zone A. This well is located in the South Plants, east and downgradient of the highest unconfined flow system contamination in this area. The deepest fall 1988 chloride contamination was at a concentration of 280,000 $\mu\text{g/l}$ in Well 36179. This well is 151 ft deep and is located in the northwest part of Basin A.

4.3.21.3 Winter 87/88 and FY89 Comparison. Data from FY89 provide a more complete understanding of the distribution of chloride in the unconfined flow system than was available in the FY88 Annual Report. In particular, the extent of chloride in the South Plants, Basin C, Basin F area, and Section 35 are better defined due to more even coverage of the FY89 well network in these areas. Plume configurations are similar in the Western Tier, North Plants, and Sections 27

and 23. Wells where chloride concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Chloride was detected in the confined flow system in 38 of 131 samples collected during the winter 1987/88 compared to 62 of 166 samples collected during the fall 1988. Table 4.3.21-1 summarizes the winter 1987/88 and fall 1988 results for each zone of the confined flow system. Areas in which the presence of chloroform in the confined flow system were further substantiated include the South Plants, Basin A Neck, Basin F area and the NBCS. Chloroform was detected in the South Plants more frequently in fall 1988 than in winter 1987/88 because newly installed confined flow system wells were added to the network. Due to the general low hydraulic conductivity and large heterogeneity of the Denver aquifer, substantial data variability is likely to occur during any single sampling period. Data interpretation based on a single sample period may not be effective in recognizing anomalous data, therefore, variations between separate sampling events should be considered appropriately.

4.3.22 Arsenic

Analyses for arsenic were performed on 484 ground-water samples collected during the fall of 1988. Arsenic concentrations ranging from 2.41 to 117 $\mu\text{g/l}$ were detected in 90 of the 484 samples analyzed. The concentration of arsenic in the balance of the samples was below CRL. The CRL for the fall of 1988 was 2.35 $\mu\text{g/l}$. Arsenic was detected in the confined flow system within zones A, 1U, 1, 2, 4, 5, and 6. The distribution of arsenic in the unconfined flow system is illustrated in Figure 4.3.22-1. Arsenic detections for FY89 monitoring programs are summarized in Table 4.3.22-1.

4.3.22.1 Unconfined Flow System. Ground-water samples from 319 wells completed in the unconfined flow system were analyzed for arsenic during the fall of 1988. Concentrations of arsenic ranging from 2.41 to 117 $\mu\text{g/l}$ were measured in 71 samples.

Although arsenic may occur naturally in ground water at RMA, there has been no value recognized by RMA investigators or regulators to represent an upgradient background level. Therefore, a plume is defined here by arsenic concentrations greater than the CRL, 2.35 $\mu\text{g/l}$. It should be noted that arsenic detections, even those very close to the CRL, were limited largely to known RMA source areas. This indicates that background levels of arsenic at RMA may be lower than 2.35 $\mu\text{g/l}$.

Table 4.3.22-1

Arsenic Analytical Results Summary

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
<u>Unconfined Flow System</u>				
	Fall 88	319	71	2.41 - 117
	Winter 89	25	20	2.72 - 44.4
	Spring 89	258	55	2.64 - 160
	Summer 89	34	28	3.33 - 122
	Winter 87/88	313	80	2.61 - >50.0
<u>Confined Flow System Zone</u>				
B	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	0	0	
	Summer 89	0	0	
	Winter 87/88	1	0	
A	Fall 88	35	3	5.95 - 36.2
	Winter 89	0	0	
	Spring 89	29	3	2.58 - 11.5
	Summer 89	0	0	
	Winter 87/88	26	3	12.9 - >50.0
IU	Fall 88	20	2	7.60 - 26.1
	Winter 89	0	0	
	Spring 89	18	3	2.42 - 19.7
	Summer 89	0	0	
	Winter 87/88	12	2	6.57 - 23.7
1	Fall 88	22	4	2.41 - 6.77
	Winter 89	6	2	6.87 - 7.68
	Spring 89	16	2	3.69 - 6.43
	Summer 89	6	3	6.33 - 111
	Winter 87/88	15	2	7.33 - 7.54
2	Fall 88	36	3	3.32 - 11.9
	Winter 89	11	1	3.76
	Spring 89	23	2	2.66 - 8.40
	Summer 89	11	4	43.5 - 61.3
	Winter 87/88	26	1	6.79
3	Fall 88	19	0	
	Winter 89	3	0	
	Spring 89	17	2	2.49 - 2.59
	Summer 89	3	2	31.4 - 87.4
	Winter 87/88	18	2	3.88 - 6.14

Table 4.3.22-1

Arsenic Analytical Results Summary (Continued)

Formation	Sampling Event	Number of Samples	Number of Detections Above CRLs	Range ($\mu\text{g/l}$)
4	Fall 88	18	2	3.82 - 4.16
	Winter 89	1	0	
	Spring 89	16	1	9.00
	Summer 89	1	0	
	Winter 87/88	16	0	
5	Fall 88	9	4	3.22 - 9.68
	Winter 89	0	0	
	Spring 89	6	3	2.49 - 10.1
	Summer 89	0	0	
	Winter 87/88	8	3	3.23 - 12.9
6	Fall 88	2	1	3.36
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	2	0	
7	Fall 88	2	0	
	Winter 89	0	0	
	Spring 89	2	0	
	Summer 89	0	0	
	Winter 87/88	0	0	
<u>Total Confined Flow System</u>				
	Fall 88	165	19	2.41 - 36.2
	Winter 89	21	8	0.857 - 61.7
	Spring 89	129	16	2.42 - 19.7
	Summer 89	21	9	6.33 - 111
	Winter 87/88	126	13	3.23 - >50.0
Explanation:			Certified Reporting Limits ($\mu\text{g/l}$)	
Fall 88	(Fall 1988 annual sampling event)		2.35	
Winter 89	(Winter 1989 quarterly Basin F sampling event)		2.35	
Spring 89	(Spring 1989 semi-annual sampling event)		2.35/2.50	
Summer 89	(Summer 1989 quarterly Basin F sampling event)		2.35	
Winter 87/88	(Annual event including the TMP/Task 25/Task 44)		2.50/3.07	

Note: Ground water from Denver Formation zones 8 and 9 was not sampled.

The fall 1988 arsenic plume map (Figure 4.3.22-1) indicates that arsenic formed a continuous plume which originated in the South Plants and Basin A. The plume extended northwest and widened to encompass the Basin A Neck, Basin F, Basin F West, and Basin F Northwest Pathways. Arsenic concentrations ranged from 2.41 to 117 $\mu\text{g/l}$ within the plume. The plume was terminated to the west by the Northwest Boundary Containment System and to the north by the North Boundary Containment System. A small plume extended north of the North Boundary Containment System along the First Creek Off-Post Pathway in Section 14.

The highest concentrations of arsenic (illustrated by the 20 $\mu\text{g/l}$ contour line) occurred in the South Plants-Basin A-Basin A Neck Pathway and northeast of Basin F. There are several areas where arsenic concentration exceed 50 $\mu\text{g/l}$, suggesting several localized sources of arsenic contamination contributing to the otherwise areally extensive plume. The arsenic plume in the First Creek Off-Post Pathway was interpreted from detections in five wells with concentrations ranging from 2.53 to 4.80 $\mu\text{g/l}$. Isolated arsenic detections of 12.5 $\mu\text{g/l}$ occurring at Wells 04036, 04037, and 04038 were considered unreliable because they were not confirmed by historical detections of arsenic in these same wells.

4.3.22.2 Confined Flow System. During the fall of 1988, arsenic was detected in 19 of 165 ground-water samples from the confined flow system. Detected concentrations ranging from 2.41 to 36.2 $\mu\text{g/l}$ were measured in wells screened in zones A, 1U, 1, 2, 4, 5, and 6. Analytical results from individual zones of the confined flow system for FY89 are summarized in Table 4.3.22-1. Point plots of these results are presented in Figures A-59 through A-61.

The greatest depth at which arsenic was detected during the fall of 1988 was 187 ft in Well 04012 (zone 6). An arsenic concentration of 3.36 $\mu\text{g/l}$ was measured at this well. This was also the lowest stratigraphic unit containing arsenic. The highest detected concentration of arsenic was 36.2 $\mu\text{g/l}$ measured in Well 36110 (zone A). This well is located between South Plants and Basin A and is screened from 61.8 to 65.2 feet below ground surface.

4.3.22.3 Winter 87/88 and FY89 Comparison. Data from FY89 provide a more complete understanding of the distribution of arsenic in the unconfined flow system than was available in the FY88 Annual Report. In particular, the extent of arsenic in Basin A, Basin A-Neck, and Basin F is better defined due to more even coverage of the well networks in these areas. Changes in plume configurations at the NBCS and NWBCS reflect the continuing impact of these treatment systems on ground-water quality. Plume configurations are similar for both sampling periods throughout RMA. Wells where arsenic concentrations varied considerably from previous or subsequent sampling rounds are listed in Table 4.3.2-2.

Arsenic was detected in the confined flow system in 13 of 126 samples collected during winter 1987/88 compared to 19 of 165 samples collected during fall 1988. Table 4.3.22-1 summarizes the winter 1987/88 and fall 1988 results for each zone of the confined flow system. Areas in which the presence of arsenic in the confined flow system was further substantiated include Sections 3, 4, and 26. Arsenic in the confined flow system was detected more frequently in fall 1988 in the Basin F area than in winter 1987/88. This may result from additional wells present in the fall 1988 network. Due to large heterogeneity of the Denver aquifer, substantial data variability is likely to occur in any single sampling period. Data interpretation based on a single sample period may not be effective in recognizing anomalous data, therefore, variations between sample rounds should be considered appropriately.

4.3.23 Trace Metals

Analytical results for the trace metals cadmium, chromium, copper, mercury, lead, and zinc for the fall of 1988 are summarized in Table 4.3-23-1. Zinc and mercury were the most frequently detected trace metals during the fall of 1988 with 113 and 18 detections, respectively. These were also the only trace metals with detections greater than an order of magnitude over their respective CRL's.

The highest concentration of zinc (758 $\mu\text{g/l}$) was measured at Well 35087 located in southwest Section 35. Fall 1988 zinc detections greater than 100 $\mu\text{g/l}$ also were measured at Wells 26041 and 27057. Well 26041 is located along the Basin F Pathway and Well 27057 is located within the Basin F West Pathway.

The highest fall 1988 mercury detection (11.0 $\mu\text{g/l}$) was measured at Well 36056. This well is located downgradient of the lime settling ponds in Basin A. The distribution of mercury in the unconfined flow system is limited predominantly to the South Plants-Basin A and Basin F Pathways.

4.4 Gas Chromatography/Mass Spectrometry (GC/MS) Results

Analysis of ground-water samples was performed by gas chromatography/mass spectrometry (GC/MS) techniques in order to provide confirmation of analytical results of gas chromatographic (GC) methods. In addition to confirmation of target compound identity and concentration, GC/MS analyses also provided an identification and quantification of Tentatively Identified Compounds (TICs), commonly referred to as nontarget compounds.

Table 4.3.23-1

Trace Metals Analytical Results Summary

Analyte	CRL μg/l	<u>Unconfined Flow System</u>		<u>Confined Flow System</u>	
		# Analyzed/ # Detections	Range μg/l	# Analyzed/ # Detections	Range μg/l
Cd	8.40	315/5	9.04-15.9	165/4	11.2-16.9
Cr	24.0	315/2	29.6-49.5	165/2	44.1-47.0
Cu	26.0	315/6	30.8-114	165/1	37.8
Hg	0.100	320/14	0.101-11.0	165/4	0.117-0.566
Pb	74.0	315/2	78.0-287	165/1	82.2
Zn	22.0	315/74	22.3-758	165/39	23.1-99.7

Investigative samples from 74 on-post and 15 off-post wells collected during the fall 1988 and winter 1989 sampling rounds were analyzed by GC/MS techniques. Appendix C (on diskette) contains the CMP analytical results for GC/MS analyses. The GC/MS analytical methods UM21 (volatile), UM25 and JJ8 (semi-volatile) are laboratory methods which are certified by PMRMA for the CMP and are based on EPA Methods 624 and 625. Method UM25 is an updated certified method which replaced method JJ8 during FY89.

Target analytes which are routinely analyzed by GC techniques are also analyzed by GC/MS techniques for confirmation purposes. The CMP target (GC) analytes and the GC/MS methods used to confirm GC target analyte detections are listed in Table 4.4-1. For low concentrations, GC/MS techniques can not verify GC results because the CRLs for GC/MS are generally higher. For some analytes the CRLs for the two types of analyses are similar. However, the greatest disparity in CRLs between GC and GC/MS analyses is found in the semi-volatile analyses of pesticides. In all cases, dilution factors have been considered when evaluating the reported detection thresholds and sample results.

Tentatively identified compounds from the ground-water samples analyzed were used to examine the need for modification of the list of target analytes. Recommendations for the addition of TICs to the CMP target analyte list are based on the observed distribution and frequency of detections of a specific TIC.

4.4.1 Confirmation of Volatile Organic Analyte Results

GC/MS methods for volatile organics were used to confirm the identity of target analytes identified by GC methods. Using the historical guidelines of previous RMA RI/FS investigations, concentrations for FY89 analyses have been considered confirmed if the GC and GC/MS concentrations are within an order of magnitude of each other. For investigative samples analyzed by both GC and GC/MS, 202 pairs of analyte identifications were reported. Of the 202 pairs of results, 74 were confirmed within the order of magnitude historical guidelines. Fifty-one volatile organic analytes detected by GC were not confirmed because the concentrations were below the CRL for the GC/MS confirmatory analyses. Seventy-seven analytes were either not identified in both samples, or concentrations fell outside the historical guidelines even though the concentration of the analyte was reported above the CRL for the confirmatory GC/MS analysis. Volatile organic results were confirmed in 49 percent of the GC/MS results reviewed, excluding the data where concentrations of volatile organics fell below GC/MS CRLs. Unconfirmed results occurred in 51 percent of the GC analyses that reported detections above the confirmatory GC/MS method

Table 4.4-1 Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC/MS)
Certified Reporting Limits for CMP Target Analytes

Target Analytes	Certified Reporting Limits (in $\mu\text{g/l}$) (CRLs)		
<u>Volatile Organics</u>	<u>GC</u>	<u>GC/MS</u> (Method UM21)	
Chlorobenzene	0.820	1.00	
Chloroform	0.500	1.00	
Carbon tetrachloride	0.990	1.00	
1,2-Dichloroethane	0.760	5.00	
Trichloroethene	0.750	1.00	
1,1-Dichloroethene	1.70	1.00	
1,1-Dichloroethane	0.730	1.00	
1,2-Dichloroethane	1.10	1.00	
1,1,1-Trichloroethane	0.760	1.00	
1,1,2-Trichloroethane	0.780	1.00	
Methylene chloride	7.40	1.00	
Tetrachloroethene	0.560	1.00	
Toluene	1.47	1.00	
Benzene	1.05	1.00	
m-Xylene (13DMB)	1.32	1.00	
Ethylbenzene	1.37	1.00	
Xylenes (o,p) (XYLEN)	1.36	2.00	
Methylisobutyl ketone (MIBK)	4.90	1.40	
<u>Semi-volatiles</u>	<u>GC</u>	<u>GC/MS</u> (Method UM25) (Method JJ8)	
Atrazine	4.03	5.90	5.60
Malathion	0.373	21.0	14.0
Parathion	0.647	37.0	19.0
Supona	0.787	19.0	9.30
Vapona	0.384	8.50	17.0
p-Chlorophenylmethylsulfone (CPMSO2)	7.46	5.30	7.20

Table 4.4-1 Gas Chromatography (GC) and Gas Chromatography-Mass Spectrometry (GC/MS)
Certified Reporting Limits for CMP Target Analytes (Continued)

Target Analytes	Certified Reporting Limits (in µg/l) (CRLs)		
	GC	GC/MS	
<u>Semi-volatiles</u>		(Method UM25)	(Method JJ8)
p-Chlorophenylmethysulfoxide (CPMSO)	11.5	15.0	29.0
p-Chlorophenylmethysulfide (CPMS)	5.69	10.0	17.0
1,4-Dithiane	1.34	3.30	21.0
1,4-Oxathiane	2.38	27.0	7.90
Aldrin	0.0500	13.0	7.50
Chlordane	0.0950	37.0	9.40
Endrin	0.0500	18.0	8.00
Dieldrin	0.0500	26.0	4.70
Isodrin	0.0510	7.80	3.70
Hexachlorocyclopentadiene (CL6CP)	0.0480	54.0	21.0
p,p'-DDE	0.0540	14.0	6.10
p,p'-DDT	0.0490	18.0	9.20
Diisopropylmethylphosphonate (DIMP)	0.392	21.0	14.0
Dimethylmethylphosphonate (DMMP)	0.188	130	33.0
Dibromochloropropane (DBCP)	0.195	12.0	19.0
Dicyclopentadiene (DCPD)	5.00	5.50	7.30

CRL. Poor reproducibility occurred predominantly in GC/MS analyses when excessive dilution was required and results were compared to more specialized analyte-specific GC methods.

In addition to investigative samples analyzed by GC and GC/MS, 25 related QC samples (i.e., rinse, field, and trip blanks) were analyzed using these two methods. From these samples, 26 pairs of volatile organic detections were reviewed. Two pairs were not confirmed because the level of detection was below that of the confirmatory CRL. Sixteen of the paired results were confirmed within the historical guidelines. A total of eight results were not confirmed even though the level of the reported detection was above the confirmatory method CRL. The higher percentage of confirmations in these QC samples compared to the investigative samples probably is due to the lower levels of concentrations reported in these samples. Low concentration levels of analytes required no dilution of the sample.

4.4.2 Confirmation of Semi-volatile Organic Analyte Results

For the fall 1988 and winter 1989 sampling rounds, 311 sets of investigative sample detections were reported for semi-volatiles. The confirmation criteria for semi-volatile organics was the same as that used in the volatile confirmation (i.e., plus or minus one order of magnitude). Of these data sets, 43 were positively confirmed in accordance with these criteria, and 217 detections were not confirmed because GC results were below the confirmatory CRLs. In addition, 51 analytes were not confirmed within historical guidelines even though reported concentrations were above the confirmatory CRL. Therefore, excluding results where confirmation was not possible because of CRL differences, 46 percent were positively confirmed and 54 percent were not confirmed within the historical guidelines. The low percentage of positively confirmed analytes versus the number of detections can be attributed to detection limits that are two orders of magnitude greater for GC/MS results than for GC methods.

Review of the CMP confirmatory data indicates that volatile organics confirmation using GC/MS is equally efficient as semi-volatile organics confirmation. Discrepancies are generally related to the different CRLs for GC and GC/MS methods. The GC/MS method is far less sensitive to the target analytes than the equivalent semi-volatile GC methods.

4.4.3 Nontarget Compound Analytical Results

Data for tentatively identified compounds (TICs) have been compiled from the fall 1988 and winter 1989 sampling rounds. Compounds identified with a specific name by the analyst and judged to produce a characteristic spectral pattern were reviewed. Compounds not easily

distinguished on the basis of spectral character alone were not investigated further. Special attention was given to compounds commonly included on target analyte lists developed for other programs, such as those lists used by EPA. Relative retention times were not considered in sorting TICs. Tentatively identified compound information has been organized to reflect a compound's relative abundance or frequency of occurrence to serve as a guide for future sampling/analytical activities. Data for TICs are ranked in Table 4.4.3-2 according to the frequency of contaminant detections. Ranges of concentrations reported for each TIC are also presented.

The ranges of concentrations reported for TICs are estimated values because authentic standards (required to quantify target compounds concentrations) were not run to determine the absolute response factor. Tentatively identified compound information was assessed routinely for the number of identifications and respective concentrations but, because they were not on the target analyte list, further quantification was not performed.

Table 4.4.3-2 shows that butylbenzylphthalate (with 103 tentative identifications) was the TIC most often identified. Butylbenzylphthalate does appear on the EPA 1988 Contract Laboratory Program Target Compound List (CLP TCL). Butylbenzylphthalate often is identified as a result of laboratory contamination. Toxicity of this compound and most other phthalates on the EPA CLP TCL list is poorly defined.

The remaining compounds in Table 4.4.3-2 were grouped into three distinct groups of compounds. These groups were CMP target analytes, non-CMP target analytes that are listed on the EPA CLP target compound list (TCL), and non-CMP target analytes that do not appear on the EPA CLP TCL. The group containing CMP target analytes represents identifications that may have gone undetected in GC analysis due to shifts in retention times or matrix interferences. The second class of compounds includes compounds such as butylbenzylphthalate.

In general, the occurrence of analytes in the third group of compounds appears to be associated with chemical sources at South Plants, Basins A and F, and to a lesser degree with Basins C, D, and E. Multiple nontarget analyte occurrences in wells usually were associated with target analyte occurrence.

4.4.4 Conclusions for GC/MS Confirmation

Analytical data collected for purposes of confirmation of volatile organic analytes were within historically defined confirmation guidelines for 49 percent of the samples reviewed. Semi-volatile GC versus GC/MS results were slightly less comparable at 46 percent confirmation. Lack of

Table 4.4.3-2 Tentatively Identified Compounds (TICs)

Compound Name	Number of Detections	Range of Concentrations (in µg/l)
Benzyl butylephthalate ^a	103	10 - 200
Dichlorobenzene	52	6 - 2000
4,4-Dioxide, 1,4-oxathiane	29	4 - 100
Trichlorobenzene ^a	16	5 - 100
Diisopropylmethylphosphonate (DIMP) ^b	14	7 - 700
n,n'-bis (1-Methylethyl)-UREA	14	4 - 20
n,n-Dipropyl acetamide	11	4 - 40
3,4-bis(Methylene)-cyclopentanone	10	6 - 60
Methyl safonylbenzene	9	7 - 10
Tetradecanoic acid	9	5 - 200
Dicyclopentadiene (DCPD) ^b	8	4 - 600
n,n-Dipropyl-acetamide	6	5 - 20
1-Chloro-4-(methyl sulfinyl)-benzene	6	5 - 50
Tetrachlorobenzene	6	6 - 20
Decanoic acid	4	8 - 20
Dibenzo furanamine	4	8 - 30
Dodecanoic acid	4	6 - 300
Bromocil	3	5 - 20
Dichloro methyl benzenemethanol	3	4 - 8
1,1,2-Trichloro-1,2,2-trifluoroethane	3	20 - 200
Hexachlorocyclopentadiene (CL6CP) ^{ab}	3	4 - 20
Hexadecanoic acid	3	8 - 90
1,1-oxy bis Benzene	2	80 - 300
Chlorophenyl methyl sulfoxide (CPMSO)	2	10 - 50
Chloro methyl sulfonyl benzene	2	5 - 40
Cynazine	2	10 - 200
n,n-Dibutyl formamide	2	4 - 10
1,1-Dichloro-2,2-diethoxy ethane	2	5 - 10
Methyl cyclopentadiene	2	8 - 20
n-Nitroso-n-propyl-t-propanamine	2	8 - 70
Octadecanoic Acid	2	10 - 20
2-Methyl-2,4-pentanediol	2	4 - 9
Trichloro ethyl benzene	2	5 - 6
Trichlorocycloalkene	2	30 - 90
Triethylene Glycol (ACN)	2	9 - 90
2-(Dichloromethyl)-1,3-dioxolane	1	50
1,3-Dithiolane	1	7
1,4-Oxathiane (OXAT) ^b	1	10
2,4-Dimethyl-2-pentanol	1	5
2-(Dichloromethyl)-1,3-dioxolane	1	60
2-Bromo-1,2-dichloropropane	1	8
2-Methoxy-3,8-dimethyl-azocine	1	6
2-Methyl-2,4-pentanediol	1	5
2-Propyl-1,3-dioxolane	1	5

a - CMP target analytes

b - EPA CLP TCL

Table 4.4.3-2 Tentatively Identified Compounds (TICs) (continued)

Compound Name	Number of Detections	Range of Concentrations (in µg/l)
3,5-Dimethyl-1,2,4-trithiolane	1	10
Analine	1	6
4-Chloro-Benzenesulfonamide	1	20
Benzaldehyde	1	30
Methoxy-benzene	1	70
4-Chloro-benzenesulfonamide	1	4
bis (2-Ethylhexyl)phthalate	1	9
Butyl benzene	1	9
Chloro-methylthiobenzene	1	6
Cyclohexanone 3,3,5-trimethyl	1	40
Cyclopentene substituted toluene	1	20
Cyclopropane, tetramethylidene	1	6
Dichloro methyl quinolinol	1	20
Dichloropropyl phenol	1	10
Diethyl ester phosphonic acid	1	7
Dihydroxy methyl ester benzoic acid	1	9
Dimethylbenzenamine	1	10
Dodecanoamide acid	1	100
Emthylsulfonyl benzene	1	5
1,1-bis(Methyl thio)-ethane	1	6
1,1-Dichloro-2,2-diethoxy-ethane	1	10
1-Phenyl-ethanone	1	200
Ethyl-methyl-benzo[B]thiophene	1	5
Fluorophenol	1	5
Hexachloro-1,3-butadiene ^a	1	9
Methyl thiirane	1	20
Methyl (methyl thio)methyl disulfide	1	8
Methylbenzene methanamine	1	40
n-Butyl-n(1-methylethyl)-formamide	1	6
n,n-Dimethyl acetamide	1	5
Thietane	1	6
Thiophene	1	8
Trichlorobenzene methanol	1	10
Trisulfide, dimethyl	1	200
1,1,2,2-Tetrachloroethane ^a	1	5
5-Methyl-1,3-cyclopentadiene	1	7

a - CMP target analytes

b - EPA CLP TCL

analyte confirmation was predominantly due to the discrepancy between GC/MS method CRLs and GC method CRLs. Another important factor was that high level samples containing multiple target analytes were more highly diluted in GC/MS method analysis versus the more specific GC methods that required less dilution due to detection selectivity or specific instrumental conditions. Detections of nontarget semi-volatile analytes generally coincided spatially with detections of target analytes and generally were located in proximity to potential contaminant source areas.

The results of the nontarget assessment indicated the presence of numerous nontarget analytes in ground-water samples from many areas of RMA. Butylbenzylphthalate was the most commonly identified TIC but was thought to be a product of laboratory contamination, in that it is a relatively common laboratory artifact. Dichlorobenzenes were present in CMP, samples historically, including 1988. In the current year they were detected in significantly high quantities. The majority of nontarget analytes commonly consisted of halogenated and nonhalogenated hydrocarbons. The compounds most commonly identified were substituted aromatic hydrocarbons, presumably because of their generally higher relative solubility in water.

4.5 Quality Assurance/Quality Control (QA/QC)

The QA/QC Plan implemented during the CMP is based on the Chemical Quality Assurance Plan, version 1.0, dated July 1989, from the Program Manager's Office at RMA, the subcontract laboratory's QA program and the requirements of the CMP contract (PMRMA, 1989a). The objectives of the Quality Assurance Program for the RMA CMP are to:

- Ensure that technically defensible and consistent field procedures are used in the collection of samples;
- Document procedures used in the collection, preservation, and handling of samples by using field data sheets, logbooks, sample control logbooks, etc.;
- Collect additional samples of all media such that data accuracy, precision, and representativeness may be assessed; and
- Perform chemical analysis of all samples, including those collected for quality control, according to documented certified procedures that will ensure data validity.

Field sampling procedures consisted of sample collection protocols that include appropriate QC sample collection, sample handling and storage, sample preservation, holding times, documentation

that is legal and defensible, and proper shipping procedures. Field QC samples consisted of trip, field, and rinse blanks and duplicate (or split) samples.

This section of the Annual Report presents an interpretation of the analytical data resulting from analysis of field-derived QC samples. Sampling and QA/QC procedures stipulate the type and minimum frequency at which field derived QC samples are to be submitted to the program laboratory. The CMP QA/QC program requires that sample duplicates (splits), field blanks, trip blanks, and rinse blanks be collected and submitted for analysis.

Sample splits are defined under the CMP as two identical sets of sample bottles that are submitted to the laboratory for an identical suite of analyses. Splits are collected by alternately filling sample bottles. The purpose of split samples is to measure the analytical variability that results from analysis of two identical samples. Field blanks consist of sample bottles filled in the field with distilled/deionized organic free water and submitted to the laboratory to determine if the sampling procedure has introduced extraneous contaminants to ground-water samples. Trip blanks consist of 40 ml VOA bottles filled by the laboratory with organic free distilled/deionized water, transported to the field site, and shipped back to the laboratory in an unopened state. These samples are used to assess if contaminants are introduced into samples during the transport and handling process. Rinse blanks evaluated the extent to which sampling equipment had been decontaminated. Organic free distilled/deionized water is poured over decontaminated field sampling equipment, collected, and transported to the laboratory for analysis.

A total of 977 investigative ground-water samples were collected during the fall 1988, winter 1989, spring 1989, and summer 1989 sampling events. In addition to these 977 investigative samples, 49 rinse blanks, 50 field blanks, 50 trip blanks, and 98 duplicate QC samples were collected.

Laboratory QC data were reported weekly to PMRMA in a QA Status Report that included all laboratory QC data, including precision and accuracy control charts for each sample lot. QC data were examined in relation to the criteria established during the analytical certification process. Deviations from the established QC criteria were identified by the laboratory, and appropriate corrective actions taken. The data were then reviewed for reliability by the Program QA officer. Any data deemed unacceptable by the Project Management QA personnel were not accepted for entry into the Installation Restoration Data Management System (IRDMS). As this process addresses the QA/QC aspects of laboratory analysis this subject is not addressed in this section of this report.

4.5.1 Evaluation of Blank Data

Chemical analysis of trip, field, and rinse blanks were performed to ensure integrity of CMP data and check for contamination from field or laboratory sources. Blanks were analyzed for volatile organics, semi-volatile organics, and inorganics.

Objectives for assessment of blank data were to identify and, if possible, quantify the magnitude of contamination introduced during the sampling and shipping process and decontamination of sampling equipment. There is no published regulatory guidance document designed to aid in the assessment of the applicability of field blank QC results with respect to the utility of the final investigative data.

Contamination detected in the field blanks was not used to correct final data but should be evaluated carefully to determine whether the detected contamination was inherent in the environment or was a result of the sampling process. Contaminants identified in the blanks that were absent in laboratory preparation blanks indicate a potential field sampling problem, a deficiency in bottle preparation, a decontamination problem, or a failure to prepare the laboratory blank in a manner similar to the field blank.

4.5.1.1 Volatile Organic Quality Control Data Review. Trip, rinse, and field blanks were collected and their data reviewed for four rounds of ground-water monitoring. These data were reviewed to identify compounds not characteristic of ground-water chemistry, but resulting from some external or internal laboratory practices. Identification of these artifact compounds is critical in evaluating the ultimate utility of affected analytical results. Nine different compounds were identified in blanks from these four sampling events. Table 4.5.1.1-1 summarizes the target analyte concentration and type of blanks for each artifact detected. Blanks analyses are listed by well number. The concentration of the blank artifact found in the related ground-water sample taken from the same location just prior to the collection of the blank sample also is presented in Table 4.5.1.1-1.

Data presented in Table 4.5.1.1-1 for volatile analyses show that chloroform (CHCL3) at levels above the CRL commonly occurred in rinse blanks. Chloroform was not identified in trip blanks, and only a single low-level detection was reported in field blanks. Chloroform found in investigative samples indicates that samples from Wells 02023, 01525, 26151, 26160, 26161, 22064, 23118, 35077, 35089, 36114, and 36177 may have been affected by CHCL3 contamination. Investigative sample concentrations are generally within an order of magnitude of the

Table 4.5.1.1-1 Quality Control Sample Artifact Summary, Volatile Organic Analyses

Well Number	Chemical Abbreviation	Blank Artifact Concentration ($\mu\text{g/l}$)	Investigative Sample Concentration ($\mu\text{g/l}$)
<u>Trip Blanks</u> (50 collected)			
02023	C6H6	1.26	<1.05
27064	CLC6H5	1.96	<0.820
<u>Field Blanks</u> (50 collected)			
02023	C6H6	3.80	<1.05
02023	CHCL3	1.23	0.581
26153	CH2CL2	10.1	<7.40
<u>Rinse Blanks</u> (49 collected)			
01510	C6H6	3.84	30.0
01510	CH2CL2	16.1	<2.48
01510	CHCL3	1.24	350
02023	C6H6	2.36	<1.05
23205	MEC6H5	2.45	1.71
23220	CHCL3	2.12	5900
23220	TCLEE	2.14	200
26153	TCLEE	11.0	<0.750
26156	CHCL3	4.18	14.0
26156	DCPD	10.5	<15.6
26156	TCLEE	1.48	3.15
26160	CHCL3	1.62	1.43
27064	CHCL3	30.1	0.643
27064	TRCLE	0.915	<0.560
33068	TCLEE	1.30	<0.750
35061	CHCL3	1.52	<0.500
35089	CHCL3	1.04	1.77
35089	CLC6H5	21.0	23.9
35089	DBCP	0.514	0.632
36114	CHCL3	0.765	2.58
36177	C6H6	2.34	28.0
36177	CHCL3	89.0	117
36177	CLC6H5	1.33	12.4
36177	TCLEE	1.76	25.1
36177	TRCLE	0.857	6.38
37355	TRCLE	1.46	14.6
37381	CHCL3	12.0	<0.500
37381	CLC6H5	10.4	2.32

concentration found in the associated field or rinse blank. On this basis, chloroform must be considered an artifact of field operations or laboratory practices.

Samples from Wells 01510, 26156, and 36177, collected just prior to collection of the related rinse blank, contained concentrations of chloroform that were above those reported for the blank. This indicates that decontamination of sampling equipment was not complete. This is most obvious in Well 36177, which contained 177 $\mu\text{g/l}$ and the related rinse blank contained 89 $\mu\text{g/l}$. The sample from Well 27064 contained only 0.643 $\mu\text{g/l}$ chloroform and the related field blank contained 30 $\mu\text{g/l}$. In this case, the rinse blank and the investigative sample were affected by some other type of field or laboratory practice. In the case of the three previously mentioned samples, the levels of chloroform detected in these samples was greater than five times the levels detected in the blank and should be considered characteristic of the investigative sample water chemistry.

Tetrachloroethene (TCLEE) was detected in six rinse blanks. In four of these cases, the related investigative sample collected just prior to the QC sample contained TCLEE at concentrations at least five times greater than those detected in the related QC sample. In the remaining two cases, the related investigative sample results did not indicate the presence of TCLEE. Of the samples related to those four cases that exhibited cross-contamination between samples (carryover), none of the investigative sample results were affected by TCLEE carryover.

Benzene (C_6H_6) was detected in a single trip blank and field blank. In both of these cases, both of the related samples reported benzene at concentrations below the method CRL. Benzene was identified in three rinse blanks. Two of these detections probably are the result of carryover from the related investigative sample. However, one of the other investigative samples collected on the same day as these two blanks had benzene concentrations greater than the CRL. Based on these observations, benzene may have been introduced during laboratory procedures or other unrelated field activities.

Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$) was detected in one trip blank and two rinse blanks. The potential for carryover is exhibited in the sample from Well 35089 because chlorobenzene was detected in the related investigative sample at a concentration of 23.9 $\mu\text{g/l}$ and in the rinse blank sample at a concentration of 21.0 $\mu\text{g/l}$. Chlorobenzene was not detected in any of the other investigative samples collected on this day.

Similarly, methylene chloride (CH_2Cl_2) was detected in a trip blank and a rinse blank, but was not detected in any of the related investigative samples except the sample from Well 01525. In

this sample, high concentrations of other target analytes required excessive dilution to bring the highest level analytes into the linear range of the method. In doing so, the CH₂CL₂ artifact concentration was artificially increased to 8400 µg/l. This result should not be considered representative of the sample chemistry.

Trichloroethene (TRCLE) was detected in three rinse blanks. In two of the three cases, carryover may have occurred; however, none of the related investigative samples exhibit TRCLE levels above the method CRL. Carryover of TRCLE is thus not expected to have impacted the investigative analytical results. A single detection of each of the following chemical constituents was also observed in rinse blanks analyzed for volatile organic constituents: toluene (MEC₆H₅), dicyclopentadiene (DCPD), and dibromochloropropane (DBCP). Of these three, two could potentially be the result of carryover from the related investigative sample. Investigative sample results are negative for all three analytes suggesting carryover of these compounds has not affected the analytical results.

Overall, it appears that sample contamination was a minor problem in FY89 volatile organic analyses.

4.5.1.2 Semi-volatile Organic and Pesticide Quality Control Data Review. In the 149 QC samples analyzed for semi-volatile chemical constituents during FY89, 11 unique types of target analytes were detected. These data are presented in Table 4.5.1.2-1.

A variety of semi-volatile target compounds was detected in three of the 50 trip blanks analyzed for semi-volatile compounds during FY89 ground-water sampling. Carryover from the investigative sample collected and transported to the laboratory with the QC trip blank was observed only in Sample 23237. As shown in Table 4.5.1.2-1, this investigative sample contained 0.581 µg/l of Vapona (DDVP) and the related trip blank contained 0.862 µg/l of DDVP. This analyte was also detected in wells 26089 and 26088 at concentrations close to those reported in the blank and related investigative sample. DDVP was detected in Well 26089 at a concentration of 1.57 µg/l and in Well 26088 at a concentration of 0.95 µg/l. In all other types of QC samples, DDVP always was detected at a higher concentration in the QC sample than in the related investigative sample. This indicates that a laboratory contamination problem may exist. A review of the overall analytical results for DDVP in the four quarters of the CMP reveals that 43 of 57 detections recorded were at concentrations near five times the method CRL. These low level values should be considered as artifacts on the basis of these QC results.

Table 4.5.1.2-1 Quality Control Sample Artifact Summary, Semi-Volatile Organic and Pesticide Target Analytes

Well Number	Chemical Abbreviation	Blank Artifact Concentration ($\mu\text{g/l}$)	Investigative Sample Concentration ($\mu\text{g/l}$)
<u>Trip Blanks</u> (50 collected)			
09010	PPDDT	0.108	<0.0490
23237	DDVP	0.862	0.581
36114	DDVP	0.603	<0.384
<u>Field Blanks</u> (50 collected)			
01510	DIMP	0.607	0.694
01510	PPDDE	0.122	<0.0540
01510	PPDDT	0.0880	0.418
23049	ISODR	0.0829	1.80
23049	DLDRN	0.124	0.637
23049	PPDDE	1.00	1.10
23237	DDVP	0.819	0.581
24161	ALDRN	0.114	<0.0500
24161	DIMP	0.916	67.0
24161	DLDRN	0.0584	3.20
26096	DITH	7.48	180
26096	OXAT	24.1	11.4
26160	DIMP	130	350
31014	DIMP	0.742	0.888
34508	DIMP	0.599	2.94
37381	DIMP	1.20	<0.392
<u>Rinse Blanks</u> (49 collected)			
23189	DDVP	1.54	<0.384
23189	SUPONA	2.26	<0.787
23189	ENDRN	1.124	<0.0500
23189	PPDDT	0.128	<0.0490
23205	DLDRN	0.0920	0.134
22305	ENDRN	0.0548	0.0810
23220	DIMP	0.598	150
24013	DLDRN	0.0518	0.534
24201	DKDRN	0.130	6.20
26140	DIMP	1.19	1.77
27064	DIMP	2.26	<0.392
35058	DLDRN	0.125	86.0
36177	DIMP	0.510	680
37321	DLDRN	0.0524	<0.0500
37354	DIMP	1.02	2.22
37376	DIMP	0.567	0.813
37381	DIMP	0.899	<0.392
37381	DMMP	0.366	<0.188

Of the field blanks collected during FY89 16 samples had detections above the GC method detection limit. Vapona was detected at a concentration of 0.581 $\mu\text{g/l}$ in a single sample, but is not thought to indicate a field problem. Diisopropylmethylphosphonate (DIMP) was detected in six of the field blanks. In all but one case, the concentration detected in the investigative sample collected just prior to the analysis of the QC blank is higher than that reported for the related QC sample. This indicates that airborne DIMP has contaminated the QC samples in the field or that analytical cross-contamination for samples in the same analytical lot has occurred. The latter explanation seems to be the most plausible. In this case, those samples in the analytical lots related to samples from Wells 01510, 24161, 16160, 31014, 34508, and 37381 may have been affected. Similarly, PPDDE, PPDDT, isodrin, dieldrin, aldrin, dithiane, and oxathiane found in the field blanks probably represent laboratory generated artifacts, because none of the compounds are very volatile or soluble in water. This indicates that results for those compounds listed in Table 4.5.1.2-1 should be suspect in those samples contained in the same lot with the respective QC sample wells listed in this table. Although the majority of detections are greater in the related investigative samples than in the QC rinse blank samples, the mechanism for the observed contamination cannot be evaluated at this time.

In conclusion, semi-volatile and pesticide results for investigative samples analyzed in the same analytical lot as the contaminated rinse or field QC samples listed in Table 4.5.1.2-1 should be utilized considering the following guidelines. Compounds identified in the investigative sample and in the related QC sample at levels of concentration within five times of each other should be considered artifacts of laboratory practices. The use of a five times cut-off for distinguishing uncommon artifacts from actual sample constituents was obtained from the U.S. EPA Laboratory (USEPA, 1988). Concentrations in investigative samples of artifacts identified in related QC samples that are greater than five times those levels identified in the blank should be considered biased high or estimated values.

4.5.1.3 Inorganic Data Quality Control Review. The QC review for the inorganic data was confined to the trace elements because of the potentially toxic nature of those artifacts. The dissolved solids (e.g., nitrate, sulfate, potassium, etc.) were not considered in this review because of their strong association with general water chemistry.

The trip, field, and rinse blanks containing detectable concentrations of trace elements are summarized in Table 4.5.1.3-1. The table compares the concentration detected in the blank to the concentration detected in the related investigative sample.

Table 4.5.1.3-1 Quality Control Sample Artifact Summary, Inorganic Analyses

Well Number	Chemical Abbreviation	Blank Artifact Concentration (µg/l)	Investigative Sample Concentration (µg/l)
<u>Trip Blanks</u> (50 collected)			
09010	CYN	11.0	13.8
22051	CYN	11.0	11.1
24013	CYN	14.2	6.43
24013	ZN	30.2	26.9
26017	AS	5.01	61.9
26096	ZN	23.4	<22.0
27064	CYN	10.6	10.7
34508	ZN	36.1	<22.0
36114	CYN	15.5	8.57
36177	CD	12.0	16.6
36177	CYN	15.2	16.6
<u>Field Blanks</u> (50 collected)			
09010	CYN	11.7	13.8
22051	CYN	15.4	11.1
26017	AS	3.50	61.9
26096	ZN	41.6	<22.0
27064	CYN	9.51	10.7
34002	ZN	28.6	<22.0
36114	CR	41.4	<24.0
36114	CYN	15.4	8.57
36177	CYN	16.3	16.6
<u>Rinse Blanks</u> (49 collected)			
09010	CYN	15.5	13.8
22051	CYN	23.0	11.1
22051	ZN	22.4	33.2
23205	ZN	26.9	<22.0
23205	CYN	11.0	<5.00
24013	CYN	6.84	6.43
26017	AS	6.71	61.9
26020	CYN	7.03	5.99
26156	CYN	6.58	8.66
27064	ZN	29.0	<22.0
36114	CR	83.3	<24.0
36114	CYN	16.9	8.57
36114	ZN	26.4	<22.0
36177	CYN	17.3	16.6
37355	ZN	76.4	<20.0
37381	ZN	103	<22.0

The most common artifact detected in the FY89 blank analyses of trace elements was cyanide (CYN). Cyanide concentrations in blanks ranged from 6.58 to 23.0 $\mu\text{g/l}$. The investigative samples affected by cyanide carryover are from Wells 09010, 22051, 24013, 27064, 36114, 36177, 26020, and 26156.

In two of the samples in which cyanide was detected in both the blank and in the related investigative sample, cyanide was detected in the rinse blanks only, and not in field or trip blanks. In all of the remaining samples, cyanide was detected in all three types of QC samples listed in Table 4.5.1.3-1. This indicates that, in all samples except those from Wells 26020 and 26156, contamination was probably related to laboratory cross-contamination. Therefore, CMP sample results for cyanide, detected at levels within five times the method CRL of 5.00 $\mu\text{g/l}$ (as per EPA Guidelines, 1988), should be viewed as laboratory-produced artifacts.

Artifacts of zinc (ZN) are the second most commonly observed inorganic constituents in blank samples. Related investigative samples in all but two of the cases shown in Table 4.5-3 appear to be unaffected by ZN carryover. This indicates that ZN artifacts are related to the chemistry of the water used in preparing the QC samples. Sample 22051 is the only sample in which ZN was detected in the investigative sample and in the rinse blank. ZN was not detected at a concentration above the method CRL in any other sample collected on the same day.

Arsenic (AS) was detected in a trip blank at 5.01 $\mu\text{g/l}$, in a field blank at 3.50 $\mu\text{g/l}$, and in a rinse blank at 6.71 $\mu\text{g/l}$. These blanks are related to a single investigative sample, 26017, in which an Arsenic concentration of 61.9 $\mu\text{g/l}$ was detected. Because Arsenic was detected in all three types of blanks, it must be assumed that the observed concentrations in both the QC and investigative sample are unrelated and are representative of actual differences in water chemistry.

Cadmium (CD) and Chromium (CR) were detected in QC samples but not in the related investigative samples. Their presence must, therefore, be related to the water chemistry of the QC samples.

Based on the QC review of the inorganic trace elements in rinse, trip, and field blanks, cyanide concentrations detected at levels near five times the method CRL should be considered questionable. All other indications are that inorganic artifacts detected during the CMP are related to QC sample water chemistry and have not significantly affected the investigative sample results.

4.5.2 Evaluation of Data for Sample Duplicates

The objectives of evaluating field duplicate sample results are to assess the potential problems of precision of the sampling and analytical systems, determine if there are any significant variations between duplicate samples, and assess the validity of the duplicate results by verifying that the results are reproducible. The CMP selected at random 10 percent of the total number of samples collected.

A field duplicate is a second sample collected from the same site, submitted to the laboratory as a separate sample, and analyzed independently. The results are an external check on the combined precision of sampling and analysis. The results may exhibit more variability than laboratory duplicates because their measurement is a combination of field and laboratory performance.

Actions taken as a result of duplicate sample analysis must be weighed carefully. It is difficult to determine if poor precision is a result of sample nonhomogeneity, sampling variability, method defects, or laboratory technique. Aqueous samples containing high levels of solids can produce erratic duplicate sample results for organic and inorganic analyses. In general, the results of duplicate sample analysis should be used to support conclusions drawn about the quality of data rather than as a basis for these conclusions.

Duplicate samples were collected at 98 well locations during the CMP and analyzed. Results were compared to determine the reproducibility of analytical results. To evaluate the large quantity of paired analytical results reported, duplicated sample results were statistically evaluated using the standard EPA duplicate sample agreement (DSA) procedure. Paired analytical results used in this statistical study included only those duplicate analyses wherein at least one positive identification and quantitation was recorded. Estimated values were excluded from the database. DSA was calculated by taking the absolute value of the difference between the two matched values and dividing this difference by the average of the two values and then multiplying this quotient by 100. The DSA value for a matched pair of results, therefore, is expressed as the percent difference that the duplicate result is away from the average of the two measured concentrations. Table 4.5.2-1 lists the average and range of these DSA values for each target analyte along with the number of matched pairs utilized in performing the statistical evaluation. A DSA value of 67 percent represents a reported concentration that is twice that of the duplicate. In general, DSA values are meant to provide a general indication of reproducibility, and should not be evaluated quantitatively.

Table 4.5.2-1 Duplicate Results Summary

Target Analyte	Test Name	Number of Duplicates	Low DSA (percent)	High DSA (percent)	Average DSA (percent)
<u>Volatiles</u>					
1,1,1-Trichloroethane	1,1,1-TCE	8	1.14	59.9	12.0
1,1,2-Trichloroethene	1,1,2-TCE	2	2.36	5.62	3.99
1,1-Dichloroethene	1,1-DCE	8	0.41	30.9	9.18
1,1-Dichloroethane	1,1-DCLE	8	1.60	35.8	14.1
1,2-Dichloroethene	1,2-DCE	4	0.401	12.1	6.34
1,2-Dichloroethane	1,2-DCLE	8	1.95	87.0	17.3
n-Xylene	1,3-DMB	2	18.1	71.8	45.0
Benzene	C6H6	23	1.72	156	55.5
Carbon tetrachloride	CCL4	7	1.93	87.2	40.2
Methylene chloride	CH2CL2	3	33.2	52.0	41.4
Chloroform	CHCL3	52	0.000	194	36.1
Chlorobenzene	CLC6H5	26	0.000	125	41.0
Dibromochloro propane	DBCP	22	0.612	137	30.0
Dicyclopentadiene	DCPD	11	2.45	16.2	8.09
Ethyl benzene	ETC6H5	3	19.6	86.1	47.4
Toluene	MEC6H5	12	0.57	114	44.3
Trichloroethene	TRCLE	39	0.000	168	27.7
Tetrachloroethene	TCLEE	23	0.000	170	31.7
Xylene	XYLEN	6	1.01	163	72.0
Total Number of Duplicates		267			33.1*
<u>Semi-Volatiles</u>					
Aldrin	ALDRN	18	0.000	196	52.5
Atrazine	ATZ	15	1.16	172	35.8
Hexachlorocyclopentadiene	CL6CP	14	2.12	119	22.7
Chlorodane	CLDAN	16	4.08	200	71.8
Chlorophenyl methyl sulfide	CPMS	6	7.41	60.3	24.7
Chlorophenyl methyl sulfoxide	CPMSO	7	0.91	124	48.7
Chlorophenyl methyl sulfone	CPMSO2	10	0.000	130	32.4
Vapona	DDVP	4	0.53	105	57.6
Diisopropylmethyl phosphonate	DIMP	54	0.000	196	28.2
Dithiane	DITH	11	5.40	195	55.6

* Weighted mean of the average DSAs

Table 4.5.2-1 Duplicate Results Summary (continued)

Target Analyte	Test Name	Number of Duplicates	Low DSA (percent)	High DSA (percent)	Average DSA (percent)
<u>Semi-Volatiles (continued)</u>					
Dieldrin	DLDRN	30	0.000	195	25.2
Dimethylmethyl phosphonate	DMMP	10	0.282	124	37.9
Endrin	ENDRN	21	2.98	169	44.3
Isodrin	ISODR	16	3.55	169	51.7
Malathion	MLTHN	6	3.19	53.9	19.6
Oxathiane	OXAT	11	2.71	140	42.8
2,2-bis (Para-chloro phenyl)-1,1-dichloroethene	PPDDE	11	2.20	65.8	28.0
2,2-bis (Para-chloro phenyl)-1,1,1-trichloroethane	PPDDT	18	3.53	181	63.5
Parathion	PRTHN	7	8.49	54.6	25.7
Supona	SUPONA	5	0.738	19.9	6.31
Total Number of Duplicates		290			38.9*
<u>Inorganics</u>					
Arsenic	AS	17	0.000	166	22.5
Calcium	CA	81	0.000	39.8	3.22
Chloride	CL	99	0.000	162	7.56
Copper	CU	3	8.12	52.9	36.2
Cyanide	CYN	21	0.200	121	25.8
Fluoride	F	98	0.000	165	11.7
Mercury	HG	3	18.3	62.1	40.7
Potassium	K	86	0.295	39.5	7.16
Magnesium	MG	75	0.000	165	5.45
Sodium	NA	81	0.000	20.7	3.43
Nitrate	NIT	89	0.000	14.5	1.95
Sulfate	SO4	99	0.000	198	13.4
Zinc	ZN	27	5.98	115	38.9
Total Number of Duplicates		779			9.19*

* Weighted mean of the average DSAs

4.5.2.1 Volatile Organic Duplicate Results. In the 98 sample duplicates analyzed for volatile organics, 267 positive identification sets were compared to assess the statistical reproducibility of the analytical results. Statistical analyses were performed on those analytes having at least two sets of matching analyte pairs. Single matched pairs were not considered statistically significant in terms of portraying method reliability for a given analyte. Volatile DSA values ranged from 0.0 to 194 percent. Chloroform had the highest DSA value and also shared the lowest value with chlorobenzene. The smallest range of DSA values was found for 1,1,2-Trichloroethene (2.4 to 5.6 percent) and 1,2-Dichloroethene (0.4 to 12.1 percent). Dicyclopentadiene precision was also quite good with a range of DSA values between 2.4 and 16.2 percent. The average DSA was calculated to minimize outlier bias in the interpretation of method precision for each analyte. The average DSA values for the various volatile analytes ranged from 3.9 to 72.0 percent. All analytes except xylene were within 100 percent of the related duplicate concentration for that analyte. The average of the mean DSA for volatiles is 30.7 percent. This indicates that duplicated results for volatile organic analytes were generally within plus or minus 45 percent of the sample result or within 30.7 percent of average of all pairs reported.

4.5.2.2 Semi-volatile Organic Duplicate Results. Duplicate results for 290 pairs of positive target analyte identifications were statistically analyzed for semi-volatile organics and pesticides. Semi-volatile DSA values ranged from 0.00 to 196 percent. The analytes that showed an overall lower range in DSA values as compared to the majority of analyte ranges included, CPMS (7.41 to 60.3 percent), malathion (3.19 to 53.9 percent), PPDDE (2.20 to 65.8 percent), parathion (8.49 to 54.6 percent), and Supona (0.74 to 19.9 percent). These lower ranges in DSA values are generally reflected in the average DSA values for the above listed analytes. The average DSA value for the semi-volatiles was 38.9 percent. A DSA of 67 represents a reported value that is twice that of the duplicate value; therefore, semi-volatile duplicated results generally were confirmed within plus or minus 58 percent of the investigative sample results, or results for the duplicate were within 38.9 percent of the average of all pairs reported.

4.5.2.3 Inorganic Duplicate Results. Duplicate results for 779 pairs of inorganic positive target analyte detections were analyzed. Single pair detections for cadmium and chromium were not included in this statistical evaluation. Inorganic DSA values ranged from 0.00 to 197 percent. Sulfate displayed the highest overall range in values, and many analytes recorded the lowest DSA value. The generally lowest ranges of DSA values are detected in the results for nitrate (0.00 to 14.5 percent), sodium (0.00 to 20.7 percent), potassium (0.290 to 39.5 percent), and calcium (0.00 to 39.8 percent). Seven of the 13 inorganic analytes had average DSA values below 10.0. Nitrate had the lowest average DSA of 1.90 percent. Zinc had the highest average DSA value of 38.9 percent. The mean of the average DSA values for inorganics is 16.8 percent; therefore,

inorganic duplicate results are generally confirmed within plus or minus 25 percent of the investigative sample result, or 16.8 percent of the average reported value for each paired result.

4.5.2.4 Summary of Duplicate Results. Duplicate results obtained for the CMP are the results of analyzing co-located water samples obtained at slightly different times from a single well. In evaluating the results from such paired samples, the nonhomogeneity of the sampling medium is believed to have little affect on the reported result. Sampling conditions, preservation, transport, storage, analysis, report generation, and QA reviews may have significantly affected the recorded result between an investigative sample and its duplicate. In general, DSA values provide guidance in the interpretation of analytical results for a specific analyte or group of chemical constituents. For example, volatile results in FY89 generally were more reproducible than semi-volatile results. Inorganic results were significantly more reliable than organic analytical results.

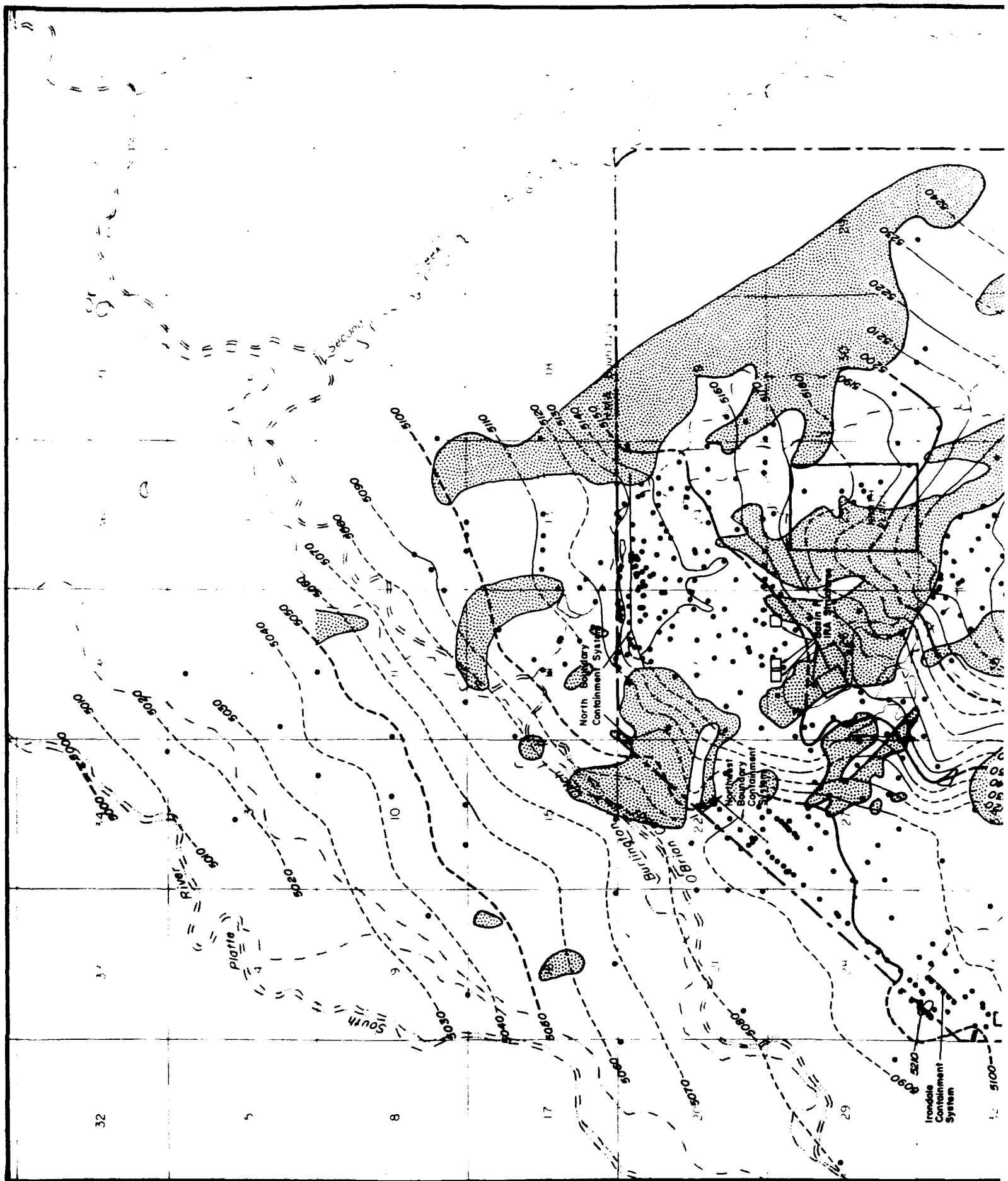
4.5.3 Anomalous Data Review

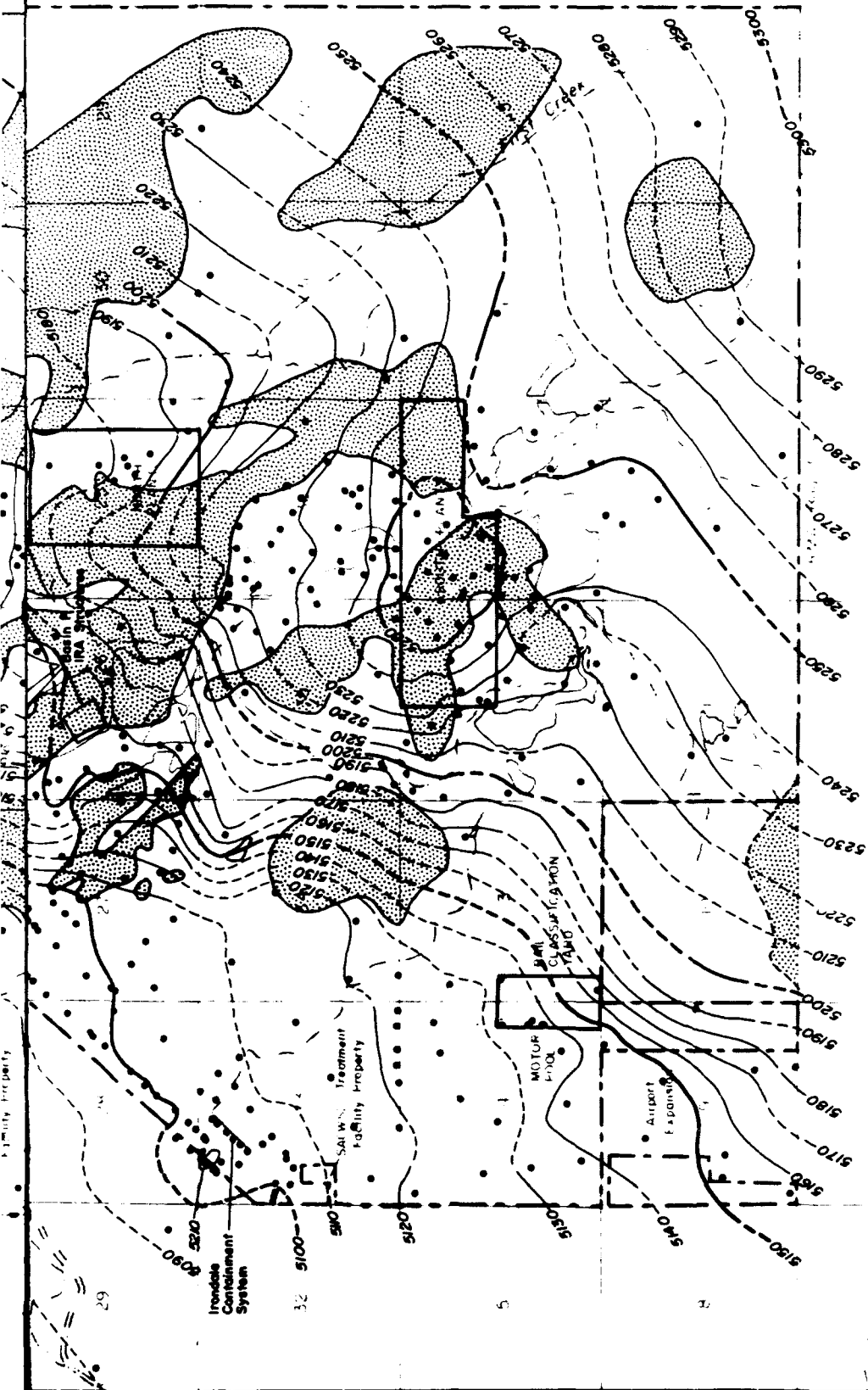
Discrepancies between data generated for the ground water program and historical data were investigated to determine the validity of the analytical results. Three computer lists were created to ascertain the extent of the anomalous data. One list contained the wells where historic values were substantially different from the present values giving an illusion of plumes that appeared and disappeared. The other two lists were generated by the computer and compared all historical data for all wells and printed out all data for analyses where concentrations varied by a factor of 10 and 100 in consecutive monitoring rounds. Possible sources for the discrepancies are transposition errors, missing dilution factors, and interlaboratory and intralaboratory method variations. The following are examples of the areas where discrepancies occurred:

- The Installation Restoration Data Management System (IRDMS) does not recalculate the detection limit if the sample required dilution during analysis.
- Analyte peaks detected during analysis were not necessarily indicative of a particular analyte, but the peak was within the calculated retention time window for the analytical method and was reported.
- Variations in the gas chromatographic procedures and operations caused analytes of interest to elute outside of the allotted time window, and thus were not reported.

- Temporal fluctuations of ± 10 percent at analyte concentrations near the certified reporting limits gave the illusion that certain compounds appeared or disappeared without hydrogeologic reason.
- Manual transposition of numbers from the GC computer printout to the IRDN data entry form.
- Chromatographic analyses of samples with numerous contaminants presented difficulties for reporting positive identification of analytes when more than one peak was detected within the required time window for a particular analyte.

Also, small changes in sampling and analytical conditions within and between laboratories may cause fluctuations in resulting data values.





Explanation

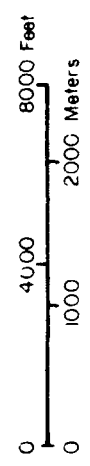
--- Equipotential Contour, Dashed where Inferred

• Well or Piezometer Location Yielding Unconfined Water Level Elevations

Approximate Areas of Unsaturated Alluvium

Containment System
 --- Physical Barrier
 --- Hydraulic Barrier

Contour Interval Equals 10 Feet
 Elevations in Feet
 Datum Mean Sea Level



Prepared for :

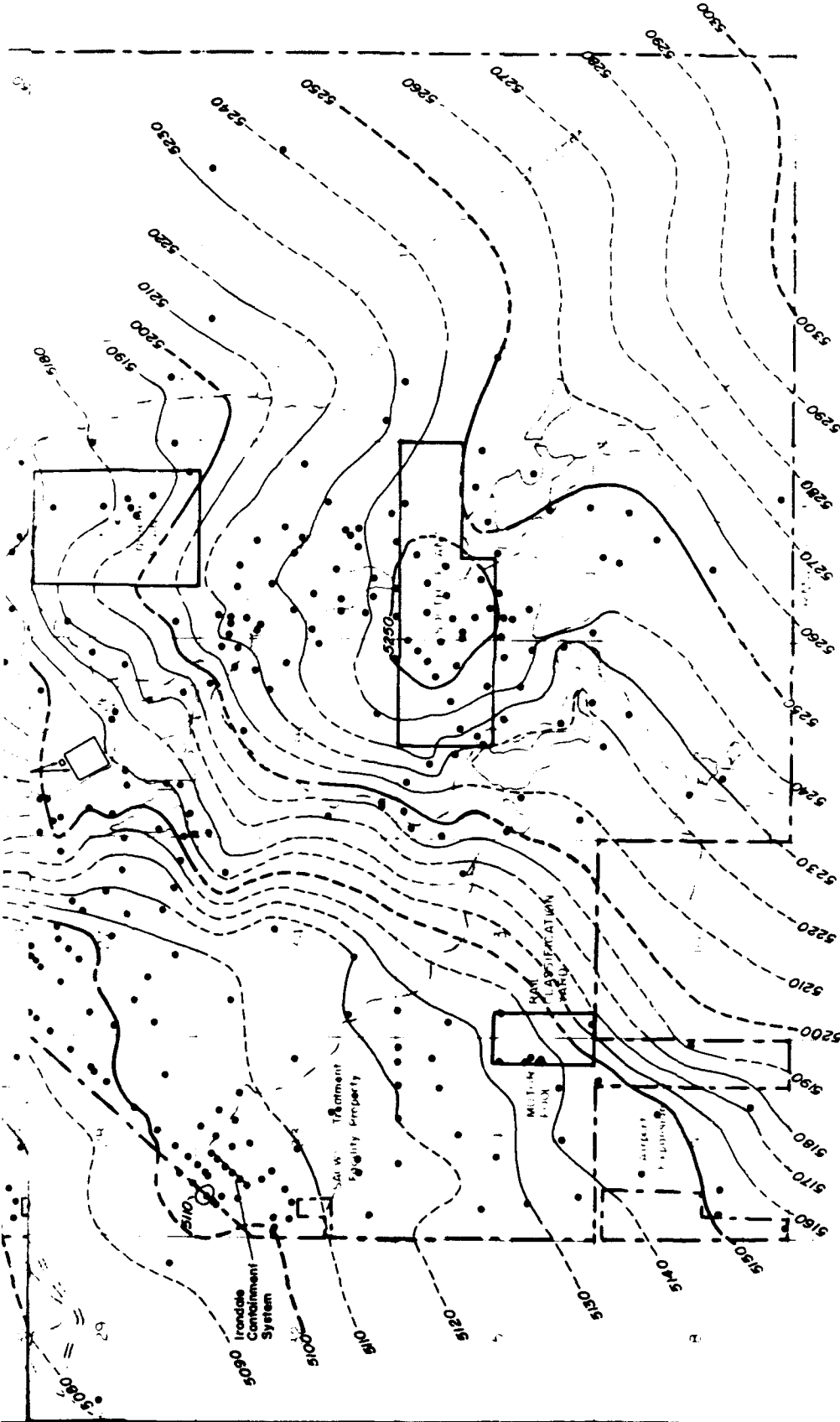
U.S. Army Program Manager for
 Rocky Mountain Arsenal
 Commerce City, Colorado

Prepared by :

R.L. Stollar & Associates, Inc.
 Harding Lawson Associates

Figure 4.1-1

Water Table Elevation Map
 of the Unconfined Flow System,
 Fall 1988



Explanation

- 5110 --- Equipotential Contour, Dashed where inferred
- Well or Piezometer Location Yielding Unconfined Water Level Elevations
- Containment System
 - Physical Barrier
 - Hydraulic Barrier

Contour Interval Equals 10 Feet
Elevations in Feet
Datum Mean Sea Level

Prepared for :

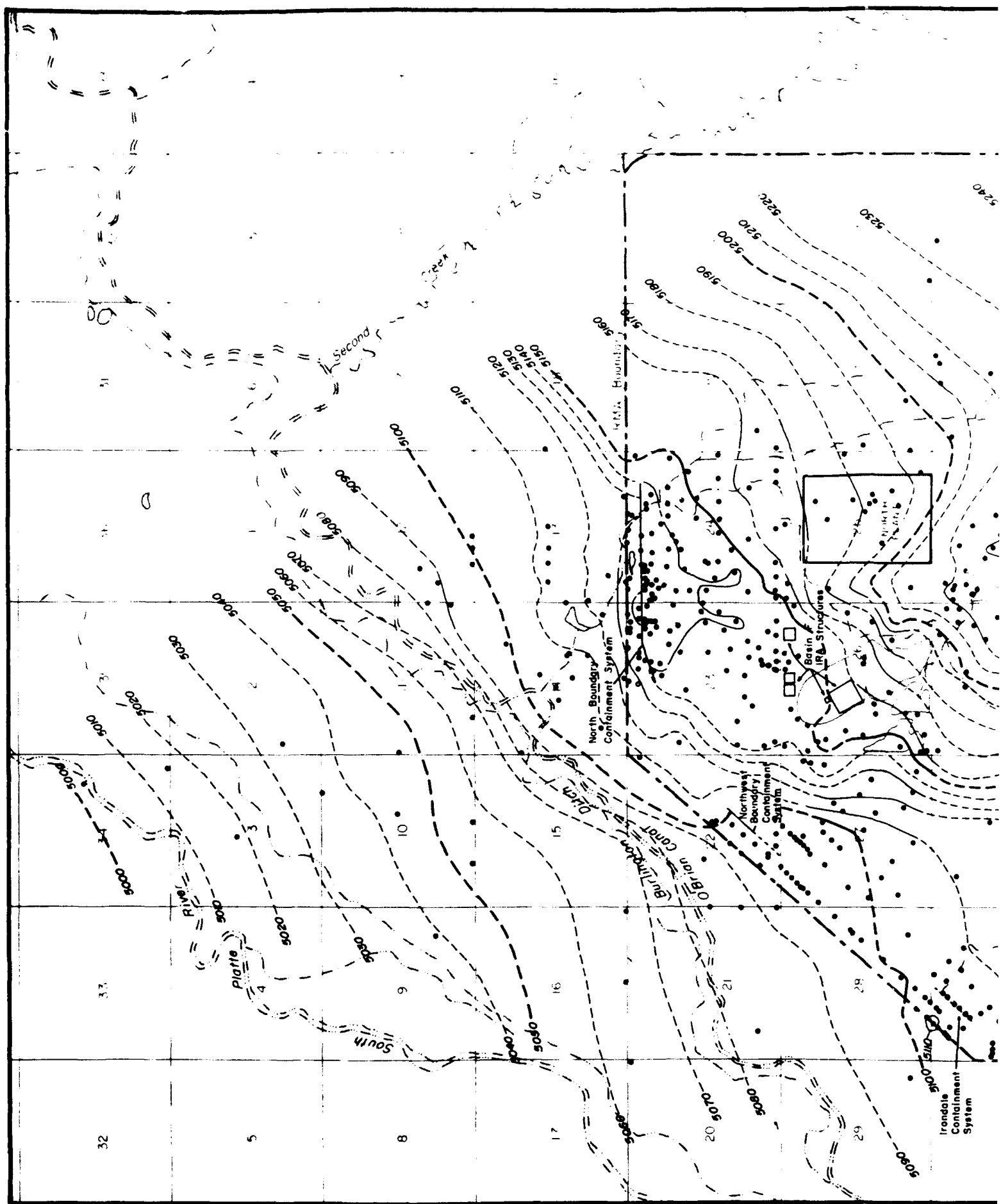
U S Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado,

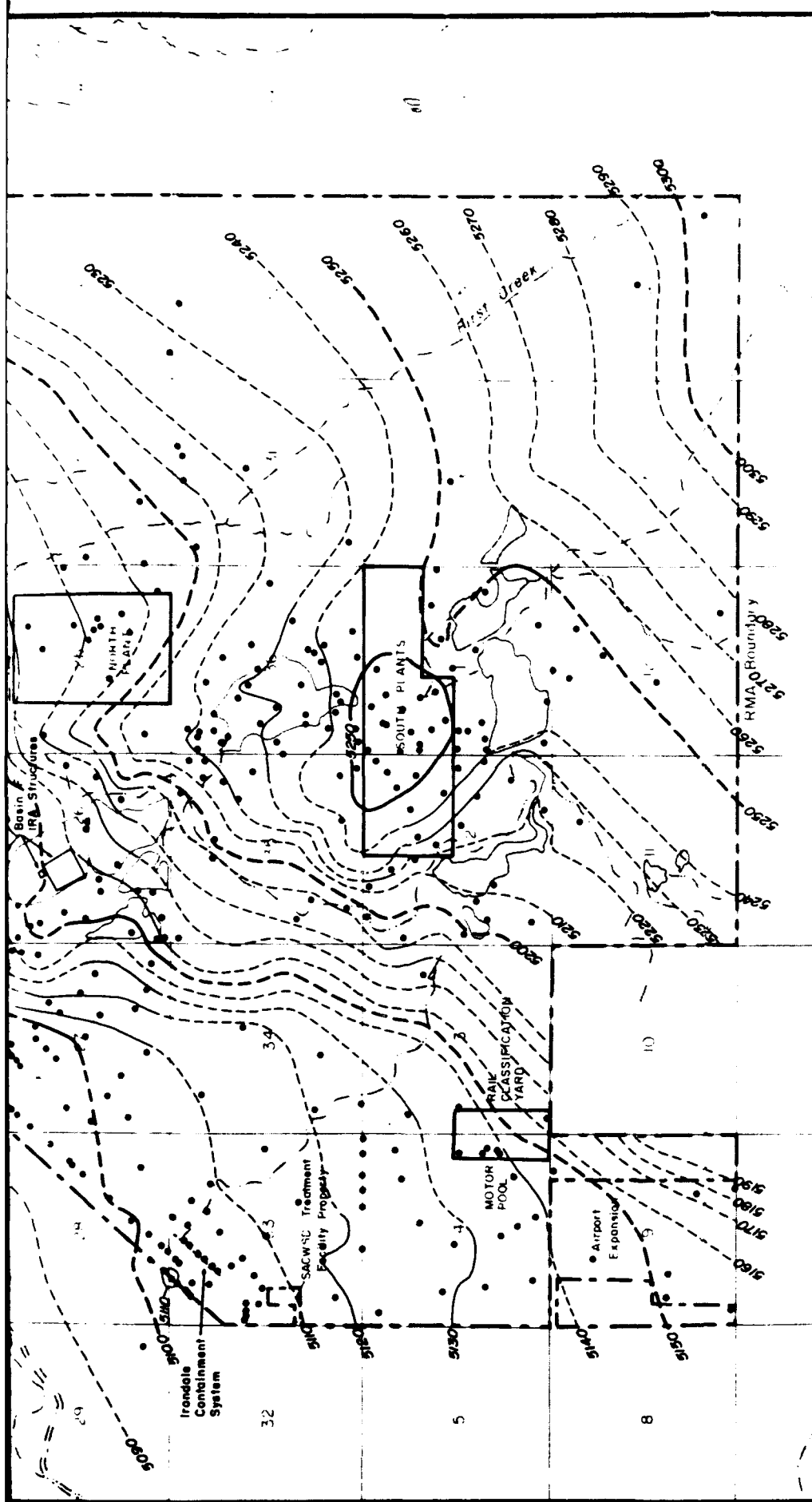
Prepared by :

H.L. Stollar & Associates, Inc.
Harding Lawson Associates

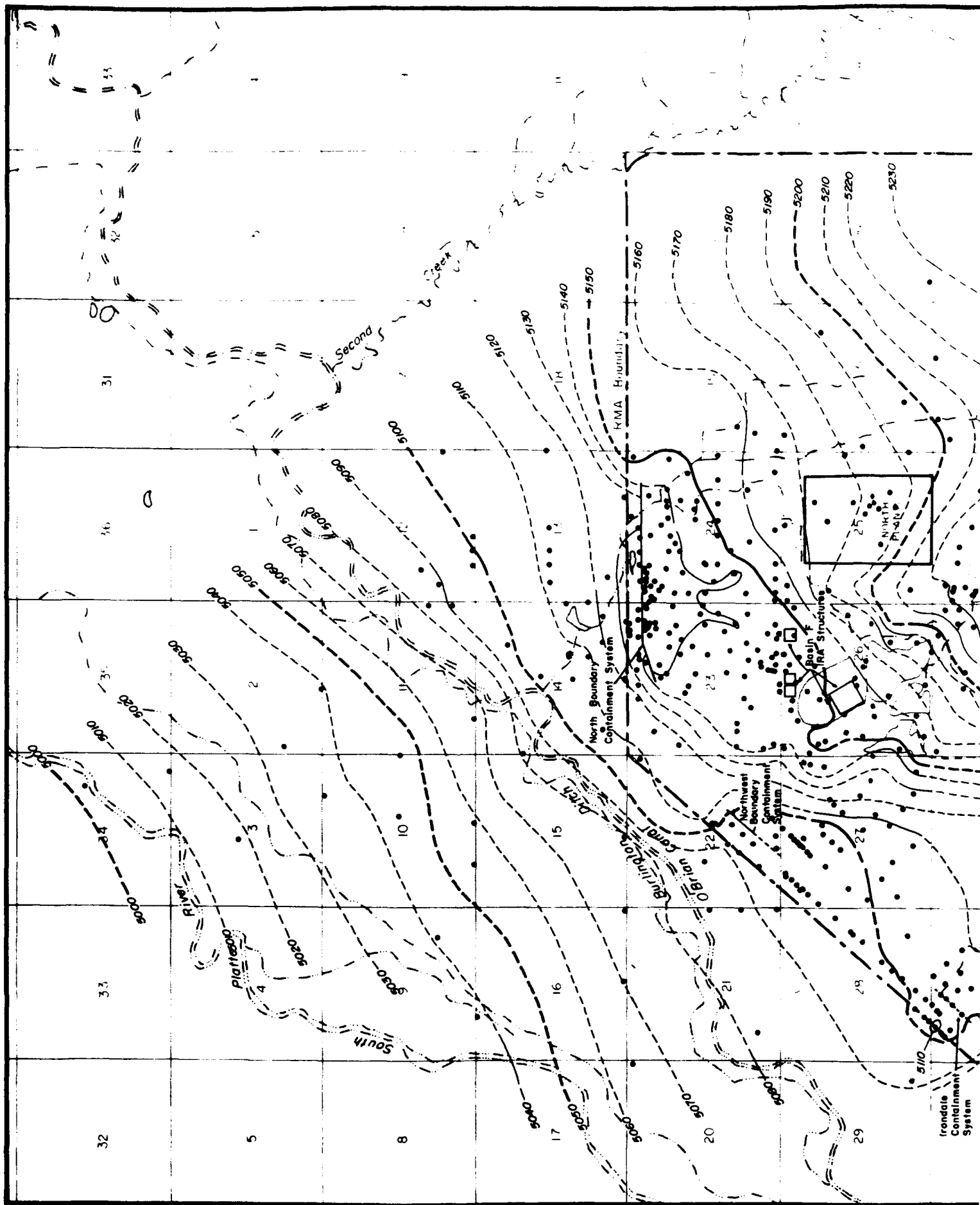
Figure 4.1-2

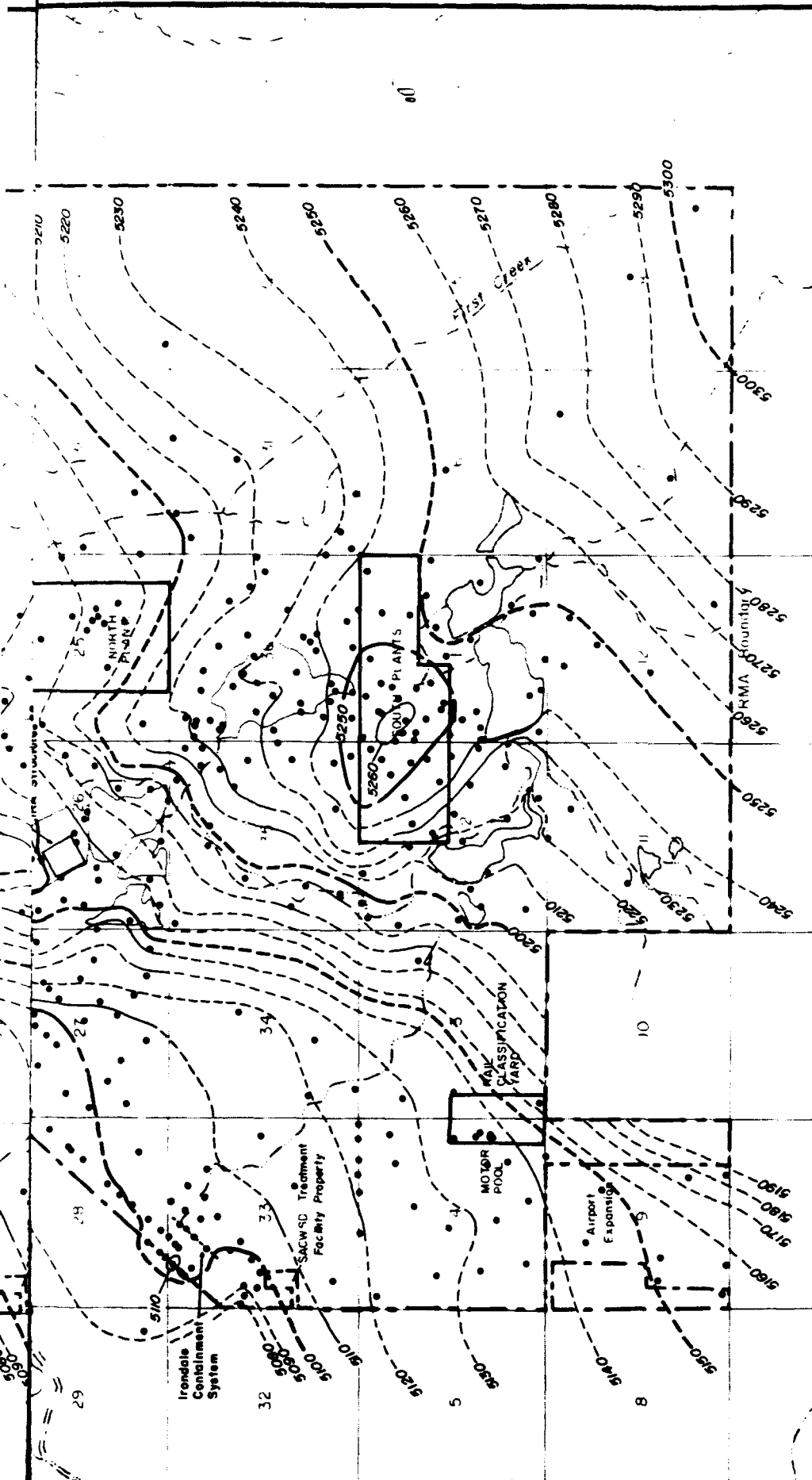
Water Table Elevation Map
of the Unconfined Flow System,
Winter 1989





Explanation --- Equipotential Contour, Dashed where Inferred • Well or Piezometer Location Yielding Unconfined Water Level Elevations Containment System — Physical Barrier — Hydraulic Barrier Contour Interval Equals 10 Feet Elevations in Feet Datum Mean Sea Level	Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: R.L. Stollar & Associates, Inc. Harding Lawson Associates
	Figure 4.1-3 Water Table Elevation Map of the Unconfined Flow System, Spring 1989 CMP Ground-Water Monitoring Annual Report FY89





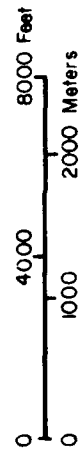
Explanation

--- Equipotential Contour, Dashed where Inferred

- Well or Piezometer Location Yielding Unconfined Water Level Elevations

Containment System
 — Physical Barrier
 — Hydraulic Barrier

Contour Interval Equals 10 Feet
 Elevations in Feet
 Datum Mean Sea Level



Prepared for :

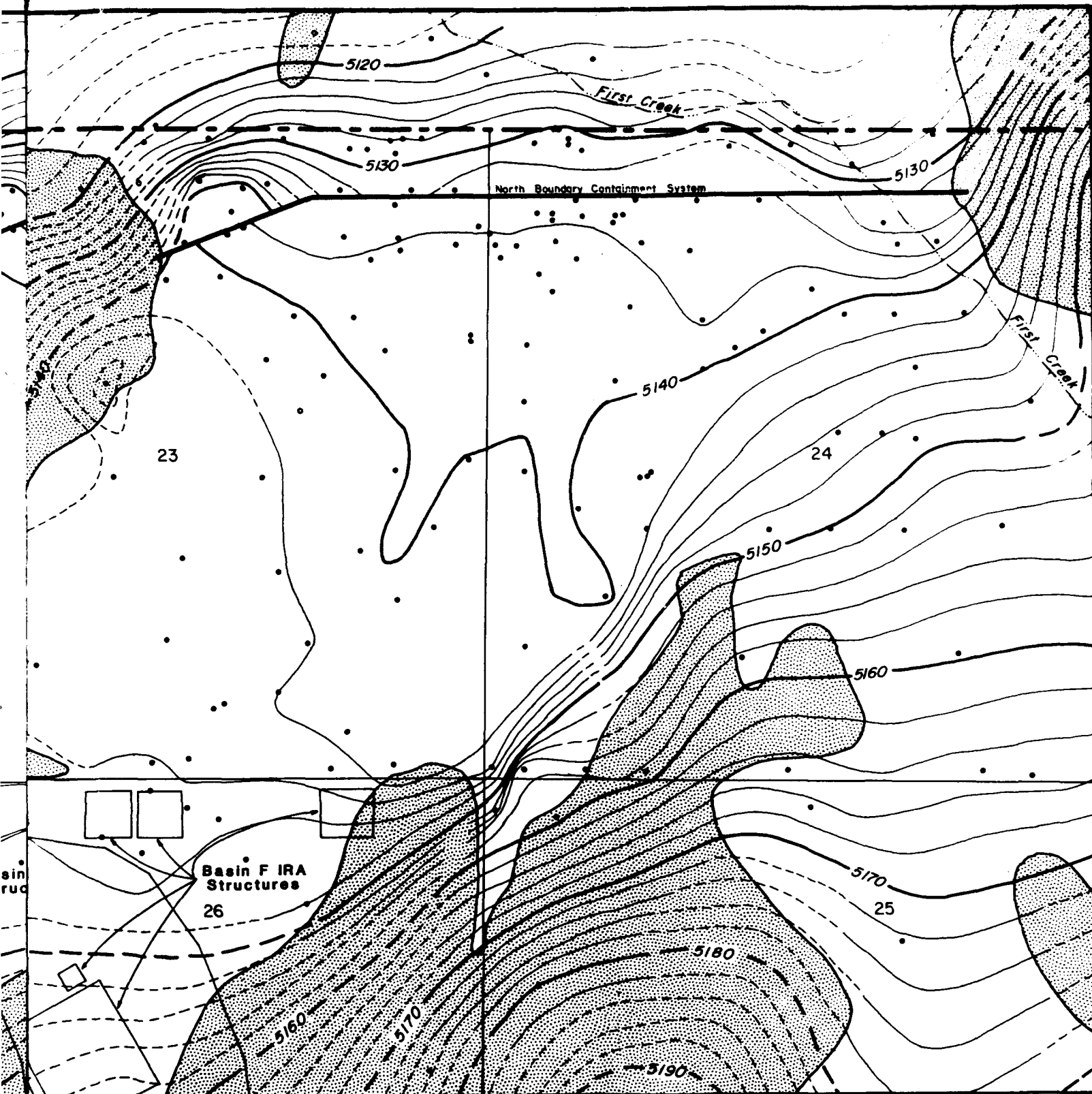
U.S. Army Program Manager for
 Rocky Mountain Arsenal
 Commerce City, Colorado

Prepared by :

R.L. Stollar & Associates, Inc.
 Harding Lawson Associates

Figure 4.1-4

Water Table Elevation Map
 of the Unconfined Flow System,
 Summer 1989



Prepared for :

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Commerce City, Colorado

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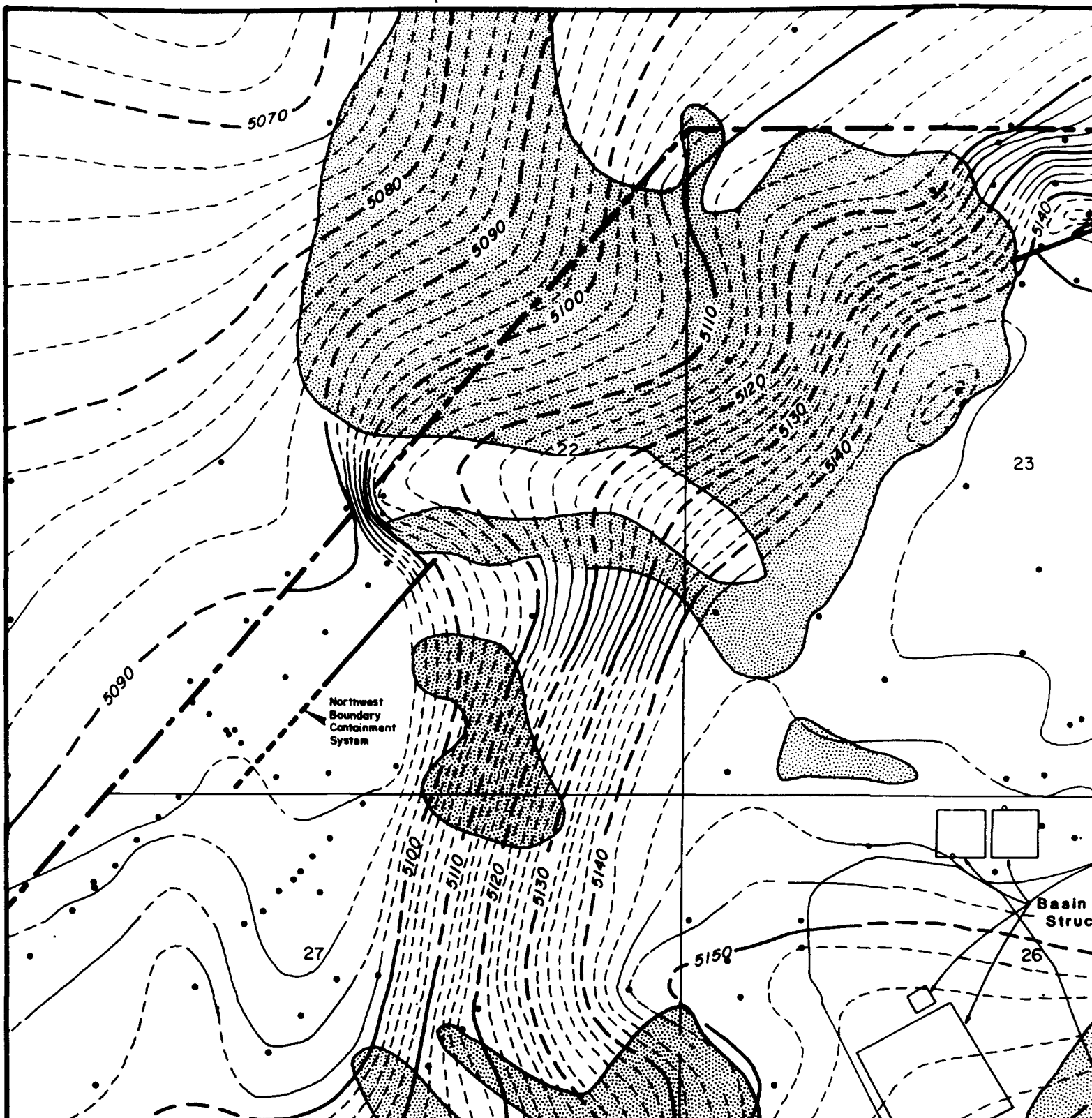
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 4.1-5

Unconfined Water Table
Elevation Contour Map of
Boundary Systems Area
Fall 1988

CMP Ground-Water Monitoring Annual Report FY89

7/12/89



EXPLANATION

— 5100 — Water Level Elevation Contour

- - - Approximate Water Level Elevation Contour



Approximate Areas of Unsaturated Alluvium

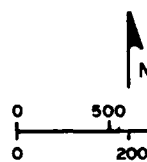
• Well or Piezometer Location Yielding Unconfined Water Level Elevation

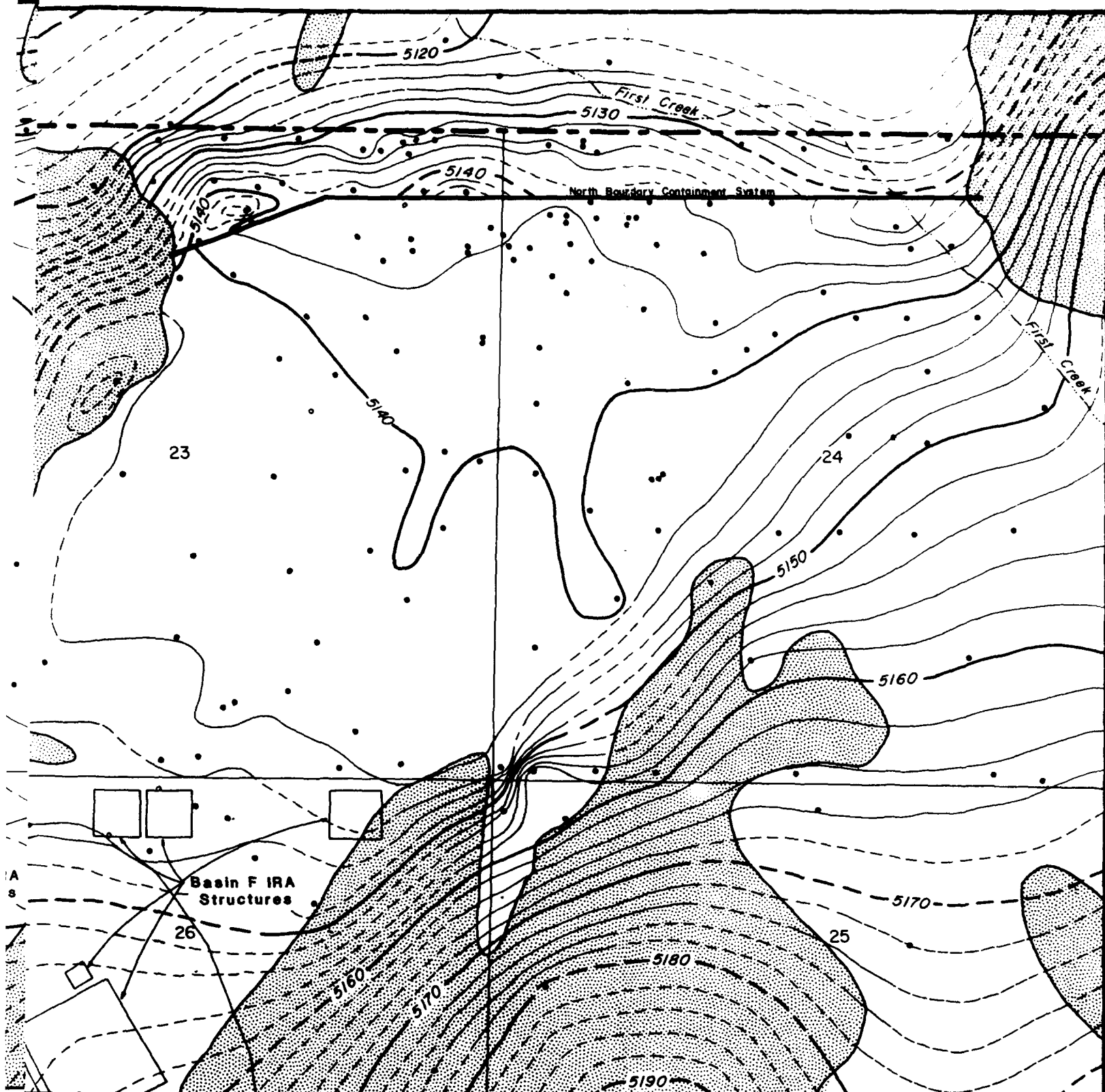
• Dry Unconfined Well or Piezometer Location

Elevations in Feet

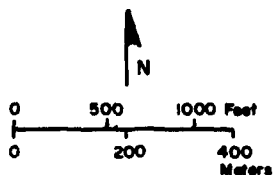
Containment System
Physical Barrier
Hydraulic Barrier

Datum Mean Sea Level
Contour Interval is 2 Feet





ment System
al Barrier
lic Barrier
n Sea Level
rval is



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Commerce City, Colorado

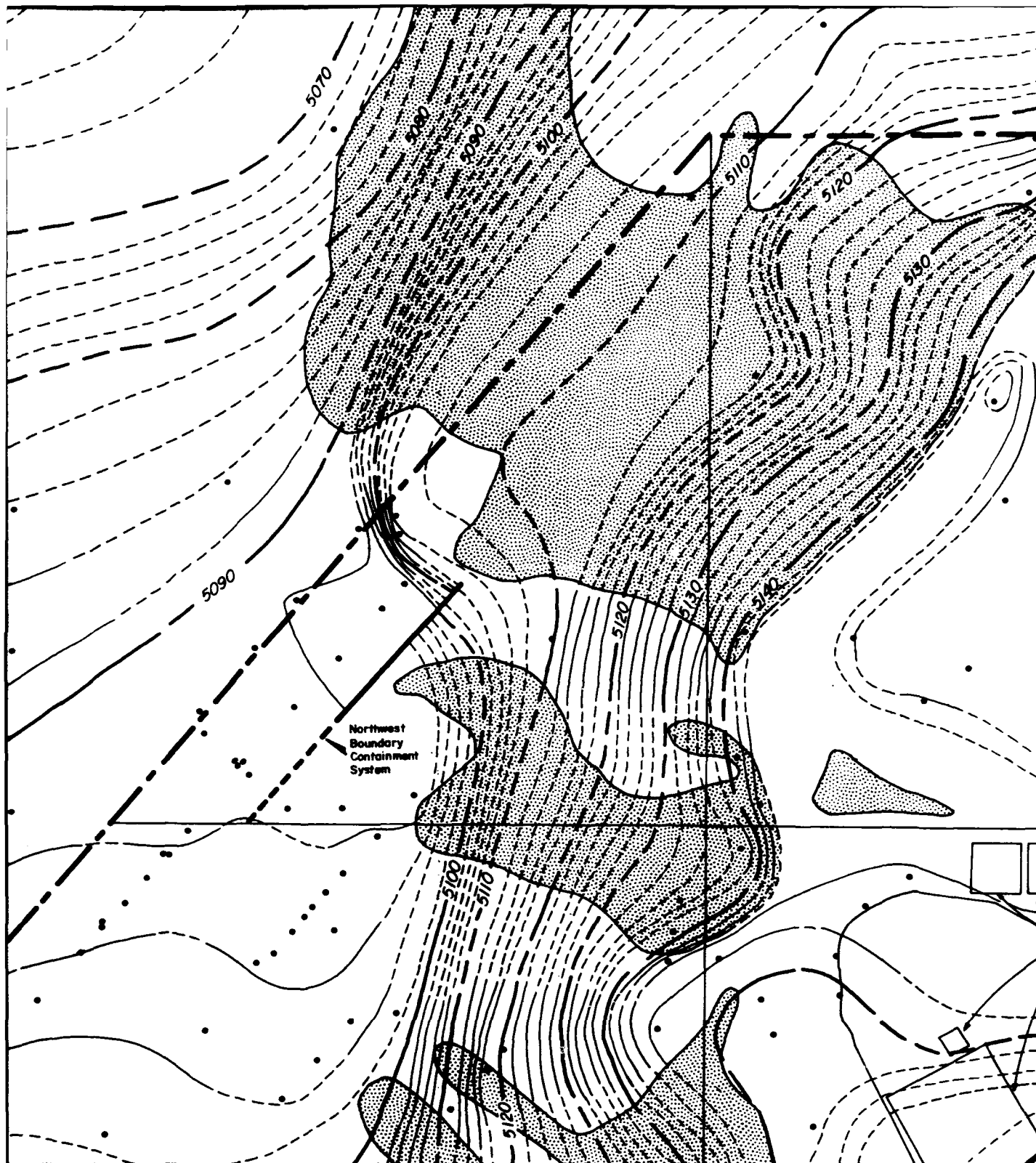
Prepared by :

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Harding Lawson Associates

Figure 4.1-6

Unconfined Water Table
Elevation Contour Map of
Boundary Systems Area,
Winter 1989

CMP Ground-Water Monitoring Annual Report FY89



EXPLANATION

— 5100 — Water Level Elevation Contour

- - - Approximate Water Level Elevation Contour



Approximate Areas of Unsaturated Alluvium

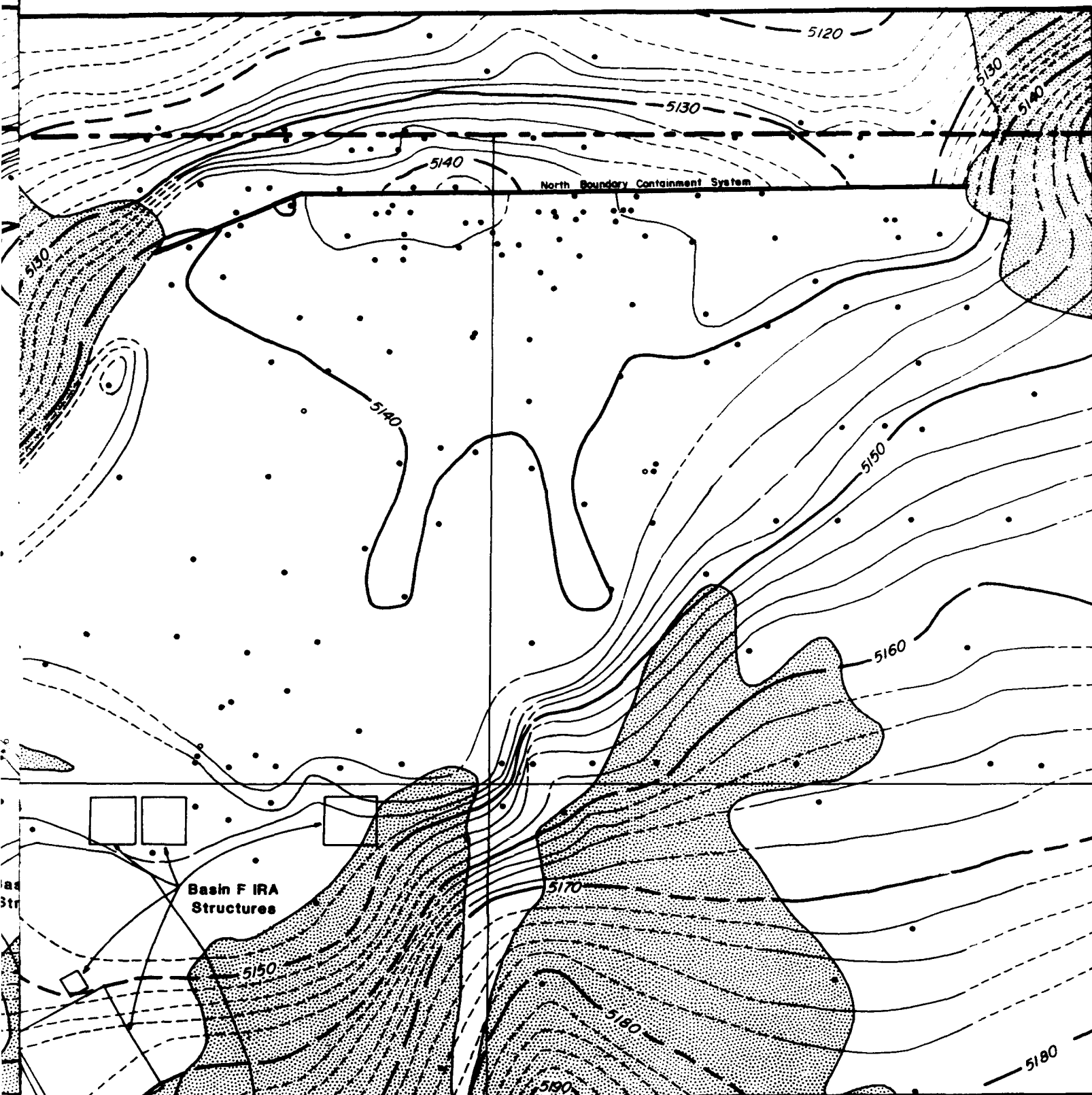
• Well or Piezometer Location Yielding Unconfined Water Level Elevation

• Dry Unconfined Well or Piezometer Location

Elevations in Feet

— Containment System
— Physical Barrier
- - - Hydraulic Barrier

Datum Mean Sea Level 0
Contour Interval is 2 Feet 0



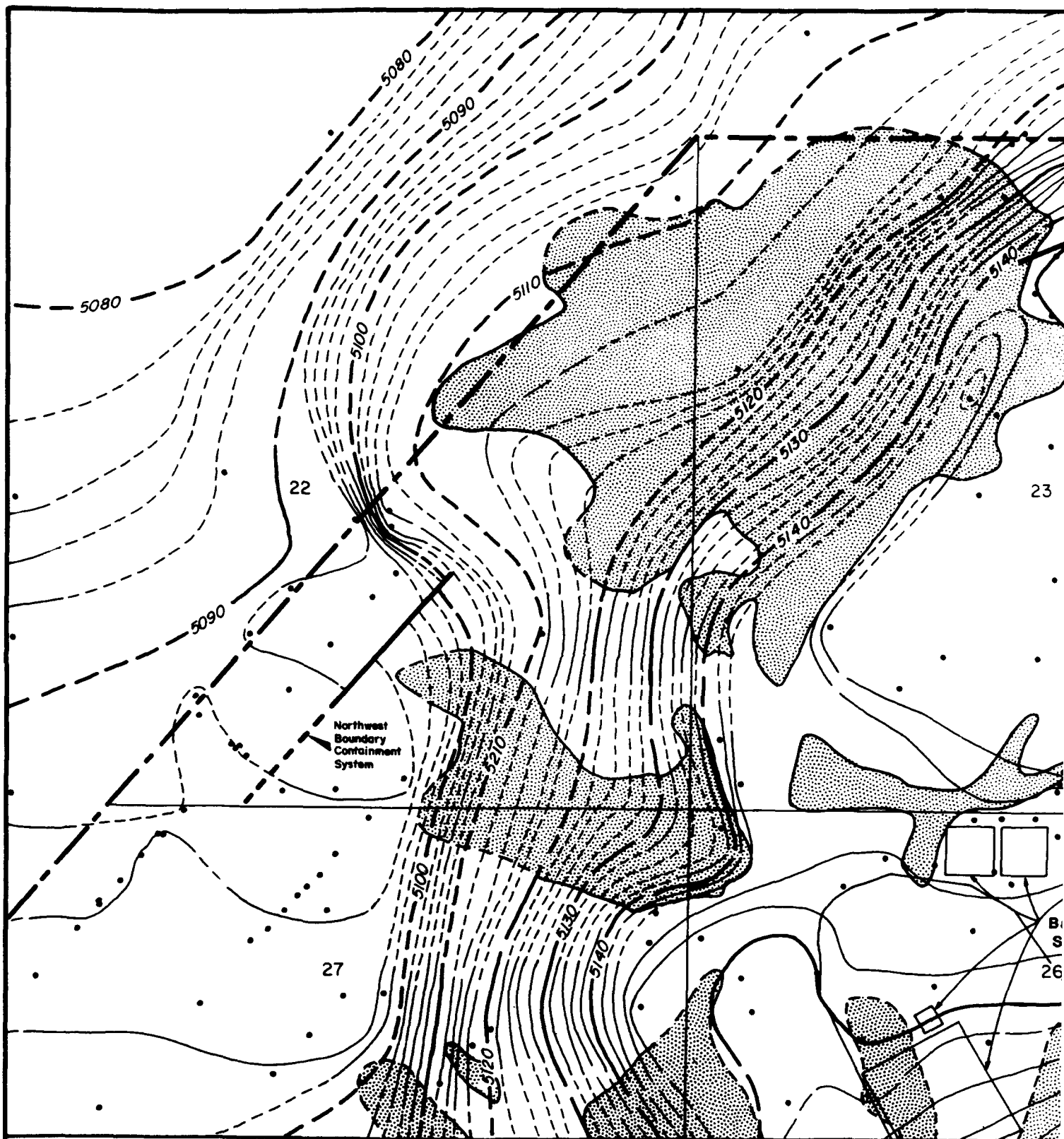
ment System
cal Barrier
ulic Barrier
50
an Sea Level
Interval is

0 500 1000 Feet
0 200 400 Meters

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Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by :
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 4.1-7
Unconfined Water Table
Elevation Contour Map of
the Boundary Systems Area,
Spring 1989

CMP Ground-Water Monitoring Annual Report FY89



EXPLANATION

— 5100 — Water Level Elevation Contour

- - - Approximate Water Level
Elevation Contour



Approximate Areas of
Unsaturated Alluvium

• Well or Piezometer Location
Yielding Unconfined Water
Level Elevation

• Dry Unconfined Well or
Piezometer Location

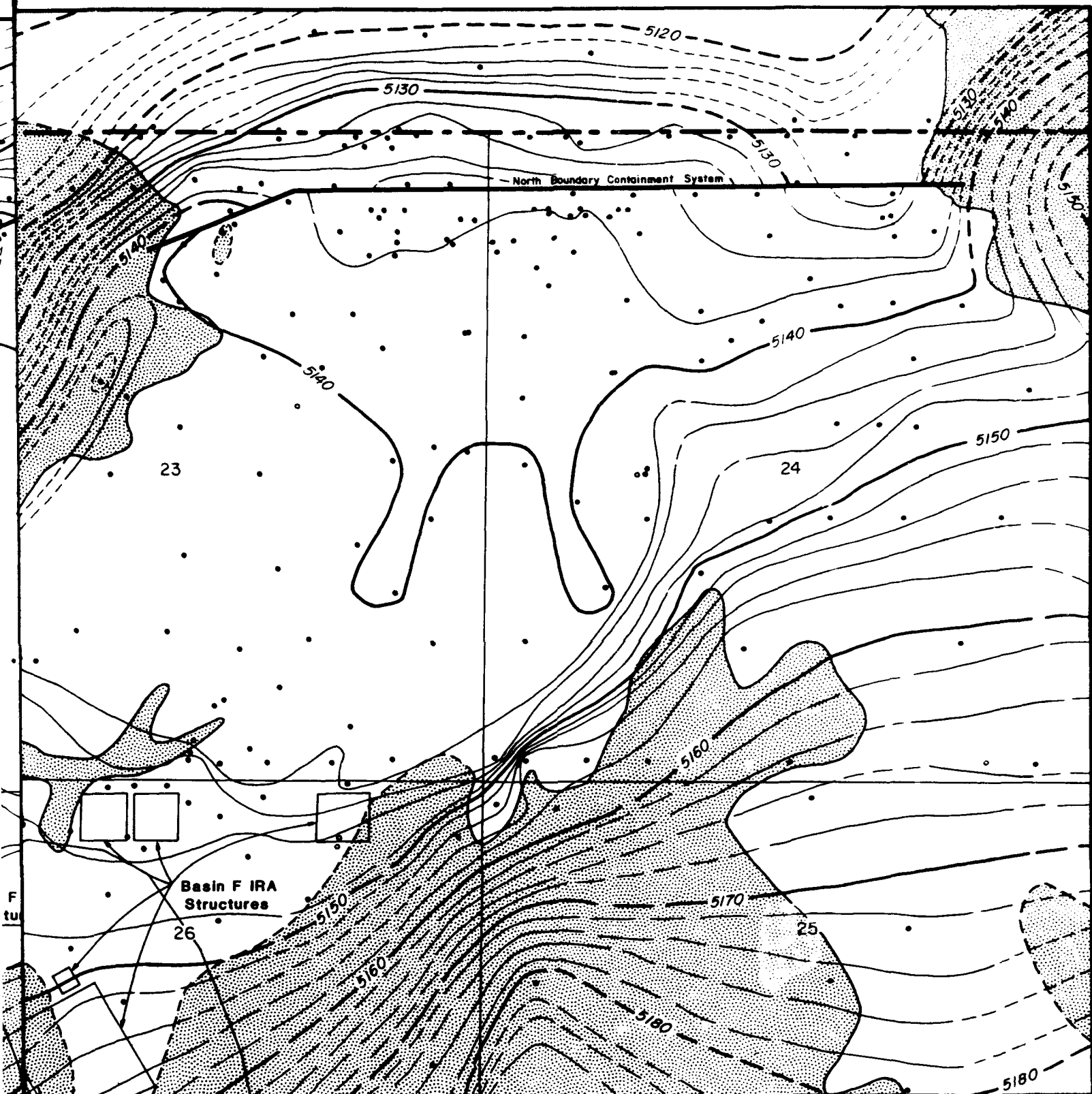
Elevations in Feet

— Containment System
— Physical Barrier
— Hydraulic Barrier

Contour Interval is
2 Feet

Datum Mean Sea Level





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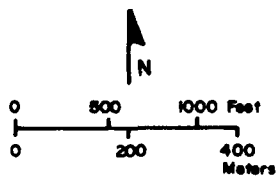
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

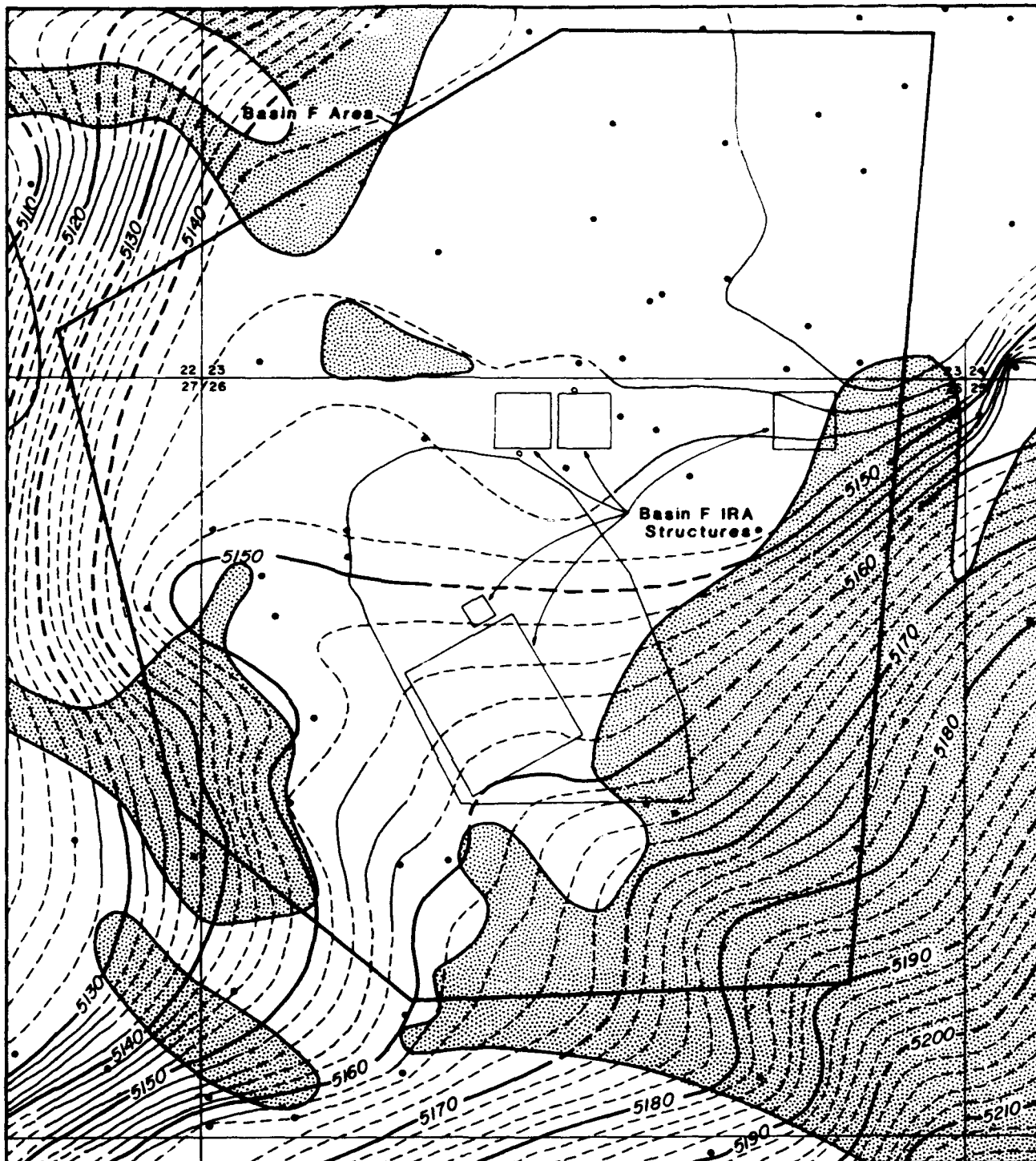
Figure 4.1-8

Unconfined Water Table
Elevation Contour Map of
the Boundary System Area,
Summer 1989

CMP Ground-Water Monitoring Annual Report FY89

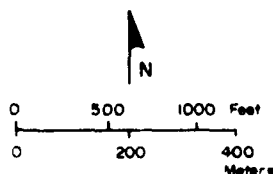
ment System
cal Barrier
ulic Barrier
N
rval is
Sea Level





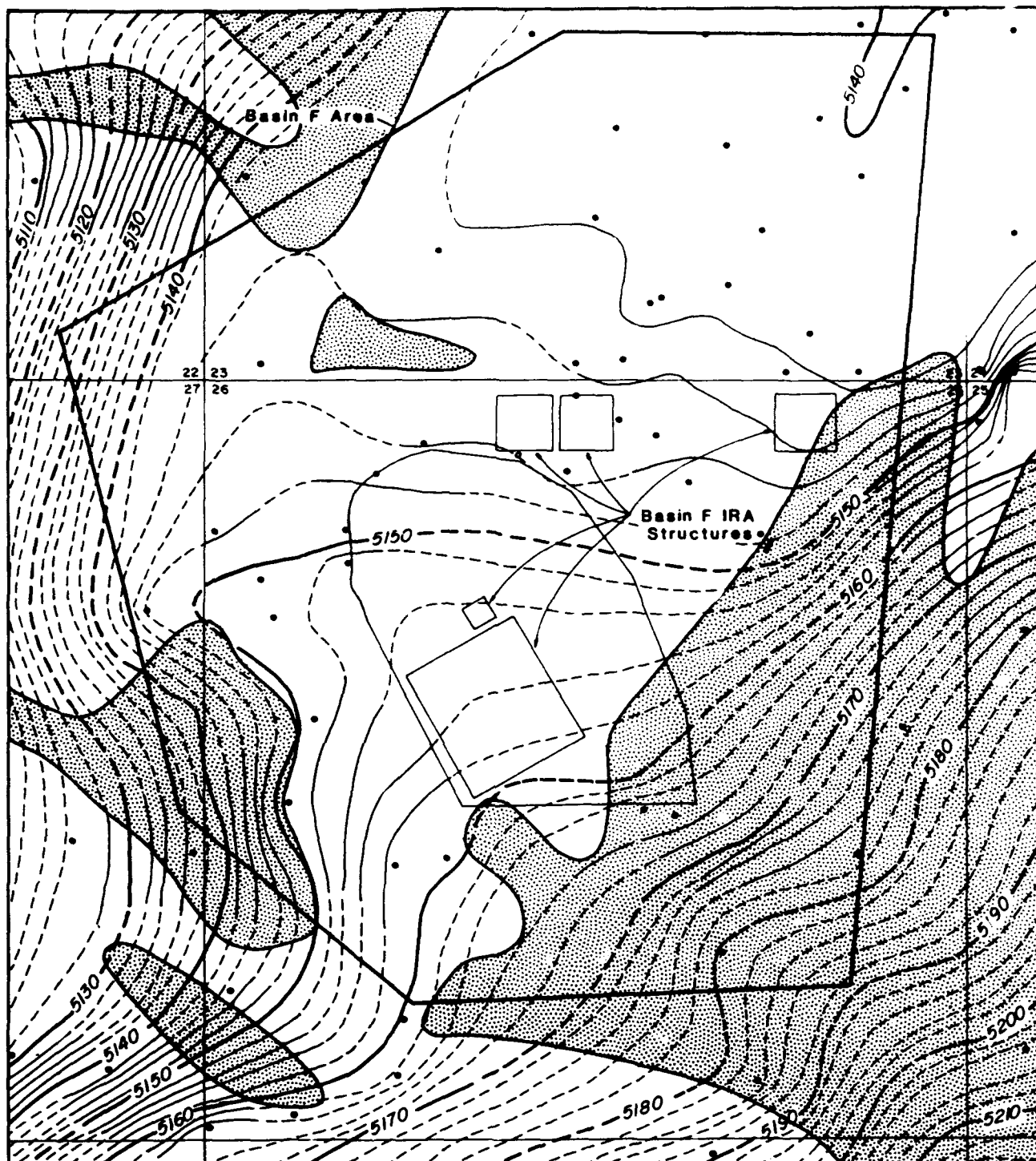
EXPLANATION

	Water Level Elevation Contour	Elevation in Feet
	Approximate Water Level Elevation Contour	Datum Mean Sea Level
	Approximate Areas of Unsaturated Alluvium	
•	Well or Piezometer Location Yielding Unconfined Water Level Elevation	
•	Dry Unconfined Well or Piezometer Location	
Contour Interval is 2 Feet		



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Figure 4.1-9
 Unconfined Water Table
 Elevation Contour Map of
 the Basin F IRA Area,
 Fall 1988
 CMP Ground-Water Monitoring Annual Report FY 89



EXPLANATION

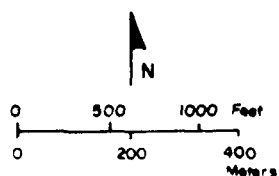
- 5210 — Water Level Elevation Contour
- - - - - Approximate Water Level Elevation Contour
- Approximate Areas of Unsaturated Alluvium

- Well or Piezometer Location Yielding Unconfined Water Level Elevation
- Dry Unconfined Well or Piezometer Location

Contour Interval is 2 Feet

Elevation in Feet

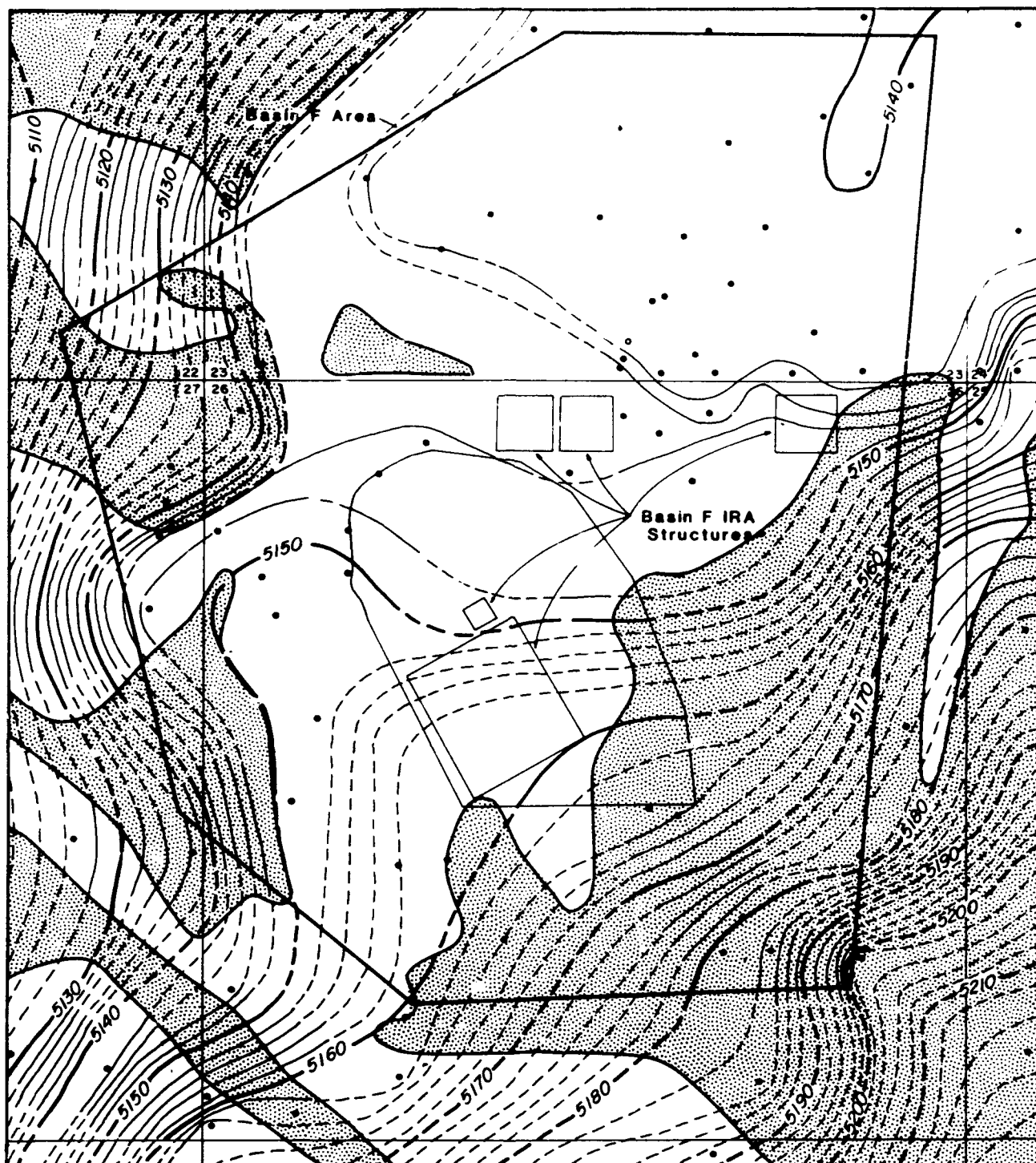
Datum Mean Sea Level



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Figure 4.1-10
Unconfined Water Table
Elevation Contour Map of the
Basin F IRA Area,
Winter 1989

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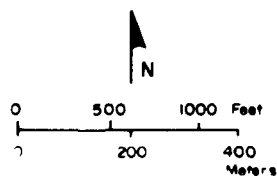


EXPLANATION

- Water Level Elevation Contour
- Approximate Water Level Elevation Contour
- Approximate Areas of Unsaturated Alluvium
- Well or Piezometer Location Yielding Unconfined Water Level Elevation
- Dry Unconfined Well or Piezometer Location

Contour Interval is 2 Feet

Elevation in Feet
Datum Mean Sea Level



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Harding Lawson Associates

Figure 4.1-11
Unconfined Water Table
Elevation Contour Map of the
Basin F IRA Area,
Spring 1989

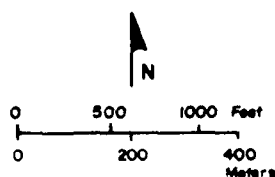
CMP Ground-Water Monitoring Annual Report FY89



EXPLANATION

- Water Level Elevation Contour
 - Approximate Water Level Elevation Contour
 - Approximate Areas of Unsaturated Alluvium
 - Well or Piezometer Location Yielding Unconfined Water Level Elevation
 - Dry Unconfined Well or Piezometer Location
- Contour Interval is 2 Feet

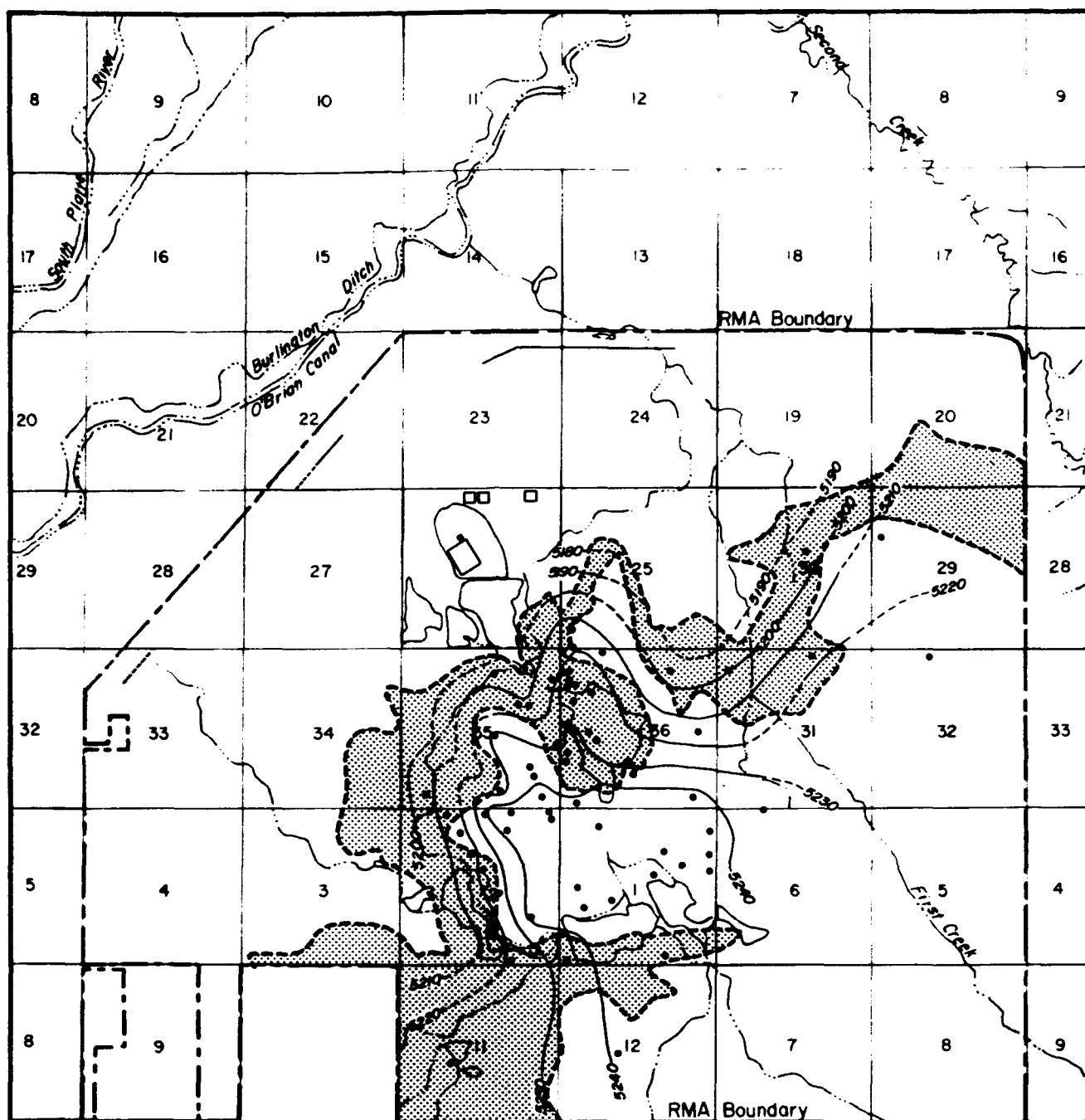
Elevation in Feet
Datum Mean Sea Level



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Prepared by:
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Harding Lawson Associates

Figure 4.1-12
Unconfined Water Table
Elevation Contour Map
of the Basin F IRA Area,
Summer 1989

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Explanation

- Well Location Yielding Water Level Elevation
Contour Interval Equals 10 Feet

5210— Elevation of the Potentiometric Surface, Feet
Above Mean Sea Level, Dashed where Inferred

Areal Extent of Subcrop Denver Zone A

Containment System
 Physical Barrier
 Hydraulic Barrier

N

0 5000 10,000 Feet
0 1000 2000 3000 Meters

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Commerce City, Colorado

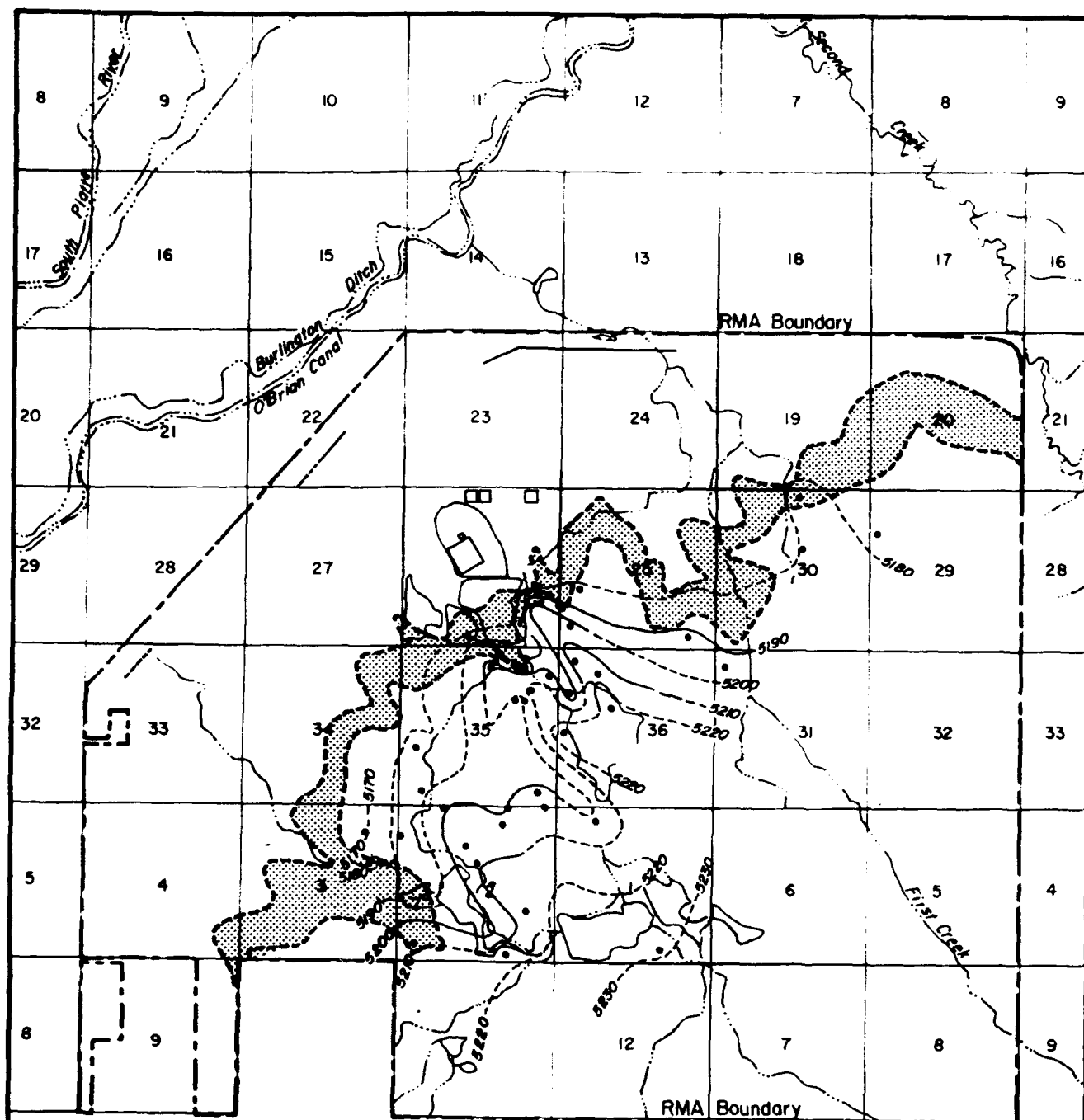
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Figure 4.2-1

Potentiometric Surface of

Denver Fm Zone A, Fall 1988



Explanation

- Well Location Yielding Water Level Elevation
Contour Interval Equals 10 Feet

5180 Elevation of the Potentiometric Surface, Feet
Above Mean Sea Level, Dashed where Inferred

Areal Extent of Subcrop Denver Zone 1U,
Including Lignitic Zone A

Containment System
Physical Barrier
Hydraulic Barrier

N

0 5000 10,000 Feet
0 1000 2000 3000 Meters

Prepared for:

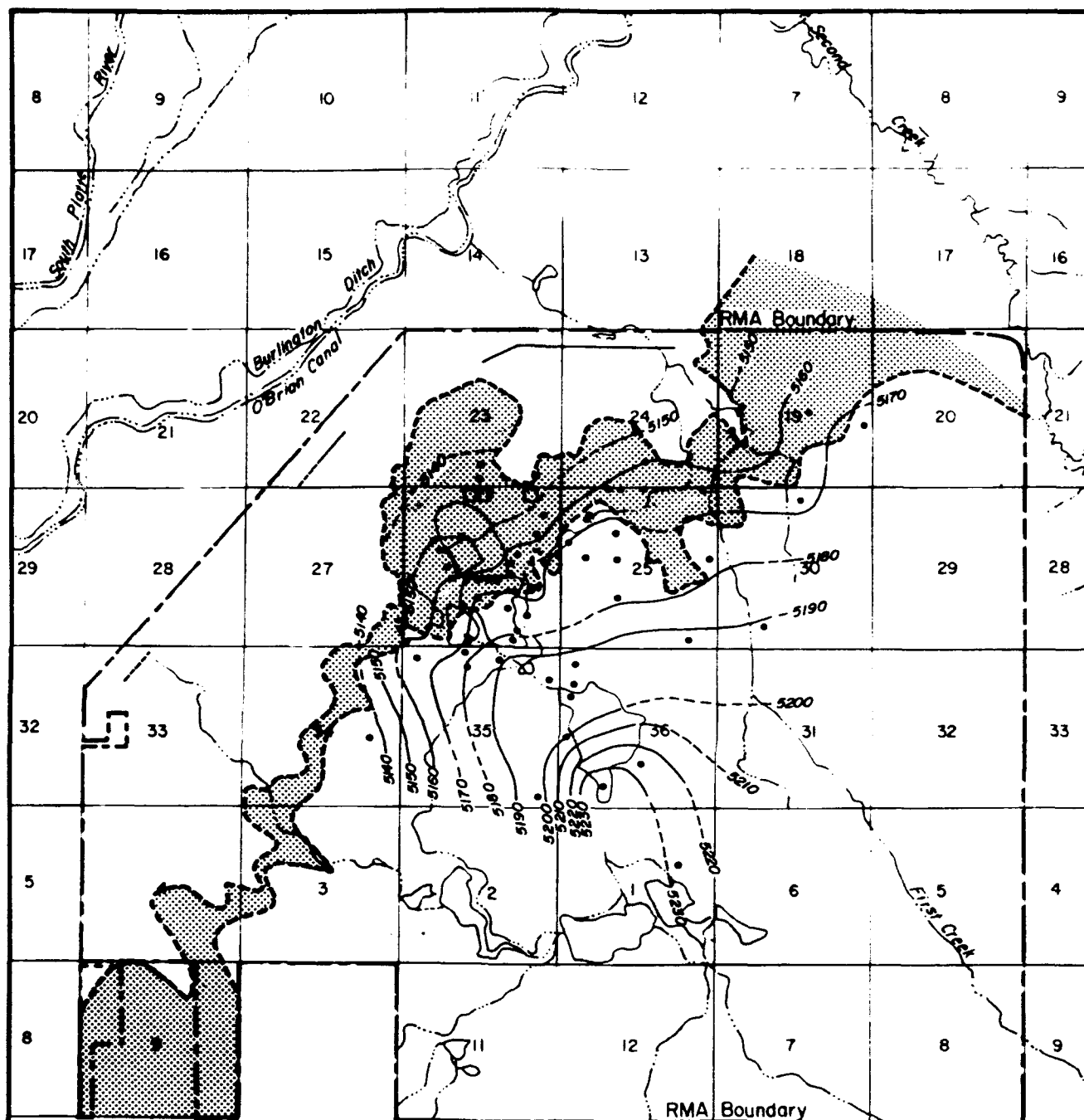
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Harding Lawson Associates

Figure 4.2-2

Potentiometric Surface of
Denver Fm Zone 1U, Fall 1988



Explanation

- Well Location Yielding Water Level Elevation
Contour Interval Equals 10 Feet

5150 Elevation of the Potentiometric Surface, Feet
Above Mean Sea Level, Dashed where Inferred

Areal Extent of Subcrop Denver Zone 1,
Including Lignite Zone B

Containment System
Physical Barrier
Hydraulic Barrier

N

0 5000 10,000 Feet
0 1000 2000 3000 Meters

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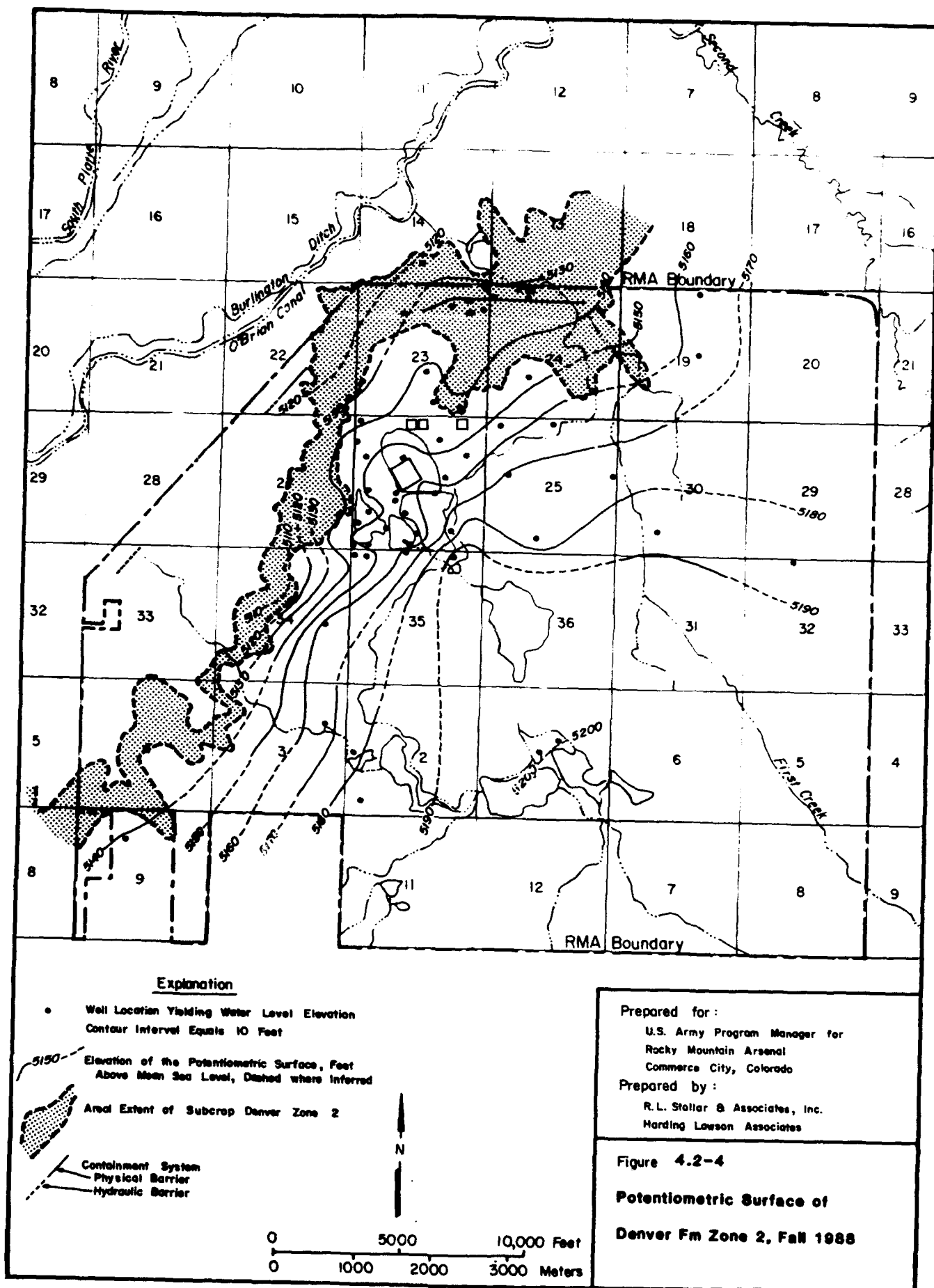
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

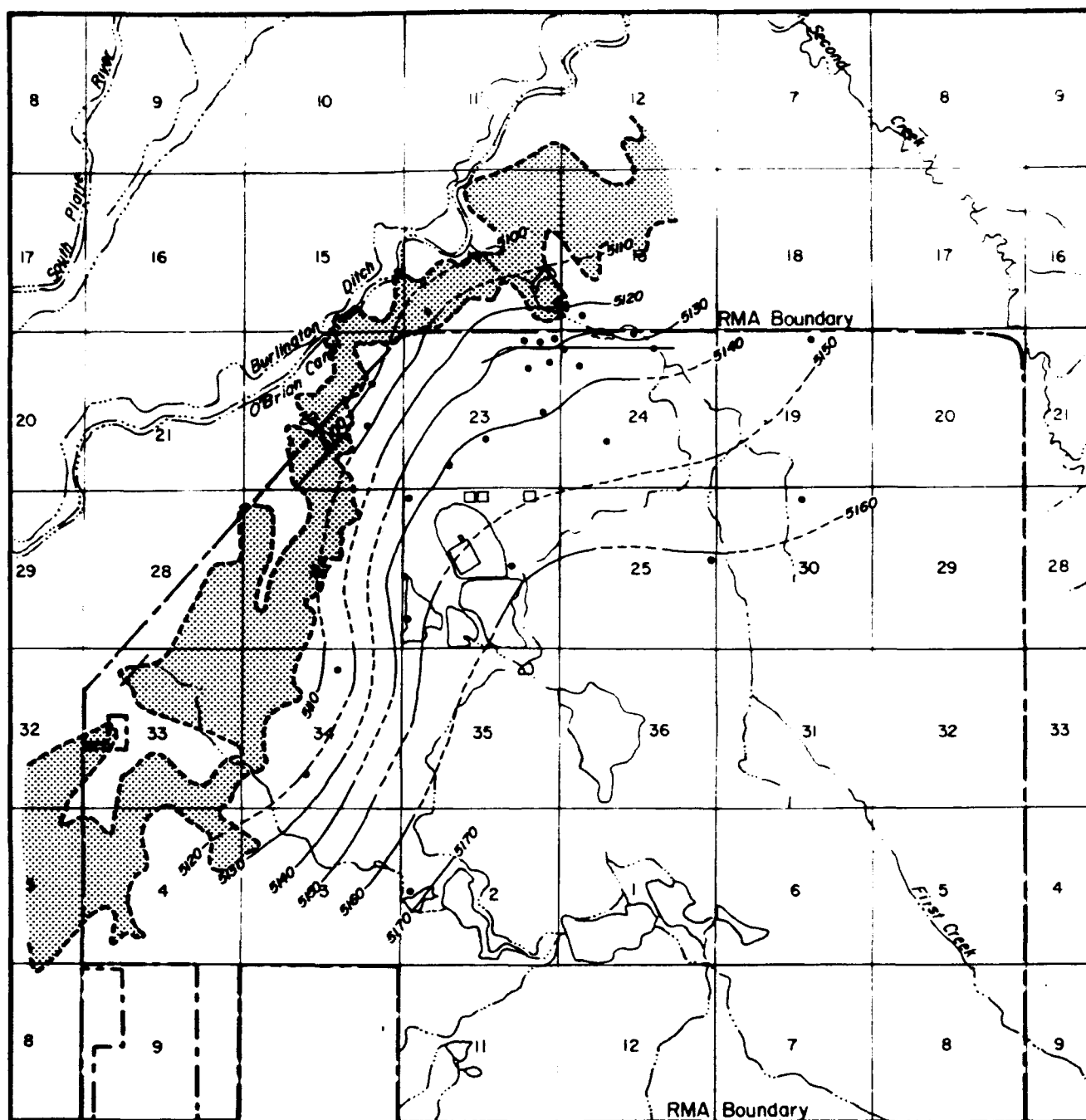
Prepared by:

R.L. Stellar & Associates, Inc.
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Figure 4.2-3

Potentiometric Surface of
Denver Fm Zone 1, Fall 1988





Explanation

- Well Location Yielding Water Level Elevation
Contour Interval Equals 10 Feet

5110- Elevation of the Potentiometric Surface, Feet Above Mean Sea Level, Dashed where Inferred

Areal Extent of Subcrop Denver Zone 3, Including Lignitic Zone D

Containment System
Physical Barrier
Hydraulic Barrier

N

0 5000 10,000 Feet
0 1000 2000 3000 Meters

Prepared for:

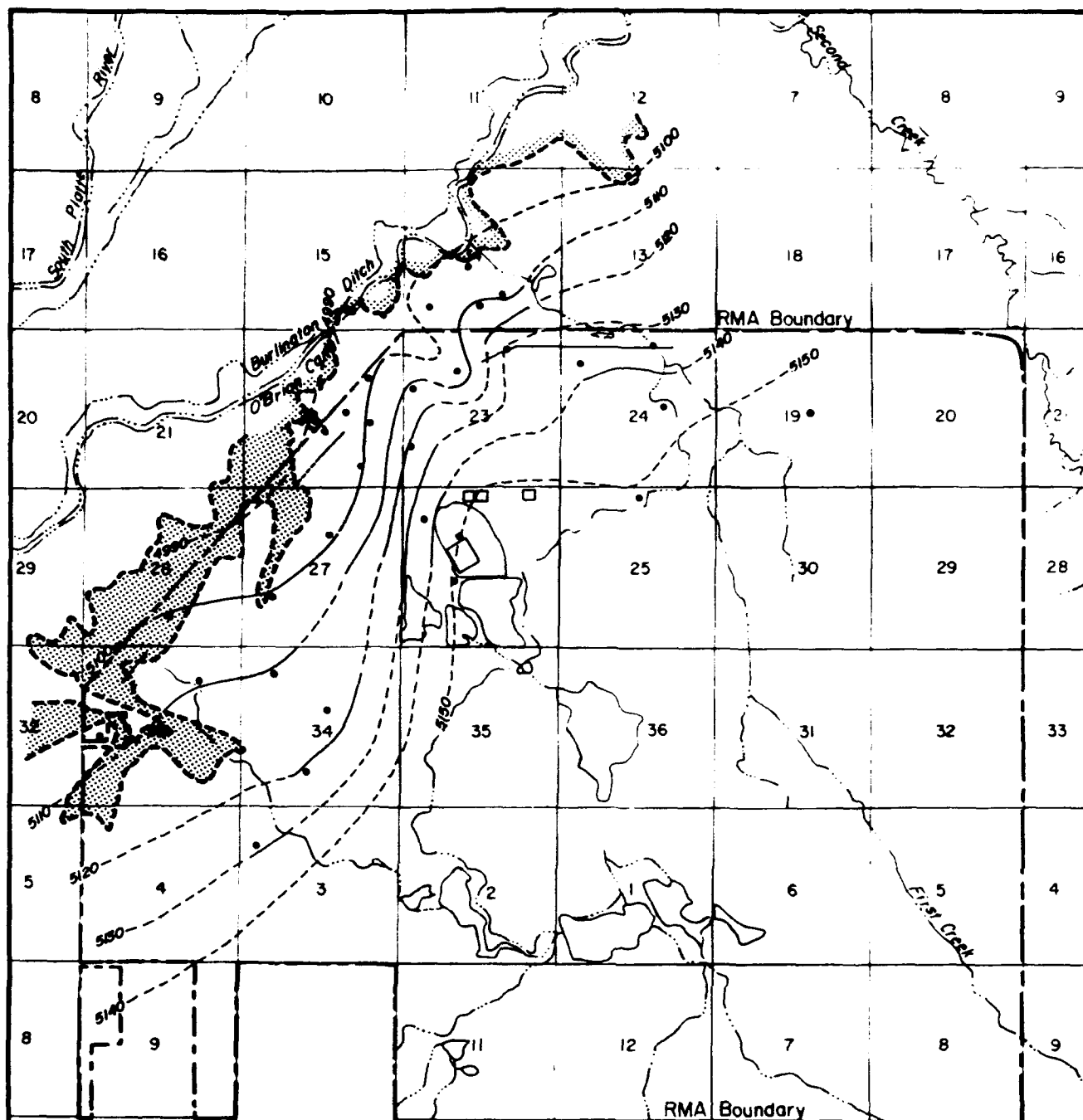
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Figure 4.2-5

Potentiometric Surface of
Denver Fm Zone 3, Fall 1988



Explanation

- Well Location Yielding Water Level Elevation
Contour Interval Equals 10 Feet

5110—Elevation of the Potentiometric Surface, Feet Above Mean Sea Level, Dashed where Inferred

Areal Extent of Subcrop Denver Zone 4

Containment System
Physical Barrier
 Hydraulic Barrier

N

0 5000 10,000 Feet
0 1000 2000 3000 Meters

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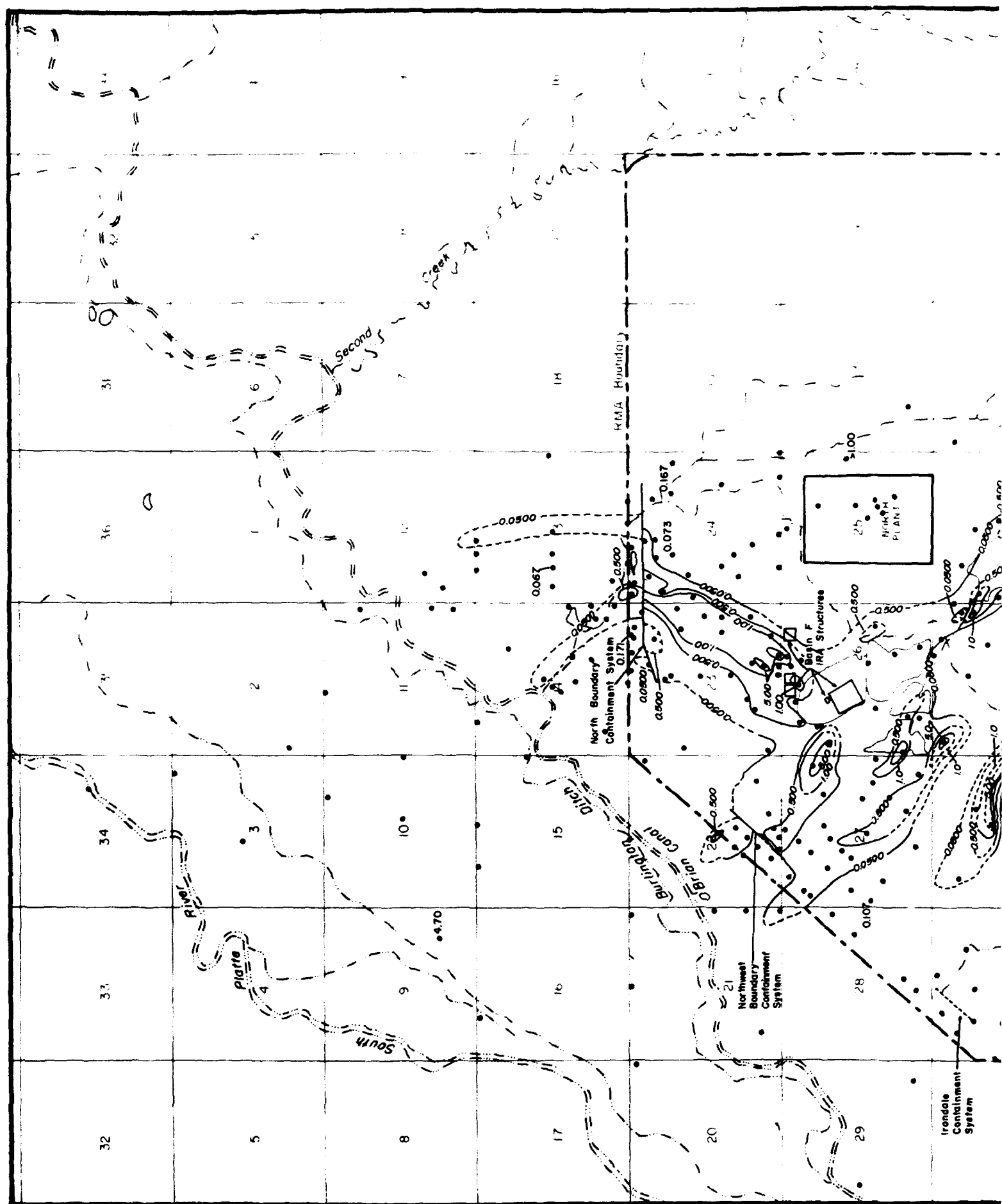
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

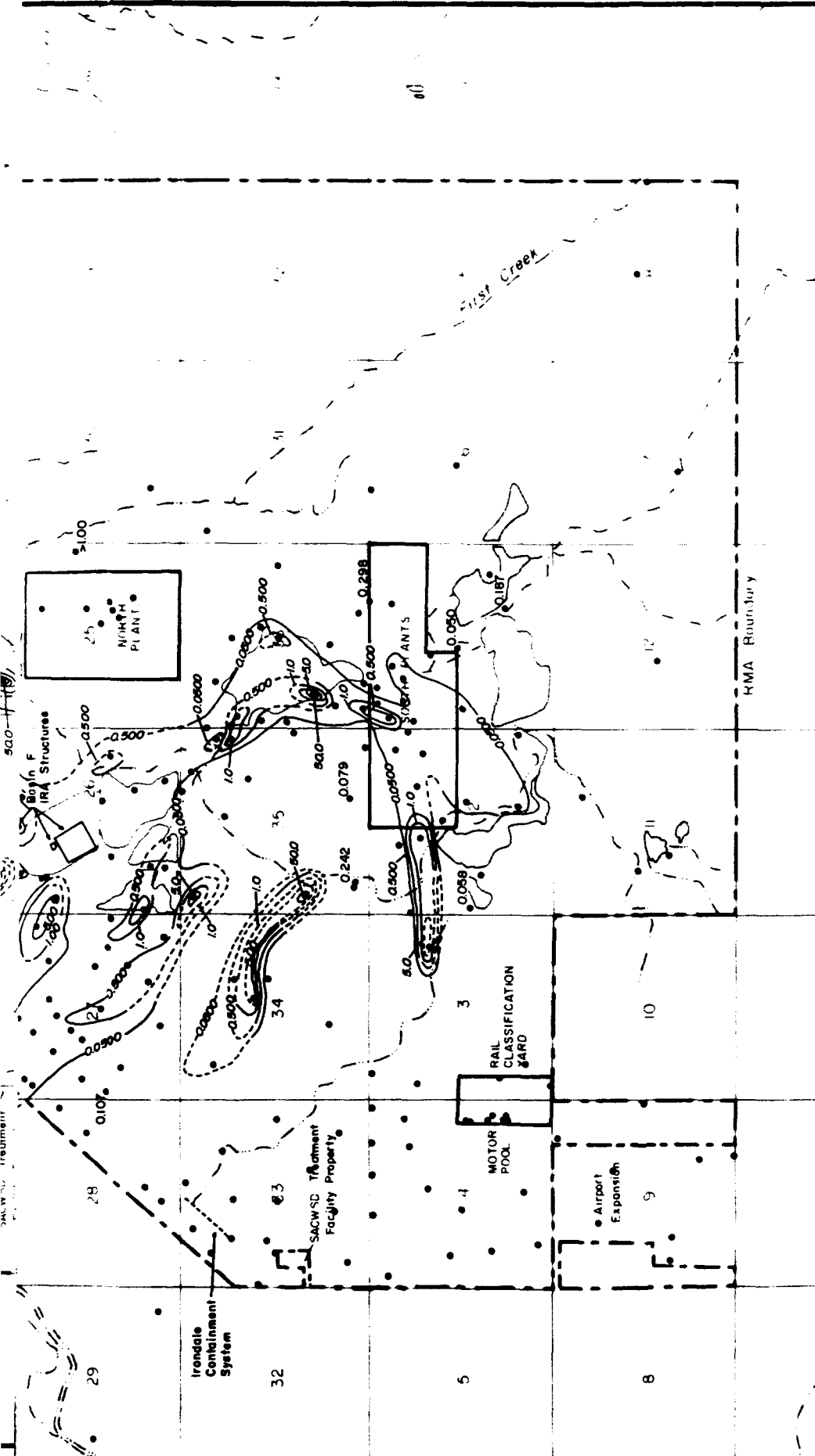
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Harding Lawson Associates

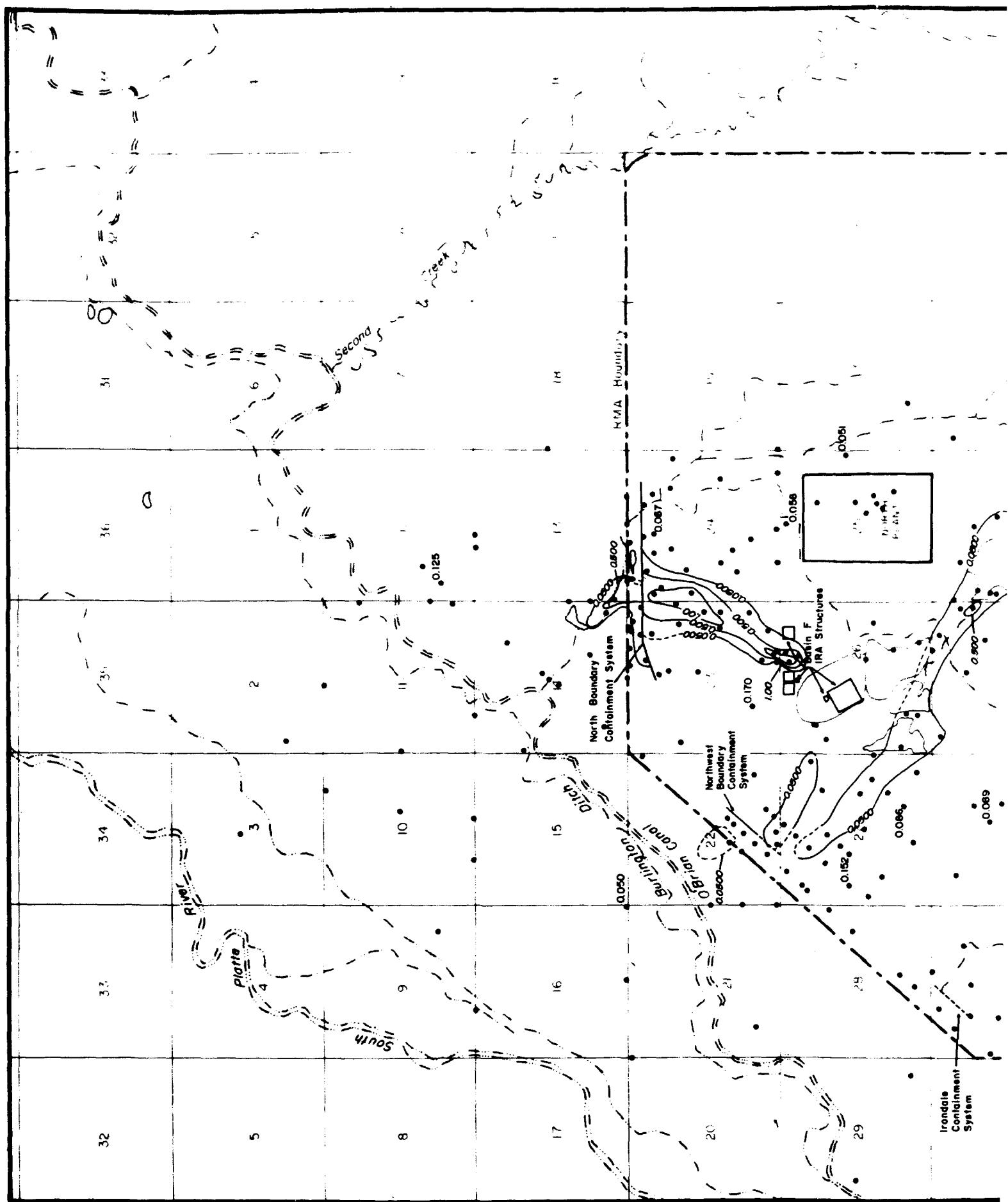
Figure 4.2-6

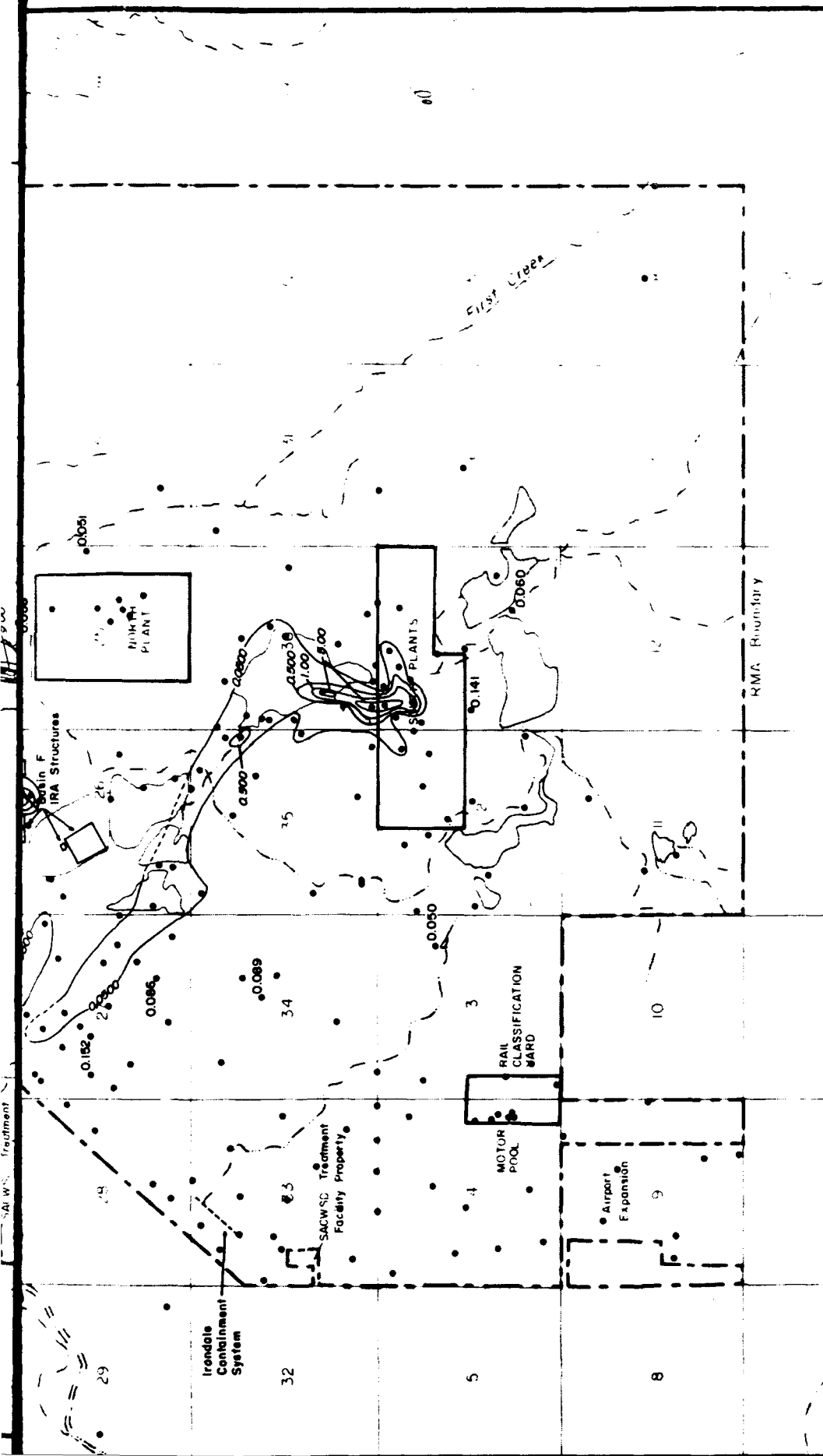
Potentiometric Surface of
Denver Fm Zone 4, Fall 1988





Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: R.L. Stollar & Associates, Inc. Harding Lawson Associates	Explanation ----- Isoconcentration Line. Dashed where Inferred 0.007. Isolated Detection or Concentration less than Highest CRL, in ug/l ----- Containment System Physical Barrier Hydraulic Barrier Irradiation Containment System SACWSD Treatment Facility Property RAIL CLASSIFICATION YARD MOTOR POOL Airport Expansion 25 NORTH PLANT 24 SOUTH PLANT First Creek HMA Boundary 0 4000 8000 Feet 0 1000 2000 Meters
Figure 4.3.2-1 Dieldrin Plumes Unconfined Ground-Water Flow System Fall 1988 CMP Ground-Water Monitoring Annual Report FY89	Isoconcentration Values (ug/l) 0.0500 0.500 1.00 5.00 50.0



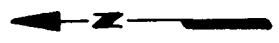


Explanation

- Isoconcentration Line,
Dashed where Inferred
- 0.005. Isolated Detection or Concentration
less than Highest CRL, in µg/l
- Containment System
 - Physical Barrier
 - Hydraulic Barrier

Isoconcentration Values (µg/l)

0.0500
0.500
1.00
5.00



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Commerce City, Colorado

Prepared by :

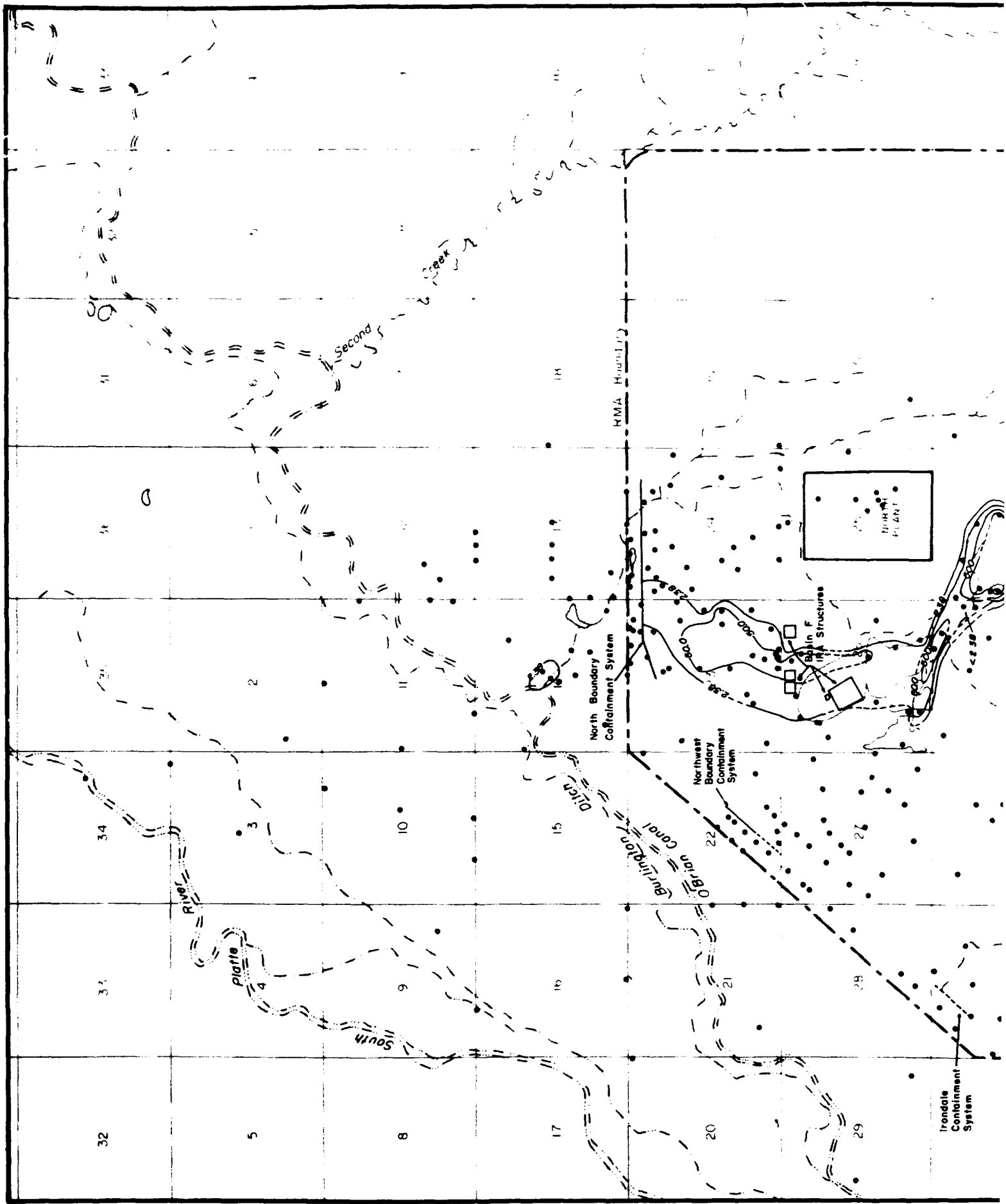
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

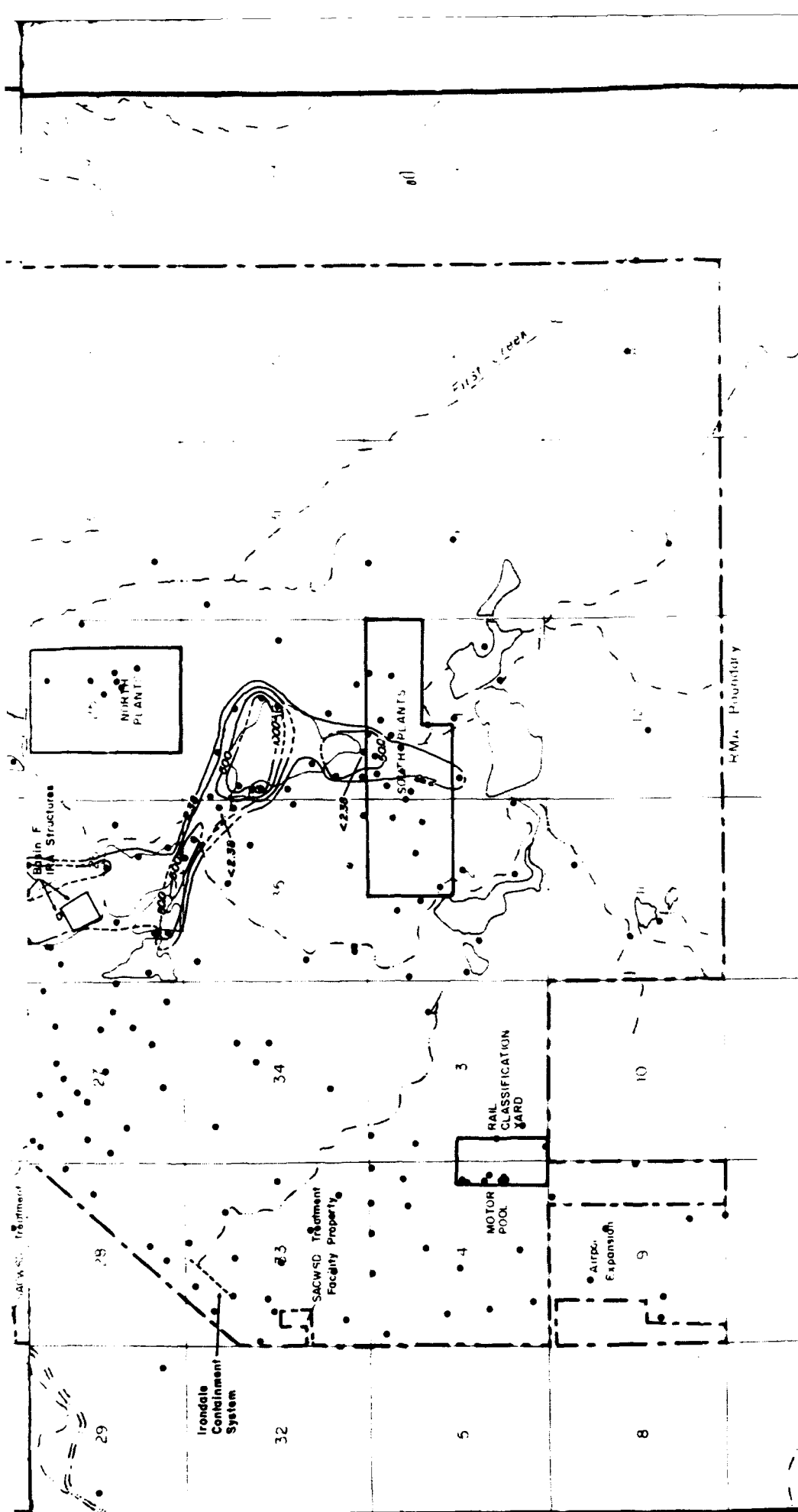
Figure 4.3.3-1

Endrin Plumes

Unconfined Ground-Water Flow System

Fall 1988





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Commerce City, Colorado

Prepared by :

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Harding Lawson Associates

Figure 4.3.4-1

Dithiane/Oxathiane Plumes

Unconfined Ground-Water Flow System

Fall 1988

CMF Ground-Water Monitoring Annual Report FY89

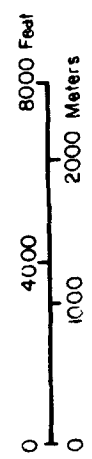
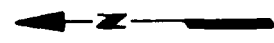
Explanation

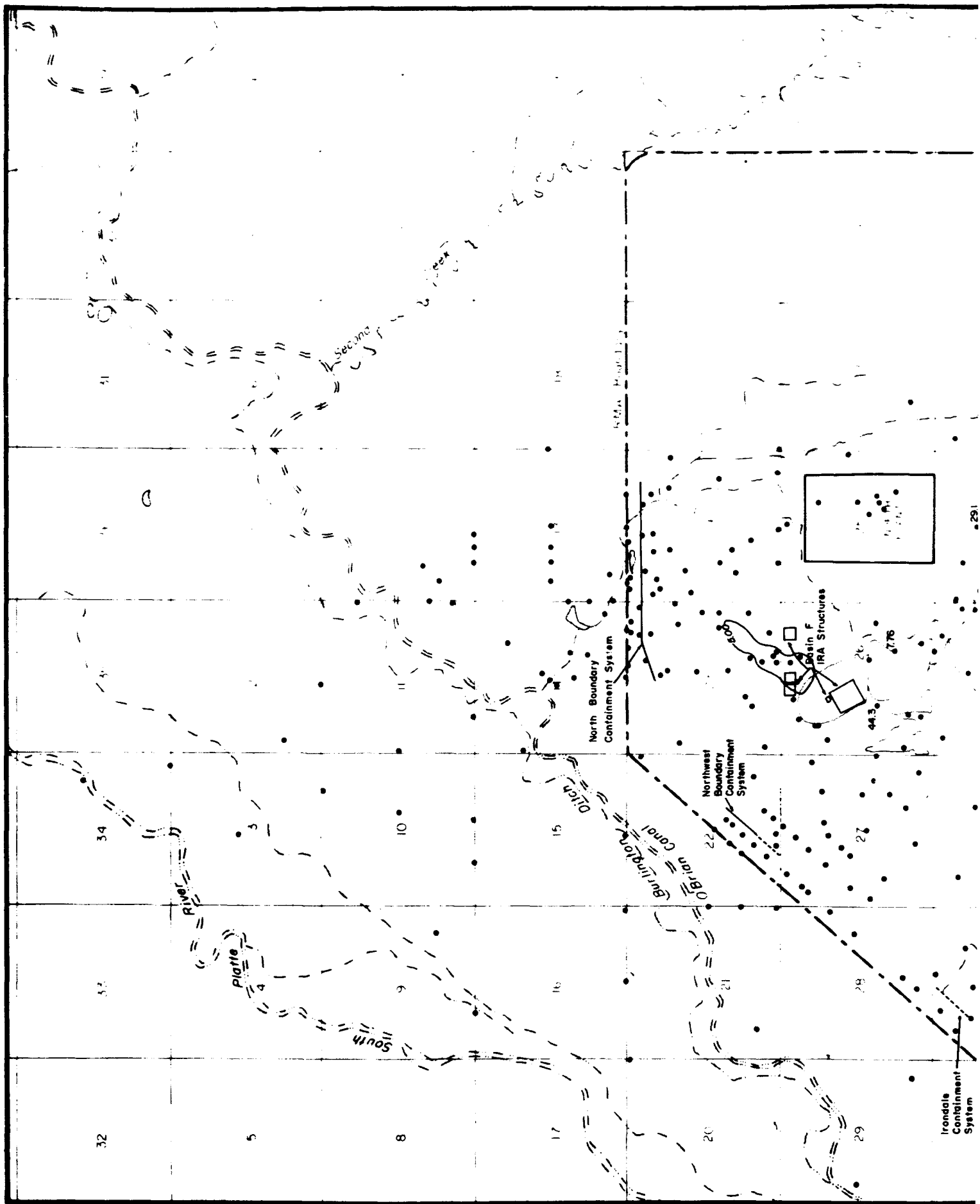
- Isoconcentration Line,
Dashed where Inferred
- o.o.s. Isolated Detection or Concentration
less than Highest CRL, in µg/l

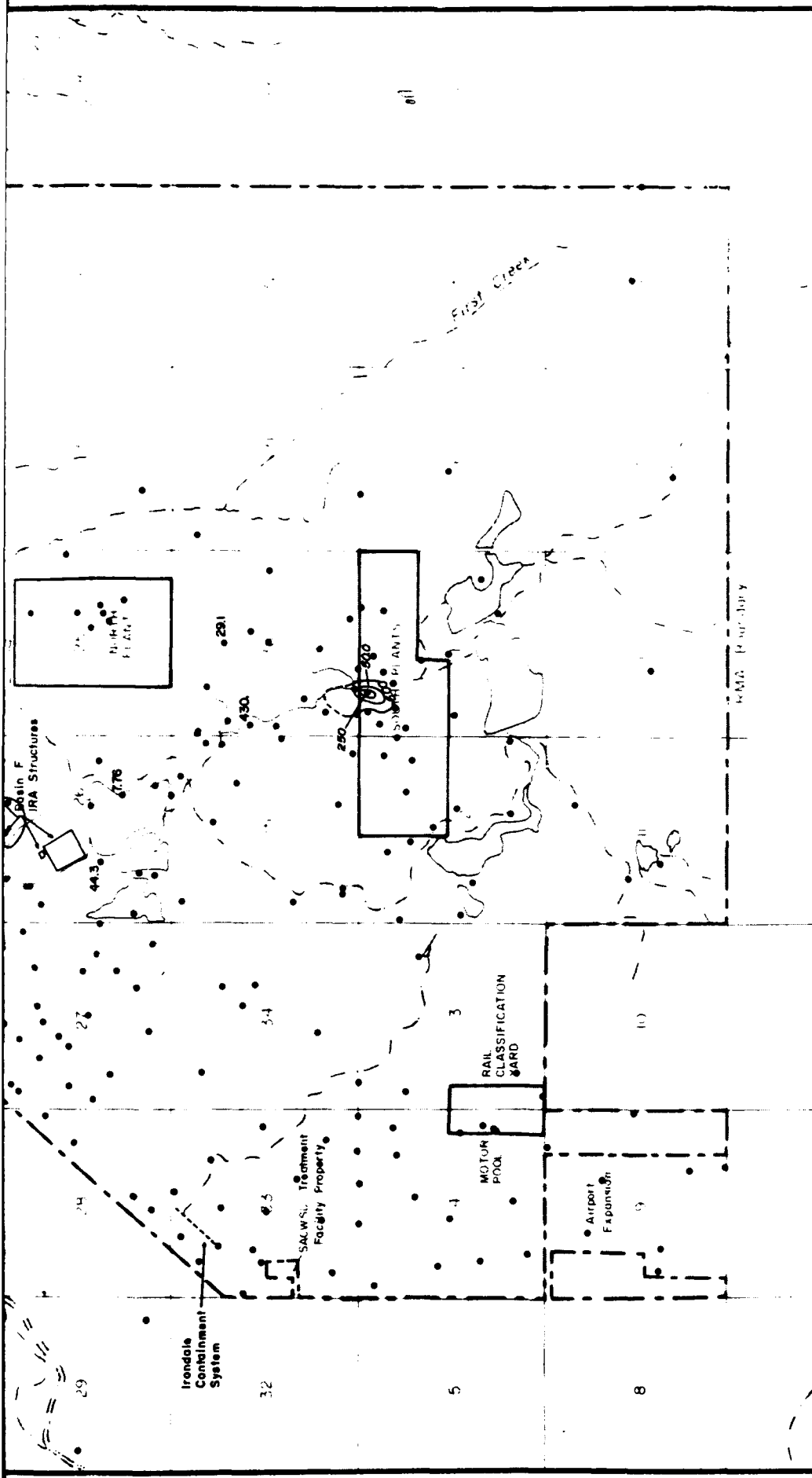
- Containment System
- Physical Barrier
- Hydraulic Barrier

Isoconcentration Values (µg/l)

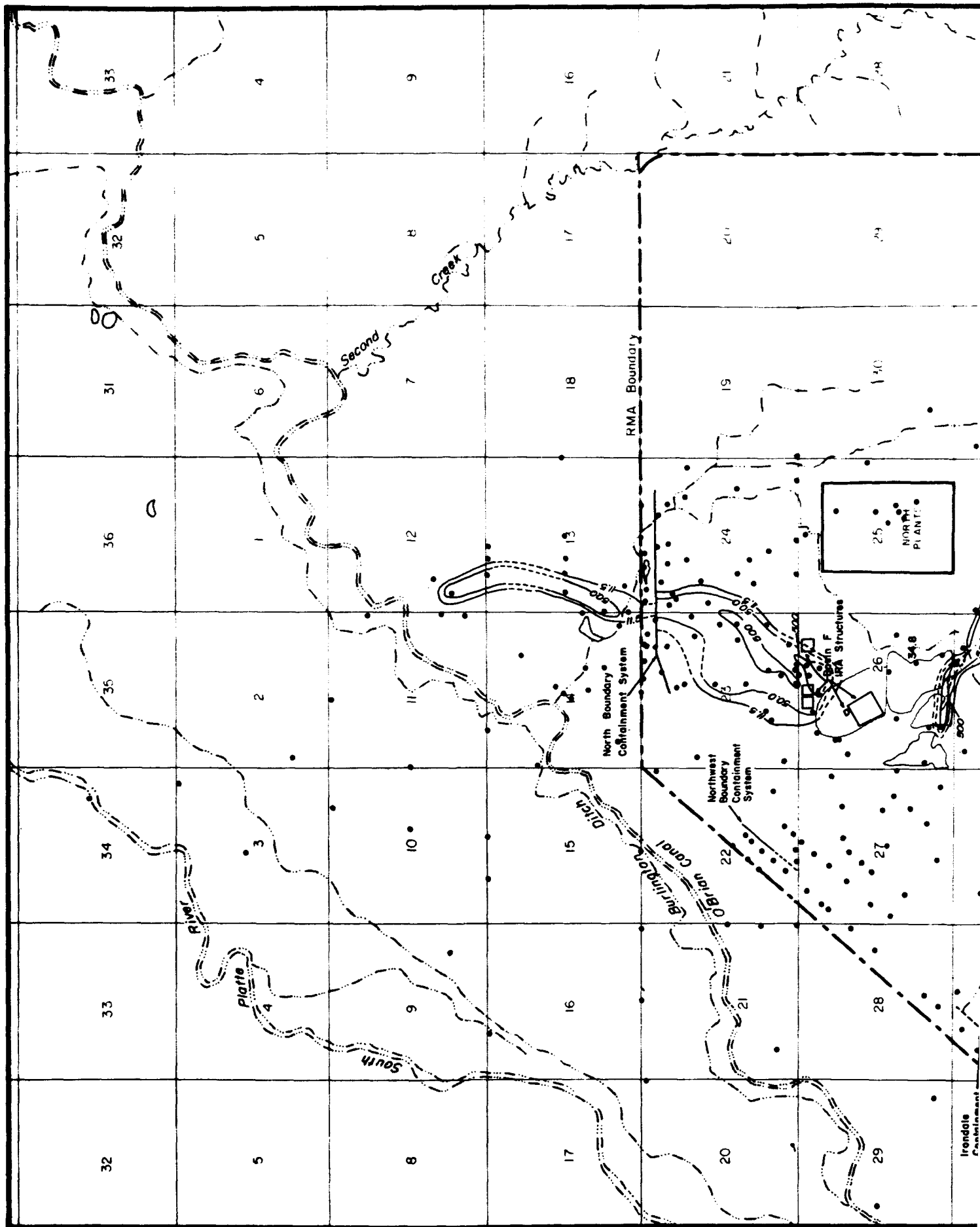
2.38
50.0
500
1000

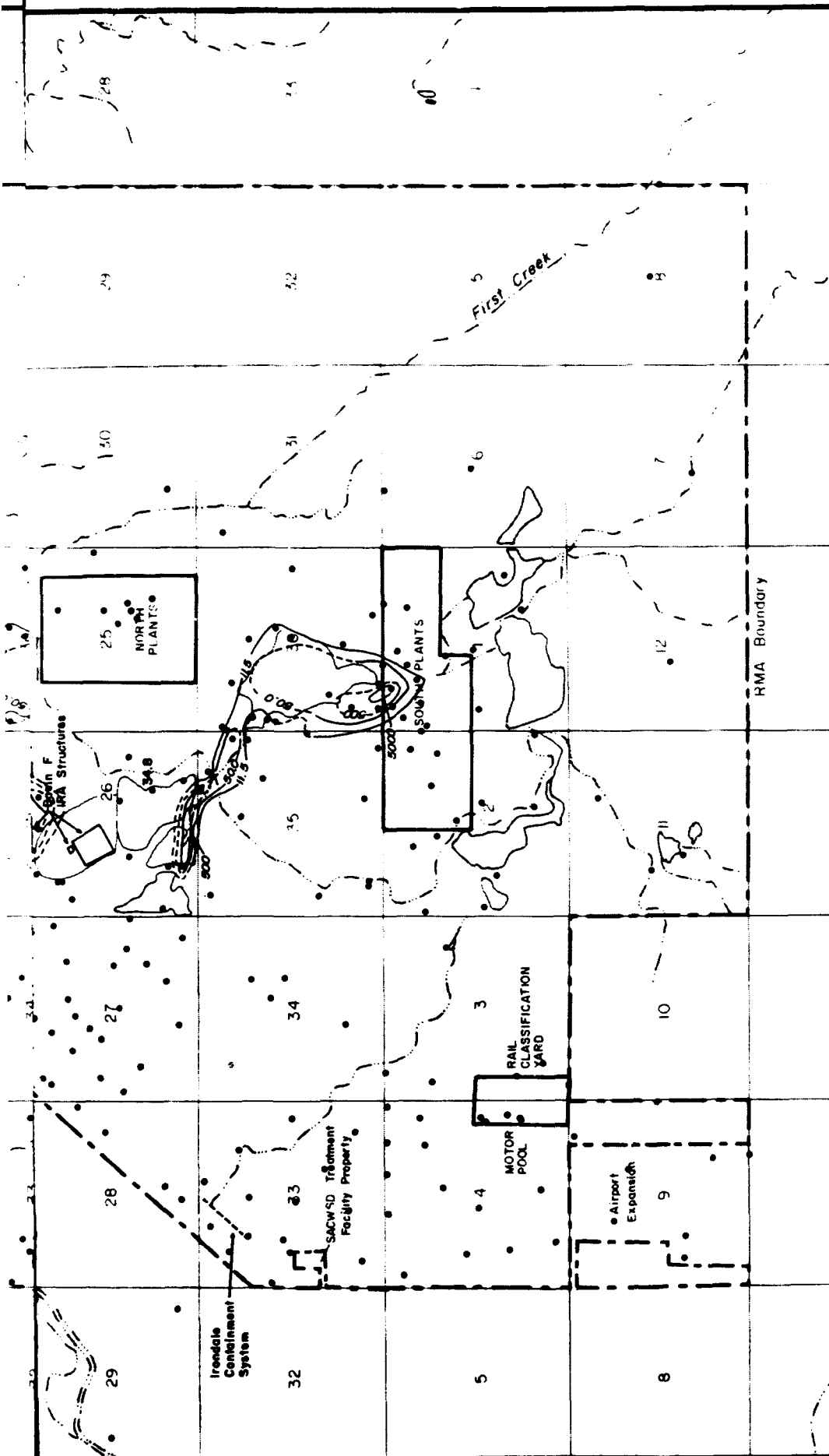






Prepared for : U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by : R.L. Stollar & Associates, Inc. Harding Lawson Associates	Explanation — Isoconcentration Line. Dashed where Inferred 7.76. Isolated Detection or Concentration less than Highest CRL, in $\mu\text{g/l}$ Containment System — Physical Barrier — Hydraulic Barrier Irrigation Containment System SALWOL Treatment Facility Property RAIL CLASSIFICATION YARD MOTOR POOL Airport Expansion First Circle Scale: 0 4000 8000 Feet 0 1000 2000 Meters
Figure 4.3.5-1 Benzothiazole Plumes Unconfined Ground-Water Flow System Fall 1988 CMP Ground-Water Monitoring Annual Report FY89	





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Commerce City, Colorado

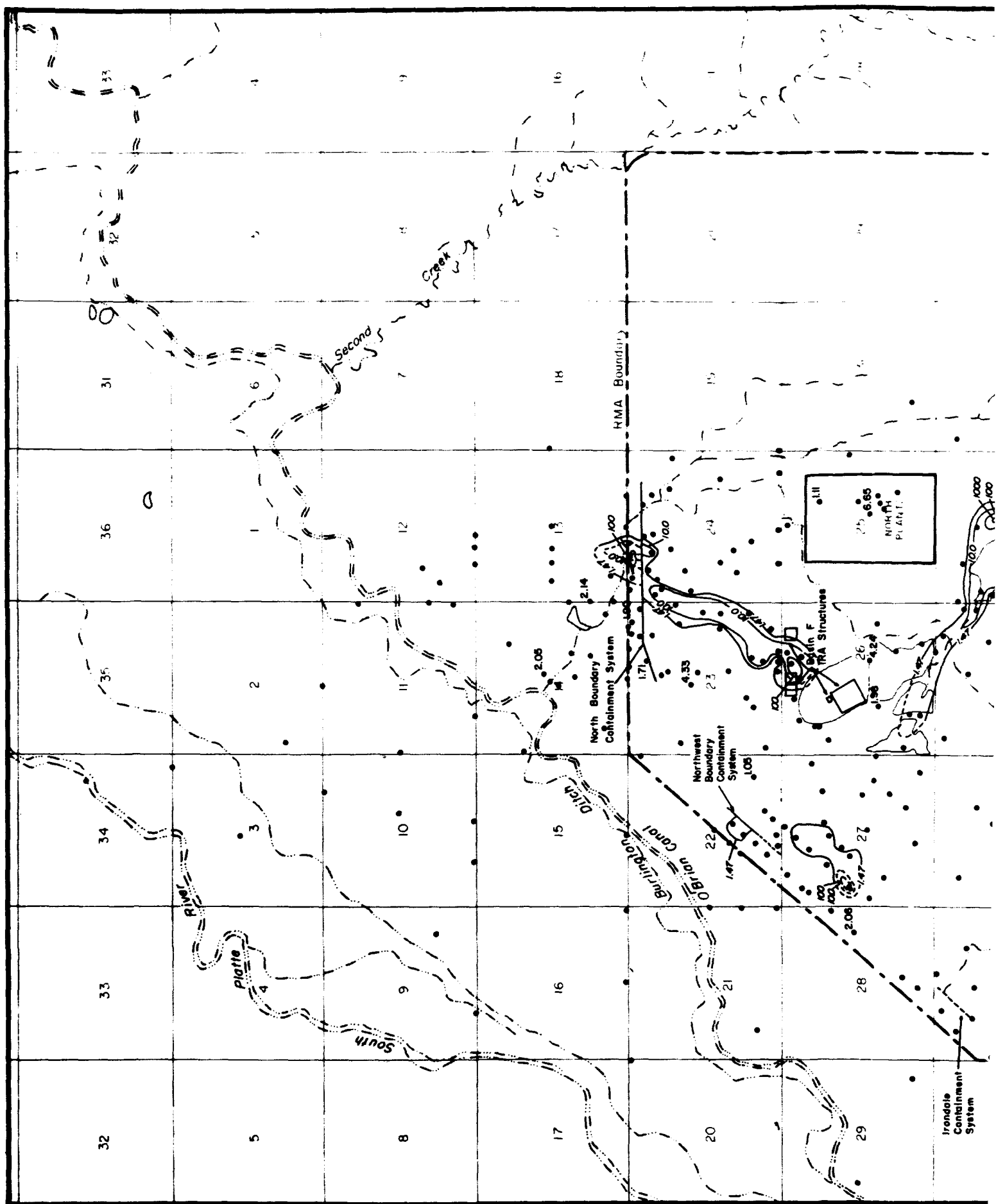
Prepared by:

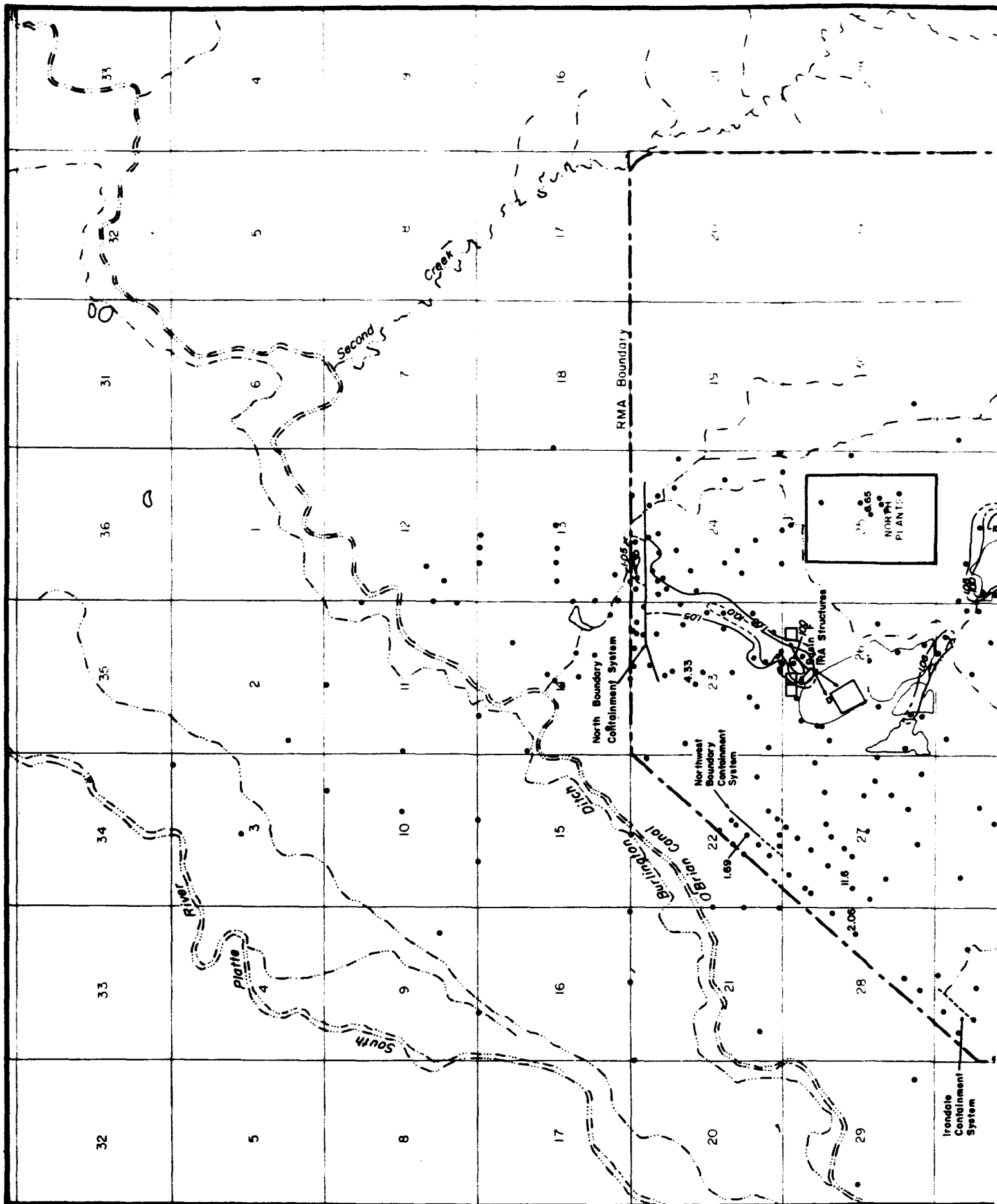
R.L. Stollar & Associates, Inc.
Harding Lawson Associates

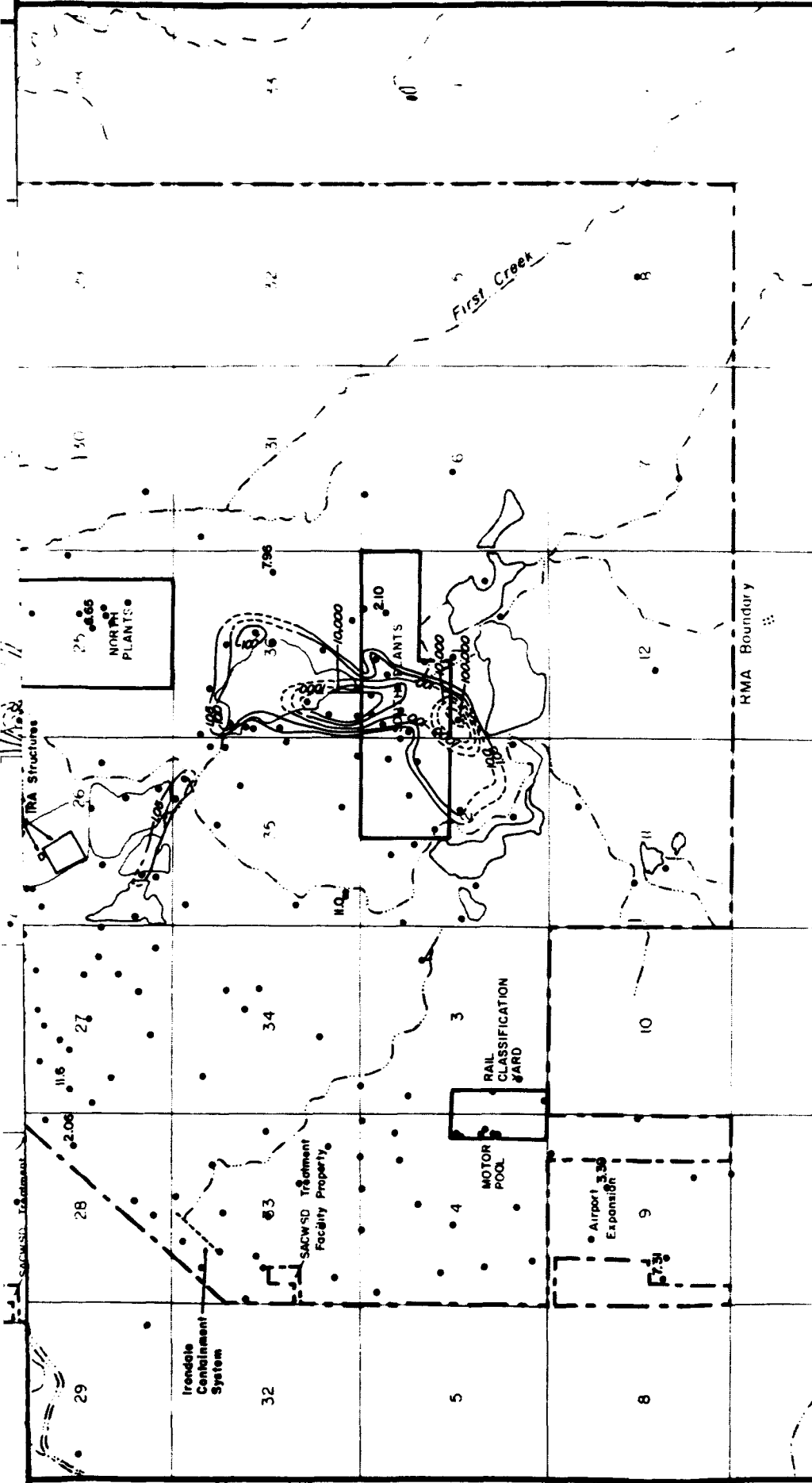
Figure 4.3.6-1

Summed Organosulfur
Compound Plumes
Unconfined Ground-Water Flow System
Fall 1988

CMP Ground-Water Monitoring Annual Report FY89







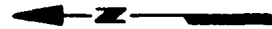
Explanation

- Isoconcentration Line.
Dashed where Inferred
- 7.9% Isolated Detection or Concentration
less than Highest CRL, in $\mu\text{g/l}$

- Containment System
- Physical Barrier
- Hydraulic Barrier

Isocentration Values ($\mu\text{g/l}$)

1.06
10.0
100
1000
10,000
100,000



0 4000 8000 Feet
0 1000 2000 Meters

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U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

Prepared by :

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Harding Lawson Associates

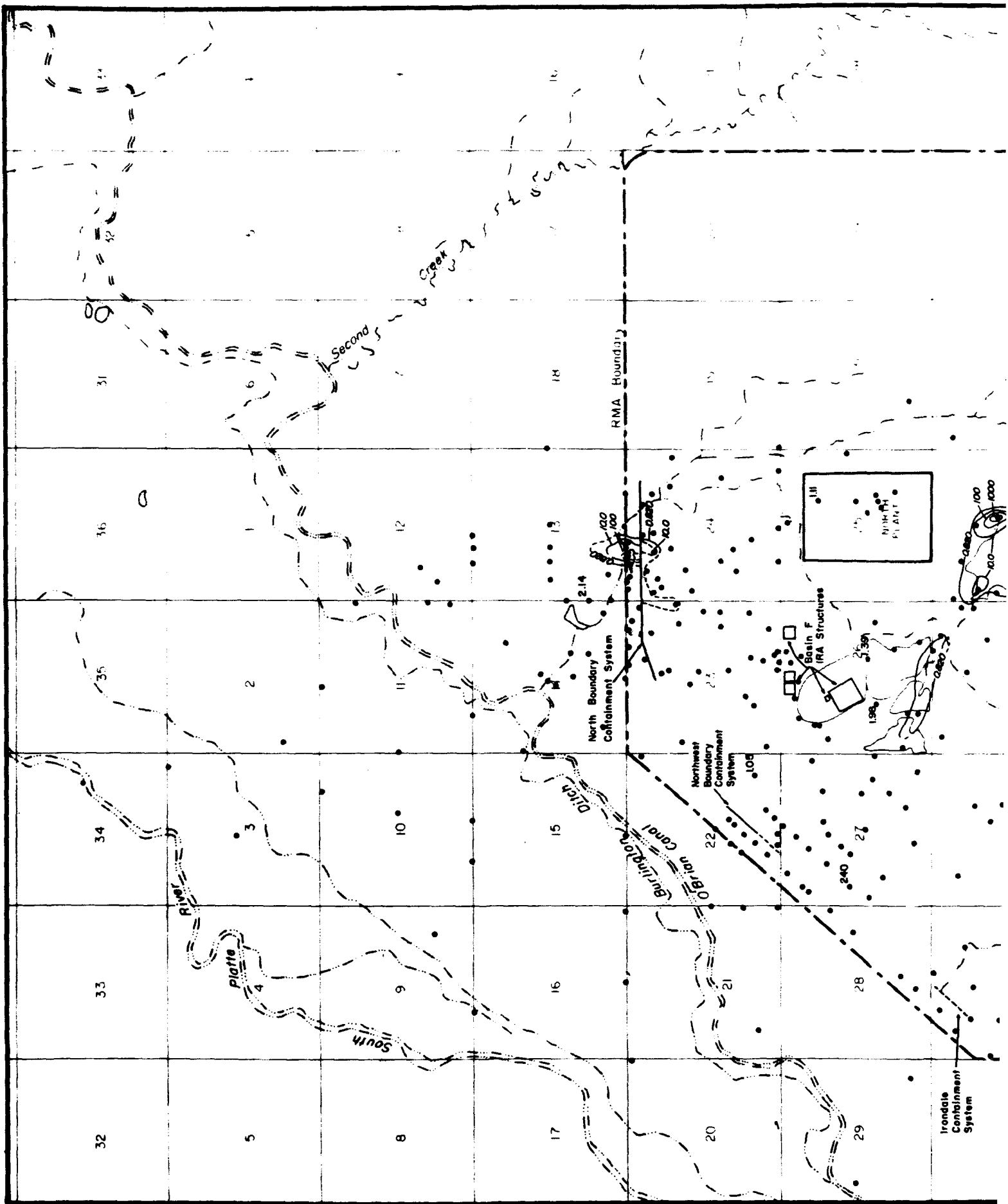
Figure 4.3.8-1

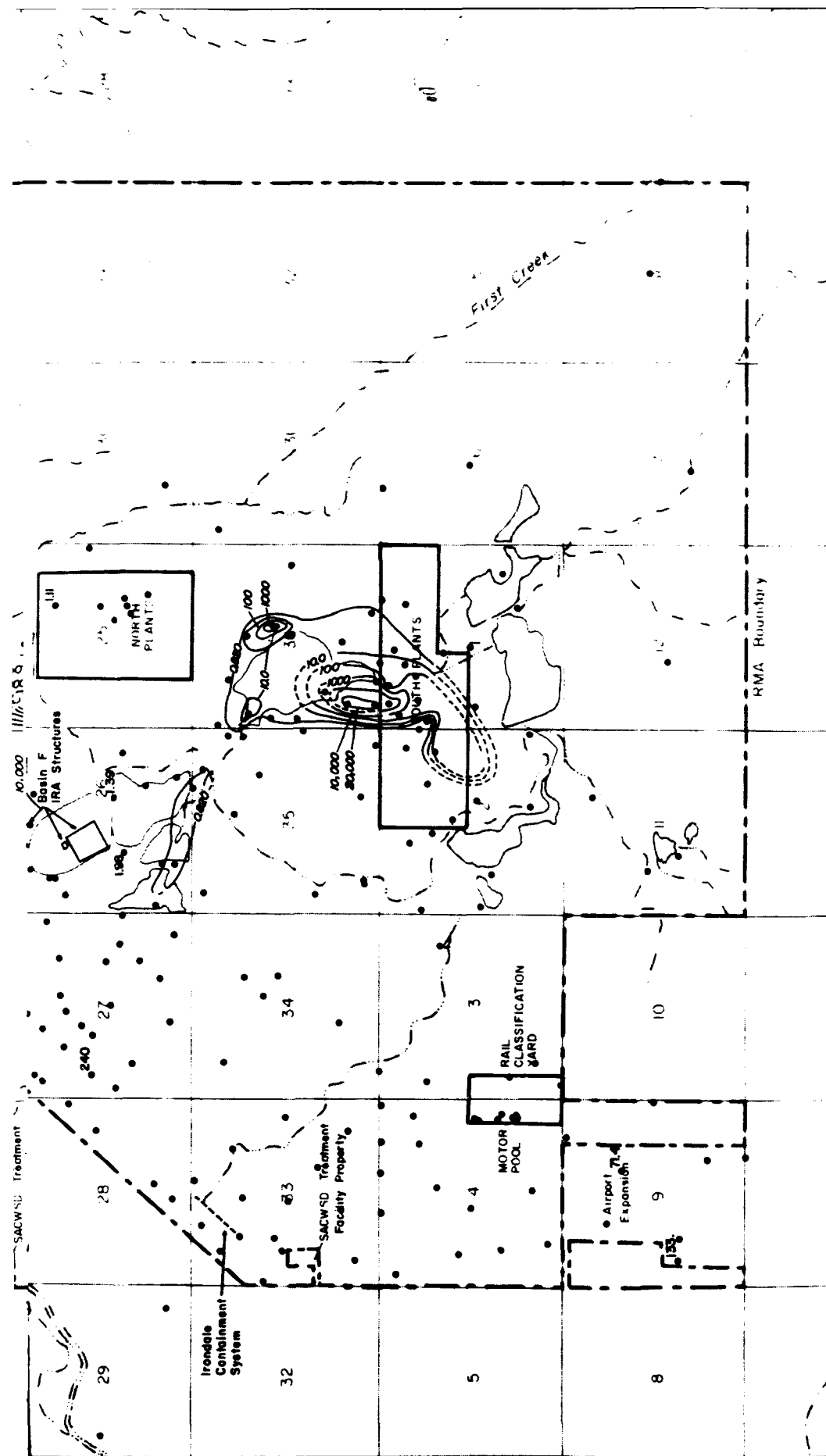
Benzene Plumes

Unconfined Ground-Water Flow System

Fall 1988

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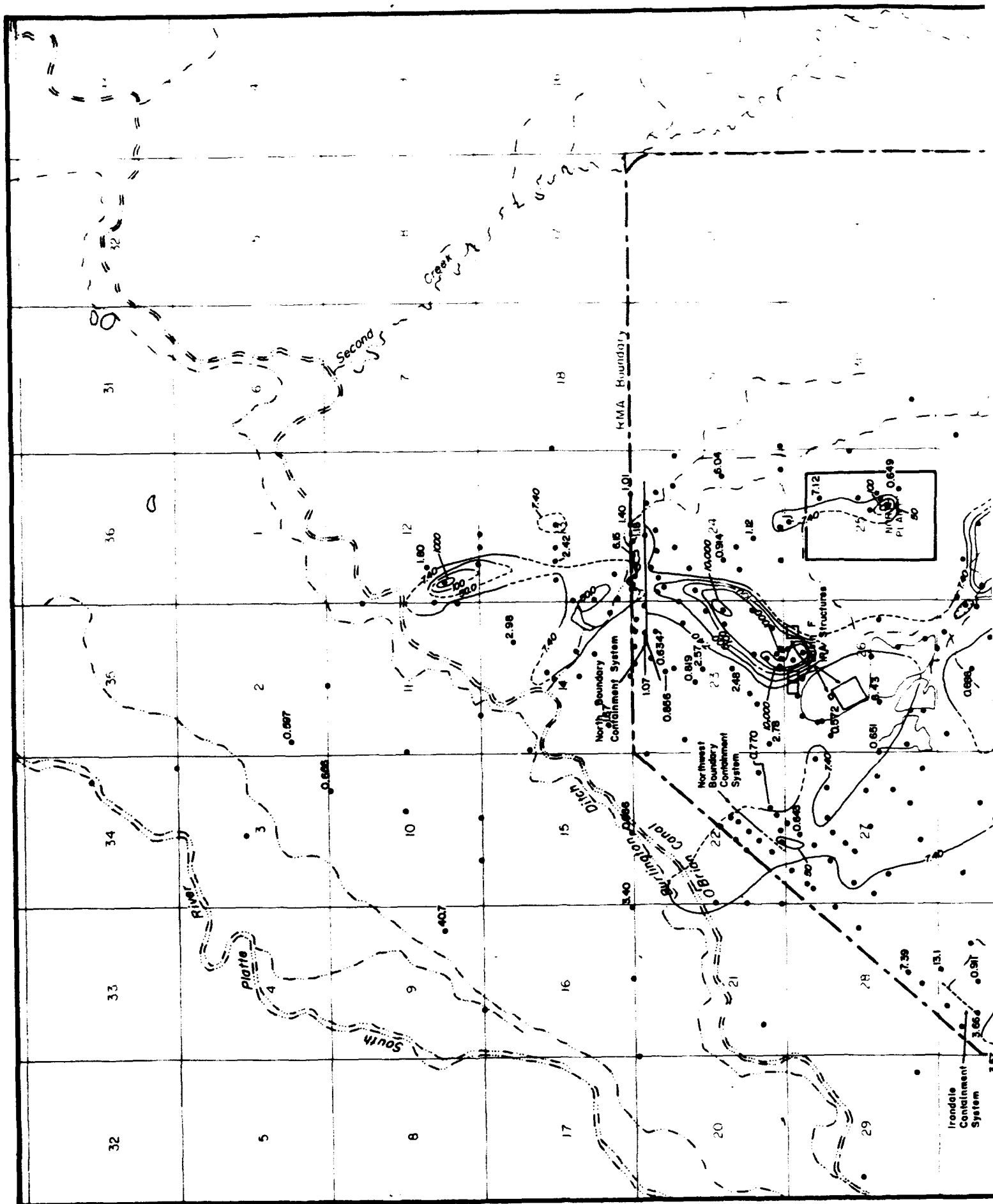
Figure 4.3.9-1

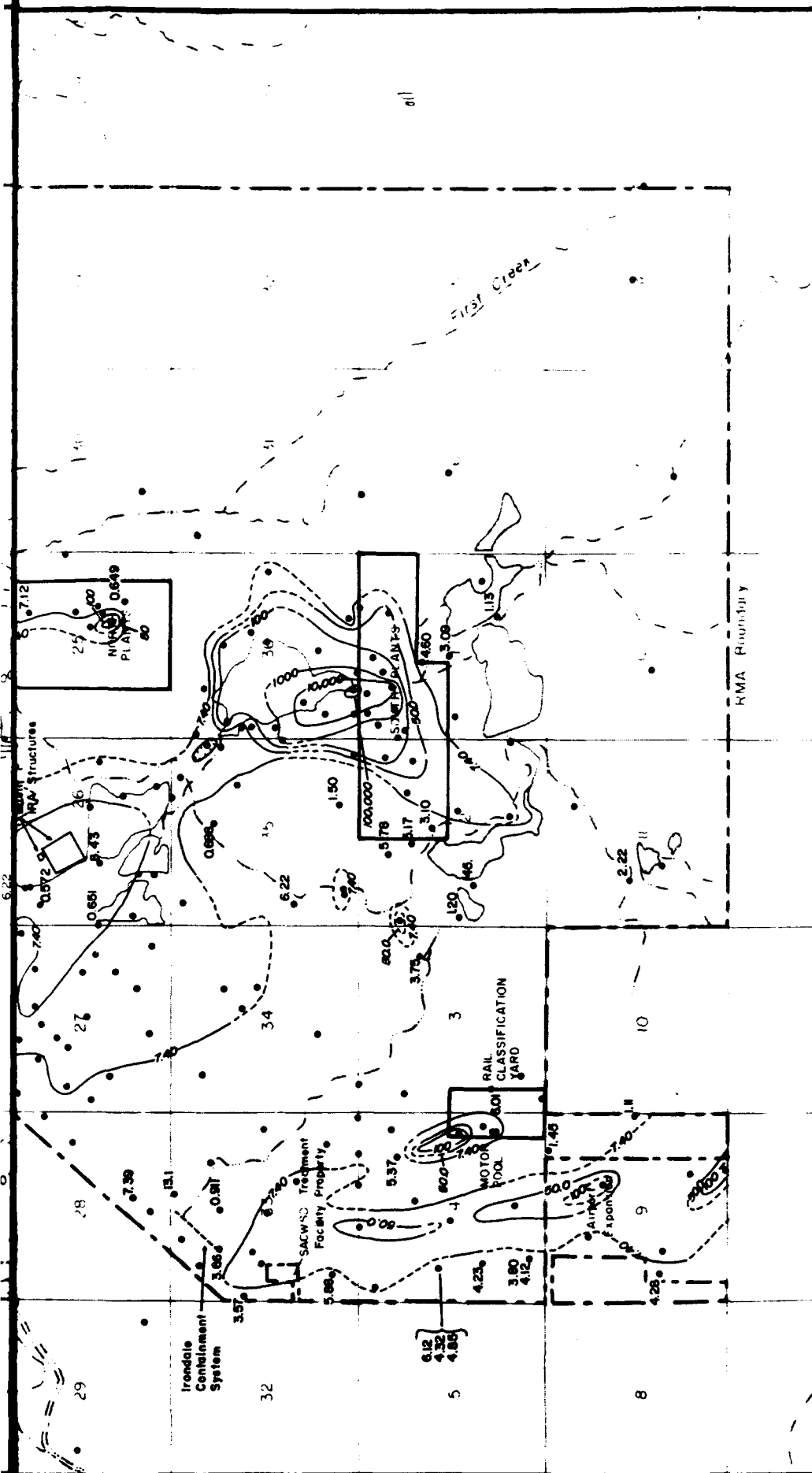
Chlorobenzene Plumes

Unconfined Ground-Water Flow System

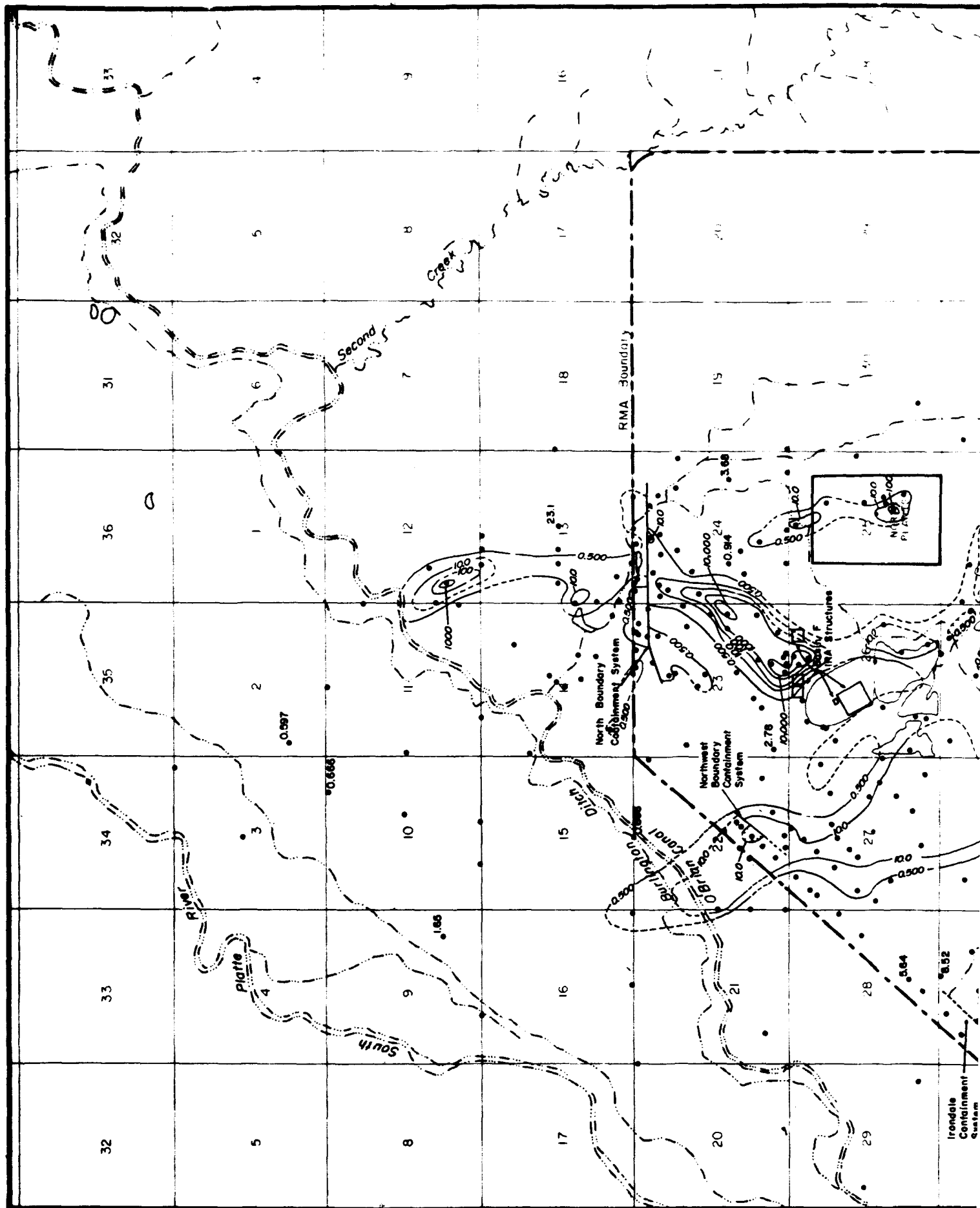
Fall 1988

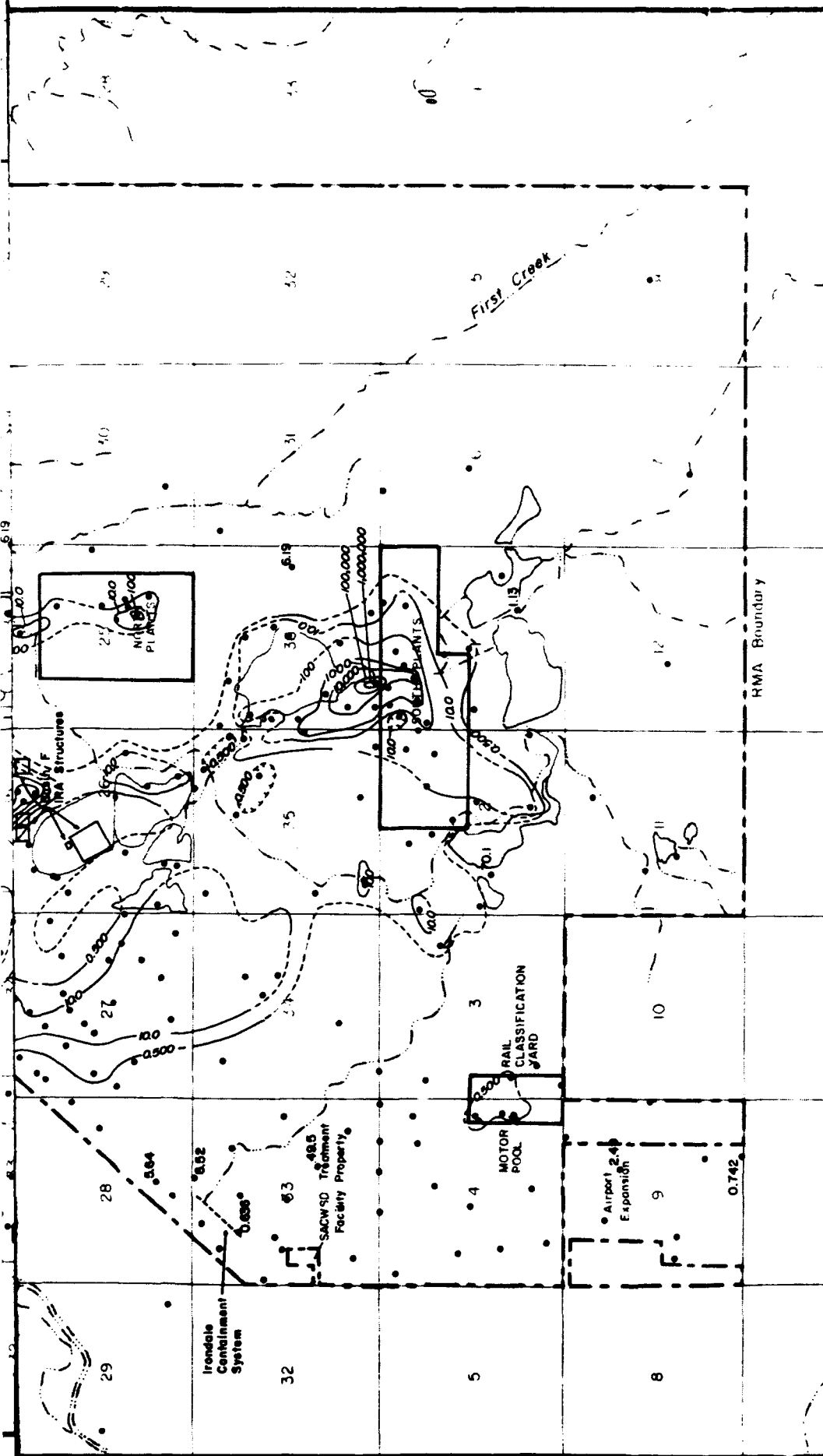
CMP Ground-Water Monitoring Annual Report FY89





Prepared for: U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by: R.L. Stollar & Associates, Inc. Harding Lawson Associates	Explanation Isoconcentration Line. Dashed where Inferred 150. Isolated Detection or Concentration less than Highest CRL, in ug/l Containment System Physical Barrier Hydraulic Barrier SUMMED COMPOUNDS <table border="0"> <tr> <td>1,1-Dichloroethane</td> <td>Trichloroethane</td> </tr> <tr> <td>1,1,1-Trichloroethane</td> <td>Tetrachloroethane</td> </tr> <tr> <td>1,2-Dichloroethane</td> <td>Carbon Tetrachloride</td> </tr> <tr> <td>1,1,1-Trichloroethane</td> <td>Chloroform</td> </tr> <tr> <td>1,1,1,2-Trichloroethane</td> <td>Methylene Chloride</td> </tr> </table>	1,1-Dichloroethane	Trichloroethane	1,1,1-Trichloroethane	Tetrachloroethane	1,2-Dichloroethane	Carbon Tetrachloride	1,1,1-Trichloroethane	Chloroform	1,1,1,2-Trichloroethane	Methylene Chloride
1,1-Dichloroethane	Trichloroethane										
1,1,1-Trichloroethane	Tetrachloroethane										
1,2-Dichloroethane	Carbon Tetrachloride										
1,1,1-Trichloroethane	Chloroform										
1,1,1,2-Trichloroethane	Methylene Chloride										
Figure 4.3.10-1 Summed Volatile Organohalogen Compound Plumes Unconfined Ground-Water Flow System Fall 1988	ISOCONCENTRATION VALUES (ug/l) 7.40 50.0 100 1000 10,000 100,000 Scale: 0 1000 4000 8000 Feet 0 2000 Meters North Arrow: N										
CMP Ground-Water Monitoring Annual Report FY89											





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Prepared by :

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Harding Lawson Associates

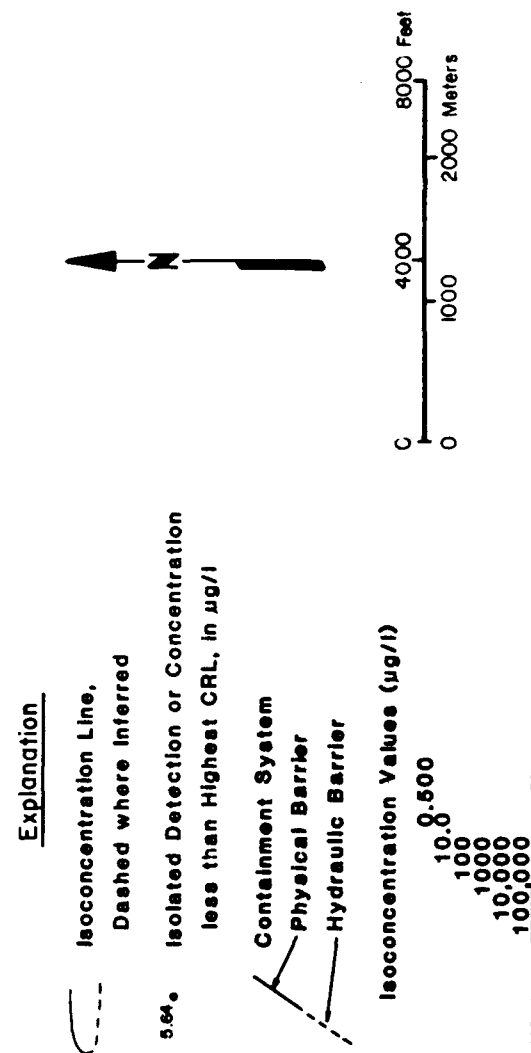
Figure 4.3.11-1

Chloroform Plumes

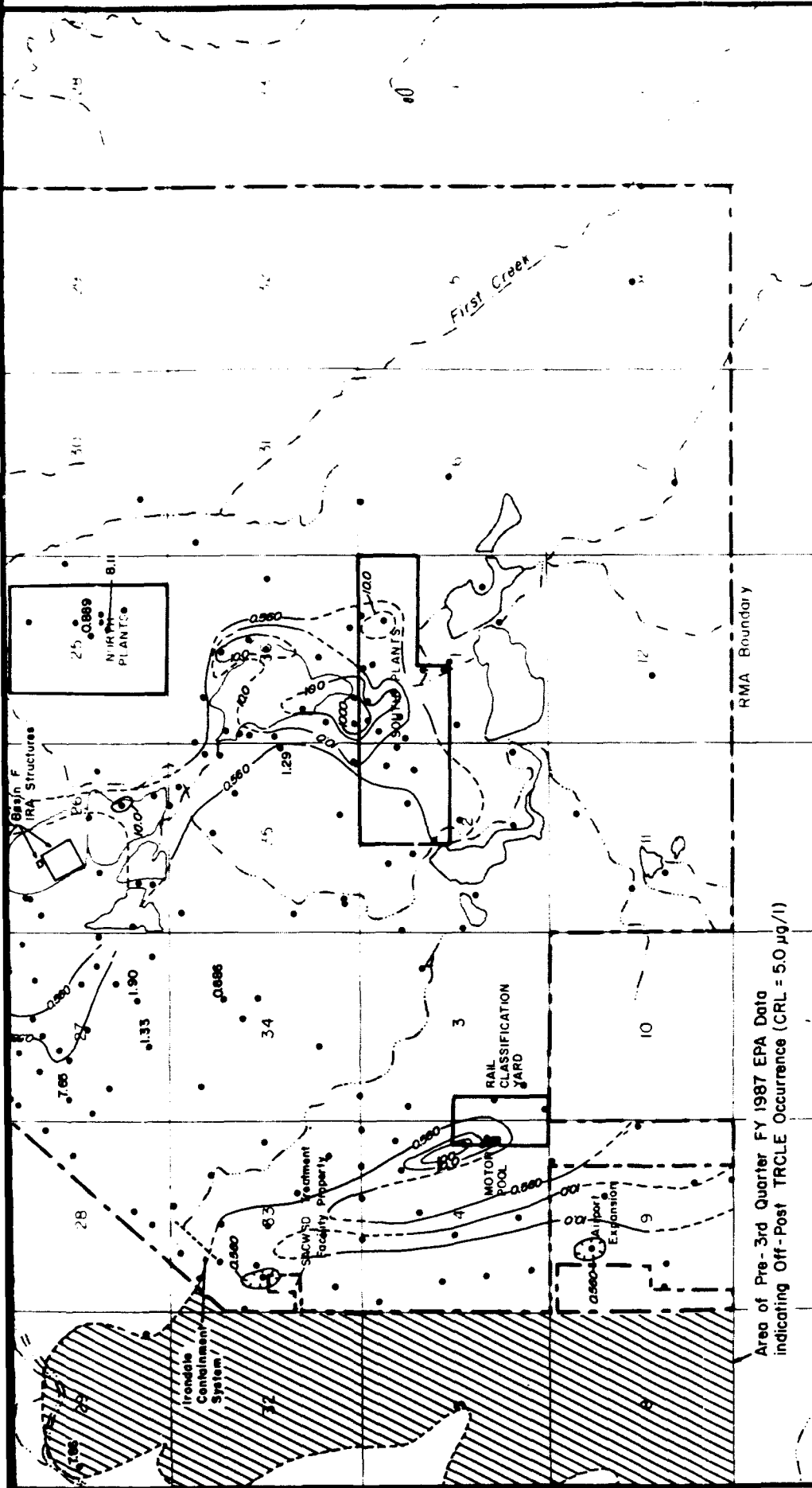
Unconfined Ground-Water Flow System

Fall 1988

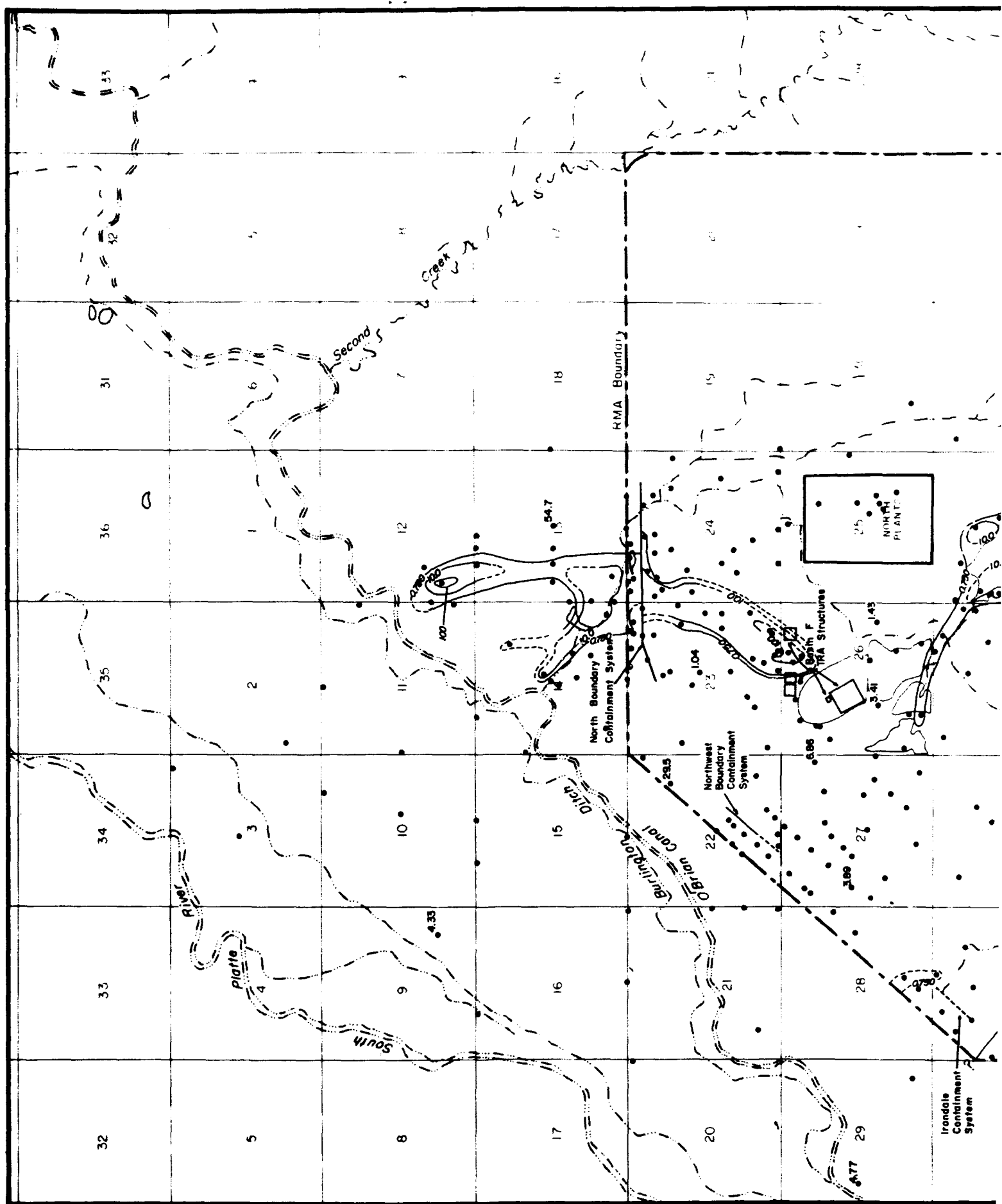
CMP Ground-Water Monitoring Annual Report FY89

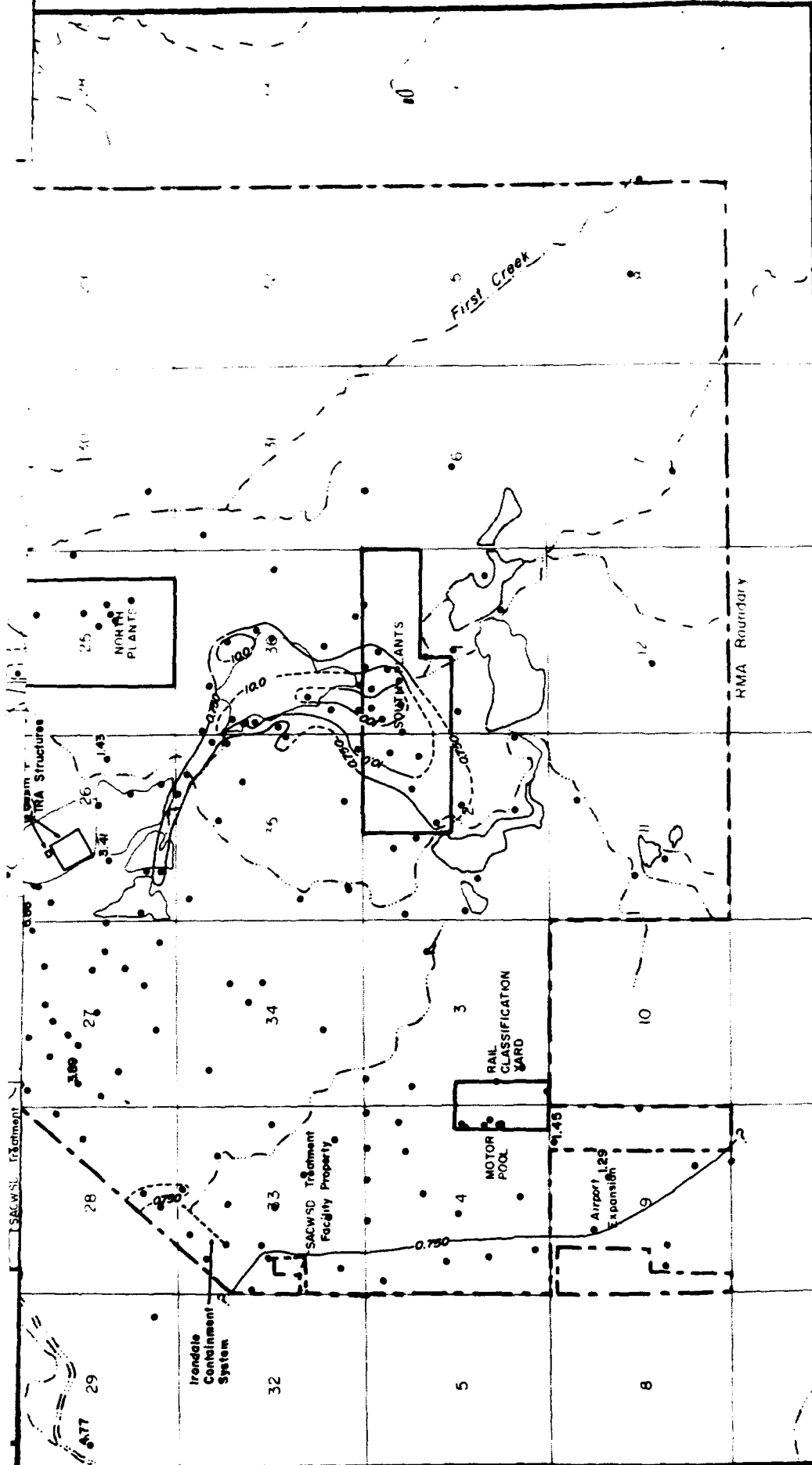






Prepared for : U.S. Army Program Manager for Rocky Mountain Arsenal Commerce City, Colorado Prepared by : R.L. Stollar & Associates, Inc. Harding Lawson Associates	Figure 4.3.12-1 Trichloroethene (TRCLE) Plumes Unconfined Ground-Water Flow System Fall 1988 CMP Ground-Water Monitoring Annual Report FY88
Explanation — Isoconcentration Line. - - - Dashed where Inferred 1.33. Isolated Detection or Concentration less than Highest CRL, in µg/l - Containment System - - - Physical Barrier — Hydraulic Barrier	Isoconcentration Values (µg/l) 0.560 10.0 100 1000 Scale: 0 4000 8000 Feet 0 1000 2000 Meters North Arrow





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Figure 4.3.13-1

Tetrachloroethene (TCLEE) Plumes
Unconfined Ground-Water Flow System
Fall 1988

CMP Ground-Water Monitoring Annual Report FY 89

Explanation

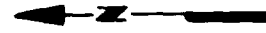
— Isoconcentration Line,
Dashed where Inferred

4.77. Isolated Detection or Concentration
less than Highest CRL, in $\mu\text{g/l}$

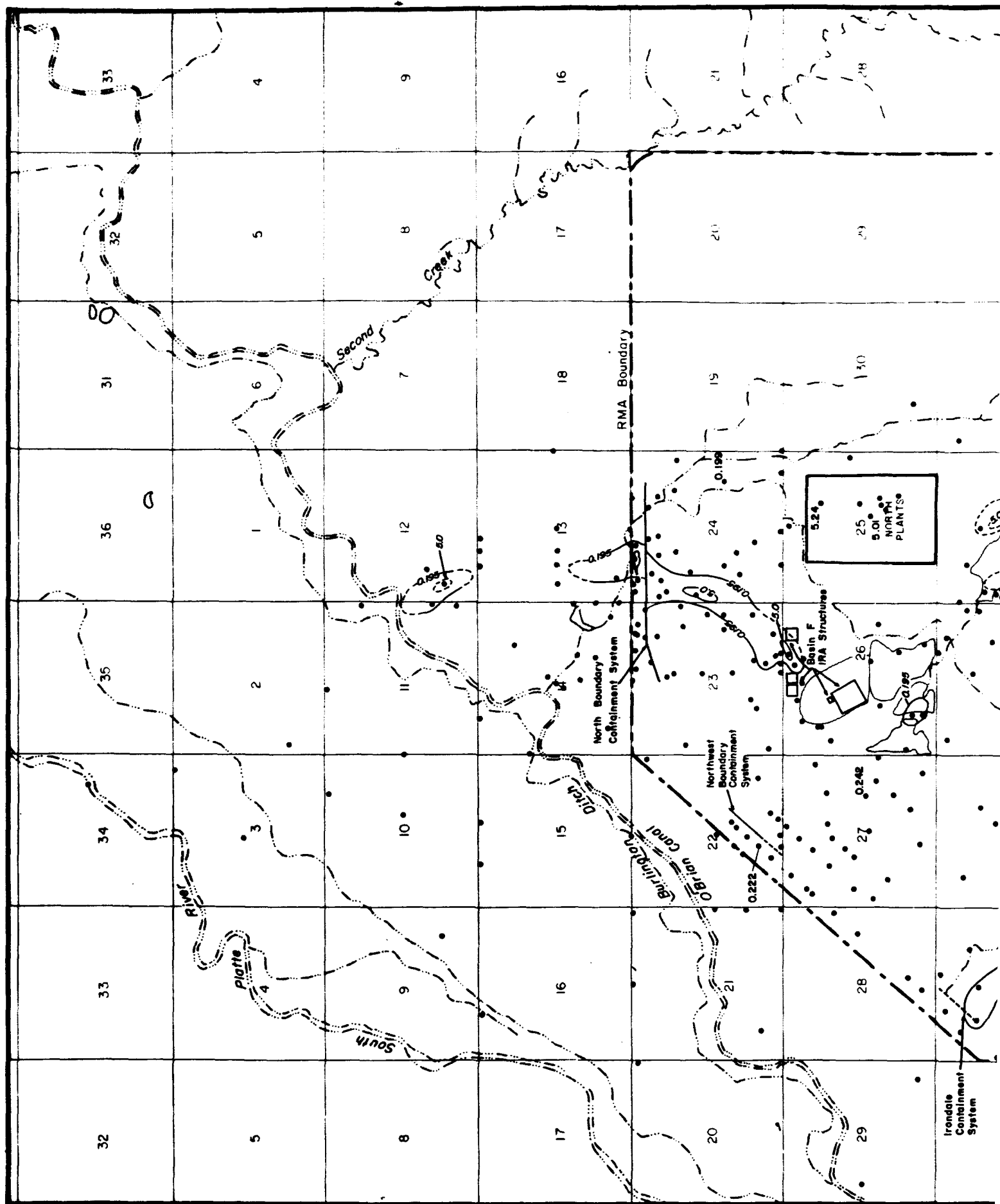
Containment System
Physical Barrier
Hydraulic Barrier

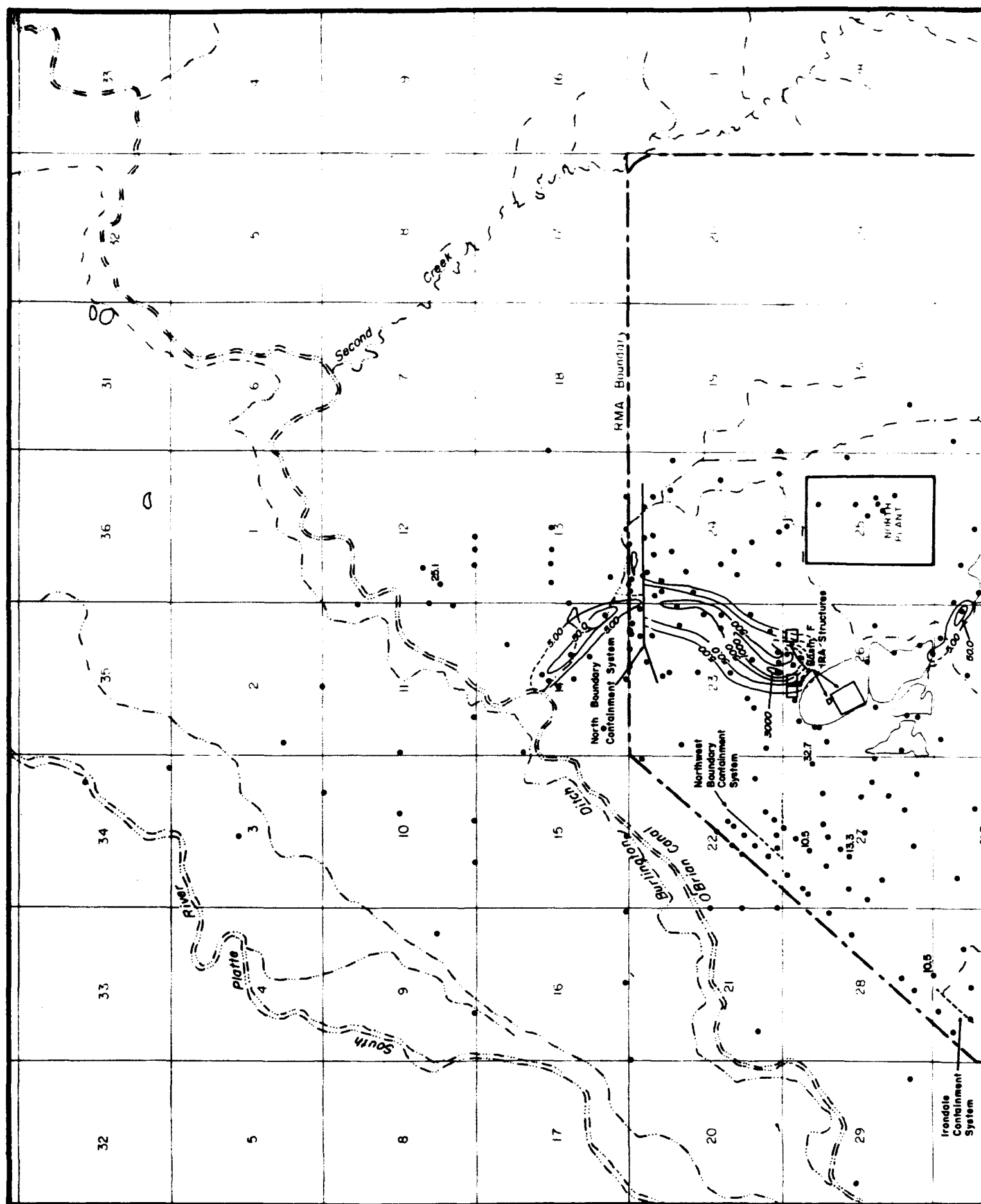
Isoconcentration Values ($\mu\text{g/l}$)

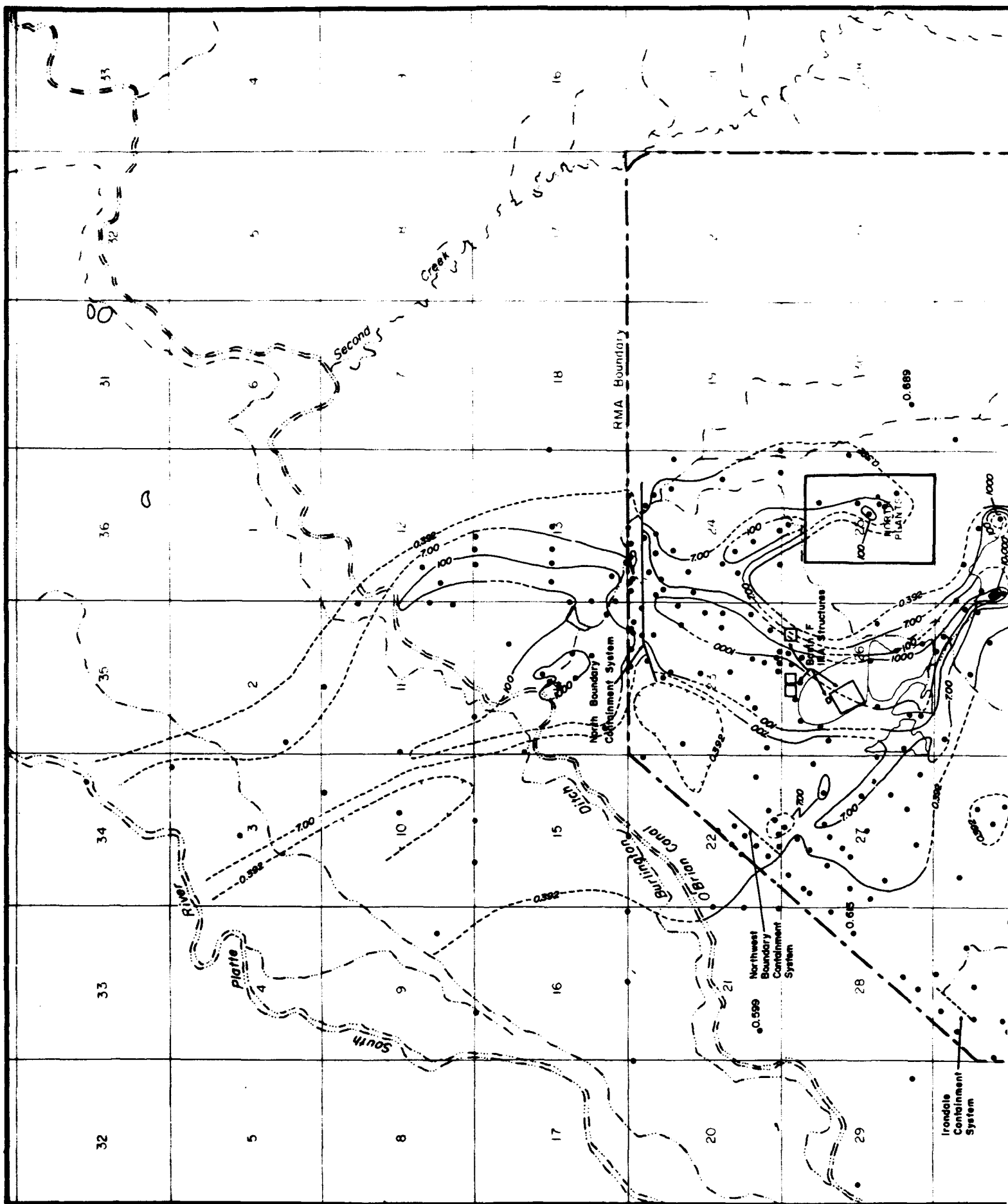
0.750
10
100

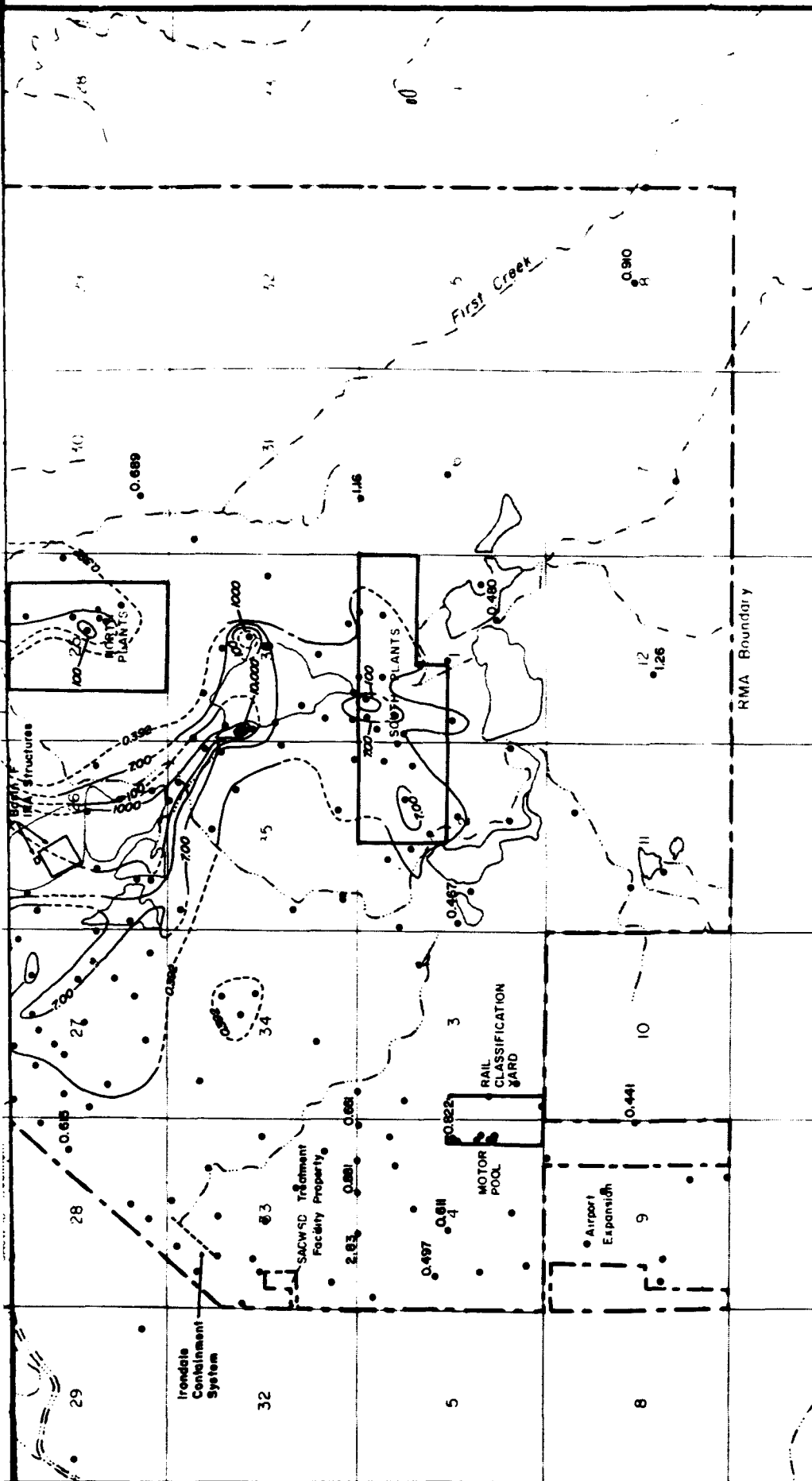


0 4000 8000 Feet
0 1000 2000 Meters









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Figure 4.3.16-1

Diisopropylmethylphosphonate Plumes (DIMP) Unconfined Ground-Water Flow System Fall 1988

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Explanation

Isoconcentration Line,

Dashed where Inferred

0.467. Isolated Detection or Concentration

less than Highest CRL, in $\mu\text{g/l}$

entertainment System

Physical Barrier

Hydraulic Barrier

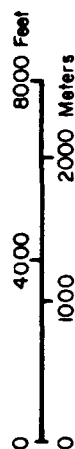
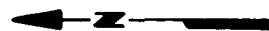
Isoconcentration Values ($\mu\text{g/l}$)

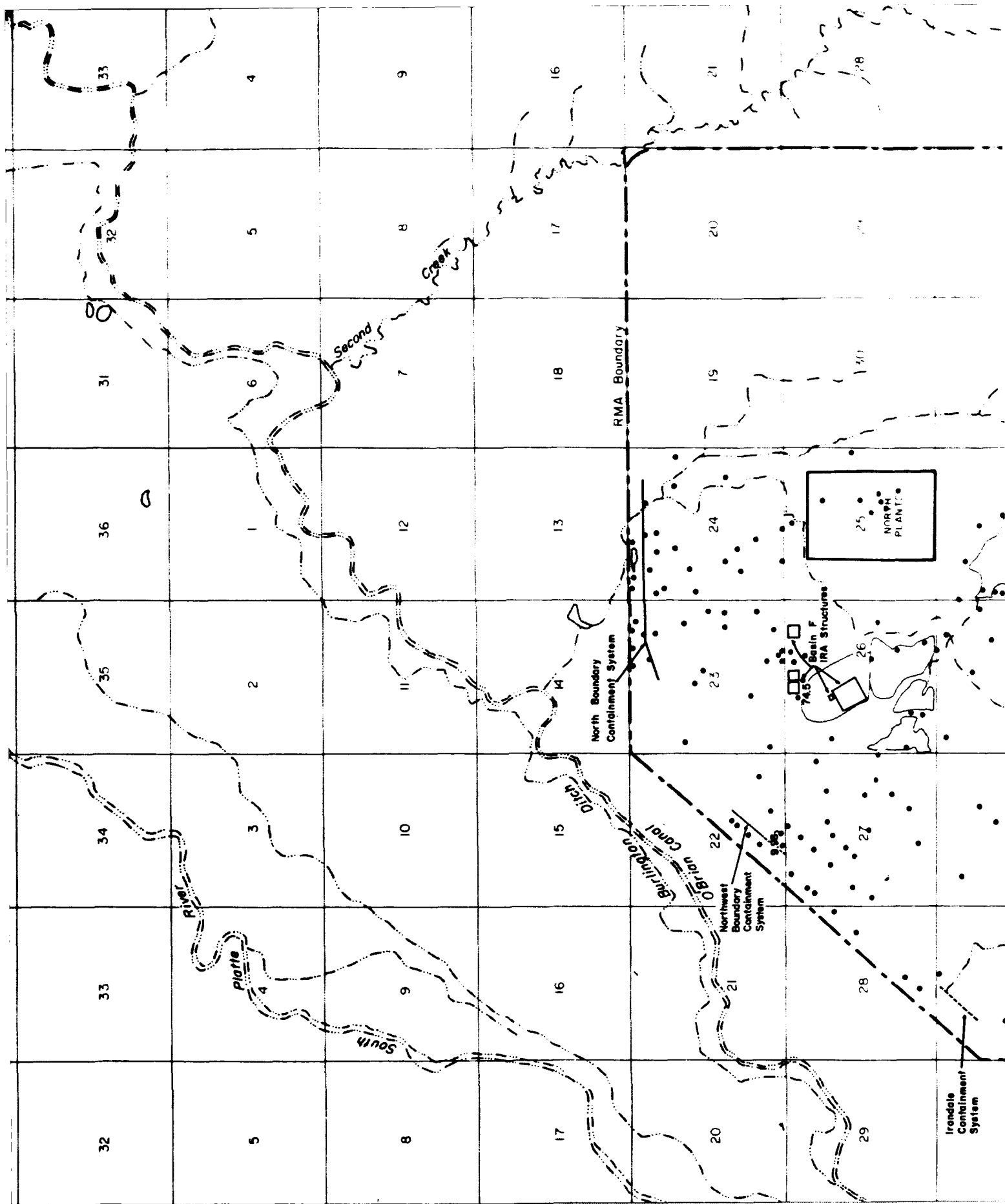
0.392

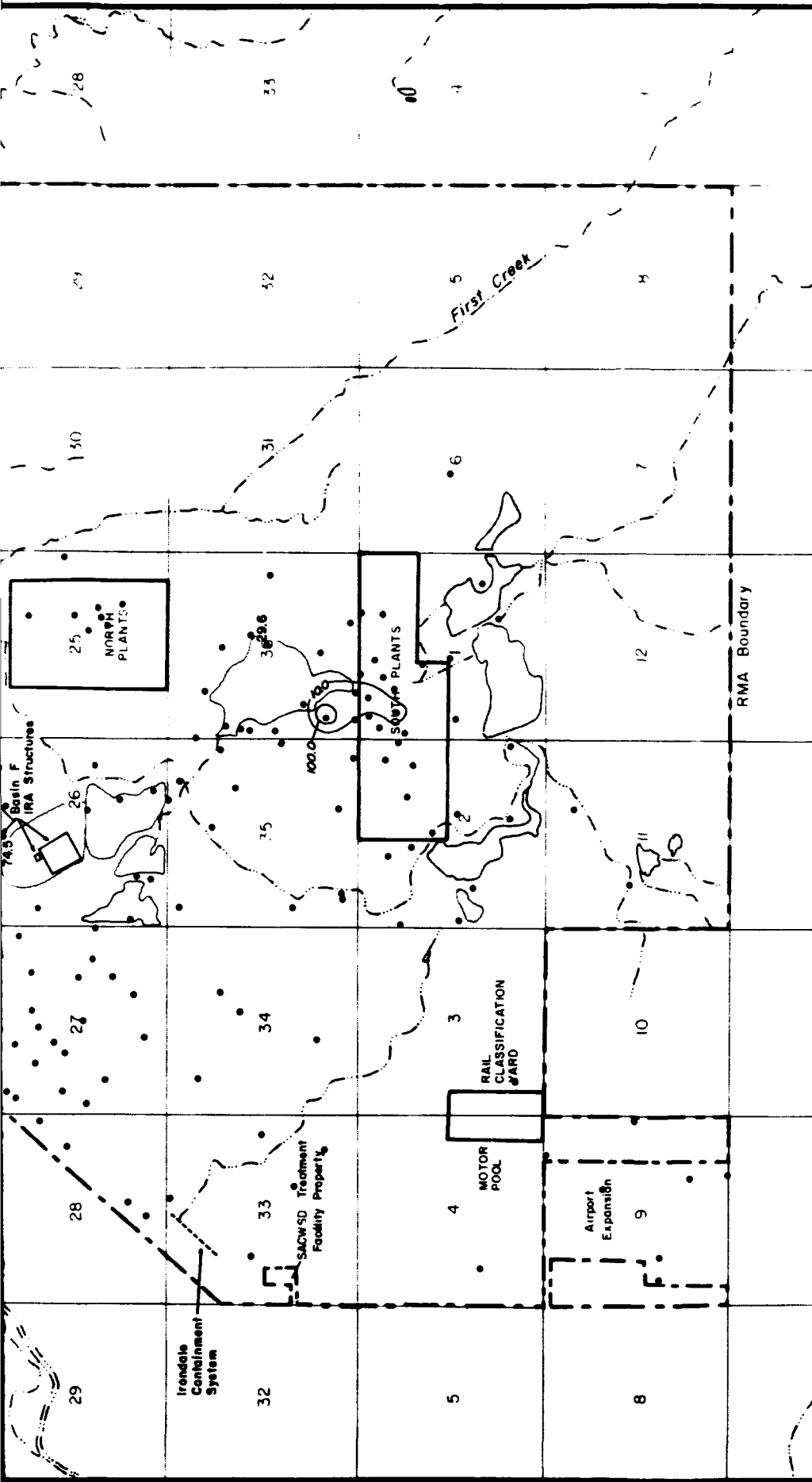
7.00

0000

10,000







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Figure 4.3.17-1

Summed Phenol Plume

Unconfined Ground-Water Flow System

Fall 1988

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Explanation

Isoconcentration Values (ug/l)

10.0
100

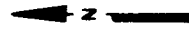
Isoconcentration Line,
Dashed where Inferred

29.6. Isolated Detection or Concentration
less than Highest CRL, in ug/l

Containment System

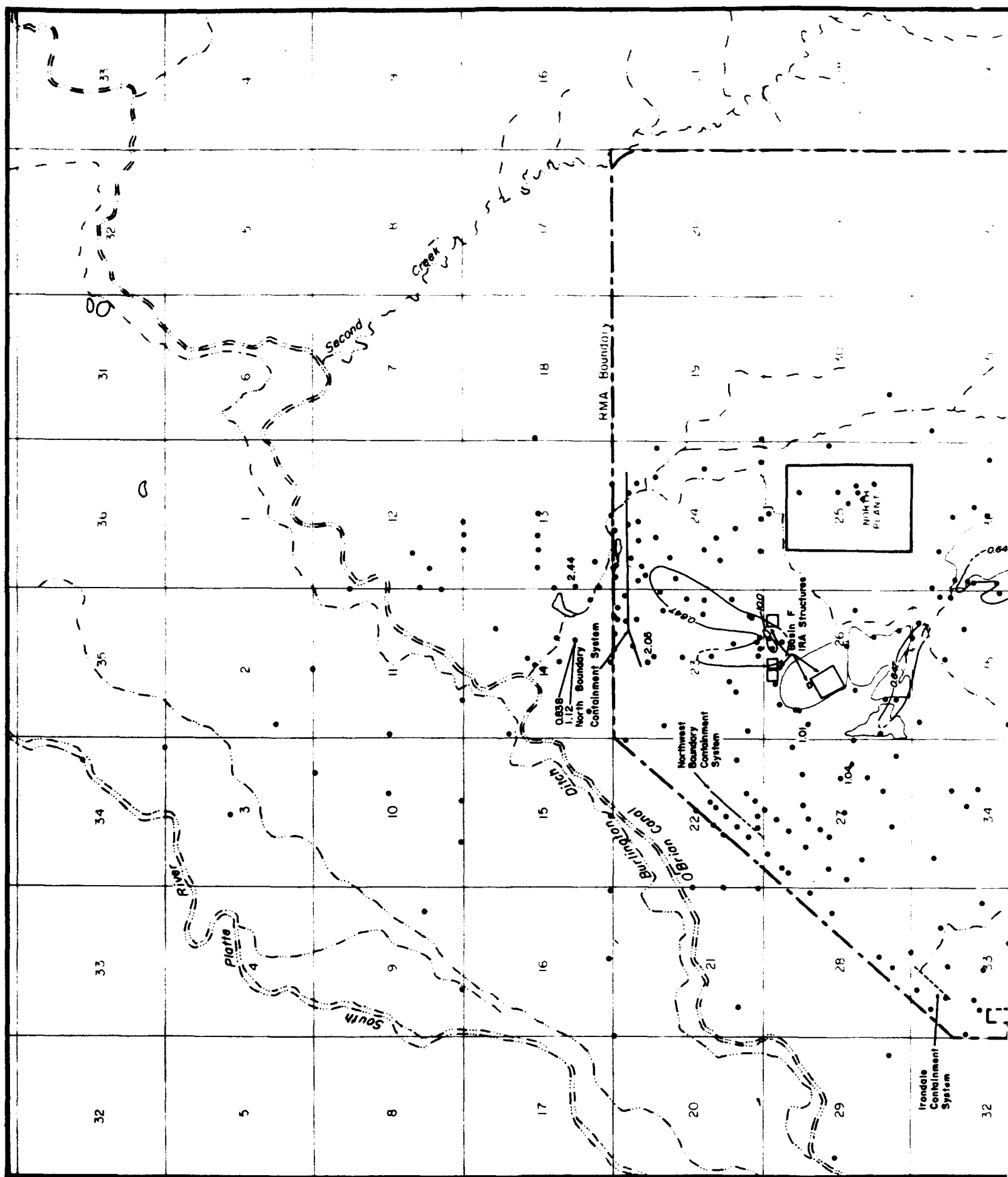
Physical Barrier

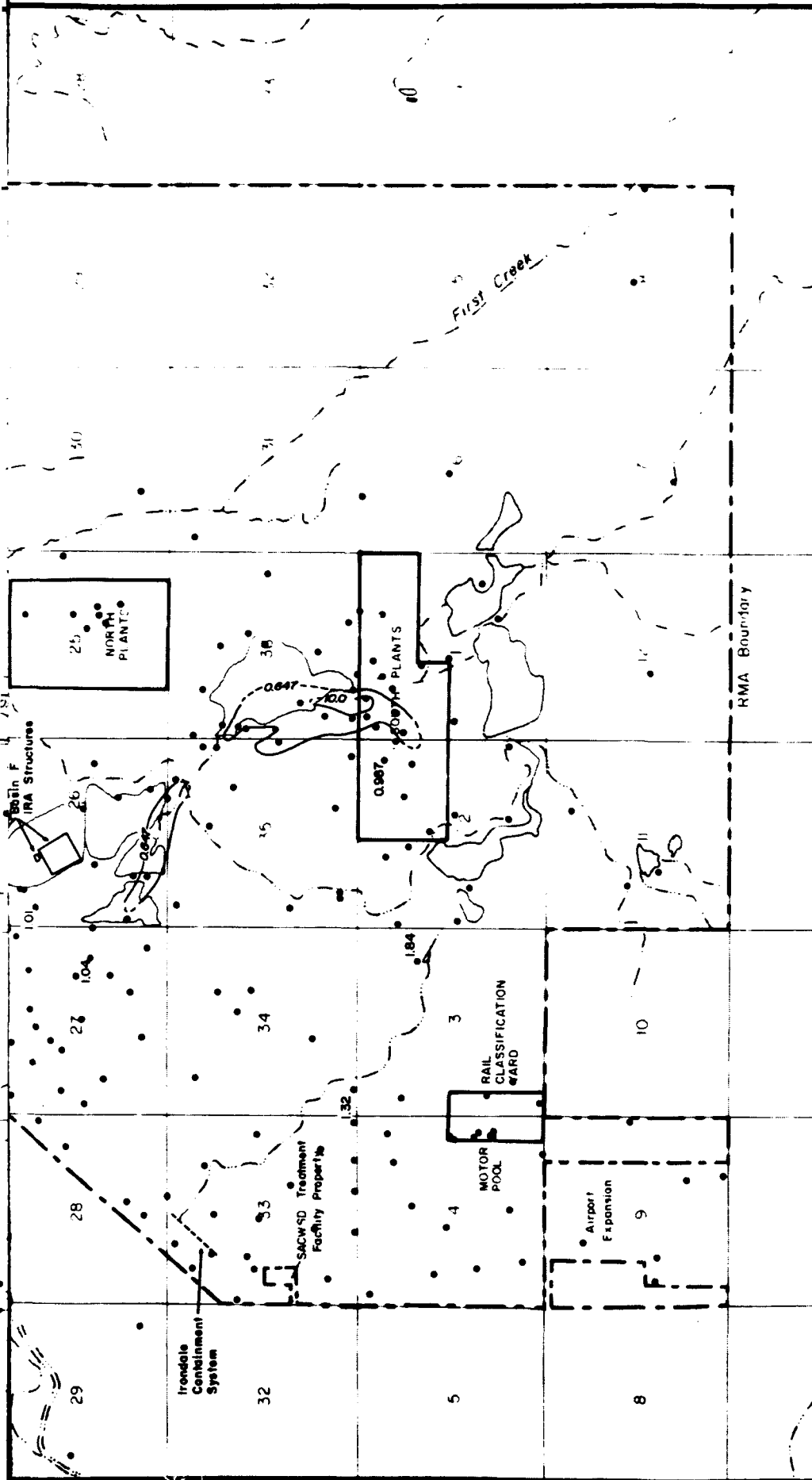
Hydraulic Barrier



0 4000 8000 Feet
0 1000 2000 Meters

SUMMED COMPOUNDS
2,4,6-Trichlorophenol
2,4-Dichlorophenol
2,4-Dinitrophenol
2-Methylphenol
4-Nitrophenol
Phenol
Perchlorophenol
2,4,6-Trichlorophenol
2,4-Dimethylphenol
2-Chlorophenol
2-Nitrophenol
4-Methylphenol/4-Cresol
4-Chloro-3-Cresol/3-Methyl-4-Chlorophenol



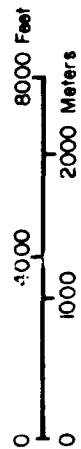
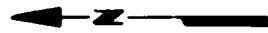


Explanation

- Isoconcentration Line.
Dashed where Inferred
- 1.32. Isolated Detection or Concentration
less than Highest CRL, in ug/l

- Containment System
- Physical Barrier
- Hydraulic Barrier

Isoconcentration Values (ug/l)
0.647
10.0



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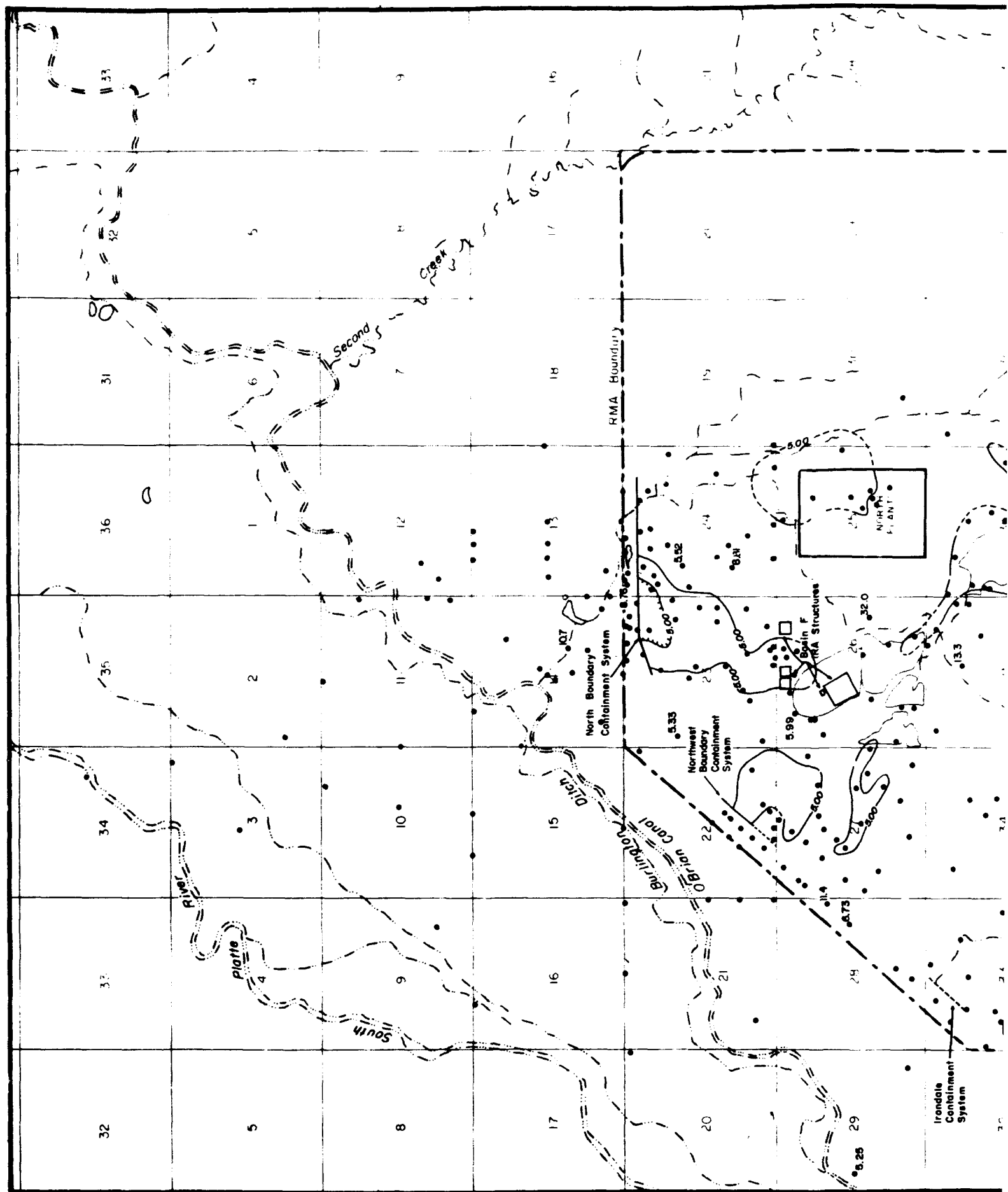
Prepared by :

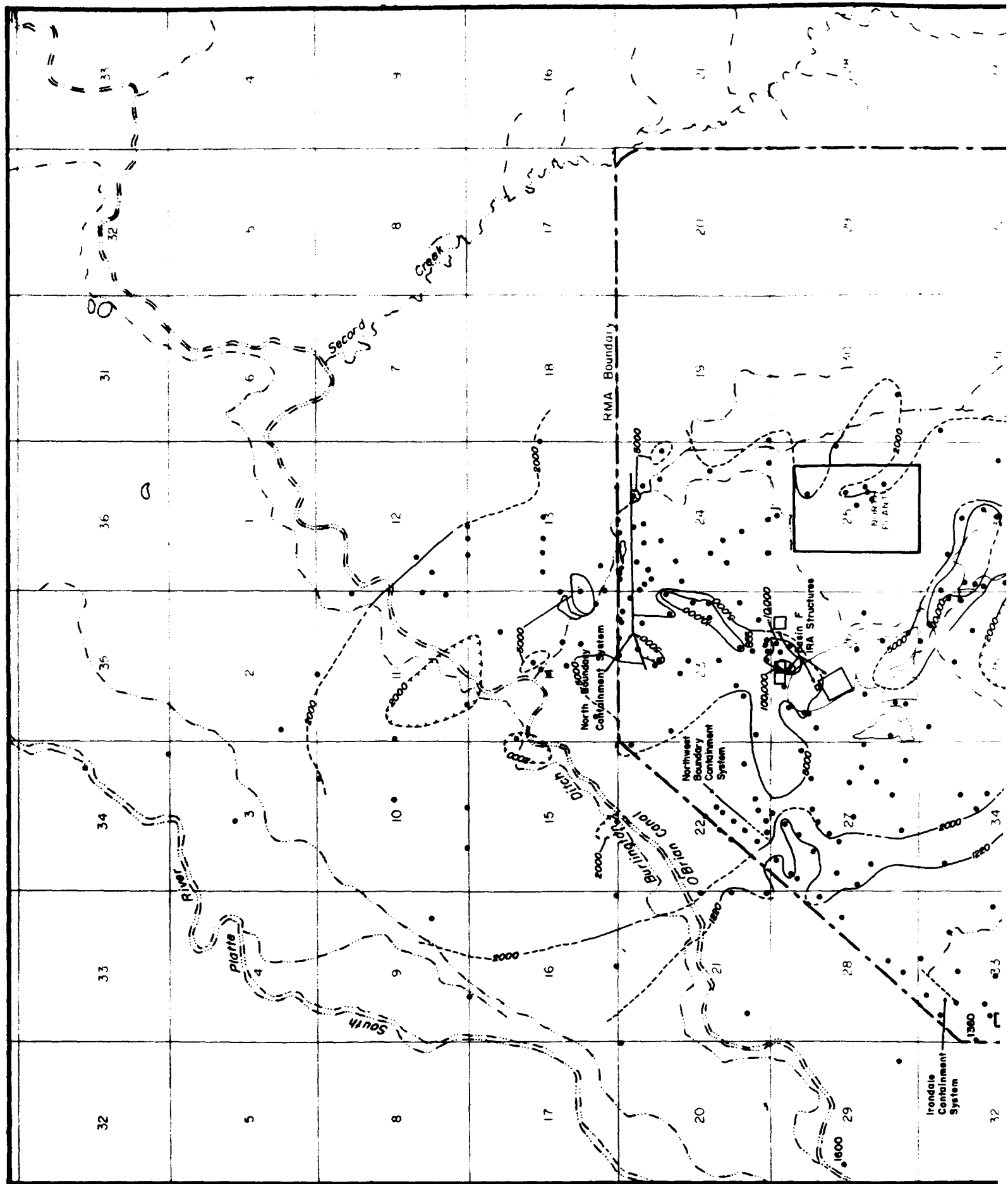
R.L. Stollar & Associates, Inc.
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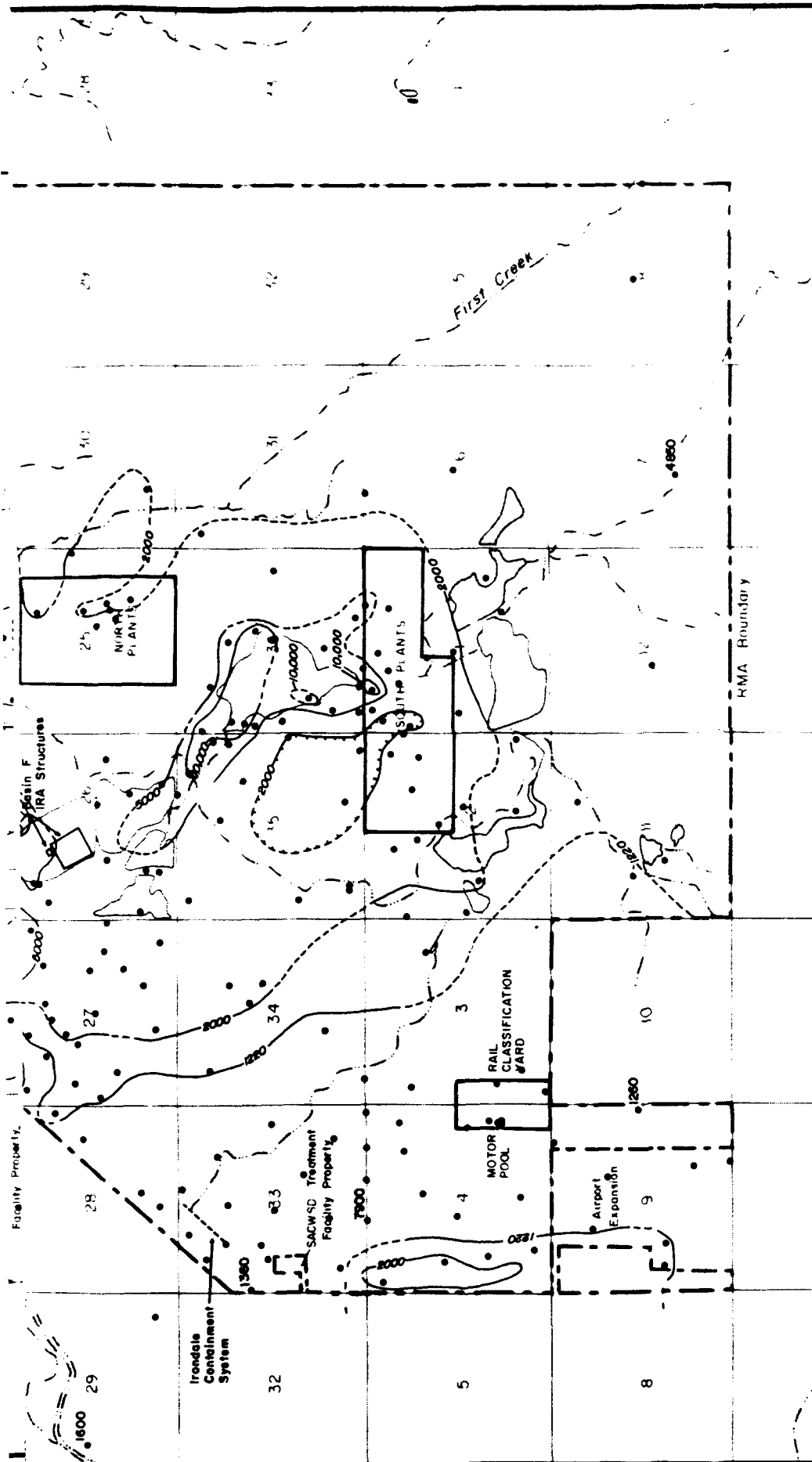
Figure 4.3.18-1

Parathion Plumes

Unconfined Ground-Water Flow System
Fall 1988







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Figure 4.3.20-1

Fluoride Plumes

Unconfined Ground-Water Flow System

Fall 1988

CMP Ground-Water Monitoring Annual Report FY89

Explanation

— Isoconcentration Line.

- - - Dashed where Inferred

7900. Isolated Detection or Concentration
less than Highest CRL, in $\mu\text{g/l}$

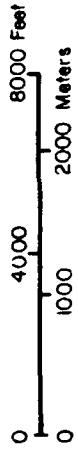
— Containment System

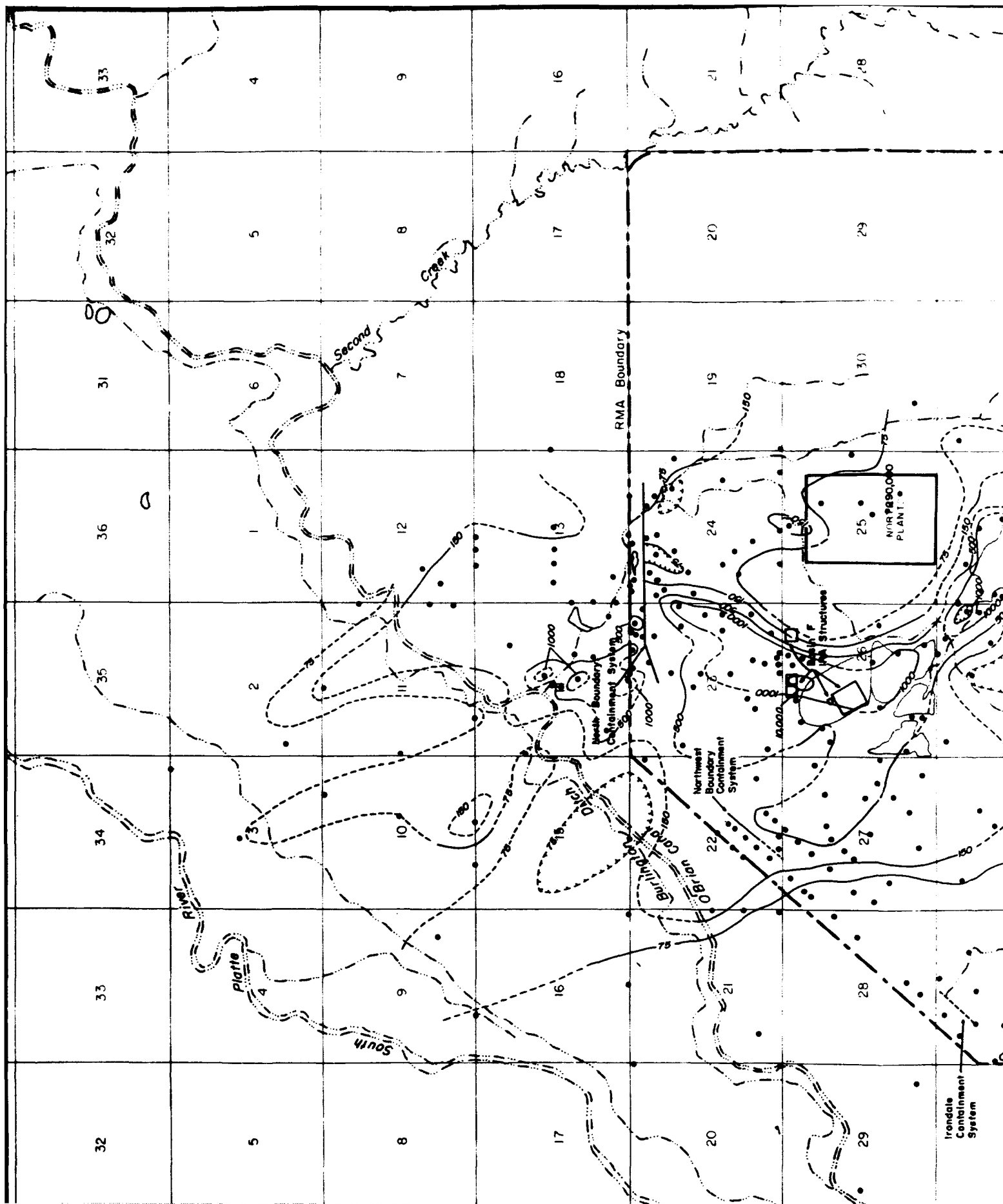
— Physical Barrier

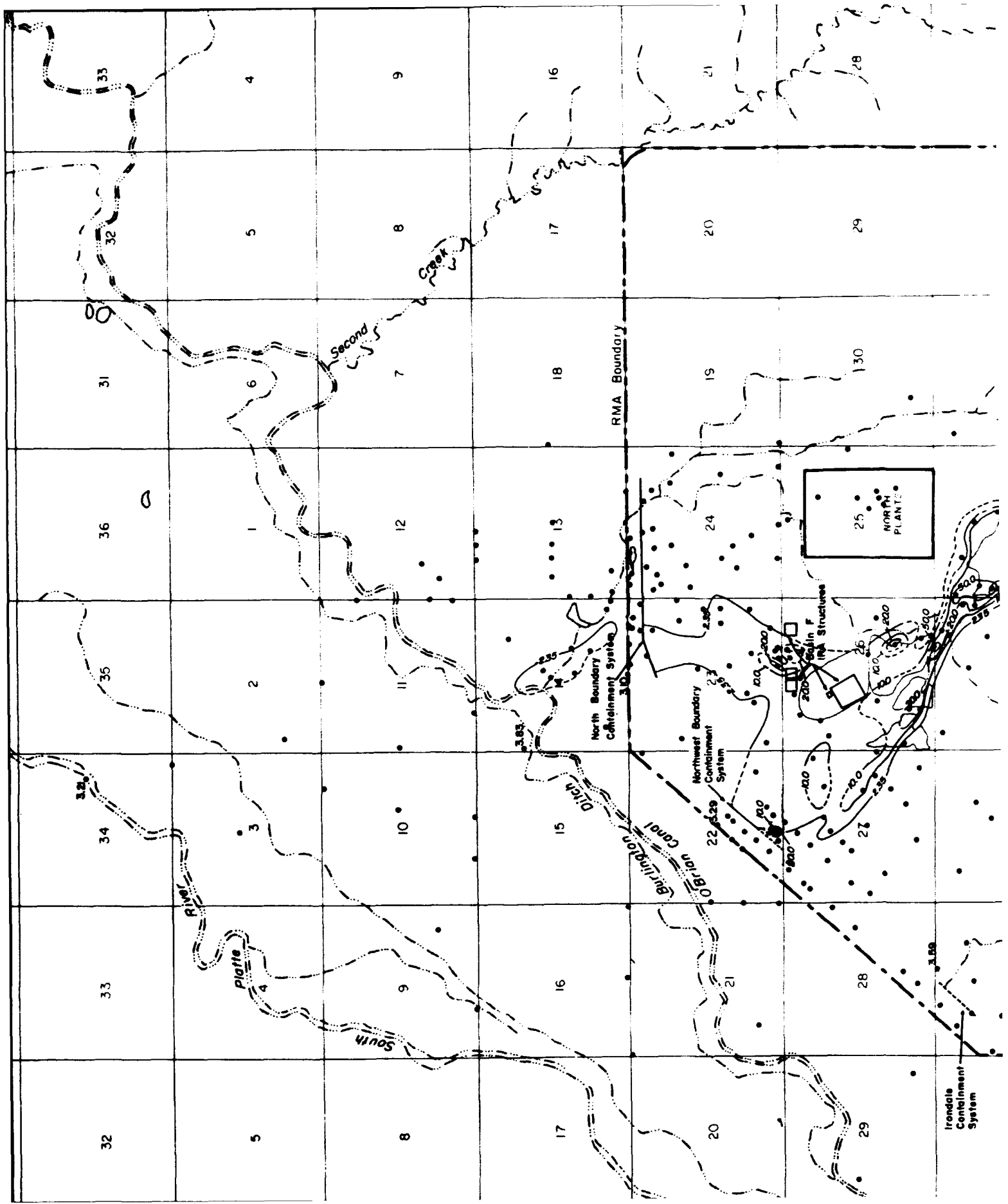
— Hydraulic Barrier

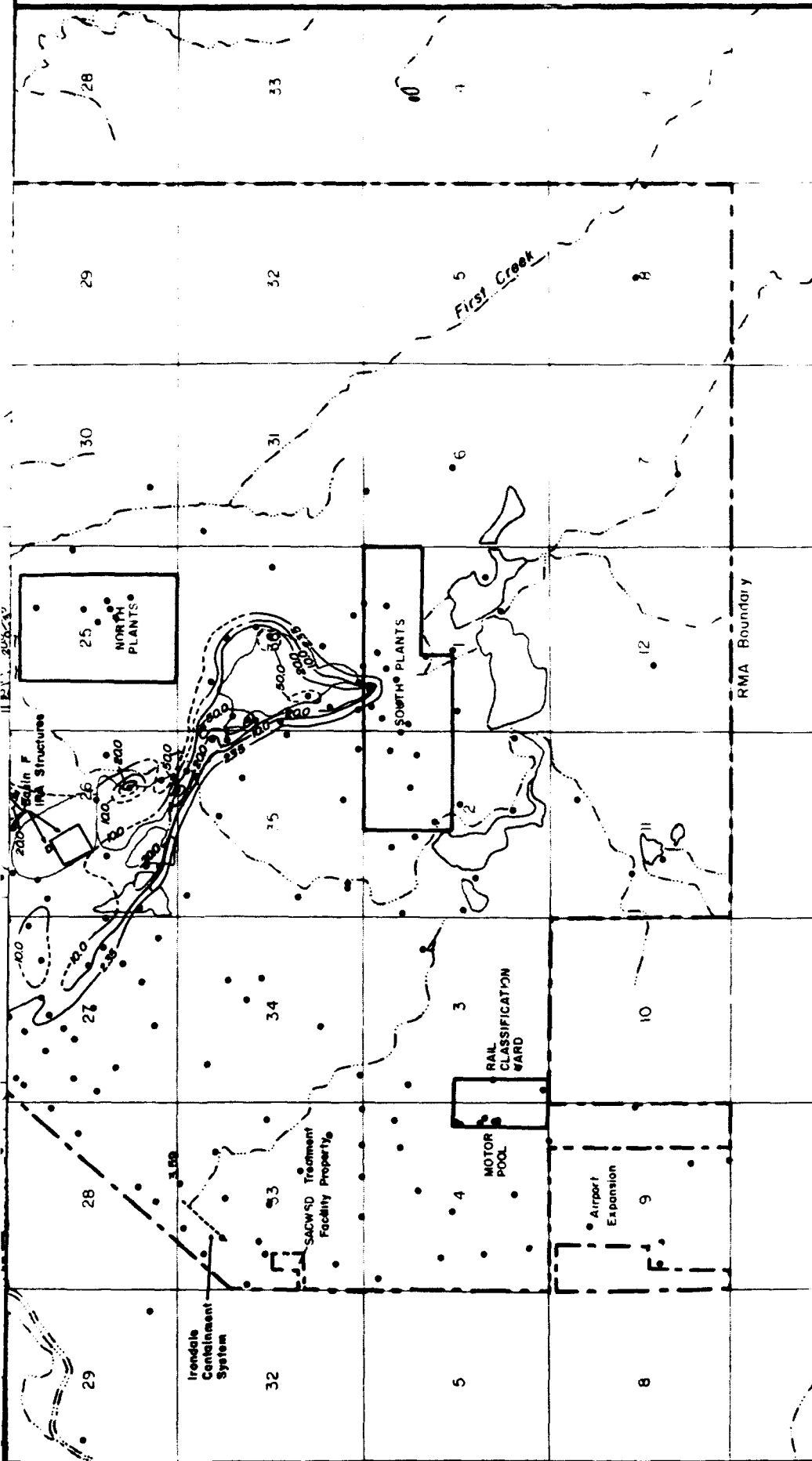
Isoconcentration Values ($\mu\text{g/l}$)

1220
2000
5000
10,000
100,000









Explanation

- Isocentration Line,
Dashed where Inferred
- Isolated Detection or Concentration
less than Highest CRL, in $\mu\text{g/l}$

- Containment System
- Physical Barrier
- Hydraulic Barrier

Isocentration Values ($\mu\text{g/l}$)

2.36
10.0
20.0
50.0

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Commerce City, Colorado

Prepared by :

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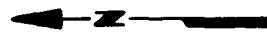
Figure 4.3.22-1

Arsenic Plumes

Unconfined Ground-Water Flow System

Fall 1988

CMP Ground-Water Monitoring Annual Report FY89



5.0 DATA ASSESSMENT

Ground-water data collected during FY89 as part of the CMP consisted of quarterly water-level data and water-quality data. Assessments of these data will be presented from three perspectives. First, the monitoring network design and laboratory analysis and reporting are discussed to assess anthropogenic influences on data. Second, potentiometric data will be discussed in terms of the geologic influences on morphology of the potentiometric surface. Third, water-quality data are assessed in terms of: the known maximum lateral and vertical extent of ground-water contamination; influences and efficacy of remedial actions; and characterization of the unconfined and confined flow systems in terms of inorganic water quality.

5.1 Anthropogenic Influences on Data Assessments

Anthropogenic influences are man-induced variables that affect the perspective from which the data are assessed. These influences include the number and locations of monitored wells in each monitoring network, CRLs used to present and compare results, variations in sampling methods, and variations in laboratory analytical methods. The potential impacts of these influences on data assessment are discussed below.

5.1.1 Monitoring Network Design

The number and distribution of wells in monitoring networks can affect the interpretation of the analytical results. Variations in well networks can lead to varying interpretations of plume configurations. For example, the addition of 38 newly installed wells to FY89 networks resulted in some changes to pre-existing interpretations. These changes are discussed in detail in Section 4.3, and are briefly summarized below:

- organosulfur, volatile aromatic, and volatile organohalogen plumes were extended in the Basin A - Basin A Neck area as a result of revised interpretations with the additional wells;
- volatile aromatic and volatile organohalogen plumes were shown to extend farther than previously thought in the South Plants area; and
- volatile organohalogens were shown to occur over a greater area in the Western Tier.

5.1.2 Laboratory Analysis and Reporting

Analyte concentrations detected above certified reporting limits (CRLs) define the maximum areal extent of contamination presented in this report. (Regulations which define contamination with respect to remedial measures are not considered.) Interpretations of analytical results are influenced by several anthropogenic variables including CRLs that may be variable either within a laboratory or among different laboratories, and the proficiency of the analyst. Additionally, the development of new analytical methods, improved instrument efficiency, and new analytical techniques, can all contribute to the lowering of CRLs. These anthropogenic variables affect the interpretation of the extent of contamination.

5.2 Potentiometric Data Assessment

The water table surface of the unconfined flow system and the potentiometric surfaces of the confined Denver Formation zones are controlled by several geologic and hydrologic factors. These factors are both environmental and anthropogenic. Geologic and hydrologic influences on potentiometric data presented in Section 4.0 are discussed briefly below (Section 5.2.1). Regional and project-area potentiometric data assessments are provided in Sections 5.2.2 and 5.2.3, respectively.

5.2.1 Geohydrologic Controls

Many geologic and hydrologic factors exert strong influences on potentiometric surfaces in the unconfined and confined flow systems. Geologic factors that affect ground-water flow in the unconfined and confined flow systems include the presence of paleochannels, the overall configuration of the bedrock surface, development of secondary porosity (e.g., fracturing, faulting), and the wide variety of lithologies (e.g., sandstone and siltstone interspersed in claystone) with concomitant widely varying hydraulic conductivity values.

Several hydrologic factors influence potentiometric data at RMA. First, the majority of ground water at RMA is the result of underflow from areas upgradient of RMA. This ground water is recharged by precipitation in upland areas of the Denver Basin, south of RMA. Thus ground-water elevations may be effected by climatic conditions at some distance from RMA. Surface recharge to the ground-water flow system from features such as the Lower Lakes and various ditches and canals (Mary, Ladora, Upper and Lower Derby, the northbog, First Creek, Sand Creek Lateral and Havana Pond) result in localized relief of the water table. These sources of surface recharge at RMA have a much greater impact on the unconfined flow system than on the deeper

confined flow system. Interaction between surface water and ground water is discussed in detail in the CMP Surface Water Annual Report. The sewer and water systems may also have local recharge/discharge effects on the unconfined and confined flow systems. The presence of sand bodies interspersed in claystone with discontinuous fracturing allows for the potential presence of partially confined or leaky aquifers, which would effect water levels in vertically adjacent water-bearing zones.

The North Boundary Containment System (NBCS), Northwest Boundary Containment System (NWBCS) and Irondale Containment System (ICS) exert artificial anthropogenic controls on the unconfined flow system. These systems are sources for local discharge and recharge of the unconfined flow system and, to a lesser extent, shallow Denver Formation sands. They have a notable localized effect on ground-water flow, as described in Sections 4.1 and 5.2.3.

In general, the water table surface in the unconfined flow system is higher than the potentiometric surface in the confined flow system. This indicates that the potential for vertical migration is downward, from higher head in the unconfined to lower head in the confined flow system. Vertical communication between the flow systems is discussed in Section 5.3.4.

Geohydrologic relationships between the unconfined and confined flow systems are complex. Head differences between the confined flow system and the unconfined flow system lessen in subcrop areas of the different Denver Formation water-bearing zones. The potentiometric heads of the confined and unconfined flow systems are similar in these areas, indicating direct hydraulic communication. Vertically adjacent zones of the confined Denver Formation also have similar potentiometric surfaces. The potential for aquifer interaction will be discussed further in Section 5.3.5.

5.2.2 Regional Potentiometric Data Assessment

The configuration of the water table is shown on a regional scale at RMA in Figures 4.1-1 through 4.1-4. The surface of the unconfined flow system decreases in elevation from southeast to northwest, following the trend of the bedrock surface. In general, ground water flows from the south-southeast to north-northwest. During the fall of 1988, the average hydraulic gradient from the southeastern to northwestern portions of RMA was approximately 0.0625. An overall increase in water levels due to a seasonal increase in recharge to the unconfined flow system is interpreted from a general shift of equipotential lines in the downgradient direction, seen by comparing the spring 1989 (Figure 4.1-3) and summer 1989 (Figure 4.1-4) unconfined flow system maps. This

seasonal increase in recharge likely reflects snowmelt runoff and increased precipitation which occur during the spring months.

In many areas, local changes in the water-table gradient may be the result of changes in gradient in the bedrock surface. In areas such as Sections 23 and 24 where the bedrock surface is relatively flat, the water table is also relatively flat, with a gradient of 0.0053, compared to other portions of RMA. In areas such as the western portions of Section 2, Section 26 and eastern Section 35, the bedrock surface drops off rapidly from east to west. This locally steeper bedrock surface is reflected in the locally steeper water-table configuration in these areas, such as eastern Section 35, which had an hydraulic gradient of 0.0167 during the fall of 1988.

A dominant feature of the regional water table surface in the vicinity of RMA is the ground-water mound beneath the South Plants manufacturing complex. This mound is coincident with a bedrock high beneath the South Plants. In this area a significant component of unconfined flow occurs through heterogeneous upper Denver Formation volcanoclastic sediments. These sediments have low hydraulic conductivities relative to surrounding alluvial material. The heterogeneous nature of Denver Formation sediments in the area of the bedrock high results in variable hydraulic conductivities, which may be reflected by the irregular configuration of the water table in this area.

In northwestern Section 33 a depression in the water-table surface is present on the fall 1988, winter 1989, and summer 1989 regional water-table maps (Figures 4.1-1, 4.1-2 and 4.1-4, respectively). This depression is the result of periodic pumping from South Adams County Water and Sanitation District (SACWSD) water-supply wells located off post, west of the RMA boundary.

5.2.3 Project Area Potentiometric Data Assessment

Selected areas of RMA are of particular interest because of potential for contaminant migration to off-post areas or because of potential effects on the ground-water flow regime by remedial activities. Discussion of potentiometric data on a project area basis is presented below. It should be noted that the following discussions for the North and Northwest Boundary Containment Systems are based on data collected from the CMP water level well networks. More detailed information based on weekly water-levels, obtained from densely spaced monitoring well networks, is available in the FY88 Operational Assessment reports of the North and Northwest Boundary Containment Systems (PMRMA, 1989b and PMRMA, 1989c, respectively).

5.2.3.1 North Boundary Containment System. Potentiometric data for the unconfined and confined flow systems were examined to evaluate the impact of the North Boundary Containment System (NBCS) on the ground-water flow regime. An operational assessment the NBCS is discussed in Section 5.3.3.1. Data from the fall of 1988 and summer of 1989 are discussed here because the fall 1988 and summer 1989 events yield the greatest time difference between each other and the October 31, 1988 start-up date of recently installed recharge trenches along a portion of the NBCS. It should be noted that, following start-up of newly installed recharge trenches, use of the bog area to recharge ground water was interrupted for a short time.

Figure 5.2-1 represents water-table profiles upgradient and downgradient of the NBCS for fall 1988 and summer 1989. Comparison of ground-water elevations south and north of the NBCS indicates that the regional south-southeast to north-northwest flow direction is maintained 350 ft south and 450 ft north of the NBCS. Further, these profiles indicate that the effect of the NBCS is quite localized, and water levels at or very near the barrier wall must be examined to see the impact of the NBCS on ground-water flow in the unconfined flow system.

Figures 5.2-2 through 5.2-5 present map views and cross-sectional views of the NBCS, in the plane of the NBCS. The map views in Figures 5.2-2 and 5.2-4 present the water table of the unconfined flow system in the area of the NBCS during the fall of 1988 and summer of 1989, respectively. The cross-sectional views in Figures 5.2-3 and 5.2-5 show the trace of the top of the water table on the barrier wall of the NBCS, both upgradient and downgradient of the barrier wall, during the fall of 1988 and summer of 1989, respectively.

Figure 5.2-3 shows the trace of the top of the water table upgradient and downgradient of the barrier wall of the NBCS as contoured from potentiometric data for fall 1988. These data predate the start up of recharge trenches installed in the western portion of the NBCS. As shown in Figure 5.2-3, potentiometric heads are greater upgradient than downgradient along most of the NBCS, with the exception of the area denoted by 1 in Figure 5.2-3. This head difference suggests that either discharge was insufficient south of the NBCS or recharge was insufficient north of the NBCS (except in area 1), which increased the head difference (hydraulic gradient) across the wall. This confirms the conditions identified under Task 36 (ESE, 1989). This increase in hydraulic gradient could, in turn, increase the potential for, and the velocity of, ground-water flow beneath or through the slurry wall. In area 1 the potentiometric surface was higher in the north than the south, creating a hydraulic barrier to contaminant migration to the off-post area.

Figure 5.2-5 shows the trace of the top of the water table on the NBCS south and north of the NBCS barrier wall during summer 1989. This period post-dates start-up of recharge trenches by

approximately six months. The three areas denoted 1, 2 and 3 in Figure 5.2-5 are areas where potentiometric heads north of the NBCS are greater than heads south of the NBCS, indicating potential areas for reversed, north to south flow. In all other areas, potentiometric heads are very nearly equal, or greater upgradient than downgradient, indicating that either no flow or normal south to north flow will occur, with potential for contaminant migration beneath the NBCS.

In confined Denver Formation wells near recharge trenches, water levels rose slightly between fall 1988 and summer 1989. These water-level increases are probably in response to start up of recharge trenches at the NBCS, and indicate some communication between unconfined and confined aquifers. For example, water levels in Well 23177, south of the NBCS, increased 1.7 ft and 2.4 ft from the fall of 1988 to the winter and spring of 1989, respectively, after the start up of recharge trenches. These increases are attributed to recharge trench activities, and indicate hydraulic communication between the alluvium and the underlying confined Denver Formation aquifers, and between the upgradient and downgradient sides of the pilot portion of the slurry wall of the NBCS. Denver Formation response to recharge trench activity is described in greater detail in Section 5.3.3.1 of this report and in a recent report detailing recharge trench start-up performance (Lutton, 1989).

5.2.3.2 Northwest Boundary Containment System. Potentiometric data for the unconfined flow system were evaluated to ascertain the impact of the NWBCS on the unconfined flow system. Figures 5.2-6 and 5.2-7 present water-table surface maps for fall 1988 and summer 1989 of the NWBCS. During the fall 1988 period (Figure 5.2-6) the potentiometric head of the unconfined flow system appears greater in the southeast than the northwest in all areas of the NWBCS. Head differences were generally greatest in the slurry-wall portion of the NWBCS. Based on these data, head differences indicate that the potential existed for downgradient (southeast to northwest) flow in the vicinity of the NWBCS during fall 1988. However, a review of a more comprehensive data set, collected by the PMRMA Technical Operations Division (PMRMA, 1989c), indicates that a reverse gradient is maintained along major portions of the NWBCS. This reverse gradient occurs in the immediate vicinity of the slurry wall/hydraulic barrier and does not propagate outward to the CMP monitoring wells which are located 200 ft or greater from the slurry wall/hydraulic barrier.

In the summer of 1989 (Figure 5.2-7) the potentiometric heads southeast and northwest of the NWBCS are nearly equal in most areas of the NWBCS. Overall, the head difference decreased markedly between fall 1988 and summer 1989, suggesting a decreasing potential for circumvention of the NWBCS. As stated above, the data set collected by the PMRMA Technical Operations Division (PMRMA, 1989c), indicates that a reverse gradient is maintained along major portions of

the NWBCS. The similarity in potentiometric heads on either side of the NWBCS would greatly reduce ground-water flow velocities. Circumvention of the system might then be impacted by factors such as bedrock fractures and slurry wall construction.

5.2.3.3 Basin F Area. The potentiometric surface of the unconfined flow system in the Basin F area is shown in Figures 4.1-9 through 4.1-12 for the fall 1988, winter 1989, spring 1989 and summer 1989 events, respectively. Figures 4.1-9 to 4.1-12 show that the water table exhibits only minor fluctuations through the time period examined. One notable exception is a slight trough in the northwestern corner of Section 26 during the spring 1989 and summer 1989 events, which is not present during the fall 1988 and winter 1989 events.

The water table gradient is relatively steep southeast and west-northwest (between 0.0100 and 0.0143) of the Basin F area, but decreases markedly in the vicinity of Basin F. The changes in water table gradient across the area correspond to the bedrock surface, suggesting that ground-water movement in the unconfined flow system is strongly influenced by bedrock topography.

As seen in Figures 4.1-9 through 4.1-12, relatively large areas in the vicinity of the Basin F area are underlain by unsaturated alluvium. In these areas of unsaturated alluvium, ground-water flow through the unconfined flow system occurs in the upper portion of the Denver Formation which is hydraulically connected to alluvial deposits, as described in Section 4.1.

5.3 Contamination Assessment

This assessment includes a summary of the contaminant sources, the areal extent of contamination, the effect of operations at the North and Northwest Boundary Containment Systems on the ground-water system, the vertical extent of contamination, and aquifer interactions. The intent of this section is to add to data presented in 1988 CMP Annual Report (Stollar, 1989b) and the Water Remedial Investigation Report (Ebasco, 1989i).

5.3.1 Sources of Contamination

Sources of contamination at RMA have been identified in various reports, including Contamination Assessment Reports and the Study Area Reports generated under the Remedial Investigation/Feasibility Study (RI/FS). As a result of RI/FS investigations, source areas were given designations as confirmed or suspected (Ebasco, 1989i). There are six major confirmed contamination source areas at RMA. These areas are the South Plants Manufacturing Complex, Basin A, Basin F, the North Plants Manufacturing Complex, the Railyard-Motor Pool area, and

the chemical sewer system. Suspected contamination source areas include the Sand Creek Lateral and Basins B, C, D, and E (Figure 1.2-1).

The South Plants area encompasses approximately two-thirds of a square mile in Sections 1 and 2. Manufacturing of various chemicals occurred from 1943 to 1982. Numerous sources exist in the South Plants resulting from industrial operations, waste disposal activities, and spills. A majority of the targeted CMP list of compounds have been documented emanating from the South Plants area.

The Basin A area includes the unlined Basin A disposal pond as well as adjacent disposal sites in Section 36. Basin A received large volumes of waste from South Plants and North Plants operations from 1943 to 1958. Areas within Section 36 were also used for trench disposal of industrial by-products, off-specification materials and munitions. As with the South Plants, a majority of the targeted CMP list of compounds have been documented in ground water beneath Basin A.

Basin F was an asphalt lined basin which received virtually all liquid chemical wastes and production waste waters at RMA from 1956 to 1978. It was last used in 1982. Removal of wastes has occurred as part of the 1988 Interim Response Action (Ebasco, 1989i). As with the South Plants and Basin A, a majority of the targeted CMP list of compounds have been documented in ground water in the area of former Basin F.

The North Plants Manufacturing Complex in Section 25 was used to manufacture the nerve gas GB (sarin) and to demilitarize Army agents between 1953 and 1984. The primary contaminants detected in ground water in the North Plants are DIMP and volatile organohalogens. As a contaminant source, the contribution of the North Plants to RMA ground-water contamination is significantly less than in the areas of the South Plants, Basin A and Basin F.

The Railyard-Motor Pool area consists of two building complexes, the Rail Classification Yard and the Motor Pool area, which are confirmed source areas in the RMA Western Tier. The Rail Classification Yard was used to store tank cars containing various chemicals. The motor pool was used for support operations. The Railyard-Motor Pool area is the documented source for plumes of DBCP and volatile organohalogens, principally trichloroethene (TRCLE). Plumes of volatile organohalogens also migrated onto the RMA Western Tier from off-post sources south or southeast of RMA. In general, the amount of contamination introduced into RMA ground water by the Railyard-Motor Pool area is much less than that introduced by source areas of central RMA.

The chemical sewer system is a gravity system that carried chemical wastes from operations at South Plants and North Plants to Basins A and F. The first chemical sewer was installed in the South Plants in 1942. Much of the chemical sewer system was constructed of vitrified clay pipe, which is known to have leaked. Because of its proximity to other contaminant source areas, contaminant plumes solely from the chemical sewer system are not readily separable.

Suspected source areas are the Sand Creek Lateral and Basins B, C, D, and E. These areas have been given this designation because of historical information indicating the presence of chemicals and/or contaminant plumes at or downgradient of these sites.

Indications of the type and mass of materials disposed at RMA were provided by Geraghty & Miller (1986). The highest reported volumes of waste were attributed to dieldrin, benzene, chloroform, fluoride and chloride. Moderate volumes of waste disposal were reported for endrin, p-chlorophenylmethyl sulfide and sulfoxide, and for DBCP. Low waste disposal volume was reported for p-chlorophenylmethyl sulfone. Many contaminants were not rated according to the volume of materials contained in disposal wastes. These include: dithiane, oxathiane, benzo-thiazole, chlorobenzene, trichloroethane (TRCLE), tetrachloroethane (TCLEE), arsenic and DIMP. Although the volume of DIMP waste was not rated, it had a history of moderate production at RMA.

5.3.2 Lateral Extent of Contamination

An assessment of the lateral extent of ground-water contamination at RMA is presented in this section. An assessment of unconfined and confined flow system contamination was conducted based upon contaminant source areas discussed in Section 5.3.1. The distributions of contaminants assessed in this section were previously described in detail in Section 4.3 of this report.

Well-defined contaminant plumes in the unconfined flow system extend from numerous sources at RMA (Figures 4.3.2-1 through 4.3.22-1). Contaminant plumes range from a few thousand feet to several miles in length. The plumes of the greatest magnitude extend from the South Plants - Basin A area and from the Basin F area. Plumes of lesser magnitude extend from sources in the North Plants and Railyard-Motor Pool areas. Contaminant migration is predominantly to the northwest. The primary contaminant flow paths in the unconfined flow system are directly related to the presence and orientation of permeable strata. These permeable strata often occur as Quaternary alluvium that fills paleochannels.

Man-made remedial systems have affected the distribution of contaminants in the unconfined flow system. Operation of the North Boundary Containment System (NBCS), the Northwest Boundary Containment System (NWBCS) and the Irondale Containment System (ICS) have resulted in decreased contaminant levels downgradient of these systems. In Section 5.3.3, the efficacy of the NBCS and NWBCS are discussed.

5.3.2.1 South Plants - Basin A Area. Because of their proximity and alignment along the same flow path, it is difficult to assess the contribution of the South Plants or Basin A individually. Therefore, the contribution of these confirmed source areas are discussed concurrently.

Contaminants originating in the South Plants - Basin A area migrate along the South Plants-Basin A, South Lakes, and Basin A Neck Pathways within the unconfined flow system. Within these pathways, contaminant migration occurred predominately within saturated alluvium. In the South Plants, however, contamination exists in the unconfined flow system within Denver Formation zone VC. Some contaminants emanating from the South Plants exhibit radial transport away from the ground-water mound in the area. However, the majority of contaminants migrate from the South Plants north toward Basin A. This is because the central processing area, where many plumes originate, is located on the north side of the South Plants ground-water mound.

Contaminant plumes present in the South Lakes Pathway include dieldrin, volatile aromatic compounds, and volatile organohalogen compounds. These compounds extend approximately 2000 ft southwest of the South Plants to Ladora Lake.

From the South Plants and Basin A area, many contaminant plumes extend northwest along the Basin A Neck Pathway toward the Northwest Boundary Containment System. However, some plumes appear to bifurcate in southeast Section 26 resulting in contamination extending north along the Basin F East Pathway. Because potentiometric data indicate that ground water in this area flows generally northeast, contamination in the Basin F East Pathway may be attributable to several causes, such as the former chemical sewer system which connected the South Plants to Basin F, historic flow directions which differ from present-day flow directions or discharge from water-bearing zones in the Denver Formation that have the potential of transporting contamination.

Contamination of the confined flow system occurs in the South Plants - Basin A area within zones A, 1U, and 1. Vertical contaminant migration may occur due to water flow along irregularly bedded but interconnected sandstone, fractures, faults, and historically through improperly sealed wells and borings. All of the improperly sealed wells that have been identified, have been closed as a part of an Interim Response Action performed during FY89.

5.3.2.2 Basin F. Contaminants within the Basin F area migrate primarily north-northeast along the Basin F Pathway toward the North Boundary Containment System. All of the contaminants discussed in Section 4.3 of this report with the exception of chlorobenzene and composited phenols are present in the Basin F Pathway. Contaminant migration within the Basin F Pathway occurs both in saturated alluvium and in unconfined portions of Denver Formation zone 2.

Several contaminants present in the Basin F Pathway continue to be identified north of the North Boundary Containment System (NBCS) in plumes occupying the First Creek and Northern Off-Post Pathways. The plume centroids for contaminants in these pathways are frequently 2000 to 7000 ft downgradient of the NBCS indicating that these plumes may represent contamination existing in off-post ground water prior to construction of the NBCS.

Plumes of a few contaminants are present northwest of Basin F within the Basin F West and Basin F Northwest Pathways. Contaminants within these pathways are intercepted by the Northwest Boundary Containment System.

Contamination of the confined flow system exists downgradient of Basin F in Denver Formation zones 2, 3, 4, and 5. Detections of contaminants in the confined flow system occur predominately beneath areas of unconfined flow system contamination.

5.3.2.3 Western Tier. The Western Tier area is characterized by contaminant plumes of DBCP and volatile organohalogens emanating from the Railyard-Motor Pool area, as well as an additional volatile organohalogen plume originating from sources south or southeast of the Western Tier of RMA. Plumes of cyanide, chloride and fluoride existing in Sections 4 and 9 also appear to originate from off-post sources.

The two volatile organohalogen plumes in the Western Tier can be differentiated from one another based upon the suite of contaminants detected in each plume. Trichloroethene (TRCLE) is the primary volatile organohalogen originating from the Railyard-Motor Pool area. Conversely, several compounds, including 1,1,1-trichloroethane, 1,1-dichloroethene, tetrachloroethene, and TRCLE predominate in the upgradient volatile organohalogen plume, entering RMA from the south.

The DBCP plume emanating from the Railyard-Motor Pool area is intercepted by the Irondale Containment System. TRCLE however, continues to be detected off-post west and northwest of RMA. The extent of off-post TRCLE contamination has been assessed by the EPA.

Only a few confined flow system wells exist in the RMA Western Tier. Analytical results from these wells indicate that DBCP and volatile organohalogen contamination apparently are limited to the unconfined flow system.

5.3.2.4 North Plants. Contamination in the North Plants area is limited predominately to DIMP and volatile organohalogens. Chloroform is the primary volatile organohalogen compound present. Contaminants originating in the North Plants migrate north. DIMP contamination originating in the North Plants extends north to the North Boundary Containment System and merges with the Basin F plume. The chloroform plume extends approximately 5000 ft north into southern Section 24. Minor amounts of cyanide, chloride (in both the unconfined and confined flow systems) and fluoride (in the unconfined flow system) may also originate in the North Plants.

5.3.2.5 Sand Creek Lateral. Several contaminant plumes are interpreted to originate in Sections 34 and 35. These contaminants occupy the Central North and Central South Pathways. These plumes may be the result of contaminants originating from the South Plants and transported via the Sand Creek Lateral where they percolated into the ground water. An alternative hypothesis is that subcropping Denver Formation water-bearing zones recharge alluvium in these areas with contaminated ground water. Contaminants present in these pathways include dieldrin, chloroform, chloride, and possibly fluoride and DIMP. These plumes extend downgradient toward the Northwest Boundary Containment System. As presently interpreted this contamination would not be intercepted by the containment system and would flow off-post along the Northwest Pathway.

5.3.3 Ground-Water Containment Systems

There are three ground-water remedial systems currently in operation at RMA. These include the North Boundary Containment System (NBCS), Northwest Boundary Containment System (NWBCS) and the Irondale Containment System (ICS). All of these containment systems are designed to intercept, treat and recharge ground water to prevent off-site contaminant migration.

One of the specific objectives of the CMP ground-water element is to provide monitoring for system operational purposes. The two systems that are operated by the Army, the NBCS and the NWBCS, are the subject of this assessment. Several previous investigations, including Task 25 (ESE, 1988), Task 36 (ESE, 1989) and the 1988 CMP Annual Report (Stollar, 1989) have addressed local contaminant distributions at both containment systems. It should be noted that the following assessments of the Boundary Containment Systems are based on data collected from CMP well networks. Information based on weekly water levels obtained from densely-spaced monitoring

well networks is available in the FY88 Operational Assessment Reports of the NBCS and NWBCS (PMRMA, 1989b and PMRMA, 1989c, respectively).

5.3.3.1 North Boundary Containment System

The NBCS consists of a soil-bentonite slurry wall extending approximately 6740 ft along the northern boundary of RMA. The system extracts and treats ground water leaving RMA. The pilot portion of the NBCS became operational in June of 1978. The system was subsequently expanded, and became operational in its present configuration in January 1982. In October 1988 recharge trenches installed to increase downgradient recharge capacity became operational.

Assessment of the NBCS focuses on two aspects of the system. First, hydraulic impacts on the unconfined and confined flow systems are examined, and second, upgradient and downgradient contaminant concentrations are compared.

Hydraulic Assessment.

The effect the boundary systems have on ground-water flow through the unconfined flow system has been studied extensively. Conversely, assessment of boundary system effects on flow through deeper zones in the Denver Formation continues to be evaluated. This section compares temporal potentiometric data from the unconfined flow system with temporal potentiometric data from deeper zones in the Denver Formation. This comparison provides information about hydraulic relationships between these zones in the boundary systems areas and, in turn, about the effects that the boundary systems have on flow through deeper units in the Denver Formation.

Several changes made to boundary system operations during the past year must be considered when interpreting the potentiometric data. Most notable is the installation of recharge trenches designed to enhance the recharge capacity north of the west portion of the North Boundary Containment System (NBCS). Ten trenches were installed at locations delineated on the well location map on Figure 5.3.3-1. Each trench is approximately 160 ft long, averages 16 ft in depth, and penetrates the entire thickness of the alluvium. The purpose of the trenches is to provide additional surface area through which increased volumes of treated water can be recharged to the alluvium (Lutton, 1989).

Trench recharge operations were started on October 31, 1988. By November 14, all of the trenches were receiving flow. During this start-up phase, the volume of water initially required to fill the recharge trenches to capacity exceeded the amount normally available from the extraction system. The additionally required recharge water was obtained in two ways. First, the volume of water

sent from the NBCS treatment plant was increased. Second, water normally sent to the north bog was diverted to the trenches. Flow to the bog was reduced in increments until, on January 11, 1989, all flow to the bog was stopped. On January 19, 1989, the volume of water received by the recharge trenches approached capacity, so flow to the bog was resumed (Lutton, 1989). Detailed information on start-up operations including tabulated flow data, is contained in the start-up performance of Ground-Water Recharge Trenches report (Lutton, 1989). These changes in boundary system operations must be considered when assessing potentiometric data in the NBCS area.

To aid in the assessment of potentiometric data around the boundary systems, diagrams have been prepared that compare hydrographs from multiple water bearing zones (Figures 5.3.3-1, 5.3.3-2). Each hydrograph represents data from an individual well. Ideally, potentiometric comparisons would be made at well cluster sites which screen the alluvium and each of the water-bearing zones of interest in the Denver Formation. In this manner, effects of the NBCS on vertical hydraulic gradients could be separated accurately from effects on horizontal gradients. However, cluster wells are limited in the boundary systems areas. Instead, groups of individual wells within relative proximity to each other are used. Wells within each group provide potentiometric data from the alluvium, and at least one confined zone in the Denver Formation. The geologic zones represented are not necessarily identical among all well groups because of the variable distribution of wells in the NBCS area. These well-groups are delineated on Figure 5.3.3-1. Five of the seven well groups are located on the north side of the barrier and two are on the south side of the barrier.

Each hydrograph presents potentiometric data collected from the winter of 1985 to the summer of 1989. Although data collected prior to 1987 were not collected under the CMP program, they are included to provide information about long term trends. Certain wells in the data base were measured more frequently than quarterly. These subquarterly measurements are predominant prior to 1987. In order to obtain a single water elevation value from each quarter between winter 1985 and summer 1989, the subquarterly measurements were averaged. The averaged values are plotted as the quarterly data points on the hydrographs. Due to variability in water elevation changes between the well-groups, the vertical scales are not consistent between diagrams. Potentiometric data are plotted using unique symbols for each geologic zone represented. These symbols are also used to delineate the well locations on the plan maps (Figures 5.3.3-1, 5.3.3-12). The stratigraphic relationships of these units are discussed in Section 2, and diagrammed on Figure 2.1-4.

Well-group 1 is located immediately north of the west end of the NBCS, and consists of four wells (Figure 5.3.3-1). Each well is completed in a separate geologic zone. The zones are alluvium, unconfined zone 2, confined zone 3, and confined zone 4. In this group, the alluvium and zone

2 are both unconfined and exhibit similar potentiometric elevations. Zones 3 and 4 are confined and exhibit potentiometric elevations similar to each other but generally 10 ft below the potentiometric elevations of the unconfined zones.

Generally, between the winter of 1985 and the spring of 1988, water elevation fluctuations in the vicinity of well group 1 were similar in the unconfined and confined zones. These fluctuations generally reflected seasonal variations. The effect of the recharge trenches is also evident showing higher water-level elevations in fall 1988/winter 1989 and lower elevations in the spring/summer as use of the recharge trenches decreased. For example, increased water levels commonly occurred in each hydrograph during the spring quarter of each year and then decreased during the summer, fall, and winter quarters. However, the water elevation fluctuations became less similar in 1989 when the alluvial and confined zone 2 water levels fluctuated by approximately 5 ft, while confined zones 3 and 4 responded with fluctuations closer to 1 foot. The fluctuations in the unconfined units corresponded with the initial operation of the recharge trench system. The response in confined zones 3 and 4 was dampened, indicating reduced vertical communication between the unconfined and confined zones in this area. Water level fluctuations in confined zones were similar to water level fluctuations in the unconfined zones when they were caused by regional factors such as seasonal variations. Localized fluctuations such as boundary system influences resulted in dampened responses in zones 3 and 4.

Well-group 2 is located on the north side of the boundary system, approximately 500 ft west of the section line dividing Sections 23 and 24 (Figure 5.3.3-1). Three wells make up this group; they are completed in the alluvium, unconfined zone 2, and confined zone 3. Water elevations from the well completed in zone 2 were unconfined but also were consistently higher than water elevations in the alluvial well. This difference should not be interpreted as an upward gradient between zone 2 and the alluvium in the vicinity of well-group 2 because these hydrographs present potentiometric data from wells which are areally separated from each other. In well-group 2, the alluvial well is approximately 500 ft north of the zone 2 well. The lower water elevations indicated on the alluvial hydrograph reflect the downgradient location of the alluvial well.

Water elevation fluctuations at well-group 2 are similar in the alluvium, unconfined zone 2, and confined zone 3. Water level elevations in each of these zones generally increased during the spring quarter of each year and then decreased during the summer, fall, and winter quarters. These fluctuations were relatively consistent for each zone from the winter of 1985 to the fall of 1988. In the winter of 1989, a rapid increase of approximately 11 ft occurred in unconfined zone 2. This increase occurred between the fall 1988 and winter 1989 quarters, and corresponded with the initial operation of the recharge trenches. Well 23203, located within 50 ft of a recharge

trench, exhibited water elevations which closely correspond to changes in the recharge rate at the trench. The unconfined nature of zone 2 in the vicinity of Well 23203 contributes to this direct response.

Unconfined wells 23045 and 23203 respond relatively directly to changes in recharge at the trenches. Well 23045, located approximately 500 ft to the north of the recharge trench, exhibits a dampened response. This dampened response is expected when distance from points of groundwater recharge or discharge is increased.

Well 23161 is completed in confined zone 3, and is located laterally approximately midway between unconfined Wells 23203 and 23045. Water elevations from Well 23161 also increased in response to the initial operation of the recharge trenches. However, the increase is dampened in comparison to the increases measured at both unconfined wells. The maximum water elevation at Well 23161 occurred after two quarters, and the increase was less than 3 feet. This dampened response is in part a function of distance from the recharge trench. More significantly, this dampened response also reflects the confined nature of zone 3.

Although water level fluctuations are dampened in confined zone 3, the trend of increasing or decreasing water elevations mimics the water elevation fluctuations in both the unconfined alluvium and unconfined zone 2. For example, the 11 ft increase in water elevations in unconfined zone 2, during winter 1989, corresponds with a 3 ft increase in water elevations in confined zone 3. If these wells were cluster wells, this comparison could provide direct information about water elevation increases in confined zone 3 relative to increases induced in unconfined zone 2. Because the confined zone 3 well is located approximately 200 ft north (downgradient) of the unconfined zone 2 well, this comparison provides limited information, but, useful operations data.

Well-group 3 is located on the north side of the slurry wall, immediately east of the section line between Sections 23 and 24. It includes wells 24161, completed in the alluvium; 24167, completed in confined zone 2; and 24168, completed in confined zone 3. The alluvial well (24161) of well-group 3 is located approximately 500 ft north of the confined wells (24167, 24168). The well-group 3 hydrographs show alluvial water elevations which are lower than water elevations in underlying confined zone 2. This relationship may reflect areal separation between the alluvial well and confined zone 2 well rather than an upward gradient between these zones. Even though the confined wells in well-group 3 are approximately 500 ft closer to the recharge trenches than the alluvial well, the water elevations in the confined wells exhibited a lower relative change in water levels during the three quarters following the initiation of recharge trench operations.

Hydrographs for well-group 3 show that water elevations from confined zone 3 were consistently higher than water elevations from confined zone 2. The wells completed in these zones are within 21 ft of each other (Well 24167 is approximately 20 ft east and 4 ft south of well 24168). Because these wells are relatively close to each other and are situated along a line nearly perpendicular to the direction of ground-water flow, the higher water elevations measured in confined zone 3 probably indicate that an upward gradient existed between confined zones 2 and 3 in this area.

Well-group 4 is located on the north side of the slurry wall, just east of the north bog. Well-group 4 includes Well 24164, completed in the alluvium; Well 24171, completed in confined zone 5; and Well 24172, completed in confined zone 2. Water elevation fluctuations in the alluvium and confined zone 2 are similar. Water elevations in both zones decreased in response to the reduced recharge at the north bog. Water elevation fluctuations in confined zone 5, however, appeared unrelated to the alluvial and confined zone 2 fluctuations. This condition probably results from the large vertical separation between zone 2 and zone 5. Zone 2 is located approximately 40 to 55 ft below ground surface, while zone 5 is approximately 121 to 135 ft below ground surface. This separation may include materials with low permeabilities in zones 3, 4, and 5 that reduce vertical hydraulic interconnection. The hydrographs indicate that in the vicinity of well group 4 the influence of the boundary system on zone 2 is significant but its influence on zone 5 is minimal.

Well group 5 is located north of the east end of the barrier. Well-group 5 includes Well 24004, completed in the alluvium; Well 24174, completed in confined zone 3; and Well 24175, completed in confined zone 4. Water elevation fluctuations generally were similar between each of the zones, although the magnitude of fluctuations was greater in the alluvium. The water elevations in confined zones 3 and 4 were within 1 ft of each other. The confined zone 3 elevations typically were higher than the confined zone 4 water elevations. It is difficult to determine if this reflects a downward gradient between these zones because the wells completed in these zones are areally separated by approximately 20 ft, and the head difference is relatively small.

An increase in water elevations occurred in all three zones at well-group 5 during the spring of 1989. This increase occurred during the same time period as the increase in well-groups 3 and 4. The well-group 5 hydrographs suggest that water elevations in the alluvium consistently were below water elevations in confined zones 3 and 4. This relationship reflects areal separation of the alluvial well from the other wells rather than an upward gradient between zones 3 and 4, and the alluvium. Although fluctuations in zones 3 and 4 were dampened with respect to the alluvium, the similarity of the fluctuations indicates that water elevation changes in the alluvium result in similar changes in zones 3 and 4.

Well-groups 6 and 7 are located on the south side of the barrier. At well-group 6, a general increase in water elevations occurred in confined zone 2 during initial operation of the recharge trenches. This increase may have resulted from north to south flow. Alluvial water elevations at well-group 6 were higher than confined zone 2 water elevations until initial operation of the recharge trenches. After start up of the recharge trenches, alluvial water elevations dropped below confined zone 2 water elevations. This change may have been caused by two factors. First, the increase in confined zone 2 water elevations may have resulted from a reversal of hydraulic gradient due to operation of the recharge trenches. Second, the decrease in alluvial water elevations may have resulted from the removal of increased volumes of alluvial groundwater from extraction wells on the south side of the boundary system.

Well-group 7 is located approximately 1200 ft east-southeast of well-group 6. Wells in well-group 7 are completed in the alluvium, unconfined zone 2, confined zone 3, and confined zone 4. An overall trend of decreasing water levels over time is exhibited by the hydrographs from these wells. However, a small increase in water elevations occurred in all the zones at well group 7 during the spring of 1989. This elevation increase may reflect initial operation of the recharge trenches and/or seasonal variations. The increase was smaller than the water elevation increase which occurred in confined zone 2 at well-group 6. Ground-water elevations from each zone in the vicinity of well-group 7 were generally within 1 ft of each other. Water elevation fluctuations in the four zones were nearly identical. Vertical gradients, however, are not consistent between the zones. This likely reflects the areal scatter between the group 7 wells. The increase in water levels during the spring of 1989 may indicate that recharge through the trenches on the north side of the boundary caused flow from north to south across the boundary. The elevation increases were consistent in all four geologic zones.

A comparison of all hydrographs from the NBCS area indicated that alluvial water elevation fluctuations generally were mimicked by water elevation fluctuations in zones 2 through 4. However, the magnitude of the fluctuations in zones 2 through 4 typically were dampened compared to the magnitude of fluctuations in the alluvium. This suggests that some vertical communication occurs between these zones in the NBCS area. Hydraulic interrelationships between geologic zones in the NBCS area vary depending on areal location. This variance can result from the localized effect of hydraulic influences such as extraction/injection wells, recharge trenches, the north bog, and the slurry wall. Heterogeneities within the geologic zones may also contribute to hydraulic relationships which vary from location to location.

In January, 1989 the recharge trench system was operated at full capacity for the first time. Increases in water elevations corresponding to recharge trench start-up were evident in nearly

every water bearing zone measured at the well-groups surrounding the trench system (well-groups 1, 2, 3 and 6). The only exceptions were water bearing zone 5, at well-group 4, and the alluvial water bearing zone at well group 6 (explanations for these exceptions were discussed earlier). Increases in water elevations corresponding with the start-up of the recharge trenches were measured in confined zone 2 south of the slurry wall (well-group 6). This suggests that recharge to the alluvium at the trenches on the north side of the slurry wall has resulted in north to south flow beneath the slurry wall in confined zone 2. Commonly, potentiometric responses in confined zone 2 are mimicked in confined zones 3 and 4. This indicates that north to south flow under the boundary is also possible in zones 3 and 4.

Subsequent to January 1989, water levels in the NBCS area generally declined. This decline likely corresponds with reductions in recharge flow which occurred during continued testing of the system.

Ground-Water Quality Analytical Data Assessment.

The NBCS was designed to intercept and effectively reduce downgradient concentrations of organic ground-water contaminants (PMRMA, 1987a). Nine contaminants were chosen for this assessment based on their current and/or historic occurrence downgradient of the NBCS. These contaminants were diisopropylmethylphosphonate (DIMP), endrin, dieldrin, dibromochloropropane (DBCP), dicyclopentadiene (DCPD), composited organosulfur compounds, chloroform, chlorobenzene, and tetrachloroethene (TCLEE).

Fluoride has current and historic occurrences downgradient of the NBCS above the CRL of 1220 $\mu\text{g/l}$ (Figures 5.3.3-5 and 5.3.3-9). However, fluoride is an inorganic contaminant which the NBCS was not designed to remove from the ground water. The hydraulic barrier provided by the NBCS should serve to prevent fluoride migration across the NBCS.

Histograms were prepared for 21 wells showing winter 1987/88, spring 1988, fall 1988, and spring 1989 concentrations of these compounds. These wells were chosen based on proximity and relative position along the NBCS and because they have been sampled during the CMP. The histograms were combined in a schematic fashion to show contaminant concentrations along the southern and northern sides of the NBCS. The schematic diagrams display the histograms in their relative east-west position along the NBCS with wells south of the NBCS below a line representing the NBCS and wells north of the NBCS above this line (Figures 5.3.3-2, 5.3.3-3, 5.3.3-4, and 5.3.3-5).

DIMP, chloroform, and dieldrin have been the most frequently detected compounds north of the barrier. Concentrations of these and other compounds are generally up to an order of magnitude lower north of the barrier than measured south of the barrier. DIMP has been repeatedly detected in wells north of the western two-thirds of the barrier. Other compounds are detected most frequently north of the barrier near the central or pilot portion of the barrier, particularly at Wells 24161 and 23204. Well 24161 is completed in alluvium with a screened interval from 13 to 18 feet below ground surface. This well is located approximately 400 ft north of the barrier. Well 23204, however, is screened from 29 to 34 ft below ground surface within unconfined Denver Formation zone 2. The barrier, which is less than 100 ft south of Well 23204, is only constructed to a depth of approximately 23 ft below ground surface. Contaminants detected at Well 23204 are suspected of migrating beneath the barrier in permeable Denver Formation strata.

Analytical results from the winter of 1987/88 through the spring of 1989 indicate that concentrations of DIMP, DBCP, and composited organosulfur compound generally are decreasing with time north of the barrier (Figures 5.3.3-2 and 5.3.3-3). The observed concentration decrease is apparent in Wells 24161 and 23204. From the spring 1988 to the fall 1988 sampling periods, DBCP and composited organosulfur compound concentrations decreased to below the CRL at these wells. These compounds were also not reported at these wells during the subsequent spring 1989 sampling round.

The concentration decreases of DIMP, DBCP, and composited organosulfur compounds at Wells 24161 and 23204 may be attributable to operation of 10 recharge trenches along the western half of the barrier. Operation of these trenches began immediately prior to the fall 1988 sampling round (Lutton, 1989). These recharge trenches were constructed for the purpose of reversing the hydraulic gradient at the barrier and minimizing the potential for contaminant migration beneath the barrier through permeable zones of the Denver Formation. At Well 23204, which is completed in unconfined Denver Formation zone 2, the compounds DCPD, chloroform, and TCLEE also decreased to near or below the CRL during the fall 1988 and spring 1989 sampling periods. This indicates that operation of the recharge trenches may be preventing contaminant migration beneath the barrier in Denver Formation strata. Alternatively, increased flow of clean water from recharge trench operations may have served to dilute contaminant concentrations. Hydraulic analysis indicates that the gradients are reversing, and this migration mechanism will be controlled.

In order to characterize the spatial and temporal differences in analyte concentrations along the two ground-water pathways to the north of the NBCS, a set of histogram plots similar to those described above were generated for wells north of the NBCS (Figures 5.3.3-6, 5.3.3-7, 5.3.3-8, and 5.3.3-9). Selected histograms were developed that correspond to the First Creek Off-Post and the

Northern Off-Post Pathways. Analytical results from the same four sampling periods noted above were assessed. Seven representative analytes are presented in these figures. Dibromochloropropane and chloroform do not occur in the First Creek Off-Post Pathway, and histograms for these analytes are presented only for the Northern Off-Post Pathway.

The winter 1987/88 data for the First Creek Off-Post Pathway (Figure 5.3.3-6) show a clear trend of increasing DIMP concentration with increasing distance northward away from the NBCS. A similar trend is evident along the Northern Off-post Pathway for the compounds DBCP and chloroform (Figure 5.3.3-8). These trends are the result of remnant plumes of contamination predating NBCS operations. Lower concentrations near the NBCS indicate the effectiveness of the NBCS in reducing off-post contaminant migration.

Figures 5.3.3-6 and 5.3.3-8 indicate that concentrations of DIMP in the First Creek Off-Post Pathway and concentrations of DBCP and chloroform within the Northern Off-Post Pathway have been decreasing since the winter of 1987/88. Concentrations of DIMP in the Northern Off-Post Pathway and composited organosulfur compounds in both pathways also appear to be decreasing. However, concentrations of dieldrin, DCPD, and endrin in both pathways show no clear trend.

Histograms illustrating long-term historical contamination of DIMP in wells south and north of the NBCS are presented in Figures 5.3.3-10 and 5.3.3-11. These figures are presented in order to evaluate contaminant distribution since the start-up of the pilot portion of the NBCS in 1978 and the current barrier, completed in 1982. Figure 5.3.3-10 indicates that DIMP concentrations south of the NBCS appear to be generally decreasing since 1978. Figure 5.3.3-11 indicates, however, that DIMP concentrations appear to be decreasing more dramatically north of the NBCS, particularly in those wells closest to the barrier as a result of the NBCS operation.

5.3.3.2 Northwest Boundary Containment System

The NWBCS consists of a soil-bentonite slurry wall and a hydraulic barrier extending approximately 2300 feet along the northwest boundary of RMA. The NWBCS became operational in January 1985 for the purpose of extracting ground water and removing associated organic contaminants, particularly DBCP, to prevent their migration across the RMA boundary (PMRMA, 1987b). The hydraulic effects of the NWBCS and selected analytical data are discussed to assess the operations of the NWBCS.

Hydraulic Assessment.

Figure 5.3.3-12 presents a potentiometric comparison of three wells near the NWBCS. The majority of wells in the vicinity of the NWBCS are completed in the alluvium. Only one well group in the area includes wells screened in deeper units (Figure 5.3.3-12). This well group is a cluster site that allows direct water elevation comparisons to be made between zones. The hydrographs for this well group indicate that the alluvium has greater head than confined zones 4 and 5. This relationship results in a downward vertical gradient between the alluvium and confined zones 4 and 5. Confined zones 4 and 5 have similar potentiometric elevations, which may indicate that vertical hydraulic communication between these zones is significant in this area. Similar to water elevation fluctuations in the zones around the NBCS, fluctuations in zones 4 and 5 mimic the fluctuations in alluvial water elevations at this well cluster.

Ground-Water Analytical Quality Data Assessment.

The NWBCS was evaluated by examining CMP chemical data from wells southeast and northwest of the barrier. Five wells southeast of the NWBCS and six wells northwest of the barrier were selected. Analytical results for the selected wells are from the winter of 1987/88, spring of 1988, fall of 1988, and spring of 1989. Three of the wells southeast of the barrier were sampled only during the winter of 1987/88 and fall of 1988.

Diisopropylmethylphosphonate, dieldrin, endrin, chloroform, and DBCP analytical results have been evaluated for this assessment. These compounds were selected because they currently are or historically have been present in the pathways southeast of the NWBCS. The areal distribution of these analytes, based on Fall 1988 results, were previously discussed in Section 4.3 of this report.

Histograms displaying the spatial/temporal distribution and concentrations of these compounds at the NWBCS are presented in Figures 5.3.3-13 and 5.3.3-14. These histograms indicate that chloroform has consistently been detected in all six wells downgradient of the NWBCS. DIMP detections occur in 10 of the 24 samples taken on the downgradient well, and dieldrin has been detected in 11 of the 24 samples. The fall 1988 plume map for dieldrin (Figure 4.3.2-1) shows that the plume is intercepted at the NWBCS. However, as indicated by the plume maps in Section 4.3, all three compounds still persist downgradient of the NWBCS.

The identification of DIMP in wells downgradient of the NWBCS is largely the result of the lowering the CRL for DIMP from 18.5 and 10.1 $\mu\text{g/l}$ to 0.392 $\mu\text{g/l}$. This observation is supported

by the fall 1988 DIMP plume map (Figure 4.3.16-1) which shows a much larger plume of DIMP than historical maps where DIMP had a higher CRL.

The histograms indicate that the occurrence of dieldrin downgradient of the NWBCS is limited to the northernmost wells selected despite the fact that dieldrin was detected in all of the upgradient wells. This indicates that dieldrin may potentially be migrating around the northern end of the barrier. However, limited well control does not allow this possibility to be confirmed or refuted.

Occurrences of endrin detections northwest of the NWBCS appear sporadic. In four wells northwest of the NWBCS, endrin was detected during only one of the four CMP sampling periods. Upgradient detections are more frequent at Wells 22008 and 22043; however concentrations were within an order of magnitude of the CRL.

Dibromochloropropane, which the NWBCS was specifically designed to intercept, occurred only sporadically southeast of the NWBCS and was not detected northwest of the system (Figure 5.3.3-12). Detections of DBCP southeast of the system were near the CRL.

5.3.4 Vertical Extent of Contamination

The vertical extent of contamination for FY89 was identified using data collected during the fall of 1988. All detections of organic compounds, arsenic, and cyanide above CRLs, and detections of fluoride and chloride above background levels of 5,000 and 75,000 $\mu\text{g/l}$ were considered in the assessment. Background levels for chloride and fluoride are based on data presented in the 1988 CMP Annual Ground-Water Report (Stollar, 1989). The deepest organic and inorganic fall 1988 detections were identified on a section-by-section basis in order to characterize the areal distribution of deep contamination. In addition, the deepest fall 1988 detections of the CMP target analytes discussed in Section 4.3 were identified. In all instances, depth of contamination was interpreted to be the depth below ground surface (BGS) to the bottom of the screened interval of the sampled well.

The description of vertical extent of contamination provided in this report is based on water-quality data obtained during a single sampling period. Due to the general low hydraulic conductivity and large heterogeneity of the Denver aquifer, substantial data variability is likely to occur in any sampling period. Data interpretation based on a single sample period may not be effective in recognizing anomalous data and may produce inconsistent results.

An extensive evaluation of the vertical extent of contamination has been undertaken as part of the RI/FS at RMA. This evaluation will be based on a comprehensive review of water-quality information utilizing the complete period of available data. Results of the evaluation will be presented in the Remedial Investigation Summary Report.

5.3.4.1 Vertical Extent of Organic Contamination. The deepest fall 1988 detections of organic compounds for each on-post RMA Section are presented in Table 5.3.4-1. Throughout most of RMA, the deepest contamination in each Section occurred within the confined flow system of the Denver Formation. However, the deepest detections in Sections 3, 6, 8, 33, and 34 occurred within the unconfined flow system. Sections 6 and 8 are located in the upgradient southeast portion of RMA. Sections 3, 33, and 34 are located in RMA Western Tier. Organic contaminants were not detected in Sections 7, 31 and 32, and there were no wells sampled in Sections 20 and 29.

The deepest off-post fall 1988 organic contaminant detection occurred in the unconfined flow system at Well 37360. This well is located approximately one mile northwest of RMA, is screened to a depth of 101 feet BGS, and contained 0.599 $\mu\text{g/l}$ of DIMP.

In many cases, the vertical extent of contamination presented in Table 5.3.4-1 was a manifestation of the data set. In 15 of the 27 Sections/areas listed, the deepest reported organic contamination occurred at the deepest well sampled within that Section.

A comparison of Table 5.3.4-1 with Table 5.3-1 of the 1988 CMP Annual Report was made to assess possible changes in the vertical extent of contamination. Within Sections 3, 24, 26, 30, and 34 the deepest fall 1988 detections occurred in the same wells identified in the FY88 Annual Report. However, differences were noted in all remaining on-post Sections. The lowering of the CRL for DIMP from 18.5 and 10.1 $\mu\text{g/l}$ during the winter of 1987/88 to 0.392 $\mu\text{g/l}$ during the fall of 1988 has resulted in more widespread fall 1988 DIMP detections. Within Sections 4, 6, 8, 9, 11, 12, and 35, fall 1988 DIMP detections between 0.392 and 10.1 $\mu\text{g/l}$ have resulted in new wells being identified as containing the deepest organic contamination.

Within Sections 28 (Well 28025) and 36 (Well 36171), fall 1988 detections of benzene effectively increased the depth of contamination compared to the 1988 Annual Report results. Both of these fall 1988 detections were supported by benzene detections in these wells during the spring of 1988. At Well 28025, benzene was not reported during the winter of 1987/88. Well 36171 was not sampled during the winter of 1987/88. Thus, in Section 36 the increased depth of contamination in 1989 is a manifestation of the sampling network. In Section 28, the increased depth of contamination may be an indication of contaminant migration.

Table 5.3.4-1 Deepest Fall 1988 Organic Compound Contamination (by Section)

Section No.	Well	Depth of Monitored Interval (ft BGS) ¹	Contaminants Detected	Concentration (µg/l)	CMP Confirmation ²	Aquifer ³
1	01048	160.0 - 210.0	Chloroform	4.90	N	Denver 2
2	02031	103.0 - 138.0	Atrazine	5.48	-	Denver 1U
			Benzene	29.1	N	
			Supona	1.43	-	
3	03523	63.0 - 73.0	Chloroform	6.01	Y	UFS
			CL6CP	0.496	Y	
			DBCP	31.0	Y	
			Malathion	0.589	-	
4	04012	181.8 - 186.8	DIMP	0.458	N	Denver 6
			DMMP	0.215	N	
5	05001	22.8 - 28.8	Chloroform	3.78	-	Denver 8
			TCLEE	1.90	-	
6	06003	9.0 - 19.0	DIMP	1.16	-	UFS
7	No contaminants detected					
8	08003	9.0 - 29.0	DIMP	0.910	N	UFS
9	09003	104.0 - 129.0	Aldrin	0.351	N	Denver 2
			DIMP	1.39	N	
11	11004	97.0 - 103.0	DIMP	2.73	N	Denver A
12	12004	109.5 - 124.5	Atrazine	7.03	-	Denver A
			DIMP	0.541	N	
19	19016	120.0 - 145.0	Chloroform	0.773	-	Denver 3
			TRCLE	2.34	-	
22	22031	124.0 - 134.0	Endrin	0.0510	N	Denver 5
23	23187	116.5 - 131.5	111TCE	0.999	N	Denver 4
24	24172	121.5 - 131.5	Benzene	2.62	Y	Denver 5
			Chlorobenzene	63.4	Y	
			DBCP	0.340	N	
			TRCLE	1.32	Y	
25	25009	70.0 - 105.0	Chloroform	0.807	N	Denver 1

Table 5.3.4-1 Deepest Fall 1988 Organic Compound Contamination (by Section) (continued)

Section No.	Well	Depth of Monitored Interval (ft BGS) ¹	Contaminants Detected	Concentration (µg/l)	CMP Confirmation ²	Aquifer ³
26	26142	138.0 - 146.0	Aldrin	2.80	Y	Denver 3
			Chloroform	2.43	N	
			Chlordane	0.210	Y	
			Dieldrin	7.10	Y	
			Endrin	1.20	Y	
			Isodrin	0.0642	N	
			PPDDT	3.30	Y	
27	27055	120.0 - 135.0	Dieldrin	0.0635	N	Denver 5
			PPDDT	0.0816	N	
28	28025	92.0 - 102.0	Benzene	10.4	Y	Denver 5
30	30011	123.0 - 133.0	DIMP	0.649	N	Denver 2
31	No contaminants detected					
32	No contaminants detected					
33	33077	105.1 - 125.1	Aldrin	0.0589	N	UFS
			TRCLE	6.95	Y	
34	34008	54.5 - 84.5	Dieldrin	0.0955	Y	UFS
35	35078	173.0 - 183.0	DIMP	0.739	N	Denver 1
			2-Methylphenol	17.2		
36	36171	133.0 - 173.0	Aldrin	0.109	Y	Denver 1
			Benzene	2.93	Y	
			TRCLE	3.71	N	
Off-post	37360	26.3 - 101.0	DIMP	0.599	N	UFS

¹ BGS - below ground surface

² Detection was confirmed by a similar detection in at least one previous or subsequent CMP sampling event. (Y=Yes; N=No; --=Data not available)

³ Denver 1 - Confined flow system zone within the Denver Formation
UFS - Unconfined flow system

Table 5.3-1 of the 1988 Annual Report identified benzene in Well 33032 (Denver Formation zone 7) as the deepest detected contamination in Section 33. However, benzene has not been reported in this well for the subsequent spring 1988, fall 1988, and spring 1989 sampling periods. Thus, the deepest fall 1988 contamination in Section 33 was trichloroethene (TRCLE) in the unconfined Well 33077.

5.3.4.2 Vertical Extent of Inorganic Contamination. The deepest fall 1988 detections of the inorganic species arsenic, chloride, cyanide, and fluoride for each on-post RMA section are presented in Table 5.3.4-2. Because they are known to be naturally occurring, fluoride and chloride concentrations were considered to indicate contamination if their respective concentrations were greater than 5,000 and 75,000 $\mu\text{g/l}$. As with the organic compounds, the deepest inorganic detections during the fall of 1988 occurred predominately within the confined flow system. Only in Sections 11, 12, 24, and 31 was the deepest fall 1988 inorganic contamination limited to the unconfined flow system.

The deepest off-post inorganic contamination occurred in the confined flow system at Well 37388 (zone 4). This well is screened to a depth of 86 ft, is located approximately 1000 ft north of RMA in Section 14 and contained 400,000 $\mu\text{g/l}$ of chloride.

Table 5.3.4-2 was compared with Table 5.3-2 of the 1988 CMP Annual Report in order to assess possible changes in the vertical extent of inorganic contamination. In 12 of the on-post sections, the wells containing the deepest contamination were the same. Many of the remaining differences result from the inclusion of cyanide during the fall of 1988 and an increase in the assumed background level for fluoride from 1720 to 5000 $\mu\text{g/l}$. (The background level for fluoride of 1720 $\mu\text{g/l}$ was used only in preparing Table 5.3-2 of the 1988 Annual Report.)

A fall 1988 arsenic detection at Well 04012 resulted in this well replacing Well 04011 as the well with the deepest inorganic detection in Section 4. However, the fall 1988 detection may be spurious because spring 1988 and spring 1989 arsenic analyses at this well were below detection. Well 23187 replaced Well 23184 as the well with the deepest inorganic contamination in Section 23. This well has a history of high chloride detections but was not included in Table 5.3-2 of the 1988 CMP Annual Report because the winter 1987/88 chloride concentration was reported only as $>90,000 \mu\text{g/l}$.

5.3.4.3 Vertical Extent of Specific Analytes. The deepest fall 1988 detections of individual analytes (discussed in Section 4.3) are presented in Table 5.3.4-3. There appear to be no clear relationships between analyte group and depth of contamination. The analytes detected at depths

Table 5.3.4-2 Deepest Fall 1988 Contamination of Selected Inorganic Species (by Section)¹

Section No.	Well	Depth of Monitored Interval (ft BGS) ²	Contaminants Detected	Concentration (µg/l)	CMP Confirmation ³	Aquifer ⁴
1	01048	160.0 - 210.0	Cyanide	12.2	-	Denver 2
2	02031	103.0 - 138.0	Cyanide	5.17	N	Denver 1U
3	03004	168.0 - 178.0	Arsenic	4.16	Y	Denver 4
4	04012	181.8 - 186.8	Arsenic	3.36	N	Denver 6
5	05001	22.8 - 28.8	Chloride Cyanide	160,000 12.9	- -	Denver B
6	No contaminants detected					
7	No contaminants detected					
8	No contaminants detected					
9	09003	104.0 - 129.0	Cyanide	31.1	-	Denver 2
11	11005	13.7 - 62.7	Cyanide	8.57	-	UFS
12	12002	19.4 - 44.0	Chloride	79,000	Y	UFS
19	19016	120.0 - 145.0	Chloride Cyanide	150,000 8.50	- -	Denver 3
22	22031	124.0 - 134.0	Chloride Cyanide	370,000 14.5	Y -	Denver 5
23	23187	116.5 - 131.5	Chloride	290,000	-	Denver 4
24	24086	33.9 - 49.9	Chloride Cyanide	130,000 12.2	Y -	UFS
25	25014	121.0 - 136.0	Cyanide	6.67	-	Denver 3
26	26153	131.1 - 136.8	Chloride	220,000	Y	Denver 4
27	27055	120.0 - 135.0	Arsenic	4.59	Y	Denver 5
28	28025	92.0 - 102.0	Arsenic Cyanide	3.51 5.26	Y N	Denver 5
30	No contaminants detected					
31	31005	20.0 - 45.0	Chloride	100,000	-	UFS

Table 5.3.4-2 Deepest Fall 1988 Contamination of Selected Inorganic Species (by Section)¹
(Continued)

Section No.	Well	Depth of Monitored Interval (ft BGS) ²	Contaminants Detected	Concentration (µg/l)	CMP Confirmation ³	Aquifer ⁴
32	No contaminants detected					
33	33031	165.0 - 175.0	Fluoride	6100	Y	Denver 6
34	34011	92.0 - 102.0	Cyanide	7.42	N	Denver 3
35	35078	173.0 - 183.0	Arsenic	2.43	N	Denver 1
			Cyanide	33.5	N	
36	36171	133.0 - 173.0	Cyanide	24.9	N	Denver 1
Off-post	37388	69.8 - 86.0	Chloride	400,000	Y	Denver 4

¹ Compounds selected for this analysis are Chloride, Fluoride, Arsenic, and Cyanide. Assumed background values for Chloride and Fluoride are 75,000 and 5000 µg/l, respectively.

² BGS - below ground surface

³ Detection was confirmed by a similar detection in at least one previous or subsequent CMP sampling event. (Y=Yes; N=No; --Data not available)

⁴ Denver 1 - Confined flow system zone within the Denver Formation
UFS - Unconfined flow system

Table 5.3.4-3 Deepest Fall 1988 Detections of CMP Target Analytes¹

Analyte	Well	Monitored Interval (ft BGS)	Detected Concentration (µg/l)	CMP Confirmation ²	Aquifer ³
1,1-DCE	33074	76.7 - 96.7	8.58	Y	UFS
1,1-DCLE	09011	72.7 - 87.2	1.31	N	UFS
1,2-DCE	33002	103.9 - 111.5	1.06	N	UFS
1,2-DCLE	36083	79.0 - 82.4	2.01	N	Denver 1U
1,1,1-TCE	23187	116.5 - 131.5	0.999	N	Denver 4
1,1,2-TCE	09013	55.0 - 75.0	0.962	Y	UFS
CCL4	36182	53.6 - 75.0	800	Y	Denver A
Chloroform	01048	160.0 - 210.0	4.90	N	Denver 2
CH2CL2	01071	64.3 - 74.3	10.0	N	Denver A
TCLEE	33048	54.0 - 114.0	1.97	Y	UFS
TRCLE	36171	133.0 - 173.0	3.71	N	Denver 1
Benzene	36171	133.0 - 173.0	2.93	Y	Denver 1
Chlorobenzene	36179	98.2 - 151.0	155	Y	Denver 1
Ethylbenzene	26133	35.0 - 55.0	10.4	Y	UFS
m-Xylene	04029	89.0 - 99.0	1.69	N	UFS
Toluene	35080	98.5 - 118.5	2.23	Y	Denver 2
Xylenes(o,p)	36179	98.2 - 151.0	2.04	N	Denver 1
1,4-Dithiane	26129	90.0 - 100.0	240	Y	Denver 2
1,4-Oxathiane	26129	90.0 - 100.0	14.6	Y	Denver 2
Benzothiazole	26133	35.0 - 55.0	25.7	Y	UFS
CPMS	26133	35.0 - 55.0	620	Y	UFS
CPMSO	36148	93.0 - 163.0	49.4	-	Denver 1
CPMSO2	36148	93.0 - 163.0	35.3	-	Denver 1
DIMP	04012	181.8 - 186.8	0.458	N	Denver 6
DBCP	36179	98.2 - 151.0	8.96	Y	Denver 1
DCPD	35084	154.0 - 174.0	16.4	N	Denver 1
Dieldrin	36148	93.0 - 163.0	0.0535	-	Denver 1
Endrin	36148	93.0 - 163.0	0.403	-	Denver 1
Parathion	04020	69.0 - 79.0	1.32	N	UFS
Arsenic	04012	181.8 - 186.8	3.36	N	Denver 6
Chloride ⁴	36179	98.2 - 151.0	280,000	Y	Denver 1
Cyanide	01048	160.0 - 210.0	12.2	-	Denver 2
Fluoride ⁴	33031	165.0 - 175.0	6100	Y	Denver 6

¹ Refers to analytes discussed in Section 4.3 of this report

² Detection was confirmed by a similar detection in at least one previous or subsequent CMP sampling event. (Y=Yes; N=No; -=Data not available)

³ Denver 2 - Confined flow system zone within the Denver Formation
UFS - Unconfined flow system

⁴ Assumed background values for Chloride and Fluoride were 75,000 and 5000 µg/l, respectively.

greater than 170 ft BGS were arsenic, benzene, chloroform, cyanide, DCPD, DIMP, fluoride, and trichloroethene. Compared to Table 5.3-3 of the 1988 CMP Annual Report, only benzene and fluoride were similarly shown to occur below 170 ft BGS.

5.3.5 Aquifer Interaction

Potentiometric data, inorganic and organic analytical results, and isotope data were examined to evaluate RMA areas where aquifer interaction may occur. All well clusters sampled during the Fall 1988 sampling round were examined. In addition, analytical results from several well clusters installed during the Fall 1988 sampling event under the RI/FS program were examined. Water-level data and chemical data from these wells are approximately contemporaneous with those from the Fall 1988 sampling event, and so were included in this investigation.

5.3.5.1 Potentiometric Head Differences. Elevations of the potentiometric surfaces of the unconfined and confined flow systems were examined to identify areas where ground water from the unconfined flow system might flow downward to permeable units within the confined Denver Formation, and areas where ground water in the confined flow system would tend to move upwards to the unconfined flow system. In all but five well clusters, potentiometric head elevations are greater in the unconfined flow system than in the confined flow system. Head difference variations in the well clusters with downward vertical gradients ranged from 0.09 ft to as much as 25 ft, depending on the stratigraphic intervals within which the clustered wells are completed. These gradients would cause ground water from the unconfined flow system to move vertically downward through permeable portions of the confined flow system.

Five instances in which potentiometric head elevations indicated an upward vertical gradient were noted. These were in Section 2 (Wells 02034 and 02035), Section 6 (Wells 06003, 06004, 06005), Section 26 (Wells 26, 27 and 26179) and Section 34 (Wells 34005, 34006 and Wells 34012, 34013). In each case, water levels were greater in wells completed in deeper confined flow system water-bearing zones than in shallower wells completed in the unconfined flow system. In general, head differences ranged from 0.09 to 1.11 ft greater in the confined flow system, depending on the stratigraphic interval in which wells were completed. This situation results in a force potential which would cause ground water to move vertically upward, from permeable portions of the confined flow system into the unconfined flow system. One instance was noted (Wells 34012 and 34013) where two confined wells, screened in Denver Zone 1 (Well 34012) and Zone 2 (Well 34-13), had an upward vertical gradient of 25 feet.

5.3.5.2 Inorganic Chemical Data. Inorganic chemical data from cluster wells sampled during the Fall 1988 sampling event were examined to determine if these data provide clear evidence of aquifer interaction. Data interpretations in Section 5.4.4 indicate that the unconfined and confined flow systems tend to have concentrations of calcium, sodium and nitrate which are more characteristic of each flow than other inorganic analytes. Therefore, analytical data were examined for well clusters which had anomalous values for calcium, sodium and nitrate. Well clusters identified as having anomalous concentrations of these analytes (in conjunction with anomalous potentiometric data, organic analyses and isotope data) were considered to indicate areas where potential existed for aquifer interaction. Areas in which inorganic chemical data indicate potential for aquifer interaction generally lie in the following areas: the South Plants Pathway, northward through the Basin A/Basin A Neck Pathways, continuing through Basins D and E, and in the Basin F Pathway.

5.3.5.3 Organic Chemical Data. Organic chemical data were examined to identify areas where aquifer interaction may occur. Because these compounds are not naturally occurring, the presence of organic analytes in confined Denver Formation water bearing zones indicates that these compounds may have been transported to the detected locations by ground water. This, in turn, suggests aquifer interaction between the unconfined and confined flow systems. The use of low concentrations of organic contaminants to assess aquifer interactions result in somewhat equivocal conclusions. This is due to a number of factors, including analyte detections noted at several well clusters in deeper confined Denver Formation wells, with the same analytes not occurring in shallower, unconfined wells. This is consistent with sporadic contamination of sandstone zones which has been noted historically (Ebasco, 1989i), probably due to contaminant migration along localized fracture zones, or lateral flow within the Denver Formation. In spite of these difficulties, however, there are several well clusters that appear to provide some insight into potential aquifer interactions at RMA.

Evidence for aquifer interaction based on organic analytical data is sometimes ambiguous or sporadic. For example, all wells in a cluster considered to show evidence for aquifer interaction generally contain several of the same compounds. However, several additional analytes are commonly detected in confined wells and not in unconfined wells, with still other analytes detected in unconfined wells and not in confined wells in the same cluster. However, organic data do indicate that potential for aquifer interaction generally exists in the following areas: the South Plants Pathway northward through the Basin A/Basin A Neck Pathways; the Basin F and Basin F East Pathways; and the Basin A Neck Pathway northwestward into Section 27.

5.3.5.4 Isotopic Evidence. Since approximately 1953 the amount of tritium in the atmosphere (and hence in surface waters and precipitation) has increased. Thus relatively "young" ground water will yield a different tritium signature than "old" ground water which infiltrated prior to 1953, or which has been isolated since that time. During the spring 1988 sampling event 13 ground-water samples were collected from the unconfined flow system in Section 23, 24 and 33 for isotopic analyses (tritium, deuterium and oxygen-18).

Results of tritium analyses in Sections 23, 24, and 33 indicate different concentrations of tritium in unconfined and confined wells, indicating different ages for ground water in these two systems, in the areas sampled (Figure 5.5-3). With one exception these data indicated that either no mixing or only limited mixing of unconfined and confined ground water has occurred in these areas. This is consistent with organic chemical data available in these areas. A much more thorough discussion of isotopic data is presented in Section 5.5. Well 23177 yielded a TU value midway between TU values characteristic of the unconfined and confined flow systems, indicating that potential for aquifer interaction exists in the area of this well. No well clusters were sampled close to Well 23177 to provide corroborating potentiometric data, and inorganic or organic analytical data.

5.4 Inorganic and Other Water-Quality Data Assessment

This section of the Annual Report provides a presentation and interpretation of inorganic analytical results, including general and water-quality parameters from samples collected during the fall 1988 annual sampling event. Although analyses for inorganic and other water-quality parameters have been components of many previous RMA ground-water investigations, the assessment of these data have been limited. The historical investigations on RMA have focused primarily on organic contaminant distributions because degradation of inorganic water quality generally results in a lesser risk to human health and the environment than contamination by organic compounds.

The emphasis of this section is to present inorganic water quality characteristics of the unconfined flow system and confined flow system from both a regional and area specific perspective.

The regional area includes all wells within the RMA on-post and off-post operable units (OUs) and encompasses the four subareas presented in Figure 5.4-1. The presentation by area is divided into four areas as shown in Figure 5.4-1: (1) Western Tier, (2) Central Area, (3) Background, and (4) Northern Area.

Background areas are defined as areas which contain wells upgradient of known RMA source areas. Analytical results from the wells upgradient of South Plants and those east of Basin A, North Plants, and the NBCS were considered representative of background conditions.

The three remaining subareas were chosen based on their hydrogeologic, geographic, and contaminant distribution differences and comparisons were made based on their individual characteristics. The Western Tier includes monitoring wells around the Rail Classification Yard and the Irondale Containment System and is characterized by a thick sequence of saturated alluvium and is downgradient of the Motor Pool and Rail Classification Yard. The Central Area includes monitoring wells in South Plants, Basin A and along the Basin A Neck and Central Pathways. The Central Area contains several prominent source areas and relatively thinner saturated alluvium oriented in paleochannels. The Northern Area includes monitoring wells in North Plants, Basin F, and along the Basin F North and Northwest Pathways. It is similar to the Central Area in that it also has relatively thinner saturated alluvium and contains source areas.

The inorganic and other water-quality data assessment presented here progresses from presentation of basic water quality data collected in the field to more complex data resulting from laboratory analytical work. Specific conductance and dissolved oxygen are field parameters measured immediately prior to sampling. The remaining data are laboratory analytical results. The first two subsections discuss the water-quality field parameters directly. The following four subsections are assessments of inorganic data received from the CMP contract laboratory, DataChem. The subjects discussed include frequency distributions, solute correlations, trilinear diagrams, and correlation coefficients.

Within each of the following six subject discussions, a brief explanation is given on the theory and applicability of each method. Each of the subjects progresses from a discussion of RMA background conditions, to regional conditions, to noteworthy localized exceptions that may be indicative of RMA activities. Exceptions to this are the discussions of frequency distributions and correlation coefficients, which are most appropriately discussed from a regional perspective.

5.4.1 Specific Conductance

Specific conductance is the reciprocal of the resistance (in ohms) measured between opposite faces of a one centimeter cube of an aqueous solution at a specified temperature. The specific conductance measurement is an indicator of ion concentration and in general is directly related to the total dissolved solids (TDS) in solution. The presence of charged ion species in solution makes the solution conductive. Therefore, the greater the concentration of charged ions in solution the greater the conductivity of the solution. Natural waters commonly have a conductance much less

than 1 mho and in order to avoid inconvenient decimals, data are commonly reported in micromhos per centimeter ($\mu\text{mhos/cm}$) at 25°C (Hem, 1989).

In ultrapure water, specific conductance approaches 0.05 $\mu\text{mhos/cm}$ at 25°C whereas the specific conductance of distilled water approaches 1.0 $\mu\text{mho/cm}$. The specific conductance values of rainwater range from 2 to greater than 100 $\mu\text{mhos/cm}$. The specific conductance value of surface and ground water is dependent on the solutes in precipitation, the rock formation in contact with the water, the length of time for water/rock interaction, temperature, and the types of ions present in solution. In areas where precipitation is low in solutes and rocks are resistant to weathering the specific conductance may be as low as 50 $\mu\text{mho/cm}$. In other areas the specific conductance of ground waters may approximate that of seawater (50,000 $\mu\text{mhos/cm}$) (Hem, 1989).

In the CMP, specific conductance is measured in the field at least once for every casing volume purged from a well to be sampled. Commonly, specific conductance and temperature stabilize prior to evacuation of five well casing volumes and thus a stable value of specific conductance is recorded immediately prior to filling sample containers. Therefore, the measured value of specific conductance at this time is expected to represent actual ground-water conditions. The accuracy and reproducibility of measuring the specific conductance in the field should be approximately ± 5 percent.

Although the actual field measurement is electroconductivity, these values have been corrected for temperature and are reported as specific conductance ($\mu\text{mhos/cm}$) at 25°C. Results of the specific conductance data are presented in Figure 5.4-2. Figure 5.4-2 includes four plots in which specific conductance is plotted as a function of depth. Also included in Figure 5.4-2 is a frequency distribution diagram of the specific conductance data. The background values fall below 3000 $\mu\text{mhos/cm}$ for both the unconfined flow system and confined flow system. The majority of the values on the regional plot fall below 3000 $\mu\text{mhos/cm}$ and there is little apparent variation with depth. The values that are greater than 3000 $\mu\text{mhos/cm}$ are generally confined to depths 20 to 60 ft below ground surface (bgs). The Western Tier plot indicates values consistent with background values whereas the Central Area and Northern Area plots are similar to each other and the regional plot. The high values between 20 to 60 ft bgs appear in both the Central Area and Northern Area plots. These high values may be related to an increase in solute concentrations in these areas.

The frequency distribution diagram includes bar graphs for the unconfined and confined flow systems. The bar graphs represent the percent of samples that have measured values within a specified interval. A detailed discussion on the construction of the frequency diagram is provided

in Section 5.4.3. As noted in the diagram, the highest percentage of samples in the unconfined flow system have specific conductance values between 500 and 1000 $\mu\text{mhos/cm}$, while the highest percentage of samples in the confined flow system (confined flow system) have values between 1000 and 1500 $\mu\text{mhos/cm}$. The majority of samples in the ranges from 0 to 500 $\mu\text{mhos/cm}$ and from 1000 to 4000 $\mu\text{mhos/cm}$ were collected from the confined flow system. The majority of samples in the ranges from 500 to 1000 $\mu\text{mhos/cm}$ and from 4000 to greater than 10,000 $\mu\text{mhos/cm}$ were collected from the unconfined flow system.

Specific conductance is expected to increase with depth due to an increase in the total dissolved solids (TDS) in the ground water. Note, however, that this effect is not expected to be great at the fairly shallow depths investigated here. The increase in TDS relates to the longer residence time of deeper water and more interaction with surrounding rock, clays, sands, etc. The increase of specific conductance with depth was not apparent in any of the plots. Rather, increased specific conductance was noted at shallower (20 to 60 ft bgs) depths in all areas except the Western Tier. It is likely that the inconsistent elevation of specific conductance at these shallower depths is a function of near-surface sources of ground-water contamination.

5.4.2 Dissolved Oxygen/Percent O_2 Saturation

The parameter, dissolved oxygen (DO), like specific conductance, is measured in the field as each casing volume is purged from a well to be sampled. The equilibrium concentration of DO in water in contact with air is a function of temperature and atmospheric pressure. The equilibrium DO value (at 1 atmosphere) in freshwater is 7.54 mg/l at 30°C. This value increases to 12.75 mg/l at 5°C (Hem, 1989). The equilibrium DO value at sea level is greater than the value at higher elevations because an increase in elevation results in a decrease in atmospheric pressure, thereby reducing the amount of oxygen that is dissolved in water. Dissolved oxygen is commonly measured to evaluate processes involving the uptake of oxygen, e.g., organic degradation or oxidation of reduced inorganic minerals. The presence of organic chemicals will also cause oxygen depletion. The DO concentration in ground water is related to recharge of precipitation because these waters entering the system are expected to contain DO concentrations similar to those of surface waters in contact with the atmosphere. The DO concentration of ground water will vary as a function of the amount of oxidizable material present along its flow path. Therefore, DO concentrations near the saturation concentration may indicate either an area of recharge or an area with no appreciable oxidizable material.

Historically, DO was included in RMA RI/FS sampling programs to serve as a QA measure for indicating whether the purging process was complete and quantifying whether or not pumped wells

were yielding aerated samples. The reproducibility of DO values from successive sampling events at RMA (irrespective of sample technique) has indicated that sample aeration is not a concern. DO is also used as an analytical parameter for characterizing ground-water quality at RMA.

For presentation and discussion purposes in this report, DO values are converted to percent O₂ saturation at the temperature of measurement. The conversion of DO values to percent O₂ saturation allows for the interpretation of the degree of oxygen depletion relative to the equilibrium concentration. The following equation is used for this conversion:

$$\% O_2 = \frac{DO}{SO} \times 100$$

where % O₂ is the percent O₂ saturation DO is the concentration of dissolved oxygen in µg/l, and SO is the amount of oxygen at saturation in µg/l.

Results of the % O₂ data are presented in Figure 5.4-3. Figure 5.4-3 includes four plots in which % O₂ is plotted as a function of depth. Also included in Figure 5.4-3 is a frequency distribution diagram of % O₂. The background % O₂ values vary from near zero to approximately 90 percent saturation. The highest background value is from a confined flow system well located in Section 19. The variability of the unconfined flow system and confined flow system background values appears independent of depth. The regional plot has no discernable pattern of % O₂ with respect to either depth or flow system. The Western Tier plot indicates that in this area, % O₂ is not solely a function of depth but generally appears to increase with depth in the confined flow system. The Central Area and Northern Area plots exhibit a general trend of decreasing % O₂ with increasing depth in the confined flow system.

The frequency distribution diagram is constructed in the same manner as the frequency diagram presented for specific conductance. The largest percentage of samples from the confined flow system have % O₂ values between 0 and 20 percent and the percentage of samples generally decreases with increasing % O₂. In general, each interval presented in Figure 5.4-3 includes approximately 10 percent of the total samples from the unconfined flow system with the exception of the 0 to 10 percent range that includes almost 20 percent of the unconfined flow system samples. In general, a higher proportion of unconfined flow system waters are closer to O₂ saturation and a significant portion of the confined flow system samples exhibit low percent saturation.

Lower % O₂ values are expected in areas of high organic chemical contamination or in flow systems where either high organic carbon or reduced inorganic minerals are present.

5.4.3 Frequency Distributions

The analytical data for eight major ions in the unconfined and confined flow systems are presented in this section. The eight major ions are sodium (Na^+), potassium (K^+), calcium (Ca^{+2}), magnesium (Mg^{+2}), chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), and sulfate (SO_4^{-2}). The data from the two flow systems have been segregated to allow for a comparison of the characteristics of both flow systems. The results of these calculations are plotted as frequency diagrams and are presented in Figure 5.4-4. The percentage of samples within each flow system is represented by a vertical bar; the solid bar represents the samples from the unconfined flow system and the cross-hatched bar represents the samples from the confined flow system. The percent of samples is calculated on the basis of total samples from each system. Of a total of 488 samples collected, 322 were from the unconfined flow system and 166 were from the confined flow system. Each diagram is divided into 10 data ranges that include those samples (in millequivalents per liter; meq/l), within the lower and upper bound of each range. A discussion of each ion and corresponding diagram follows.

5.4.3.1 Sodium. The frequency distribution of sodium is presented in diagram A of Figure 5.4-4. The largest percentage of samples from the unconfined flow system occurs within the 0.04 (CRL) to 5 meq/l range. At increasing concentrations, the percentage of samples from the unconfined flow system decrease with the exception of the 50 to 100 meq/l range. In contrast, the confined flow system has the largest percentage of samples within the 10 to 20 meq/l range. This distribution indicates that the confined flow system exhibits higher sodium concentrations. Higher sodium concentrations are commonly indicative of ground waters that have had longer residence times as a result of cation exchange. Sodium at RMA, was introduced to soil surface water, and ground water by neutralizing agents, by-products of GB manufacture, breakdown products of GB, and numerous salts including sodium chloride (Geraghty and Miller, 1986)

5.4.3.2 Potassium. The frequency distribution of potassium is presented in diagram B of Figure 5.4-4. The highest percentage of samples in the confined flow system occur within the 0.004 (CRL) to 0.05 meq/l range. The unconfined flow system has the highest percentage of samples within the 0.05 to 0.1 meq/l range. This distribution suggests that potassium concentrations are generally higher in the unconfined flow system. Potassium has the tendency to be easily adsorbed onto clay mineral structures. This may contribute to the lower concentrations measured for the confined flow system which occurs predominately through the Denver Formation. Potassium has not been identified as a significant component of waste streams historically discharged at RMA (Geraghty and Miller, 1986).

5.4.3.3 Calcium. The frequency distribution of calcium is presented in diagram C of Figure 5.4-4. The distribution of calcium is generally similar for each flow system except in the 0.05 (CRL) to 1.0 meq/l range and in the 5.0 to 10 meq/l range. Approximately 20 percent of the confined flow system samples have concentrations between 0.05 and 1.0 meq/l. In contrast, the unconfined flow system has less than one percent of its samples within this concentration range. The unconfined flow system has over 40 percent of its samples in the 5.0 to 10 meq/l range, while the confined system has less than 20 percent in this range. This indicates that elevated calcium concentrations are generally present in the unconfined flow system. Calcium is commonly a constituent of igneous rocks, cementing materials in sandstone and caliche. Calcium was also present in waste streams generally associated with caustic processes at RMA (Geraghty and Miller, 1986). Calcium carbonate deposits from these processes are present in the lime pits and in surficial depressions in Basin A. In addition, with longer residence times in sedimentary aquifers calcium exchanges with sodium, decreasing aqueous calcium concentrations, and increasing aqueous sodium concentrations.

5.4.3.4 Magnesium. The frequency distribution of magnesium is presented in diagram D of Figure 5.4-4. Over 65 percent of the confined flow system samples have concentrations less than or equal to 1.0 meq/l. In contrast, nearly 90 percent of unconfined flow system samples have concentrations greater than 1.0 meq/l. This indicates that higher concentrations of magnesium are more prevalent in the unconfined flow system. Increased levels in the unconfined flow system may result from contamination associated with incendiary, chlorine, and caustic production.

5.4.3.5 Chloride. The frequency distribution of chloride is presented in diagram E of Figure 5.4-4. Most RMA ground-water samples contain chloride at concentrations ranging from 0.02 to 5.0 meq/l. Nearly 75 percent of confined flow system samples are within this range and approximately 60 percent of unconfined flow system samples are within this range. As chloride concentrations increase to 30 meq/l, the percentage of confined flow system samples decreases more than the percentage of unconfined flow system samples. Between 5.0 and 20 meq/l, the unconfined flow system has a larger percentage of samples. This indicates that elevated levels of chloride occur more predominantly in the unconfined flow system. Chloride is a "conservative" constituent of ground water not being readily removed from the system. Therefore, higher concentrations of chloride in the unconfined flow system suggest an introduction of chloride laden waters directly into the unconfined flow system. Chloride was commonly used in RMA manufacturing processes.

5.4.3.6 Fluoride. The frequency distribution of fluoride is presented in diagram F of Figure 5.4-4. Both flow systems show similar frequency distributions, with the unconfined flow system exhibiting a slightly higher percentage of samples with concentrations above 0.2 meq/l. Sources of fluoride include manufacturing processes at RMA and naturally-occurring volcanic constituents of the Denver Formation.

5.4.3.7 Nitrate. The frequency distribution of nitrate is presented in diagram G of Figure 5.4-4. Nearly 70 percent of the confined flow system samples have concentrations ranging from 0.005 to 0.25 meq/l. In contrast, over 60 percent of the unconfined flow system samples have concentrations greater than 0.25 meq/l. The elevated concentrations in the unconfined aquifer suggest leaching of nitrate from surficial anthropogenic practices. Commonly, nitrate leaching is associated with agricultural and livestock practices.

5.4.3.8 Sulfate. The frequency distribution of sulfate is presented in diagram H of Figure 5.4-4. Over 70 percent of samples from the unconfined flow system have concentrations of sulfate ranging from 0.01 to 10 meq/l. The percent of unconfined samples decreases with increasing concentrations. The confined flow system exhibits a similar distribution except that a larger percentage of samples contain concentrations above 10 meq/l; over 50 percent of confined flow system samples have concentrations above 10 meq/l. The decrease in percent of samples with increasing concentration is also noted in the samples from the confined flow system. The relatively higher percentage of samples with elevated concentrations in the confined flow system may result from increased sulfur content common in rocks with volcanic origin such as the Denver Formation.

5.4.4 Solute Correlations

The interactive relationship between chemical constituents may be visualized in a scatter plot in which one constituent is plotted on the abscissa and the other on the ordinate. A positive correlation between the constituents is realized if a straight line with a positive slope can be fitted through the points on the plot. Some constituents are known to have a negative correlation because they are utilized differently in a chemical system and this type of correlation is most noticeable in the ratio of the constituents. Calcium and sodium are examples of constituents generally having a negative correlation.

The negative correlation between calcium and sodium is a result of ion-exchange reactions. Sodium is a monovalent cation whereas calcium is a divalent cation that is more strongly bonded and tends to replace sodium ions. Typically, the observed relationship between sodium and calcium is that calcium ions replace sodium ions in the soil matrix. As calcium ions replace sodium ions

in the soil the displaced sodium ions are dissolved in ground water which, in turn, relates to an increase in the concentration of sodium. This process occurs along the flow path and commonly results in the decrease of the calcium/sodium ratio (Ca/Na) in ground water with increased depth. At RMA this natural process is sometimes overshadowed by waste disposal practices which allowed increased Na concentrations in near surface soil and ground water as a result of disposal of sodium chloride-rich wastes.

Results of the Ca/Na data are shown in Figure 5.4-5. Figure 5.4-5 includes four plots with Ca/Na ratios plotted as a function of depth. The background unconfined flow system values generally fall between 0.5 and 2.0 and the background confined flow system values are less than 1.0 with the exception of one value of approximately 1.5. The regional plot generally indicates that the confined flow system has lower Ca/Na values than the unconfined flow system. The Western Tier Ca/Na plot shows a marked contrast between the unconfined flow system and confined flow system. The values for the unconfined flow system vary between 1.0 and 3.5 with the exception of one value less than 1.0 whereas the values for the confined flow system are in general consistently less than 0.5. The Central Area and Northern Area Ca/Na ratio plots have values generally less than 2.0 with the confined flow system values typically lower than the unconfined flow system values. Unlike the Western Tier Ca/Na plot, the Central Area and Northern Area Ca/Na plots have very few data points with values above 2.0. In general, these trends confirm hypothesis put forth in this section.

The distribution of Ca/Na ratios is usually dependent on depth and rock type. An exchange of cations during transport through the flow system is expected to decrease the ratio with depth. The lower Ca/Na values seen in the Central Area and Northern Area may be the result of either the introduction of saline waters into the flow systems during RMA operations or the discharge of ground water from the confined flow system into the unconfined flow system. The observed Ca/Na values from the Western Tier more closely correlate with background values indicating that for these areas little water-quality degradation by these inorganic constituents has occurred.

5.4.5 Trilinear Diagrams

Trilinear diagrams are used to classify ground water using basic constituents which contribute to water quality. The trilinear diagrams used in Figures 5.4-6 through 5.4-8 are composed of two equilateral triangles positioned at the lower left and lower right; the bases align vertically and the vertices point toward each other. The upper central portion of the diagram is diamond shaped. The cationic (positive charge in solution) triangle is represented by magnesium and calcium each at one vertex and sodium and potassium at the remaining vertex. The anionic (negative charge in

solution) triangle is represented by sulfate at one vertex, bicarbonate at another vertex, and chloride and nitrate at the remaining vertex. The vertex of each triangle represents 100 percent of an ion or group of ions for either cations or anions. The composition of the ground water with respect to cations and anions is indicated by a point plotted within the respective triangle. The sum of the coordinates at each point equal 100 percent. The points within the triangles are extended upward into the central plotting field (diamond) by projecting them along lines parallel to the upper edges of the central field.

The utility of trilinear diagrams is that they enable the viewer to visually characterize the ground-water composition of a flow system. In addition, the visual comparison of flow systems may result in areas that indicate a mixing of ground water. If mixing occurs between ground waters of different compositions, the resultant ground-water composition will fall along a mixing line between the end-member compositions of the original ground waters. Therefore, if equal proportions of a 100 percent calcium-rich ground water mixed with a 100 percent sodium and potassium-rich ground water, the resultant ground water would be 50 percent calcium-, sodium-, and potassium-rich.

The data used in the trilinear diagrams were subjected to a screening procedure to assess their useability. Data from 488 monitoring wells (322 unconfined flow system and 166 confined flow system) sampled during the fall 1988 monitoring event were screened as follows. Data from 11 unconfined flow system and 77 confined flow system wells were eliminated because the measured ground water pH was greater than 8.3. Ground water with a pH greater than 8.3 contains a significant concentration of carbonate but to calculate this concentration one of the pH endpoints for the alkalinity titration must be 8.3. This endpoint was not used in the alkalinity titrations of the fall 1988 ground-water samples. Since the alkalinity values obtained from the titration are used in the calculation of carbonate and bicarbonate concentrations those data associated with a pH greater than 8.3 could not be accurately utilized in this assessment. Data from two unconfined flow system and four confined flow system wells were eliminated because they had no associated alkalinity data. Data from 11 unconfined flow system and three confined flow system wells were eliminated because one or more of the pertinent ionic data had an associated "less than" or "greater than" qualifier. Data from 37 unconfined flow system and nine confined flow system wells were eliminated because their calculated charge balance was more than 10 percent. The value of plus or minus 10 percent was used to screen for analytical variability. A total of 154 wells (61 unconfined flow system and 93 confined flow system) were deleted from interpretative use, leaving data for 334 wells.

The trilinear diagrams for the unconfined flow system and confined flow system regional and background wells are shown in Figure 5.4-6. The background trilinear diagram, composed of 11 unconfined flow system wells and six confined flow system wells, indicates little difference in the cationic data and exhibits scattering in the anionic data for both the unconfined flow system and confined flow system. The regional trilinear diagrams for the unconfined flow system and confined flow system indicate ground waters of similar composition. Data from 249 monitoring wells were used in the construction of the unconfined flow system diagram and data from 67 monitoring wells were used in the construction of the confined flow system diagram. Similar to the background trilinear diagram, the regional trilinear diagrams also exhibit a scattering in the anionic data and a tighter grouping of the cationic data.

The unconfined flow system trilinear diagram for the Western Tier was constructed from data from 55 monitoring wells and indicates a tighter grouping for both the anionic and cationic data (Figure 5.4-7). There is no confined flow system trilinear diagram for the Western Tier because the data did not pass the screening procedure described above. Eleven confined flow system wells were affected.

The unconfined flow system and confined flow system trilinear diagrams for the Central Area are presented in Figure 5.4-7. Data from 80 monitoring wells were used in the construction of the unconfined flow system diagram and data from 45 monitoring wells were used in the construction of the confined flow system diagram. The diagrams indicate little difference in ground-water composition for the flow systems in this area. The differences seen in the anionic data between the two diagrams may result from the number of wells used from each system. The Central Area unconfined flow system trilinear diagram differs from the Western Tier trilinear diagram. The trilinear diagrams show a shift mostly in the cationic data; the ground water in the Western Tier is more calcium rich whereas the ground water in the Central Area is more sodium and potassium rich. There is more scatter in the anionic data for the Central Area data than the Western Tier data and this may be due to the difference in the number of wells representing each area.

The unconfined flow system and confined flow system trilinear diagrams for the Northern Area are presented in Figure 5.4-8. Data from 68 monitoring wells were used in the construction of the unconfined flow system diagram and data from 17 monitoring wells were used in the construction of the confined flow system diagram. The diagrams indicate little difference in the composition of the ground waters for the flow systems in this area. The reduced scatter in the confined flow system anionic data may result from a limited number of wells plotted. However, these diagrams do indicate a difference in ground-water composition between the Western Tier unconfined flow system and Northern Area unconfined flow system. This difference may be attributable to either

the hydrogeologic regime, the geographic location, or waste water disposal practices. The trilinear diagrams similarly exhibit a shift in the cationic and anionic data. The cationic data for the Western Tier indicate more calcium-rich ground water whereas the data for the Northern Area indicate more sodium and potassium-rich ground water. The anionic data for the Western Tier indicate more bicarbonate-rich ground water whereas the data for the Northern Area indicate more chloride, nitrate, and sulfate-rich ground water. These observations may be explained by the introduction of sodium chloride-rich waste waters from RMA operations to unlined basins on Basin F in the central area to the shallow ground water system.

5.4.6 Correlation Coefficients

A correlation analysis was performed on the inorganic data for both the unconfined flow system and confined flow system. This analysis aids in assessing the degree to which two variables are related. The analysis yields a sample correlation coefficient, r , which is used to interpret the strength of the relationship. The value of r lies between the region of -1 to $+1$. Those values between -1 and 0 indicate inverse relationships and those between 0 and $+1$ indicate direct relationships. The values at ± 1 indicate perfect relationships and the relationship becomes progressively weaker as the values tend toward 0 .

The results of this analysis are presented in Table 5.4.6-1. Table 5.4.6-1 is a diagonal matrix with the analytes positioned horizontally and vertically along both axes. The values of 1 along the diagonal indicate a perfect relationship and corresponds to like analytes. The italicized values in the upper right triangular portion of the matrix represent the unconfined flow system and the values in the lower left triangular portion of the matrix represent the confined flow system. The r value for an analyte pair is obtained by extending a vertical and horizontal line from a given r to each analyte. For example, the analyte pair $\text{NO}_3^- - \text{F}^-$ has an r value of $.035$ in the unconfined flow system and $.52$ in the confined flow system. These values indicate that a more direct relationship for this analyte pair exists in the confined flow system although the correlation even in the confined flow system is not considered strong.

Table 5.4.6-1 is used as an indicator of the water-quality differences between the unconfined flow system and confined flow system. Water-quality differences occur as a function of the strength of the relationship between the analyte pairs. The r values in Table 5.4.6-1 generally indicate that the ions have a stronger direct relationship in the unconfined flow system than in the confined flow system. The exceptions to the stronger direct relationship in the unconfined flow system is noted in the $\text{Mg}^{+2}-\text{Cl}^-$ and $\text{NO}_3^- - \text{F}^-$ pairs. These pairs have a stronger direct relationship in the

Table 5.4.6-1 Inorganic Correlation Coefficients for the UFS and Confined Denver Formation¹

		Na ⁺	K ⁺	Ca ⁺²	Mg ⁺²	Cl ⁻	F ⁻	NO ₃ ⁻	SO ₄ ⁻²	
Confined Flow System	Na ⁺	1	.85	.66	.79	.26	.0022	.13	.55	
	K ⁺	-.024	1	.30	.52	.17	.025	.14	.20	
	Ca ⁺²	-.0055	.36	1	.90	.32	.0010	.11	.94	Unconfined
	Mg ⁺²	.029	.42	.31	1	.31	-.0036	.12	.87	Flow
	Cl ⁻	-.049	.30	.45	.54	1	.035	.052	.29	System
	F ⁻	.20	-.099	-.052	-.12	-.15	1	.035	-.0095	
	NO ₃ ⁻	.37	-.20	-.062	-.26	-.36	.52	1	.058	
	SO ₄ ⁻²	.094	.25	.20	.57	.45	.16	-.014	1	

¹ The italicized values in the upper right triangular portion of the matrix represent the UFS. Those values in the lower left triangular portion of the matrix represent the confined Denver Formation.

confined flow system. Although the r value for $Mg^{+2}-Cl^{-}$ in the confined flow system is higher, the r value for this pair in the unconfined flow system is close in magnitude.

5.4.7 Inorganic Data Assessment Summary

The analytical results of the inorganic data have been presented in the preceding subsections in the form of concentration versus depth plots, frequency diagrams, trilinear diagrams, solute correlations, and correlation coefficients. Each presentation included a discussion of the two flow systems by specific area with the exception of the frequency diagrams and correlation coefficients. This section summarizes the integrated results of the preceding subsections and compares the results of the two flow systems by area.

A statistical summary of the inorganic data is presented in Table 5.4.7-1. This table includes the minimum, maximum, and arithmetic mean for the eight ions, % O_2 , and specific conductance in the unconfined and confined flow systems and the integrated data sets from both flow systems. A comparison of the arithmetic mean of both systems indicates that the analyte concentration is lowest in the confined flow system with the exception of sulfate. A similar comparison of the maximum values indicates that the unconfined flow system contains the highest analyte concentrations.

5.4.7.1 Unconfined Flow System. The background water quality of the unconfined flow system is characterized by ground water with Ca/Na ratios between approximately one and two, specific conductance values less than 2000 $\mu mhos/cm$, % O_2 values between 1 and 60 percent and non-dominance in cations but dominance in sulfate and bicarbonate anions.

The water quality of the unconfined flow system in the Western Tier is similar to background water quality with the following exceptions. A large percent of samples have % O_2 values greater than 60 percent and these values are independent of depth. This is in agreement with hydrologic data showing that the thick unconfined flow system in this area is well mixed as a result of greater ground water flow velocities. The majority of Western Tier samples have Ca/Na ratios greater than two and these values are also independent of depth.

The water quality of the unconfined flow system in the Central Area departs from most of the characteristics of background water quality. The ground water in the Central Area is characterized by a majority of Ca/Na ratios that are significantly lower than one. A percentage of the samples have specific conductance values between 2500 and 20,000 $\mu mhos/cm$ and these values occur at depths below 40 feet. Although most of the samples fall within the % O_2 range of background

Table 5.4.7-1 Statistical Summary of Ion Concentrations*, Percent Oxygen Saturation and Specific Conductance in RMA Ground Water, Fall, 1988

	Flow System		Combined	Flow System	
	Unconfined	Confined		Unconfined	Confined
NITRATE (NO ₃ ⁻)					
Minimum	0.05	1.8	0.05	0.01	0.01
Maximum	740	160	740	17	460
Mean	17	16	17	0.52	2.5
SULFATE (SO ₄ ⁻²)					
Minimum	0.01	0.01	0.01	0.02	0.02
Maximum	0.01	0.3	2.5	73	500
Mean	2.5	0.07	0.1	13	12
PERCENT OXYGEN SATURATION					
Minimum	1	0.15	0.15	1.10	1.10
Maximum	170	130	170	126	2107
Mean	9.5	7.4	8.8	22	36
SPECIFIC CONDUCTANCE (micromhos/cm at 25° C)					
Minimum	1.4	0.05	0.05	6	6
Maximum	91	42	91	19000	19000
Mean	4.9	2	3.9	2000	1900
CHLORIDE (Cl ⁻)					
Minimum	0.14	0.04	0.04	12	12
Maximum	540	150	540	9800	19000
Mean	14	6	11	1600	1900
FLUORIDE (F ⁻)					
Minimum	0.03	0.04	0.03	6	6
Maximum	17	0.74	17	9800	19000
Mean	0.25	0.13	0.21	1600	1900

* Concentrations are in milliequivalents/liter (meq/l), except where noted

samples, a number of samples are above 60 percent. In addition, there is a shift in the Central Area water quality to ground water that is more dominant in sodium, potassium, chloride, and nitrate in comparison to the background ground water. This difference is a direct result of the introduction of sodium/chloride-rich waste waters into the unconfined flow system from lined and unlined basins.

The water quality of the unconfined flow system in the Northern Area is similar to that in the Central Area with one exception. The cations in the ground water are similar to those in the Central Area but the anions shift slightly away from a bicarbonate type to a sulfate type.

5.4.7.2 Confined Flow System. The background water quality of the confined flow system is characterized by ground water with Ca/Na ratios generally less than one, specific conductance values less than 2300 $\mu\text{mhos/cm}$, % O_2 values generally less than 60 percent with one value near 88 percent, slightly dominant in sodium and potassium, and dominant in sulfate.

The water quality of the confined flow system in the Western Tier is similar to background water quality with the following differences. The Ca/Na ratios in the samples from the Western Tier are consistently less than one. The % O_2 values exhibit an increase in saturation with increasing depth.

The water quality of the confined flow system in the Central Area differs somewhat from background water quality. The characteristics of the ground water in the Central Area include higher specific conductance values and more samples with chloride and nitrate dominance when compared to background. This increase in dissolved solids (chloride, sodium) may have resulted from downward migration of waste waters from the unconfined flow system.

The water quality of the confined flow system in the Northern Area is similar to that in the Central Area with one exception. The ground water is predominately sulfate type.

5.4.7.3 Comparison of Water Quality at Well Clusters. The general water-quality characteristics of the two flow systems have been presented on an areal basis to compare the two systems. General trends have been noted in the comparison between background and downgradient water quality. These trends result mainly from differences due to depth and geographical location (i.e., water quality in the Western Tier more closely resembles background than the downgradient water quality in the Central and Northern Areas). To assess the applicability of the general trends noted in the areal comparison to specific areas, the water quality of the two flow systems at selected well clusters was compared. The selection of the well clusters was based on geographical location and

those wells used in the isotopic data assessment presented in Section 5.5 of this Annual Report. Therefore, 29 wells in 11 well clusters from the Western Tier and Northern Area were used in this assessment. A list of these wells is provided in Table 5.4.7.3-1.

The analytical data for the 29 wells have been compiled and are presented in Table 5.4.7.3-1. This table includes the analytical data for: 8 major ions, Ca/Na ratios, specific conductance, % O₂, deuterium, O-18, tritium, and screened interval. The significance of the deuterium, O-18, and tritium values will be discussed in Section 5.5.

As noted in previous sections, the Ca/Na ratio tends to decrease with increasing depth. The decrease generally results from a decrease in calcium and this is noted in most of the wells listed in Table 5.4.7.3-1. Although the concentration of sodium is expected to increase with depth due to ion exchange reactions, the concentration of sodium in the wells listed in Table 5.4.7.3-1 exhibit increasing and decreasing trends with depth. The three well clusters in sections 23 and 24 contain the highest sodium concentrations in the unconfined flow system for the 29 wells listed in Table 5.4.7.3-1. These elevated concentrations may be the result of the recharge of saline waters into the unconfined flow system in this area during RMA activities. In addition, the sodium concentrations in the confined flow system in these section 23 and 24 wells are elevated with respect to the remaining wells in Table 5.4.7.3-1 with the exception of 24198. The tritium data suggest little or no mixing of the ground water from the two flow systems yet the elevated sodium concentrations are apparent in both systems.

As noted in Table 5.4.7.3-1 the trend for specific conductance values generally mimics the trend in the ionic concentrations. The majority of the ionic concentrations and specific conductance values decrease with increasing depth. However, this is not the expected trend. A relationship of increasing specific conductance with increasing depth is expected (Hem, 1989). Increased solute concentrations with depth result from a longer residence time of ground water; therefore, the specific conductance values associated with the confined flow system would normally be greater than those values associated with the unconfined flow system. The observed relationship is likely due for surface disposal practices that have resulted in increased ionic concentrations in ground water near the surface.

The concentration versus depth plots for % O₂ exhibited variability with depth except in the Western Tier confined flow system wells. The % O₂ data in Table 5.4.7.3-1 exhibit a general trend of decreasing % O₂ with depth with one exception in the Section 3 well cluster.

Table 5.4.7.3-1: Comparison of Water Quality in Selected Well Clusters

Site/Aquifer	Sand Unit	Na	K	Ca	Mg	Cl	F	NO ₃	SO ₄	Ca/Na	Specific Conductance (at 25 °C)	% O ₂	Deuterium (ppt)	O-18 (ppt)	Tritium (TU)	Screened Interval (ft. bgs)
03002	ALL	1.60	0.06	3.29	0.76	0.76	0.04	0.350	0.92	2.1	534	51.0	NA	NA	NA	43.0 - 103.0
03003	DEN	2.70	NA	0.42	NA	0.16	0.25	0.243	0.44	0.2	245	9.5	NA	NA	NA	136.0 - 146.0
03004	DEN	2.22	0.01	0.20	NA	0.05	0.19	0.243	0.60	0.1	169	96.3	NA	NA	NA	168.0 - 178.0
04007	A/D	4.48	0.10	9.48	1.79	2.45	0.07	0.529	7.08	2.1	1366	48.7	NA	NA	NA	39.2 - 78.0
04008	UNC	2.00	0.02	1.04	0.11	0.16	0.19	0.001	0.52	0.5	434	3.5	NA	NA	NA	88.0 - 98.0
04010	A/D	1.82	0.07	4.55	0.95	0.96	0.04	0.586	1.50	2.5	659	75.4	NA	NA	NA	65.0 - 90.0
04011	DEN	2.14	NA	0.35	NA	0.09	0.36	0.143	0.19	0.2	247	42.9	NA	NA	NA	153.0 - 158.0
04012	DEN	2.69	NA	0.16	NA	0.06	0.24	0.329	0.02	0.1	118	49.6	NA	NA	NA	181.8 - 186.8
09002	A/D	5.22	0.13	8.98	1.58	1.97	0.06	0.929	6.87	1.7	1246	40.6	NA	NA	NA	64.0 - 84.0
09003	DEN	2.49	0.02	0.94	NA	0.14	0.08	0.003	1.12	0.4	388	3.5	NA	NA	NA	104.0 - 129.0
23188	ALL	36.10	0.17	22.46	16.45	47.95	0.41	0.031	14.16	0.6	6253	NA	-92.0	-10.4	58.9	37.5 - 47.5
23189	DEN	18.70	0.07	7.98	0.89	2.03	0.11	0.207	22.90	0.4	1455	60.8	NA	NA	NA	57.5 - 67.5
23190	DEN	15.22	0.03	3.54	0.17	1.95	0.14	0.037	15.20	0.2	1884	13.6	-114.0	-14.1	3.6	102.5 - 107.5
23223	A/D	56.55	0.24	37.92	29.62	98.73	0.89	0.672	24.98	0.7	10288	31.0	NA	NA	NA	15.4 - 31.6
23224	DEN	12.18	0.05	2.51	NA	1.41	0.10	0.003	10.20	0.2	1207	5.8	NA	NA	NA	78.6 - 94.8
23225	DEN	10.87	0.04	0.80	NA	1.33	0.13	0.003	9.58	0.1	1148	2.3	-111.0	-13.5	3.9	104.4 - 115.3
24196	ALL	10.87	0.08	8.98	4.37	2.82	0.15	0.250	13.53	0.8	1686	98.6	-111.0	-13.6	42.5	16.5 - 27.4
24197	DEN	8.70	0.04	4.97	0.86	0.45	0.07	0.026	9.37	0.6	1330	73.9	-120.0	-14.6	5.3	58.4 - 69.4
24198	DEN	2.81	0.01	0.39	NA	0.37	0.20	0.006	1.04	0.1	428	NA	-120.0	-15.1	5.2	79.1 - 116.3
33025	ALL	2.17	0.07	5.49	1.11	1.27	0.04	0.479	2.06	2.5	733	66.4	NA	NA	NA	41.0 - 61.0
33026	DEN	2.73	0.01	0.45	NA	0.26	0.12	NA	1.02	0.2	304	3.6	NA	NA	NA	98.0 - 108.0
33030	ALL	2.78	0.09	5.99	1.43	1.55	0.05	1.072	2.91	2.2	903	78.9	NA	NA	NA	55.0 - 115.0
33031	DEN	2.22	0.01	0.26	NA	0.08	0.32	0.069	0.02	0.1	226	21.1	NA	NA	NA	165.0 - 175.0
33032	DEN	4.25	0.01	1.11	NA	0.04	0.09	0.129	0.37	0.3	1100	35.6	NA	NA	NA	190.0 - 200.0
33033	A/D	1.72	0.06	3.52	0.77	0.87	0.04	0.322	0.96	2.0	503	45.4	NA	NA	NA	38.7 - 53.7
33034	DEN	3.15	0.03	1.73	0.18	0.65	0.09	0.171	2.71	0.5	498	37.1	NA	NA	NA	74.0 - 84.0
33079	ALL	2.78	0.10	6.49	1.20	1.75	0.05	0.715	4.37	2.3	1037	58.1	-103.0	-13.3	34.1	61.1 - 81.1
33078	ALL	2.01	0.08	4.47	0.89	0.99	0.04	0.715	1.85	2.2	693	78.3	NA	NA	NA	82.3 - 102.3
33077	A/D	2.50	0.08	5.04	1.00	1.21	0.05	0.786	2.08	2.0	794	79.5	-105.0	-13.5	30.4	105.1 - 125.1

Notes:

meq/l = milliequivalents per liter
 unthos/cm = micromhos per centimeter
 ppt = parts per thousand
 TU = tritium units
 ft. bgs = feet below ground surface
 NA = not analyzed

The % O₂ in ground water is dependent on the amount of: (1) organic material, (2) reduced inorganic minerals, or (3) organic chemicals present in the flow system. Therefore, the trend of % O₂ with depth is dependent on the presence of oxidizable material and the length of time the water has been resident in the system and not solely a function of depth.

5.5 Isotopic Data Assessment

Data from a pilot program to monitor ground water for isotopic signatures further assessed the degree of hydraulic connection between the unconfined and confined flow system.

Isotopic samples were analyzed for deuterium, oxygen-18 and tritium (commonly notated ²H, ¹⁸O, and ³H respectively). These isotopes were selected because they have been successfully used to assist in the hydrogeologic characterization of a wide variety of sites and aquifer systems.

Ground-water samples for isotopic analyses were collected from seven unconfined and six confined wells in Sections 23, 24, and 33 during the Spring 1988 sampling round (Figure 5.5-1). Wells sampled in Section 33 (not shown in Figure 5.5-1) are 33077 and 33079, located approximately 100 ft northeast of the SACWSD Treatment Facility Property.

In selecting wells to be sampled for isotopic analyses consideration was given to location, depth of screened interval, and lithology (unconfined or confined flow system). Wells in well clusters were preferred over isolated, scattered wells, to aid in comparing isotopic signatures between the unconfined and confined flow systems. Both shallow and deep (wells with screened intervals greater than the screened intervals of confined wells sampled) unconfined flow system wells were sampled to determine if the unconfined flow system had a single isotopic signature, or if deep unconfined wells more closely resembled confined flow system isotopic signatures.

The 11 samples in Sections 23 and 24 were collected from wells located upgradient of the North Boundary Containment System (NBCS). Five samples were collected from the unconfined flow system and six samples were collected from the confined flow system. In Sections 23 and 24, the maximum relief of the topographic surface is 20 ft, and the surficial geology is characterized by alluvium deposited during postglacial periods. In this area, the bedrock depth varies from 14.5 to 54.0 feet. The screened intervals of the five unconfined flow system wells in Sections 23 and 24 (23095, 23188, 24196, 24106, and 24188) range from 7 ft to 48 ft deep. The confined flow system wells are completed in Zones 2 through 5, which consist of interbedded claystone, siltstone, and sandstone. Screened intervals in these wells range from 43 to 116 ft deep.

The Section 33 wells (33077 and 33079) are completed in the unconfined flow system at depths of 102 and 125 ft, respectively. The subsurface of Section 33, in the RMA Western Tier, is characterized by a greater thickness of alluvium than that in Sections 23 and 24. Depth to bedrock in Section 33 can be as much as 130 ft. Samples were collected in Section 33 to evaluate if isotopic signatures are characteristic of the hydrostratigraphic interval sampled and independent of depth.

It is difficult to determine an absolute isotopic abundance for stable isotopes; thus, laboratories quantify measurements relative to a common standard. For the isotopes ^2H and ^{18}O , the reference is Standard Mean Ocean Water (SMOW). Values are reported in delta units (δ) in parts per thousand (per mil or ‰) deviation from SMOW. A negative value reflects depletion of the heavier ^2H or ^{18}O in the sample, and a positive value indicates a relative enrichment in these heavier isotopes.

5.5.1 Tritium Analytical Results

Isotopic analyses for deuterium, oxygen-18, and tritium have been used successfully to assist in the hydrogeologic characterization of a wide variety of sites and aquifer systems. Tritium is an isotope of hydrogen commonly notated as ^3H , where the number 3 denotes the atomic mass of this hydrogen atom. Hydrogen most commonly occurs as an element with an atomic mass of 1 (^1H); thus, tritium (^3H) is significantly heavier. Tritium is also radioactive, which means that it decays to lighter hydrogen isotopes over time.

Tritium (^3H) is an unstable isotope of hydrogen with a half-life of 12.4 years and a relative abundance of $^3\text{H}/\text{H} = 1.0 \times 10^{-18}$. Tritium in the atmosphere typically occurs as the molecule ^3HHO , which is produced naturally from cosmic ray reactions and enters ground water with recharging precipitation. Prior to the advent of above-ground nuclear testing in 1953, precipitation over North America had a natural background level of 10 to 15 tritium units (TU). (A TU is the concentration of one atom of ^3H for every 10^{18} total hydrogen atoms.) Since 1953, the amount of tritium in the atmosphere has increased, attaining a high in the early 1960s (Figure 5.5-2) during times of active nuclear testing and decreasing to present levels.

Because of the relationship between ground-water age and tritium concentration, tritium radioisotope analyses are most often used as an investigative tool for evaluating relative ground-water ages. Recently infiltrated (modern) water tends to have appreciably higher TU values. In areas of spatially different water-bearing units, tritium is useful in identifying zones subject to relatively fast recharge and possible hydraulic connections. However, because TU values in precipitation change with atmospheric conditions and have varied considerably over time, it is

not possible to assign an absolute age to a tritium-dated water. For example, if a water has a TU value less than 5 to 10, the water was recharged prior to 1955 but further definition of the date of recharge is not possible. Today, atmospheric background levels in the Northern Hemisphere range between 50 and 100 TU; during the early 1960s, concentrations well above 1000 TU were measured (Fritz, 1981). Water containing 1000 TU when recharged in 1964 would contain approximately 250 TU today due to the radioactive decay of tritium. Water containing 5 TU which was recharged in 1952 (three half-lives) would contain less than 1 TU today.

The TU values reported for the unconfined flow system ranged from 31.3 to 58.9, and the TU values reported for the confined flow system ranged from 2.5 to 18.2 (Table 5.5.1-1). Average TU values for the confined and unconfined flow systems are 6.45 and 43.2, respectively. The highest TU value in the confined flow system (18.2 TU) was recorded for the shallowest well (23177 at 43.0 ft); the remaining five confined flow system samples all yielded TU values below 6.0. Although deeper than the Section 23 and Section 24 unconfined flow system wells, the wells in Section 33 yielded TU values greater than 30, consistent with values detected in the unconfined flow system wells in Section 23 and Section 24.

Results of tritium analyses indicate a difference in the TU values reported for the unconfined flow system and confined flow system (Figure 5.5-3). Reported TU values for the unconfined flow system are indicative of water less than 35 years old. This implies that precipitation recharge to the unconfined flow system has occurred in the last 35 years. Reported TU values for the confined flow system, except Well 23177, were less than 6, which generally is indicative of older water recharged prior to the influx of tritium to the atmosphere in the 1950s. It should be noted that although these low TU values are indicative of older waters, these waters could contain up to 10 percent younger unconfined flow system water as a result of mixing and still retain low tritium values. For example, the mixing of 90 percent water containing 3 TU and 10 percent water containing 30 TU would result in a final tritium ratio of approximately 6 TU.

Results of tritium analyses indicate that confined flow system water generally is older than unconfined flow system water. The low TU values detected in samples from confined flow system wells also indicate either minimal or a low level of hydraulic communication with the unconfined flow system. A geologic cross section through Sections 23 and 24 (A-A' in Figure 5.5-1) is included to illustrate the relationship of tritium with depth (Figure 5.5-4). Analytical results of ground-water samples from confined flow system wells are presented in Table 5.5.1-2.

Table 5.5.1-1 Summary of CMP Spring 1988 Isotopic Analytical Results

Well Number	Screened Interval (feet BGS)	Flow System	Sand Zone	Deuterium (‰ +/- 2.0)	Oxygen-18 (‰ +/- 0.1)	Tritium (TU)
23095	44.3-48.3	Unconfined		-96.0	-11.4	50.2 +/-2.6
23188	37.5-47.5	Unconfined		-92.0	-10.4	58.9 +/-2.7
24106	12.0-20.0	Unconfined		-102	-12.7	33.2 +/-2.4
24188	7.0-17.0	Unconfined		-103	-13.3	31.3 +/-2.4
24196	16.5-27.4	Unconfined		-111	-13.6	42.5 +/-2.5
			Average	-101	-12.3	43.2
			Standard			
			Deviation	6.49	1.21	10.4
			Maximum	-92.0	-10.4	58.9
			Minimum	-111	-13.6	31.3
23177	33.0-53.0	Confined	2	-102	-13.3	18.2 +/-2.3
24197	58.4-69.3	Confined	2	-120	-14.6	5.30 +/-2.2
23190	102-108	Confined	3	-114	-14.1	3.60 +/-2.2
24198	79.1-116	Confined	3	-120	-15.1	5.20 +/-2.2
23192	106-116	Confined	3	-117	-14.2	2.50 +/-2.1
23225	104-115	Confined	5	-111	-13.5	3.90 +/-2.2
			Average	-114	-14.1	6.45
			Standard			
			Deviation	6.24	0.61	5.34
			Maximum	-102	-13.3	18.2
			Minimum	-120	-15.1	2.50
33077	105-125	Unconfined		-105	-13.5	30.4 +/-2.4
33079	61.1-81.1	Unconfined		-103	-13.3	34.1 +/-2.5

TU = Tritium unit

Table 5.5.1-2 Contaminants Detected in Wells Sampled in CMP Spring 1988 Isotopic Study*

Well Number	23095	23188	24106	24188	24196	23177	24197	23190	23192	24198	23225
Aquifer	UFS	UFS	UFS	UFS	UFS	Denver	Denver	Denver	Denver	Denver	Denver
Confined Denver Fm Sand Zone						2	2	3	3	3	5
Aldrin	LT 0.050	0.222	LT	LT	LT	LT	LT	LT	LT	LT	LT
Bicycloheptadiene	44.1	LT 5.90	LT	LT	LT	LT	LT	LT	LT	LT	LT
Benzothiazole	5.88	LT 5.00	LT	LT	LT	LT	LT	LT	LT	LT	LT
Benzene	20.0	LT 1.05	LT	LT	LT	LT	LT	LT	LT	LT	LT
Chloroform	390	0.557	4.34	LT 0.500	7.09	2.66	3.52	LT	LT	LT	LT
Chlorobenzene	28.5	2.00	LT 0.820	3.50	LT	4.89	1.05	1.70	LT	LT	LT
p-Chlorophenylmethylsulfoxide	240	LT 11.5	LT	LT	LT	LT	LT	LT	LT	LT	14.8
p-Chlorophenylmethylsulfone	340	160	LT 7.46	LT	LT	LT	LT	LT	LT	LT	LT
Dicyclopentadiene	1800	25.8	LT 5.00	LT	2300	LT	LT	LT	LT	LT	13.9
Diisopropylmethyl phosphonate	450	870	LT 18.5	LT	LT	LT	LT	LT	LT	LT	LT
Dithiane	90.0	47.0	LT 1.34	LT	LT	LT	LT	LT	LT	LT	LT
Dieldrin	2.10	0.530	0.225	LT 0.050	LT	LT	LT	LT	LT	LT	LT
Endrin	LT 0.050	0.139	LT	LT	LT	LT	LT	LT	LT	LT	LT
Toluene	25.1	LT 1.47	LT	LT	LT	LT	LT	LT	LT	LT	LT
Oxathiane	16.0	6.0	LT 2.38	LT	LT	LT	LT	LT	LT	LT	LT
Tetrachloroethene	29.7	1.89	LT 0.750	LT	LT	LT	LT	LT	LT	LT	LT
Trichloroethene	24.5	4.19	LT 0.560	LT	LT	LT	LT	LT	LT	LT	LT
Xylene	2.40	LT 1.36	LT	LT	LT	LT	LT	LT	LT	LT	LT

* Concentrations in µg/l

Note: LT = Values less than the Certified Reporting Limit (CRL)

UFS = Unconfined flow system

In general, measurable concentrations of RMA contaminants were detected in wells completed in the unconfined flow system. Three of the confined flow system wells sampled (23225, 24197, and 23190) contained detectable concentrations of target compounds reported during the spring 1988 sampling event. The paragraphs below provide detailed information on these three confined flow system wells, a discussion of the observed extent of contamination, and a discussion of the wells located in Section 33. A discussion of hypotheses that may explain these detections follows the discussion of the wells.

Newly installed confined flow system Well 23225 contained measurable concentrations of chlorophenylmethyl sulfoxide (CPMSO) and dicyclopentadiene (DCPD) and yielded a TU value of 3.90 during the spring 1988 sampling event. No historical water-quality data are available for this well. Well 23225 is the deepest well (screened from 104 to 115 ft in Zone 5) in a three-well cluster. The two shallower wells (23223 and 23224) were not sampled for isotopic analysis. The spring 1988 analytical data indicated that the shallowest well in the cluster, Well 23223 (screened from 15.5 to 31.5 ft in the unconfined flow system), contained detectable concentrations of a wide variety of organic compounds, including CPMSO and DCPD (Table 5.5.1-3). The intermediate well, Well 23224 (screened from 78.5 to 94.8 ft in Zone 3), contained no reported detections of these compounds. The low TU value would indicate that if mixing with unconfined flow system waters has occurred, the degree or percentage of mixing is minimal. Although extremely high concentrations of contaminants were detected in the unconfined flow system, analyses from Well 23224 would suggest that contaminants in Well 23225 did not originate by vertical leakage from the unconfined flow system at this location. However, a combination of vertical leakage at an upgradient location and horizontal migration at depth may account for the observed contaminant concentrations in Well 23225.

Newly installed confined flow system Well 24197 yielded a TU value of 5.30 and contained reported concentrations of chloroform (CHCL3) and chlorobenzene (CLC6H5) during the spring 1988 sampling event. The field rinse blank associated with this well also contained CHCL3 and CLC6H5, at concentrations higher than the investigative sample. No historical water-quality data are available for comparisons with recent data from this well. Because detections in the field rinse blank (a QA/QC sample) were higher than the detections in the investigative sample, detections of contaminants in Well 24197 must be considered suspect. Well 24197 is the intermediate well (screened from 58.4 to 69.3 ft in Zone 2) in a three-well cluster. The deepest well, Well 24198 (screened from 79.1 to 116 ft in Zone 3), contained no detectable concentrations of organic compounds and yielded a TU value of 5.2. The shallowest well in the cluster, Well 24196 (screened from 16.5 to 27.4 ft in the unconfined flow system), contained detectable concentrations of CHCL3 and diisopropylmethylphosphonate (DIMP) (Table 5.5.1-3) and yielded

Table 5.5.1-3 Contaminants Detected in Clustered Wells Sampled in CMP Spring 1988 Isotopic Study*

Well Number	23188	23190	24196	24197	24198	23223	23224	23225
Aquifer	UFS	Denver	UFS	Denver	Denver	UFS	Denver	Denver
Confined Denver Fm Sand Zone		3		2	3		3	5
Aldrin	0.222	LT	LT	LT	LT	LT	LT	LT
Bicycloheptadiene	LT	LT	LT	LT	LT	32.6	LT	LT
Benothiazole	LT	LT	LT	LT	LT	LT	LT	LT
Benzene	LT	LT	LT	LT	LT	1.82	LT	LT
Chloroform	0.557	LT	7.09	3.52	LT	7.68	LT	LT
Chlorobenzene	2.00	1.70	LT	1.05	LT	LT	LT	LT
p-Chlorophenylmethylsulfoxide	160	LT	LT	LT	LT	17.8	LT	14.8
p-Chlorophenylmethylsulfone	25.8	LT	LT	LT	LT	210	LT	LT
Dicyclopentadiene	870	LT	2300	LT	LT	360	LT	13.9
Diisopropylmethyl phosphonate	47.0	LT	LT	LT	LT	1300	LT	LT
Dithiane	0.530	LT	LT	LT	LT	92.0	LT	LT
Dieldrin	0.139	LT	LT	LT	LT	1.20	LT	LT
Endrin	LT	LT	LT	LT	LT	1.10	LT	LT
Toluene	6.02	LT	LT	LT	LT	8.45	LT	LT
Oxathiane	1.89	LT	LT	LT	LT	11.2	LT	LT
Tetrachloroethene	4.19	LT	LT	LT	LT	15.3	LT	LT
Trichloroethene	LT	LT	LT	LT	LT	9.11	LT	LT
Xylene	LT	LT	LT	LT	LT	LT	LT	LT

*Concentrations in µg/l

Note: LT = Values less than the Certified Reporting Limit (CRL)

UFS = Unconfined flow system

a higher TU value of 42.5, which is indicative of younger water. In conclusion, the detection of contaminants in confined flow system Well 24197 appears to be anomalous and until confirmed, should be considered a result of field-induced cross contamination.

Confined flow system Well 23190 contained a detectable concentration of CLC6H5 and yielded a TU value of 3.60 during the spring 1988 sampling event. However, no historical CLC6H5 detections have been recorded for this well during sampling events from the Initial Screening Program (ISP) to the present. Well 23190 (screened from 102 to 108 ft in Zone 3) is in a cluster with Well 23188 (screened from 37.5 to 47.5 ft in the unconfined flow system). Well 23188 yielded a high TU value of 58.9, which is indicative of water recharged in the last 35 years. Analytical results from Well 23188 indicate the presence of several RMA contaminants. However, CLC6H5 concentrations in Wells 23190 and 23188 for the spring 1988 event were essentially identical, with CLC6H5 the only analyte detected in Well 23190. Because Well 23190 did not contain the same chemicals as shallower Well 23188, a spurious detection of CLC6H5 in Well 23190 and/or the absence of direct connection between unconfined flow system and confined flow system at this location are plausible explanations for these contradictory data. As previous sampling events did not detect CLC6H5 in Well 23190 prior to the spring 1988 event, this detection should be considered suspect.

Wells 33077 and 33079, both completed in the unconfined flow system, are located in Section 33 in an area where the saturated thickness of the alluvium can be as much as 130 ft. TU values of 30.4 (33077) and 34.1 (33079) were detected in the wells at depths of 125 and 102 ft, respectively. The deep confined flow system wells (greater than 100 ft; Table 5.5.1-1) in Sections 23 and 24 yielded TU values less than 6. Thus, comparison of TU values in the deep confined flow system wells with the deep unconfined flow system TU values indicate that the TU values are not depth dependent but are characteristic of the hydrostratigraphic unit. Well 33077 contained detectable concentrations of 1,1,1-trichloroethane (111TCE) (0.875 $\mu\text{g/l}$), CHCl_3 (0.622 $\mu\text{g/l}$), and trichloroethene (TRCLE) (7.37 $\mu\text{g/l}$). Well 33079 contained detectable concentrations of 111TCE (6.63 $\mu\text{g/l}$), 1,1-dichloroethene (11DCE) (2.20 $\mu\text{g/l}$), and TRCLE (3.13 $\mu\text{g/l}$).

The following four hypotheses have been developed in an attempt to explain coincident contaminant detections in shallow confined flow system wells and low tritium activities in Wells 23225, 23177, 24197, and 23190.

1. Mixing/Hydraulic Connection - Measurable hydraulic connection between the unconfined flow system and the confined flow system

2. Pre-1953 Contaminant Release - Introduction of contaminants into the confined flow system prior to 1953
3. Free-Phase Contaminant Transport - Introduction of contaminants into the confined flow system as a concentrated, free organic phase
4. Sampling and Analytical Errors - Introduction of organic contaminants during sampling and analysis

Each hypothesis is discussed in the following paragraphs.

The tritium and organic analytical data from Well 23177 are intermediate to the values reported for the confined flow system and unconfined flow system wells. The 18.2 TU value from Well 23177 is significantly higher when compared to the TU values for the other confined flow system wells (<6). The TU value for Well 23177 is also lower than the lowest value reported for the unconfined flow system wells (31.3 TU). Detectable CHCL3 and CLC6H5 concentrations in Well 23177 were reported during the spring 1988 sampling event; however, only CHCL3 had been detected in three of six previous sampling events. Detectable concentrations of DIMP had been reported in historical data (five of six sampling events) but no detectable concentrations of DIMP were reported for the spring 1988 sampling events. Results of the tritium and organic analytical data indicate a possible mixing of waters from the two aquifers. Well 23177, located immediately upgradient of the NBCS, is the shallowest confined flow system well investigated. The well is screened from 33.0 to 53.0 ft in Zone 2, and the depth to bedrock at this location is 14.5 ft. Zone 2 has been shown to subcrop in this general area. The Well 23177 log indicates that there is weathered claystone from 14.5 to 29.0 ft and that sandy claystone occurs from 29.0 to 35.5 ft. These geologic factors may contribute to the vertical hydraulic communication between the unconfined flow system and the confined flow system indicated by tritium data for this location.

In addition to contaminant transport via vertical flow across aquifers, a horizontal flow path through respective confined flow system sandstones must also be sufficiently rapid to have transported contaminants from source areas to confined flow system wells in Sections 23 and 24 for this scenario to be viable.

Upon examination, some of the chemical data (Wells 23225, 24197, and 23190) appear to contradict the isotopic data with respect to whether or not the confined flow system is in hydraulic communication with the unconfined flow system. Isolated detections of target organic compounds at depth in confined flow system Wells 23190 and 23225 may indicate limited but detectable

hydraulic communication between the unconfined flow system and confined flow system units. The isotopic signatures of these unconfined flow system and confined flow system wells are distinct and indicate that if any mixing of the two water-bearing units is occurring, the fraction of unconfined flow system water would be less than 10 percent. Although present concentration levels of organic contaminants in confined flow system wells are similar to unconfined flow system concentration levels, the mixing could have occurred over a long time span. Historically, concentrations of organics in unconfined flow system waters were substantially higher. Mixing may result from one or more of the following: (1) hydraulic leakage down poorly sealed boreholes, (2) hydraulic connection via faults/fractures, or (3) vertical flow across confining beds.

The presence of chemical compounds in confined flow system wells that yielded low TU values may be attributable to contaminants introduced to the confined flow system prior to the 1953 to 1956 time frame. However, only two of the four chemical compounds detected in the subject confined flow system wells were associated with manufacturing activities conducted prior to 1953. DCPD was used as a raw material in the manufacture of aldrin and endrin from 1952 to 1974, and CLC6H5 was used as a solvent in the synthesis of thionyl chloride during the manufacture of Lewisite in the 1940s. Several of the compounds detected in confined flow system wells of Sections 23 and 24 were not used at RMA prior to 1953. CHCL3 was associated with insecticides manufactured from 1963 to 1975, and CPMSO was a decomposition product of herbicides manufactured from 1966 to 1975. DCPD and CLC6H5 were the only target compounds detected in confined flow system wells (23225, 24197, and 23190) that had the potential to infiltrate the confined flow system and retain the pre-1953 tritium signature.

The third hypothesis for explanation of coincident low tritium activity with detectable organic contamination of the confined flow system zones is the introduction of concentrated free-phase organic compounds, with little accompanying unconfined flow system water, directly into the confined flow system zones. This type of release would be likely only in the South Plants Area, the Basin F area, or along chemical sewer lines. Organic liquids with densities greater than that of water would be vertically transported more rapidly than unconfined flow system ground waters and possibly in directions reverse to that of ground-water flow. If a concentrated mass of organic fluid was transported downward through saturated materials, some dilution or dissolution would occur, but limited mixing of the central mass would occur. Once organic fluids reached zones of lower hydraulic conductivity, the organic fluid would gradually dissolve and be transported downgradient. The small amount of entrained unconfined flow system water would not substantially increase the tritium values for the shallow confined flow system. The result of this process would be contaminated confined flow system ground waters with low levels of tritium activity and a continuing contaminant source at depth.

The fourth possible hypothesis for the presence of detectable contaminant concentrations in the confined flow system wells without a related change in the isotopic signature involves either sampling procedures that were compromised, or analytical results that were in error. Analytical results from Well 24197 provide an example of data that are suspect because of the presence of detectable concentrations of contaminants in the rinse blank.

Chlorobenzene was the only target analyte detected in Well 23190. Numerous organic compounds, including CLC6H5, were detected in the shallower well in the cluster (23188). However, historical sampling of this well (23188) on numerous occasions did not yield CLC6H5 detections. Based on this information, additional water-quality sampling should be performed to confirm or refute these data.

It should be noted that two of the wells (23225 and 24197) that yielded organic contaminant detections were newly constructed. As such, the historical data base for the new wells is incomplete.

5.5.2 Deuterium and Oxygen-18 - Analytical Results

Deuterium and oxygen-18 are not radioactive isotopes and are therefore called "stable" or "environmental" isotopes. Deuterium (^2H) is another isotope of hydrogen with an atomic mass of 2. Oxygen commonly occurs with an atomic mass of 16, but small amounts of ^{17}O and ^{18}O exist in nature. These heavier isotopes of oxygen and the heavier isotopes of hydrogen fractionate (or selectively separate) from the more common lighter isotopes (e.g., ^1H , ^{16}O) during precipitation and evaporation processes.

Interpretation of stable isotope data is more complex than interpretation of tritium data. Tritium data yield fairly simplistic relative age information; conversely, stable isotope data do not provide age estimates but provide data indicative of climatic conditions of recharge. As such, interpretation is more difficult. Deuterium (^2H) is commonly plotted as a function of oxygen-18 (^{18}O) and compared with the global (average) meteoric water line (Figure 5.5-5). The global meteoric water line, which is the result of an empirical linear relationship between deuterium and oxygen-18 found in continental precipitation throughout the world, is described by the following equation:

$$\delta^2\text{H} = 8\delta^{18}\text{O} + 10$$

where δ = the difference per mille (parts per thousand) relative to standard mean ocean water (SMOW).

This relationship of deuterium to oxygen-18 abundance is a global average, and the relationship for any particular area may deviate from this relationship either in the slope (8) of the line or the intercept (+10) on the y-axis. To accurately assess stable isotope information for an area, the slope of the local meteoric water line must be calculated.

Deuterium and oxygen-18 are fractionated with respect to ^1H and ^{18}O , respectively, during precipitation and evaporation. During these processes the lighter isotope will evaporate first and precipitate last, leaving the resultant water isotopically heavier (i.e., the δD and $\delta^{18}\text{O}$ values are more positive). Fractionation is also a function of temperature; thus, as temperature decreases, the resultant water from precipitation is isotopically lighter (i.e., the δD and $\delta^{18}\text{O}$ values are more negative). Additionally, because fractionation is affected by temperature the isotopic signature is dependent on elevation and latitude. Distance from the main evaporation source (the ocean) also affects the isotopic signature, as continued transport in the atmosphere further depletes heavier isotopes.

Aside from fractionation due to changes of physical state, additional processes contribute to changes in the ratios of the stable isotopes once surface water has percolated into the subsurface. Mixing waters with differing isotopic ratios and exchange with other fluids or with the rock matrix may also alter the isotopic composition of ground water.

The deuterium and oxygen-18 values reported for the unconfined flow system, excluding those in Section 33, ranged from -111 to -92.0 per mil and -13.6 to -10.4 per mil, respectively (Table 5.5.1-1). Average values for deuterium were -101 per mil and -12.3 per mil for oxygen-18. The deuterium and oxygen-18 values reported for the confined flow system ranged from -120 to -102 per mil and -15.1 to -13.3 per mil, respectively (Table 5.5.1-1). Average values for deuterium were -114 per mil and -14.1 per mil for oxygen-18. Average deuterium and oxygen-18 values for samples from wells in Section 33 were -104 per mil and -13.4 per mil, respectively, which are generally consistent with values for unconfined flow system wells in Sections 23 and 24.

A linear regression of the stable isotope data describes a line with a slope of 6.59 and a y-intercept of -20.5 (best fit line, Figure 5.5-5), which would indicate either an enrichment in ^{18}O or a depletion in ^2H relative to the global meteoric water line (Figure 5.5-5). Mechanisms for an enrichment in ^{18}O are known, but are not plausible at RMA. A process specific to depletion in ^2H is not known. Differences between the global meteoric water line and the best fit line in Figure 5.5-5 reflect relatively minor deviations of the local system relative to the global average.

No RMA surface-water samples were analyzed for stable isotopes; therefore, comparison of isotopic data with representative local precipitation values is not possible. However, the subparallel trend of the best fit line (Figure 5.5-5) with respect to the global meteoric water line (Figure 5.5-5) suggests that isotopic signatures of ground water are representative of precipitation in the area surrounding RMA, because climatic conditions in the area surrounding RMA are considered to be similar to those reflected by the global meteoric water line.

The stable isotope data indicate that, with a few exceptions, water from the unconfined flow system and the confined flow system are isotopically distinct. The majority of the unconfined flow system samples were isotopically heavier (averaging -100 for δD and -12.3 for $\delta^{18}O$) than the samples from the confined flow system wells (averaging -114 for δD and -14.1 for $\delta^{18}O$). This distinction could have resulted from either (1) a difference in the temperatures at which these waters were formed or (2) evaporation of water in the unconfined flow system. The tritium data confirm an age difference between these waters, but additional data are necessary to establish a correlation between the stable isotope data and recharge temperatures. Data presented in Figure 5.5-5 indicate that most water of the confined flow system plots near the lower left portion of the best fit line, indicating lower temperatures of recharge or higher elevation of recharge areas for the confined flow system relative to the unconfined flow system. Isotopically heavier water of the unconfined flow system in the upper right portion of the graph (Figure 5.5-5) suggest higher temperatures or lower elevation recharge. Stable isotope data from the shallowest well sampled in the confined flow system (23177) plot approximately midway between the end points defined by unconfined and confined wells in Figure 5.5-5, and they tend to more closely resemble unconfined isotopic signatures. Stable isotope data agree with tritium data (Figure 5.5-3) for Well 23177, which suggests that there is some degree of hydrologic communication between unconfined and confined flow systems in the area of Well 23177.

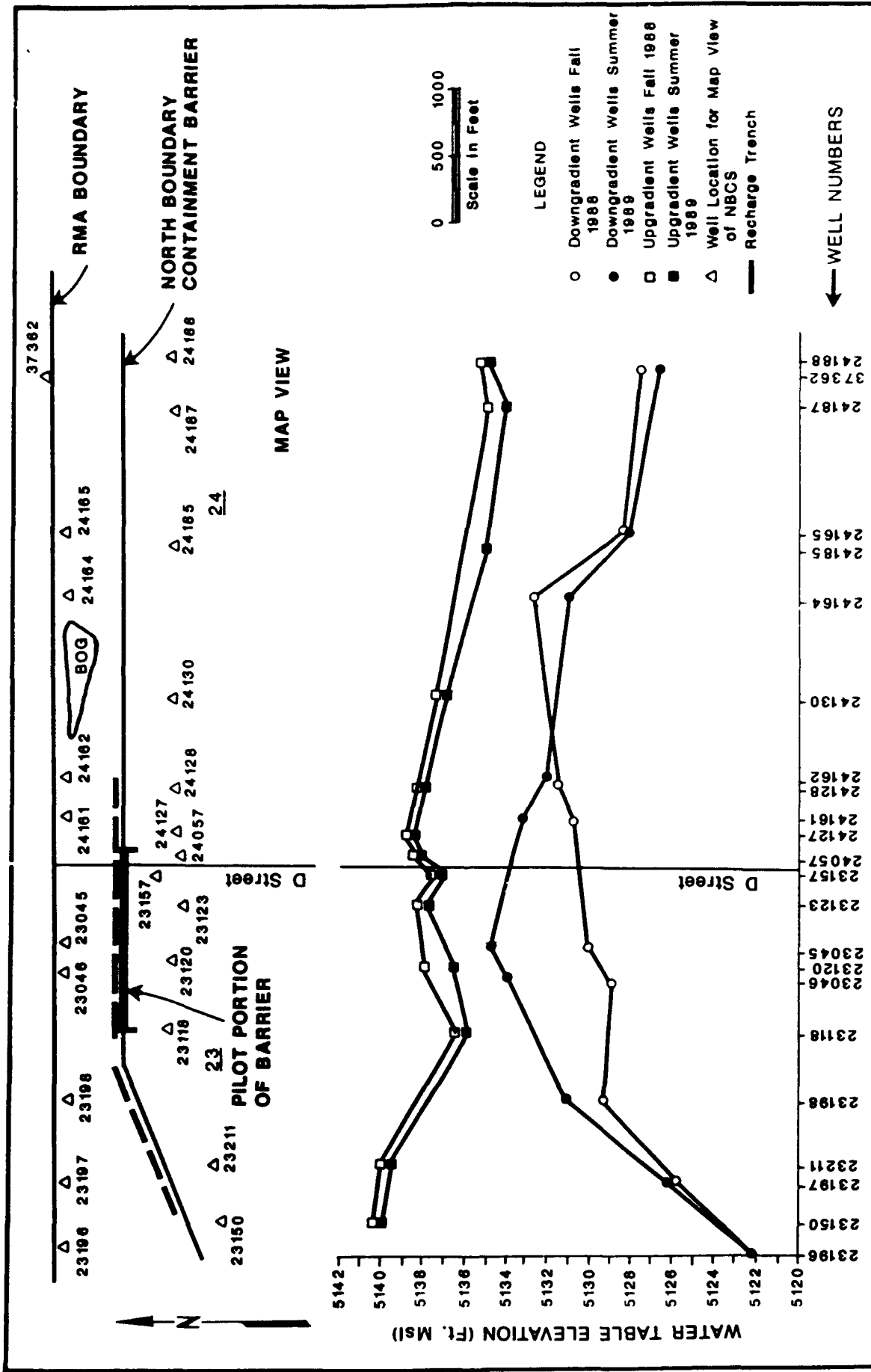


Figure 5.2-1

WATER TABLE PROFILES ALONG EAST-WEST LINES 450 FT. DOWNGRADIENT AND 350 FT. UPGRADIENT OF NORTH BOUNDARY CONTAINMENT BARRIER

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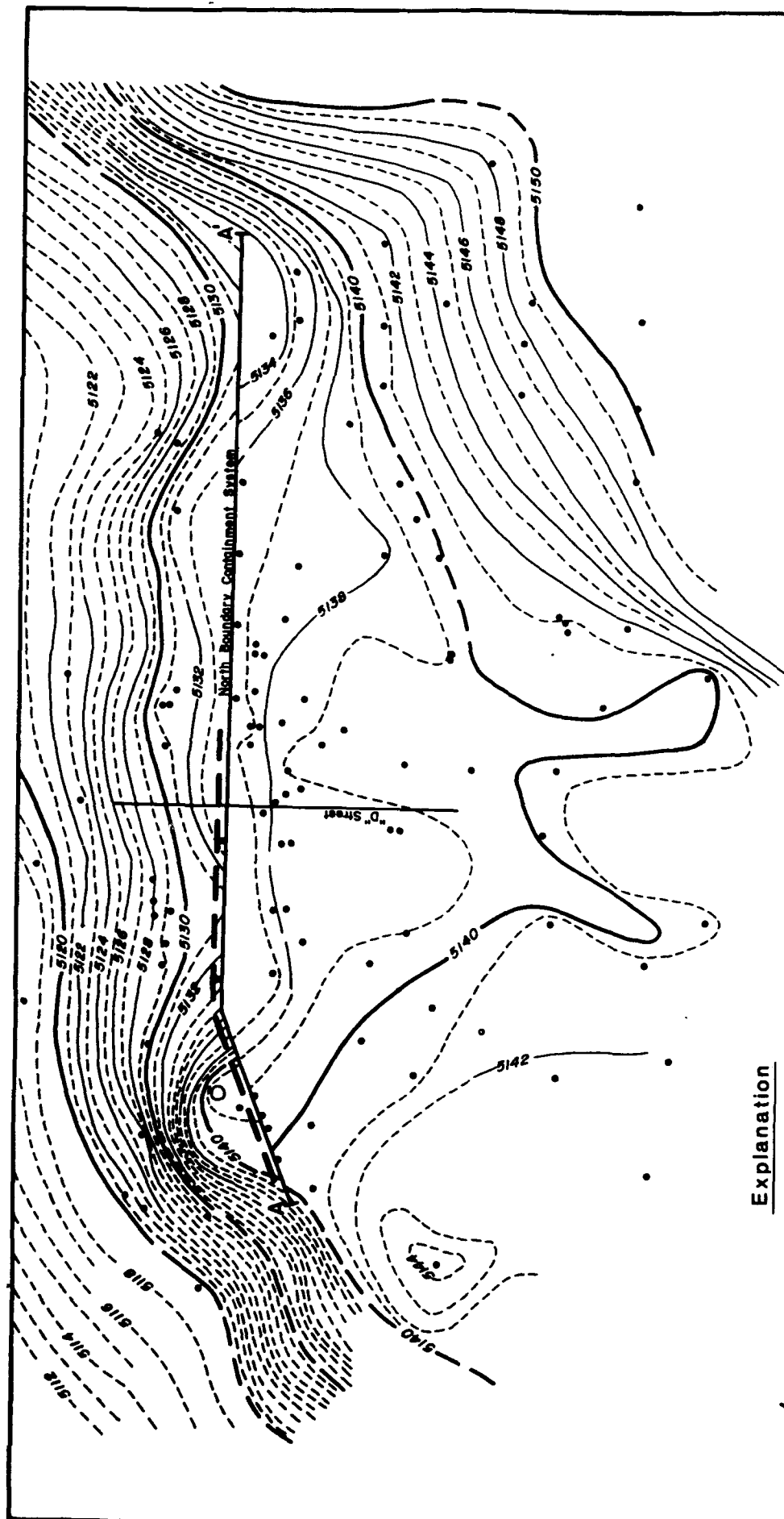
Program Manager for

Rocky Mountain Arsenal

Commerce City, Colorado

CMP GWA FY89

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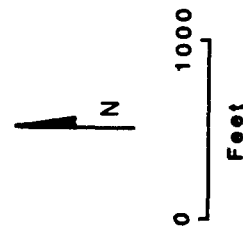
Explanation

Water Table Elevation
(1' contour interval)

Recharge Trench

Well Location

Cross Section



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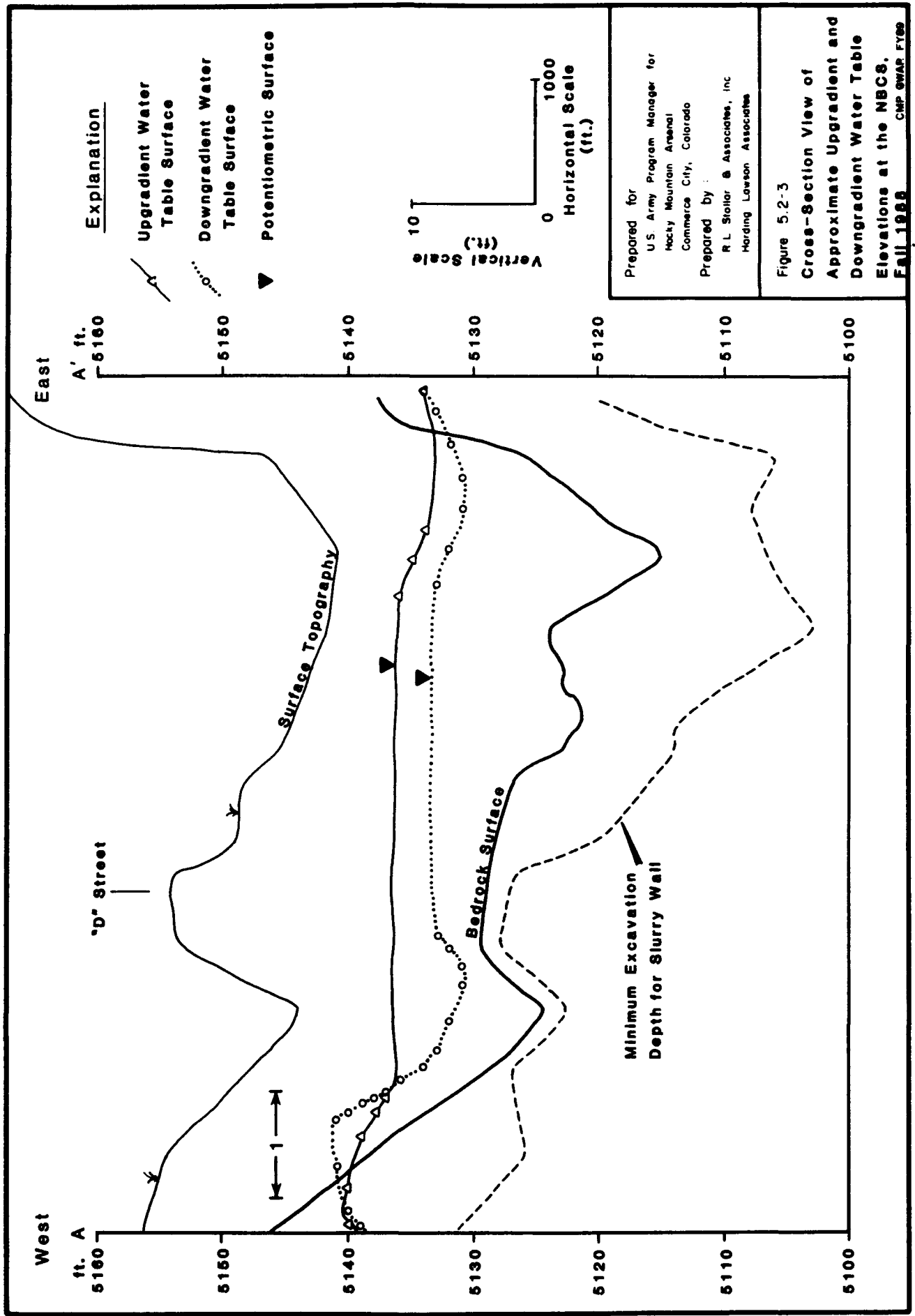
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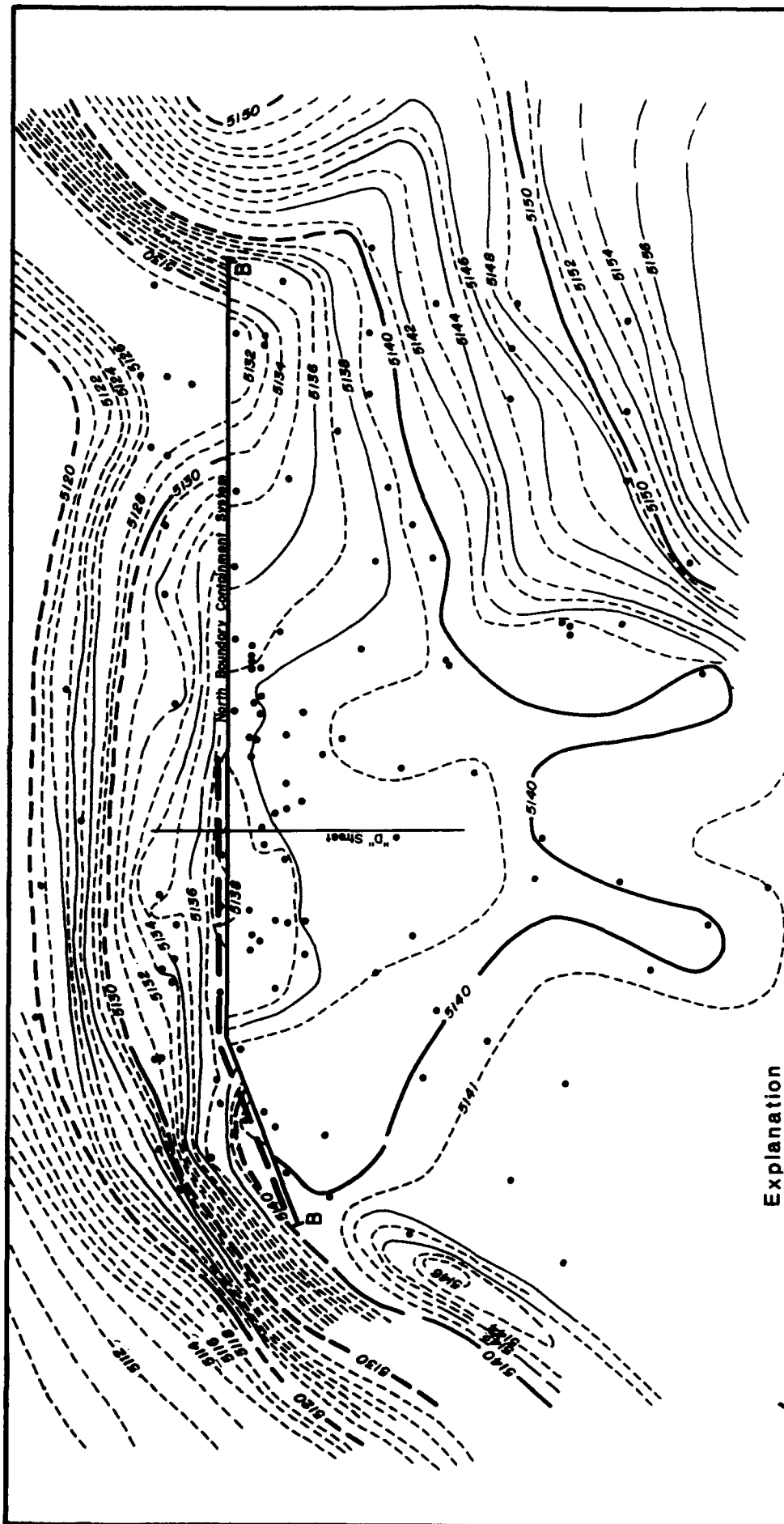
Figure 5.2-2

Map View of Approximate
Upgradient and
Downgradient Water
Table Elevations at the
NBCS Slurry Wall.

Fall 1988

CMP GWA R FY89





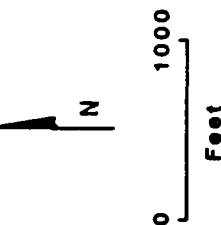
Explanation

Water Table Elevation
(1' contour interval)

Recharge Trench

Well Location

Cross Section



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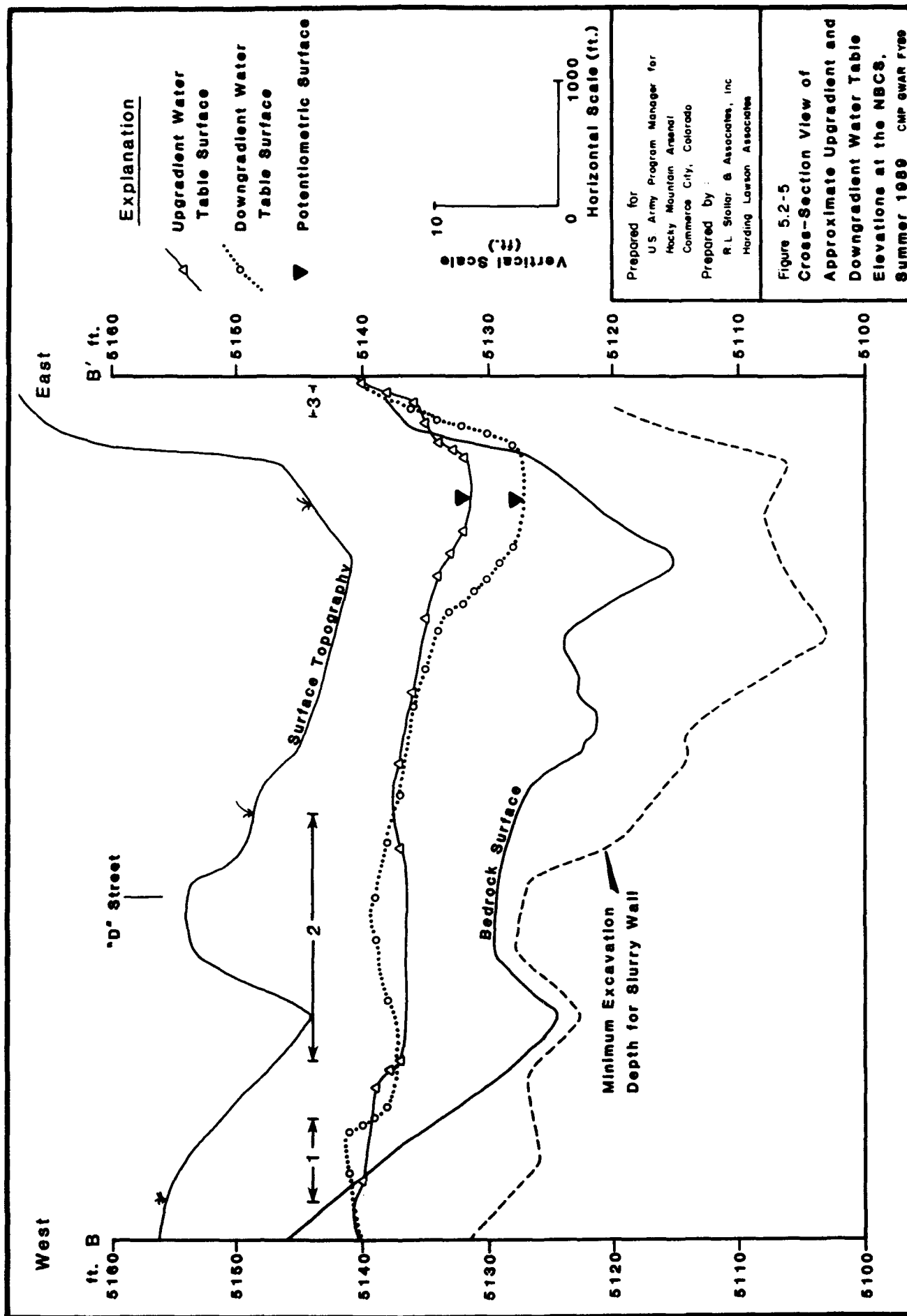
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado

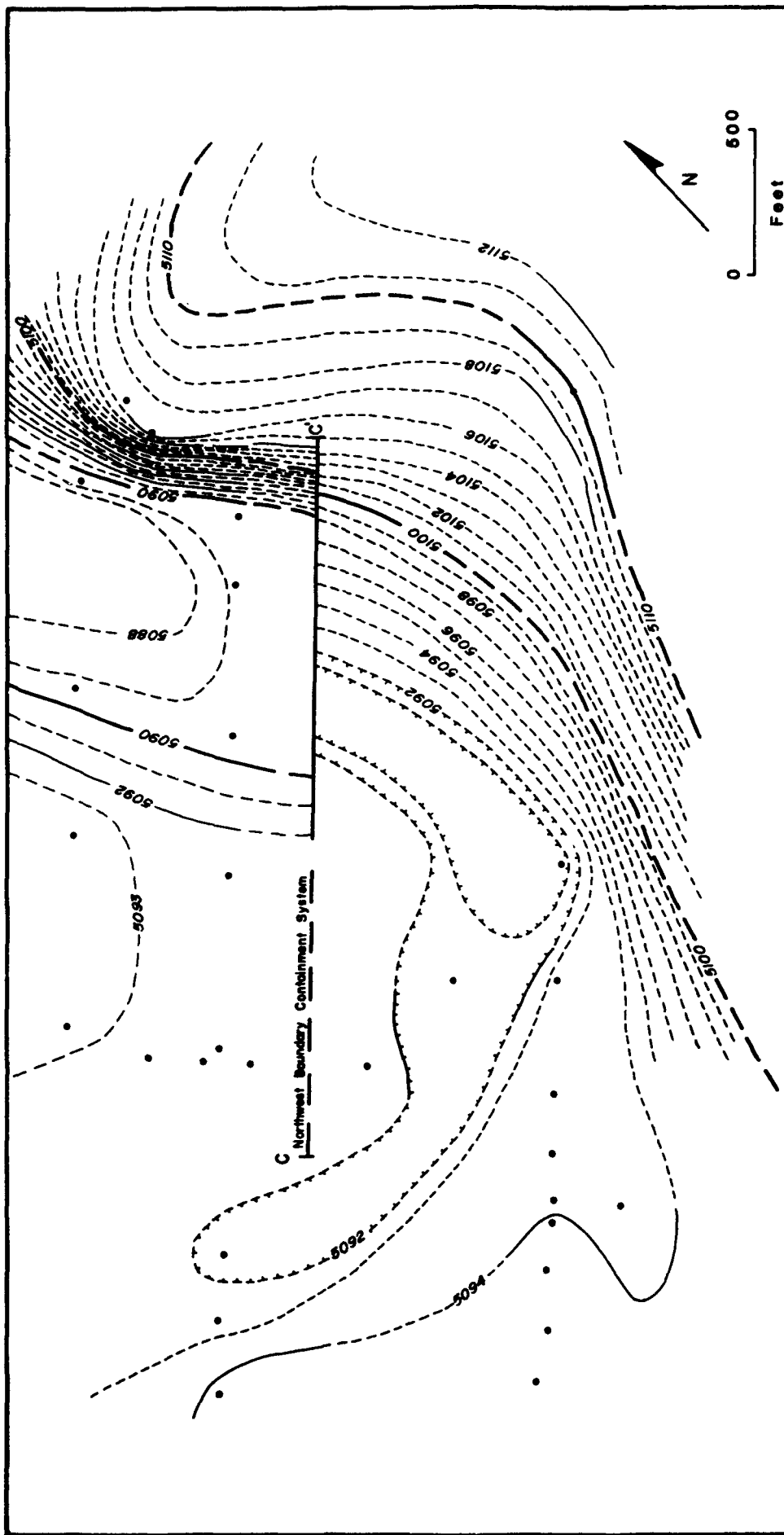
Prepared by:

R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 5.2-4

Map View of Approximate
Upgradient and
Downgradient Water
Table Elevations at the
NBCS Slurry Wall,
Summer 1989
CMP 9WAR FY89





Explanation

Water Table Elevation
(1' contour interval)

Well Location

Containment System

Physical Barrier

Hydraulic Barrier

Cross Section

Depression In

Water Table

Surface

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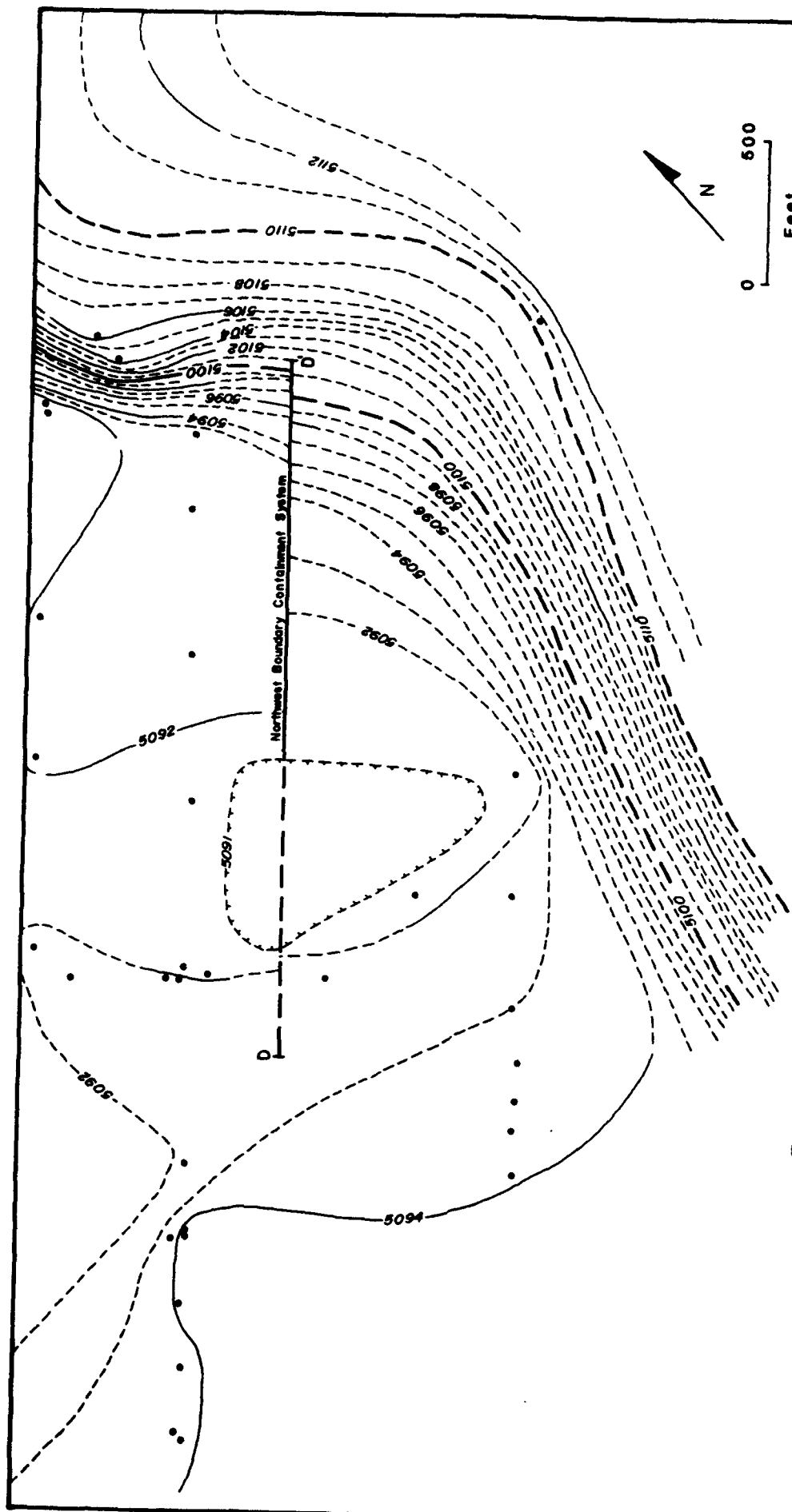
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Figure 5.2-6

Map View of Approximate
Upgradient and
Downgradient Water
Table Elevations at the
NWBCS, Fall 1988

CMP GWA# FY89



Explanation

- Water Table Elevation (1' contour interval)
- Well Location
- Containment System
 - Physical Barrier
 - Hydraulic Barrier
- Cross Section
- Depression in Water Table Surface

Figure 5.2-7

Map View of Approximate Upgradient and Downgradient Water Table Elevations at the NWBCS, Summer 1989

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Commerce City, Colorado

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CMP GWAR FY89

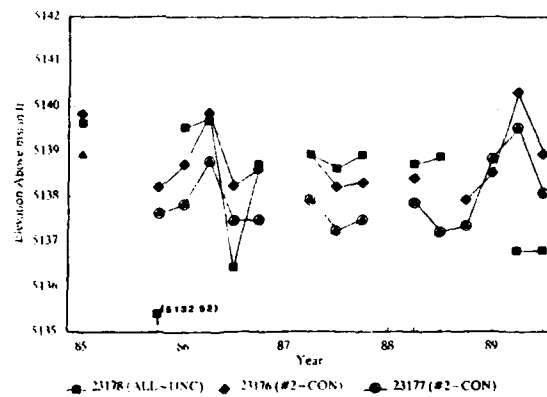
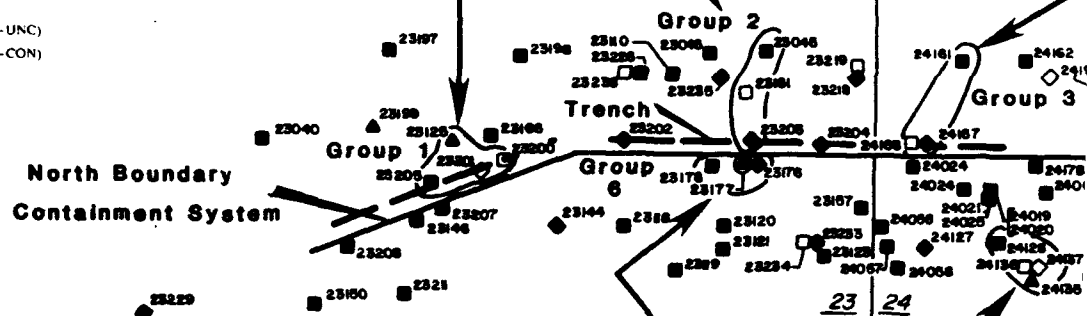
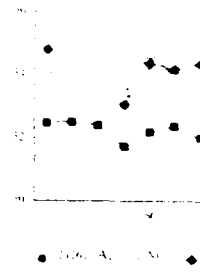


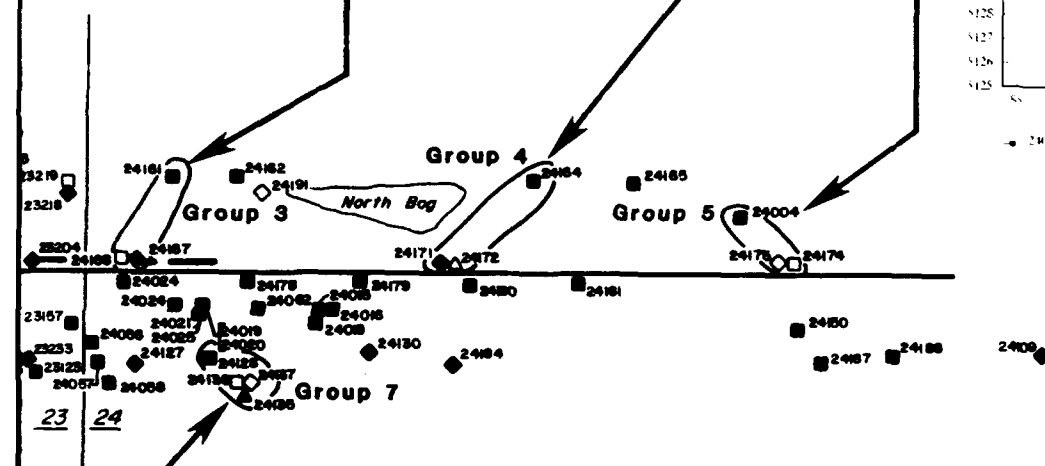
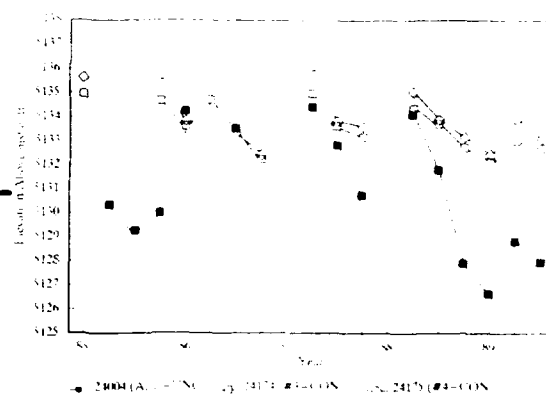
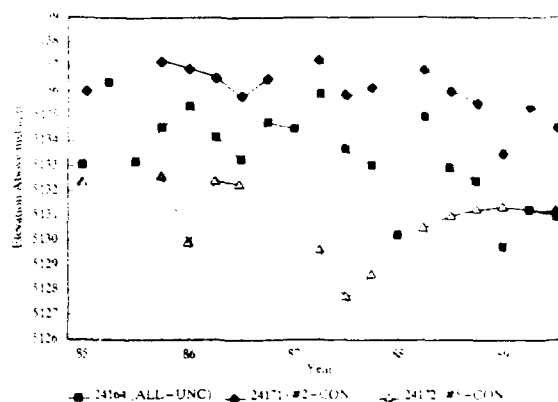
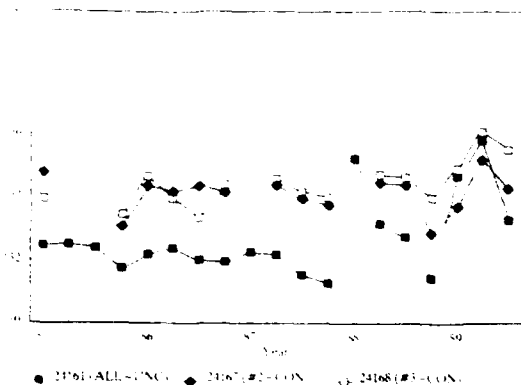
Figure 3: Appendix 1

Screened Geologic Interval

Symbol

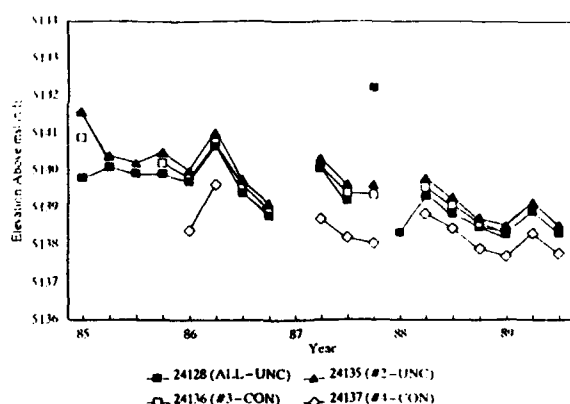
- Alluvial-Unconfined
- ▲ #2-Unconfined
- ◆ #2-Confined
- #2-Confined
(Group 6 only)
- #3-Confined
- ◇ #4-Confined
- △ #5-Confined

A scale bar labeled "Feet" with markings at 0 and 800.



ROCKY MOUNTAIN ARSENAL LOCATION

	22	23	24	19	20
	27	26	25	30	29
28	33	34	35	36	31
	4	3	2	1	6
5		11	12	7	8



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Commerce City, Colorado

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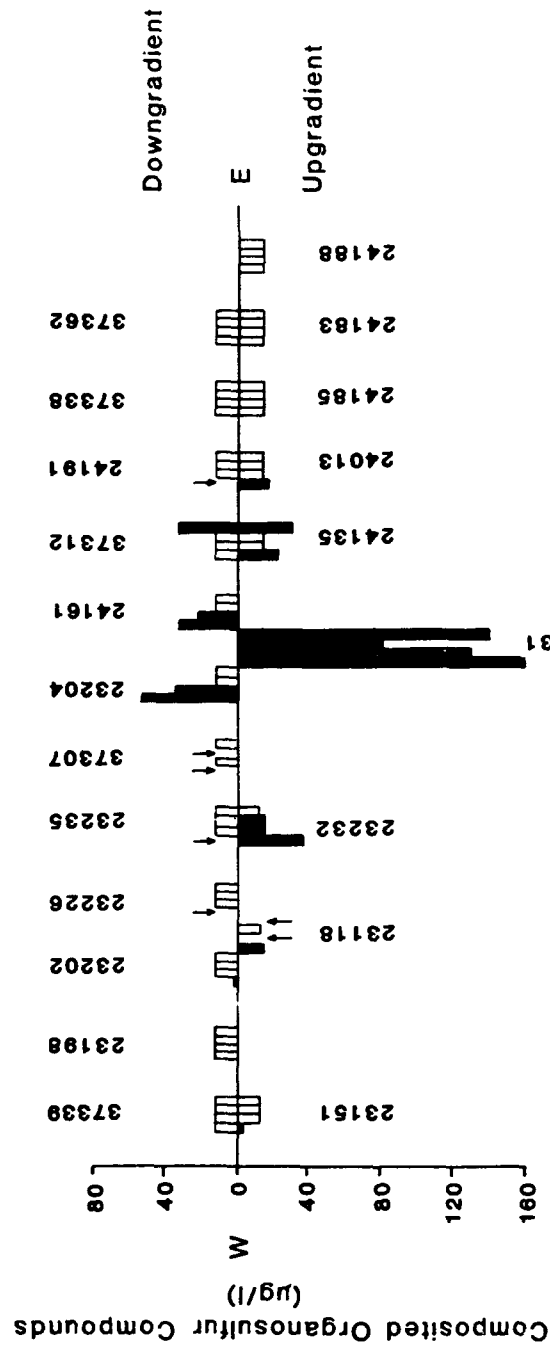
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Harding Lawson Associates

Figure 5.3.3-1

Potentiometric Comparisons of
Water Bearing Zones in the
North Boundary Containment
System Area

CMP GVAR FY86

Upgradient



Explanation

The Four Bars (L-R) Correspond to
Winter 87/88, Spring 88, Fall 88,
and Spring 89 Sampling Events
Open Bars are Below the CRL,
Solid Bars are Detections

GT Greater Than Value
↑ Sample Not Collected

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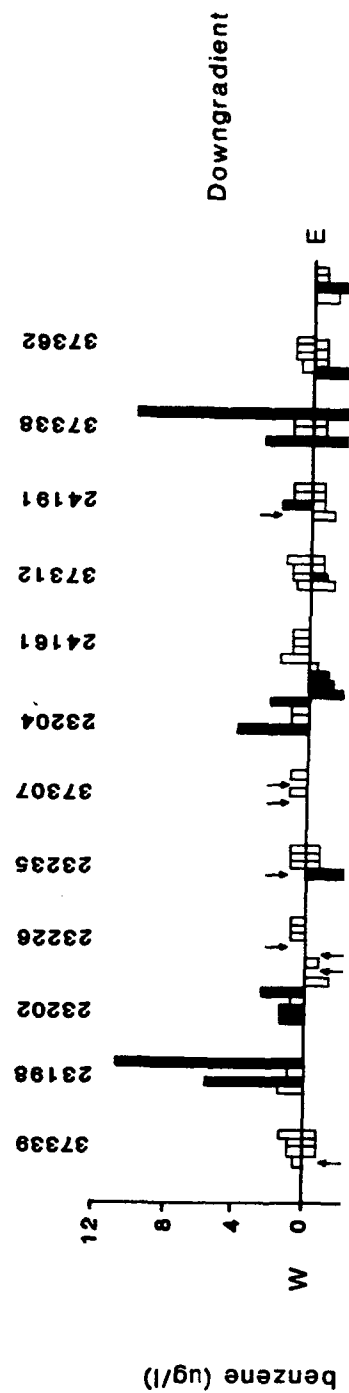
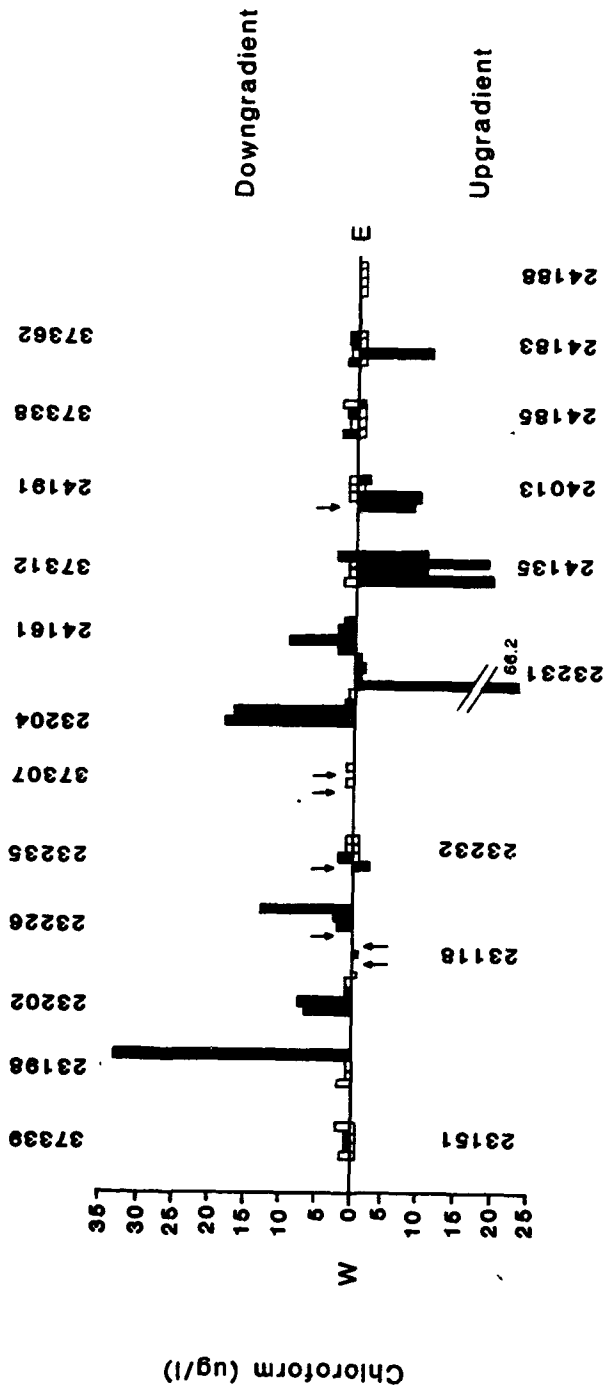
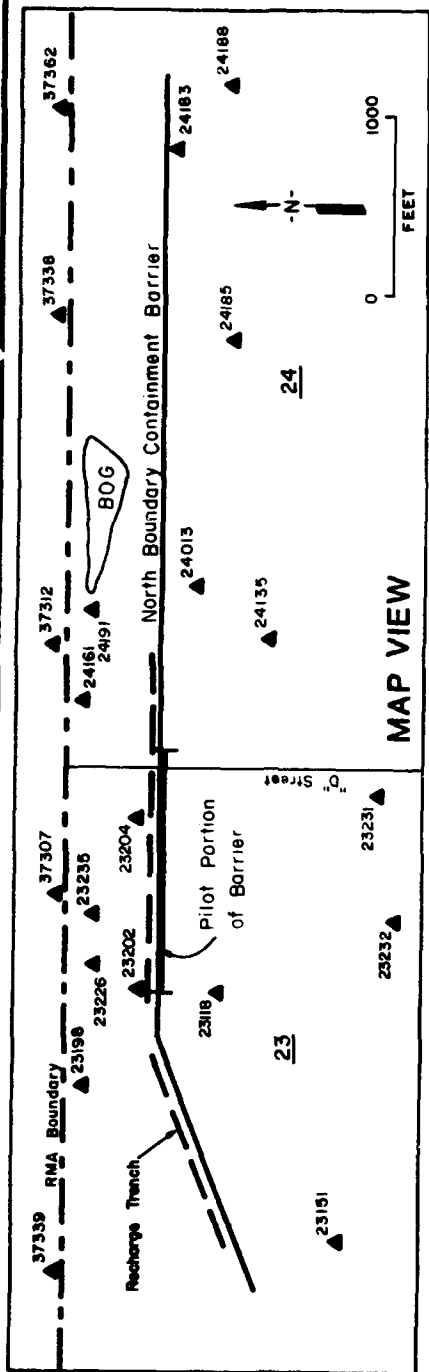
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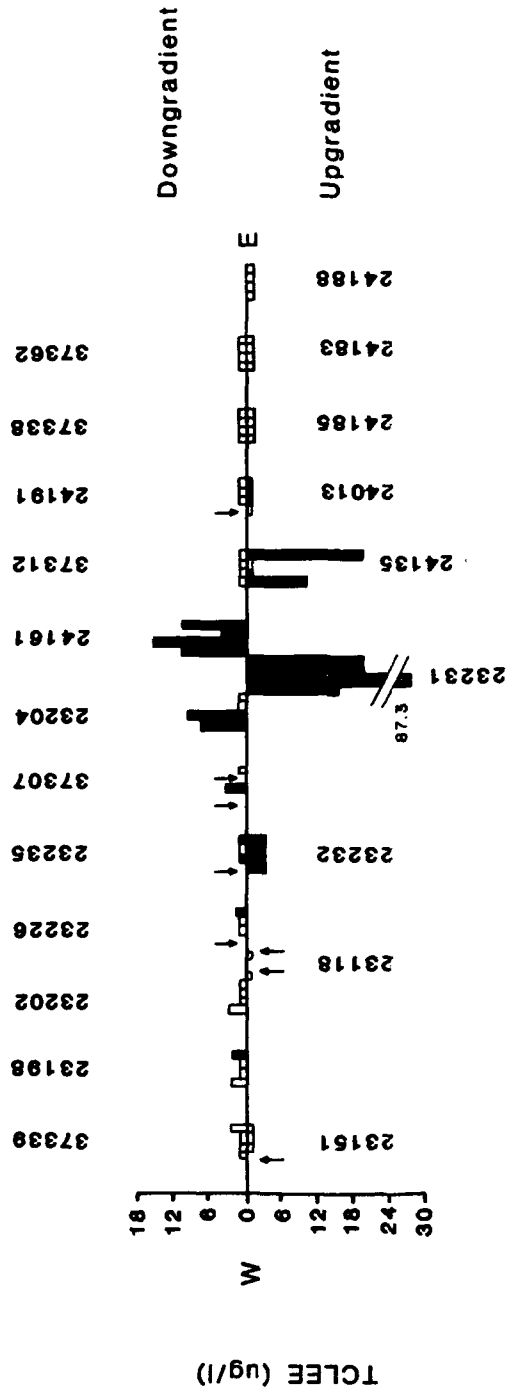
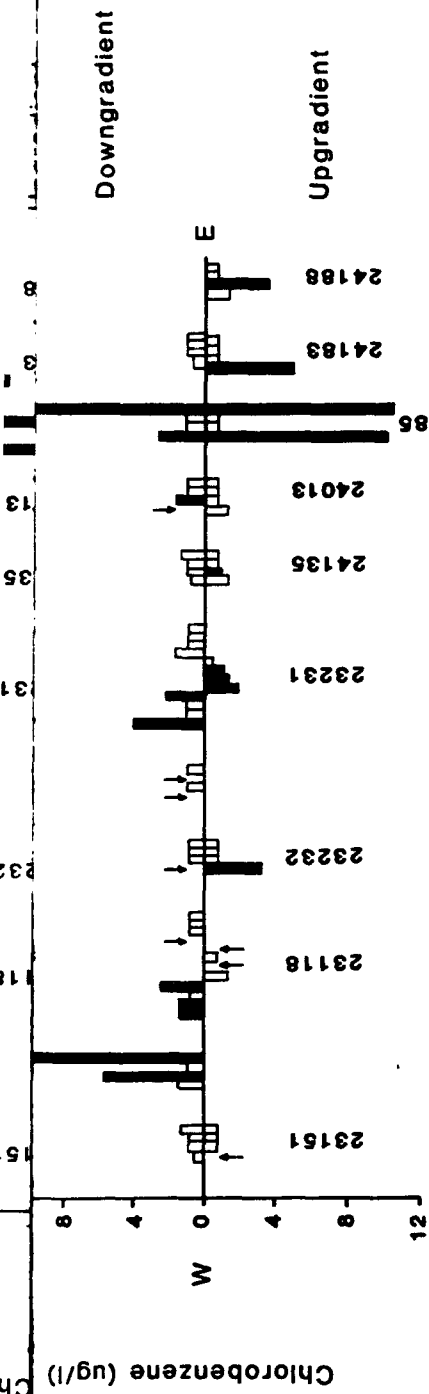
Figure 5.3.3-3

Contaminant Distribution

**Histograms for Wells Near the
North Boundary Containment System**

CMP GWAR FY89





Explanation

The Four Bars (L-R) Correspond to
 Winter 87/88, Spring 88, Fall 88,
 and Spring 89 Sampling Events
 Open Bars are Below the CRL,
 Solid Bars are Detections

OT Greater Than Value
 ↑ Sample Not Collected

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U.S. Army Program Manager for
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Prepared by

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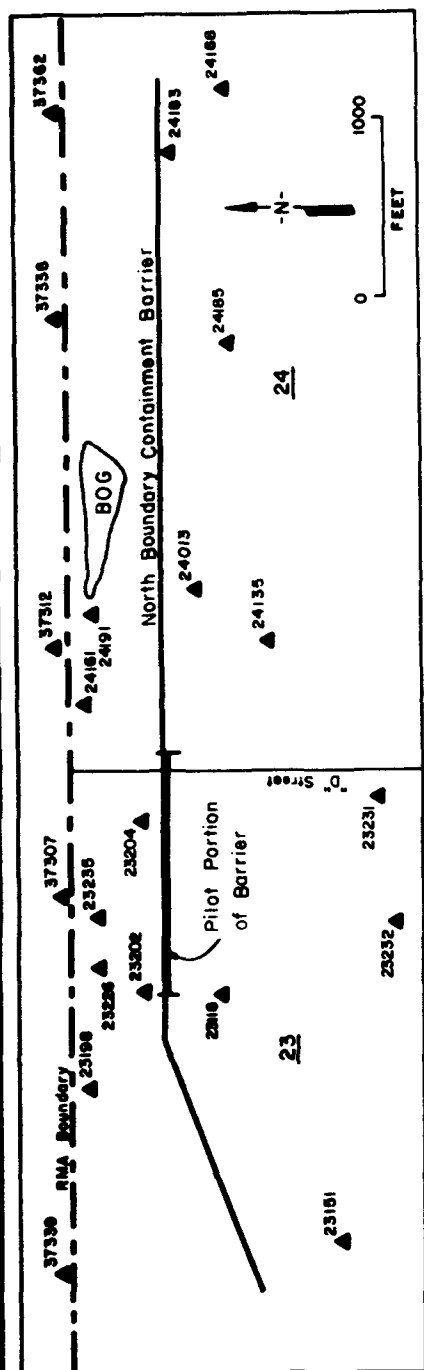
Figure 5.3.3-4

Contaminant Distribution

Histograms for Wells Near the

North Boundary Containment System

CMP GWAR FY89





Explanation



The Four Bars (L-R) Correspond to
 Winter 87/88, Spring 88, Fall 88,
 and Spring 89 Sampling Events
 Open Bars are Below the CRL,
 Solid Bars are Detections
 Greater Than Value

or

↑ Sample Not Collected

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Prepared by :

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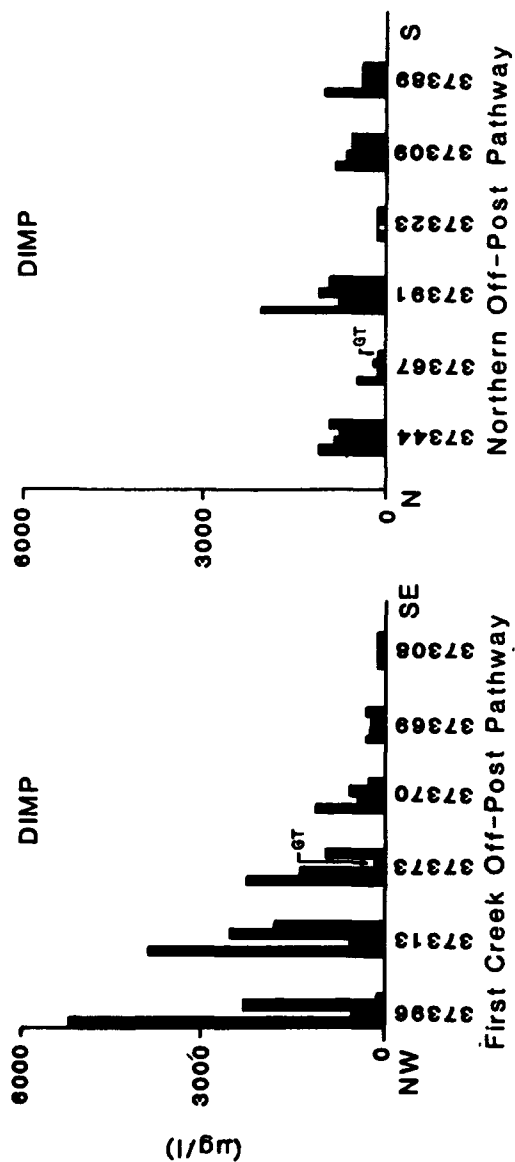
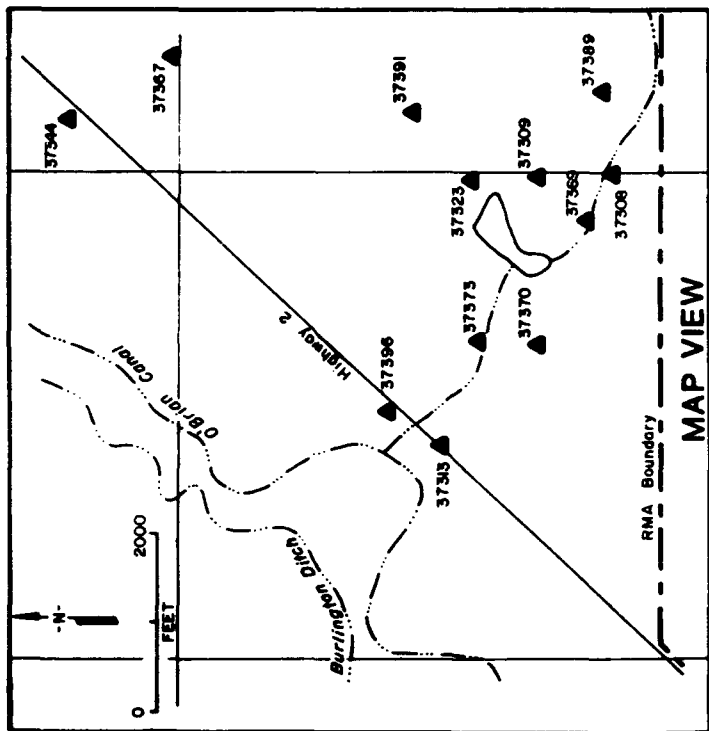
Figure 5.3.3-5

Contaminant Distribution

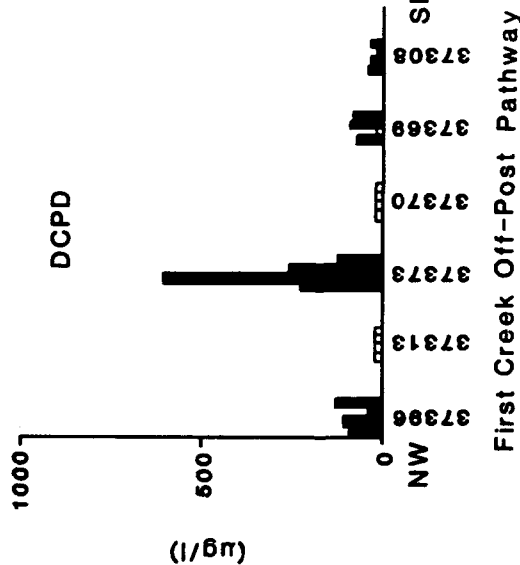
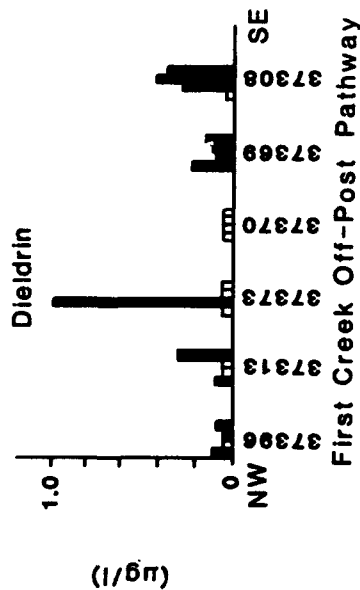
Histograms for Wells Near the

North Boundary Containment System

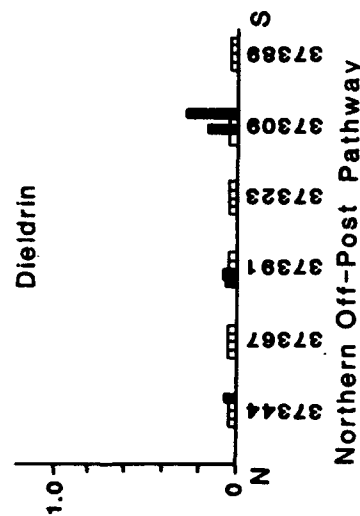
CMP GWA FY89



First Creek Off-Post Pathway



Northern Off-Post Pathway



Explanation



The Four Bars (L-R) Correspond to
 Winter 87/88, Spring 88, Fall 88,
 and Spring 89 Sampling Events
 Open Bars are Below the CRL.
 Solid Bars are Detections

↑ Sample Not Collected
 GT Greater Than Value

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 Rocky Mountain Arsenal
 Commerce City, Colorado

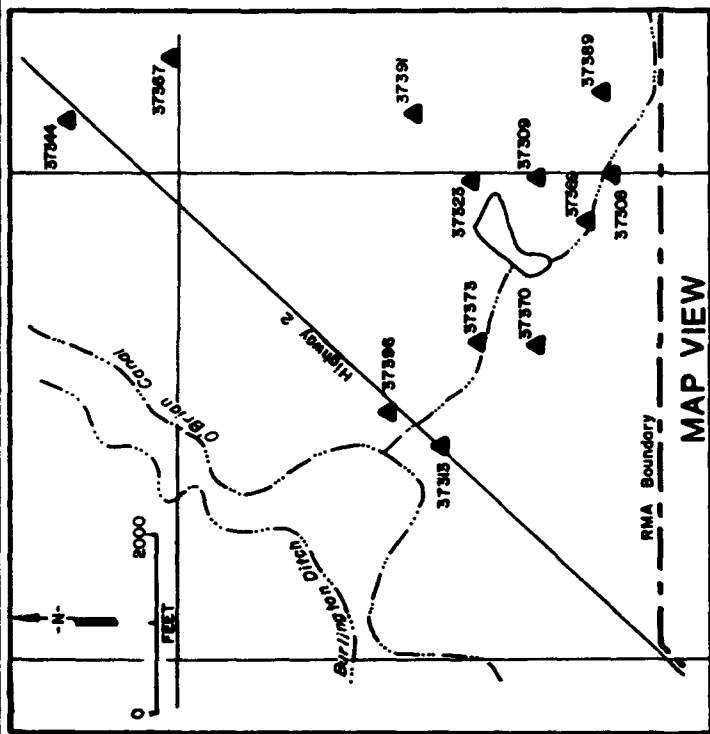
Prepared by

R.L. Stollar & Associates, Inc.
 Harding Lawson Associates

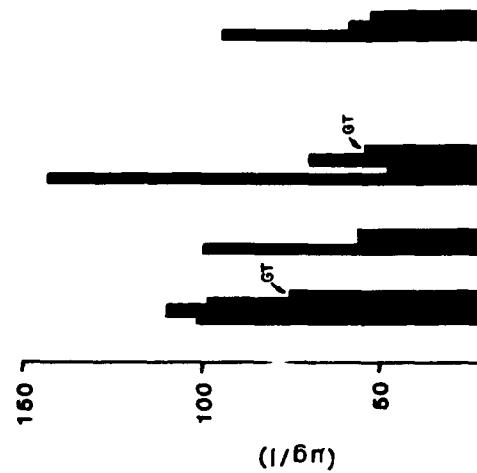
Figure 5.3.3-6

Contaminant Distribution
 Histograms for Wells in the
 First Creek and Northern
 Off-Post Pathways

CMP GWAR FY89



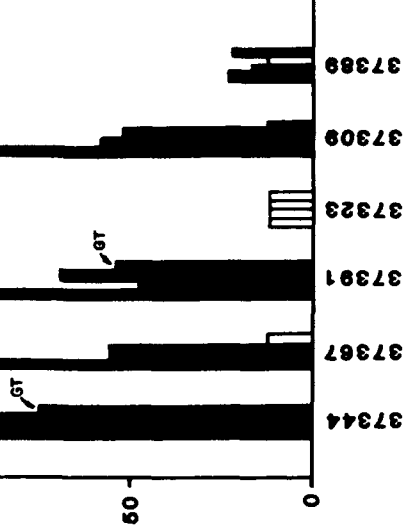
Composited Organosulfur Compounds



Composited Organosulfur Compounds



(l/gn)



Northern Off-Post Pathway

(l/gn)



First Creek Off-Post Pathway

Explanation

The Four Bars (L-R) Correspond to
Winter 87/88, Spring 88, Fall 88,
and Spring 89 Sampling Events
Open Bars are Below the CRL,
Solid Bars are Detections

↑ Sample Not Collected
GT Greater Than Value

Prepared for :

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Commerce City, Colorado

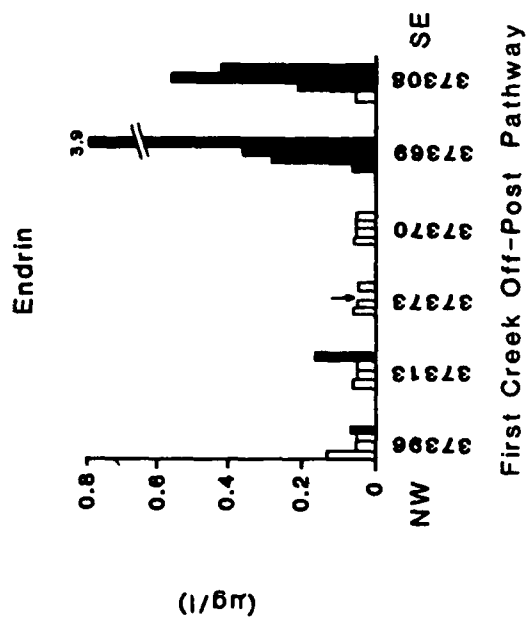
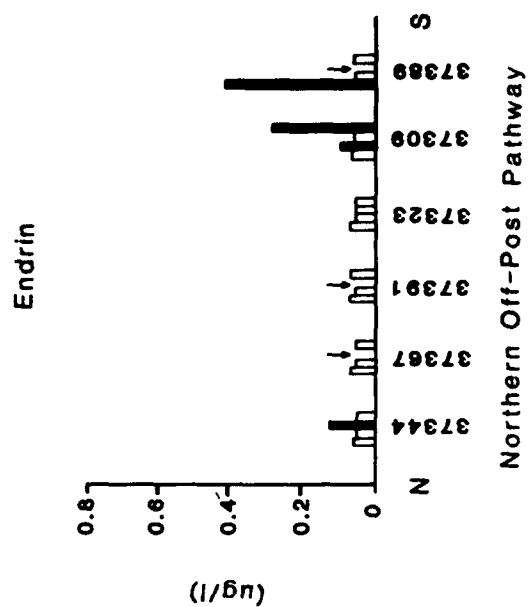
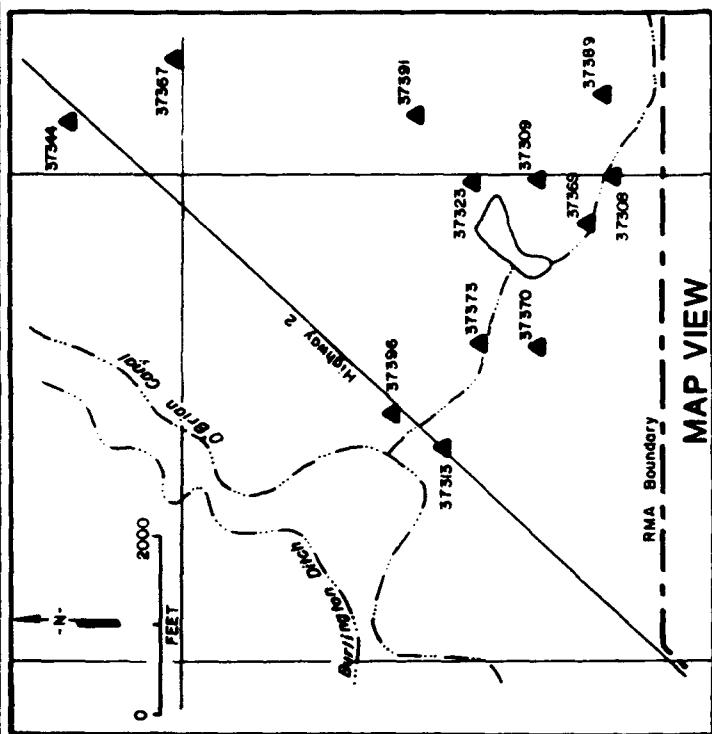
Prepared by :

R.L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 5.3.3-7

Contaminant Distribution
Histograms for Wells in the
First Creek and Northern
Off-Post Pathways

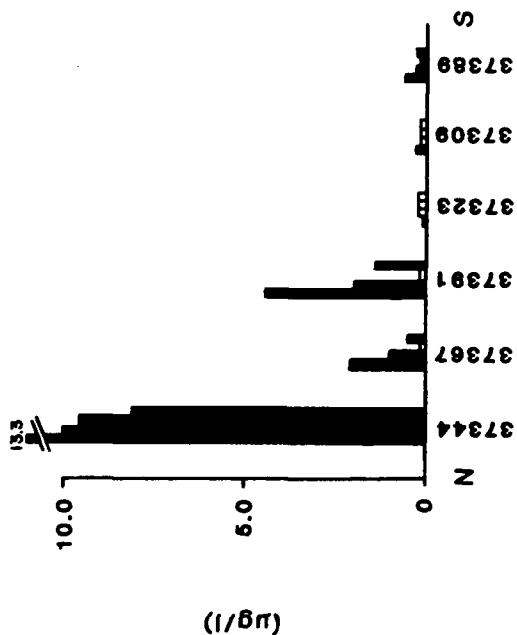
CMP GWA FY89



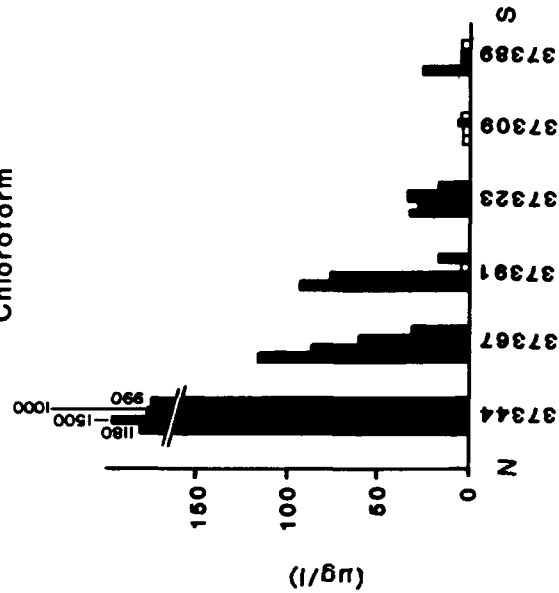
NW SE
37396 37308
37313 37369
37373 37370
First Creek Off-Post Pathway

N S
37344 37367
37391 37323
37309 37389
Northern Off-Post Pathway

DBCP



Chloroform



Northern Off-Post Pathway

Northern Off-Post Pathway

Explanation



The Four Bars (L-R) Correspond to
Winter 87/88, Spring 88, Fall 88,
and Spring 89 Sampling Events
Open Bars are Below the CRL.
Solid Bars are Detections

↑ Sample Not Collected
GT Greater Than Value

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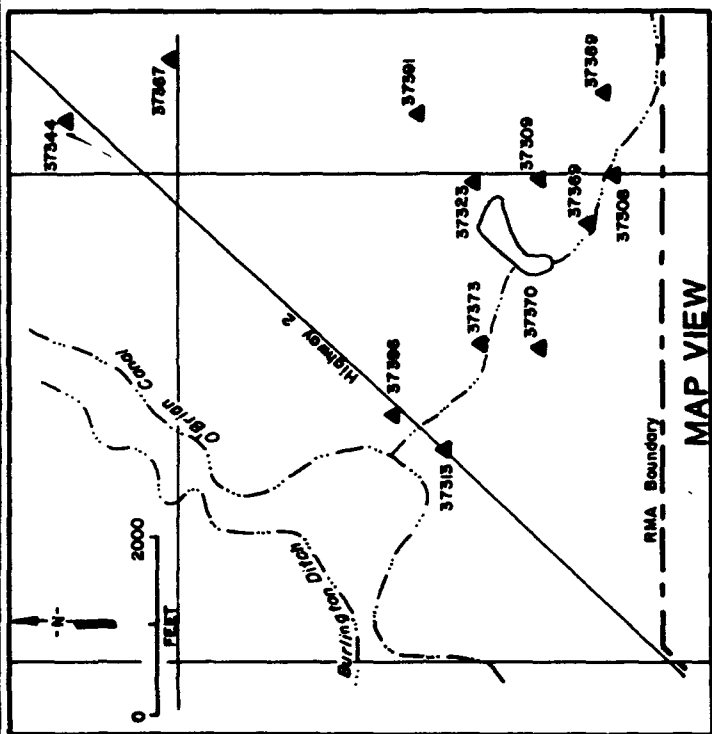
Prepared by

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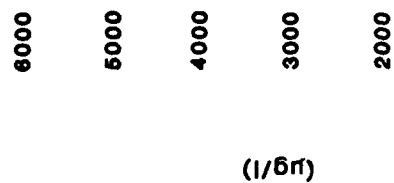
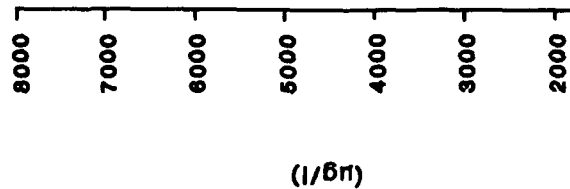
Figure 5.3.3-8

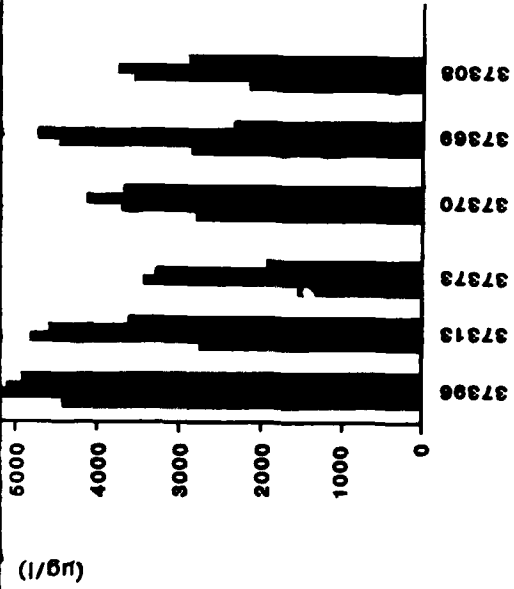
Contaminant Distribution
Histograms for Wells in the
First Creek and Northern
Off-Post Pathways

CMP GWAR FY89

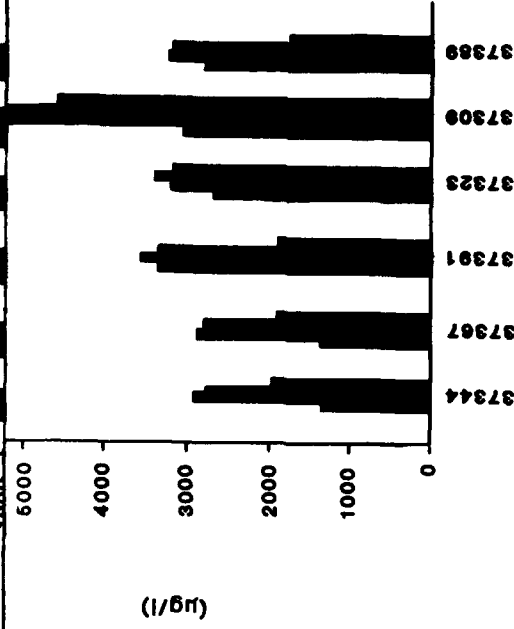


Inorganic Fluoride





First Creek Off-Post Pathway



Northern Off-Post Pathway



Explanation

The Four Bars (LR) Correspond to
 Winter 87/88, Spring 88, Fall 88,
 and Spring 89 Sampling Events
 Open Bars are Below the CRL,
 Solid Bars are Detections.

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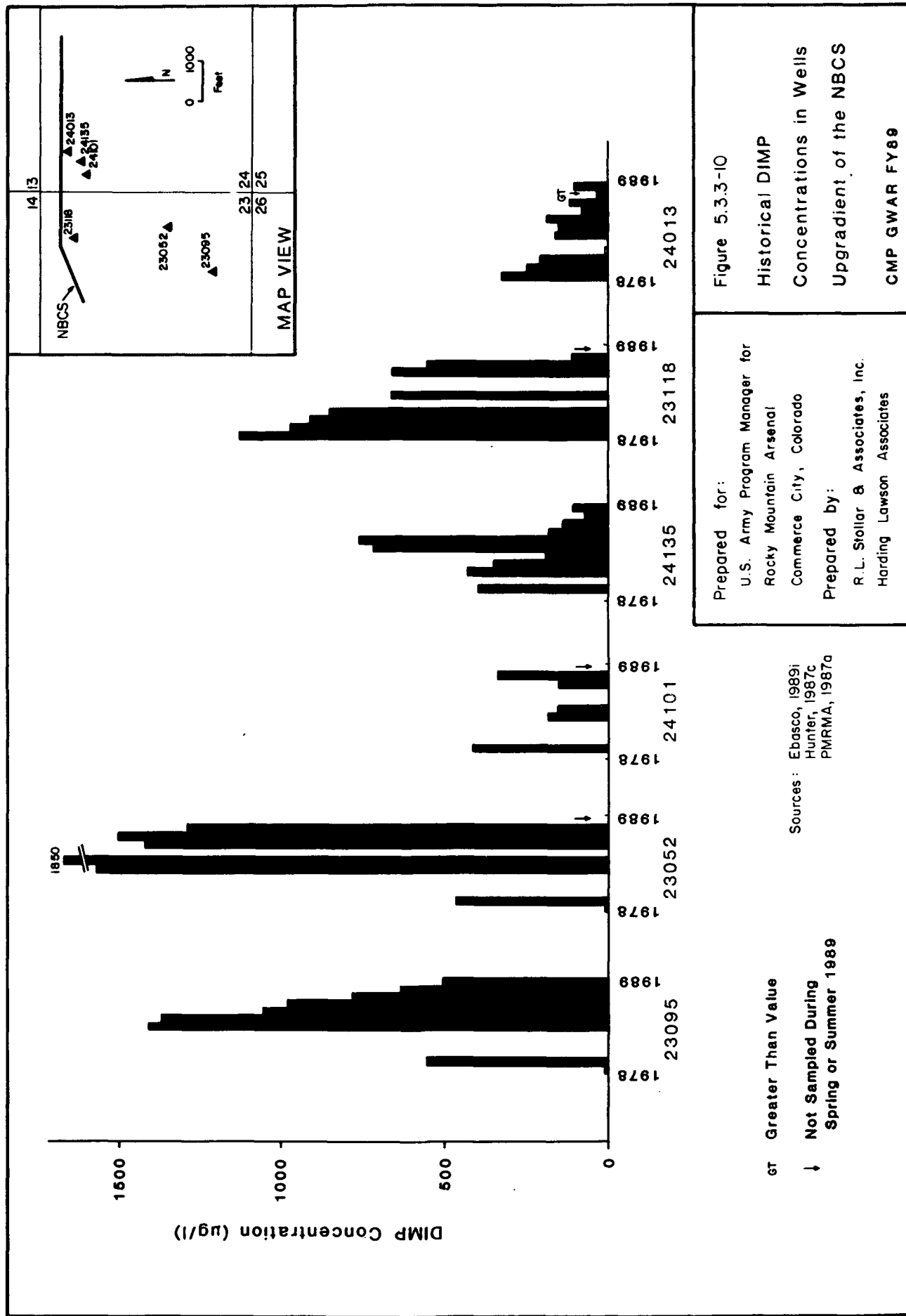
R.L. Stollar & Associates, Inc.
 Harding Lawson Associates

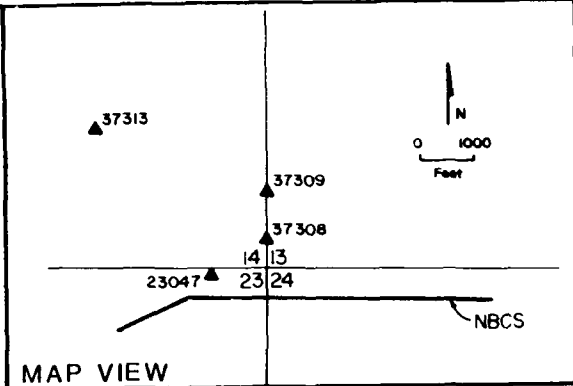
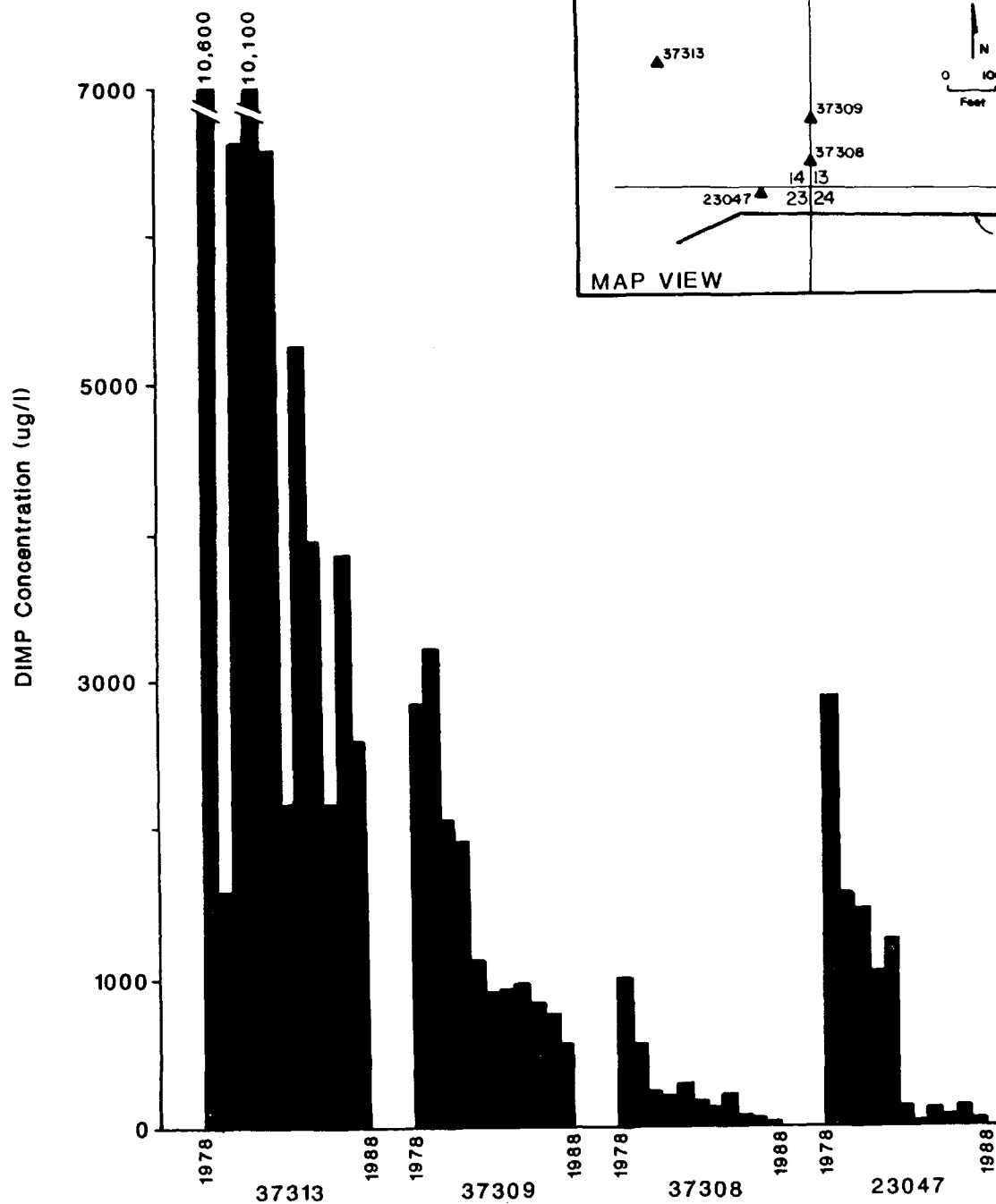
Figure 5.3.3-9

Contaminant Distribution

Histograms for Wells in the First
 Creek and Northern Off-Post
 Pathways

CMP GEAR FY89





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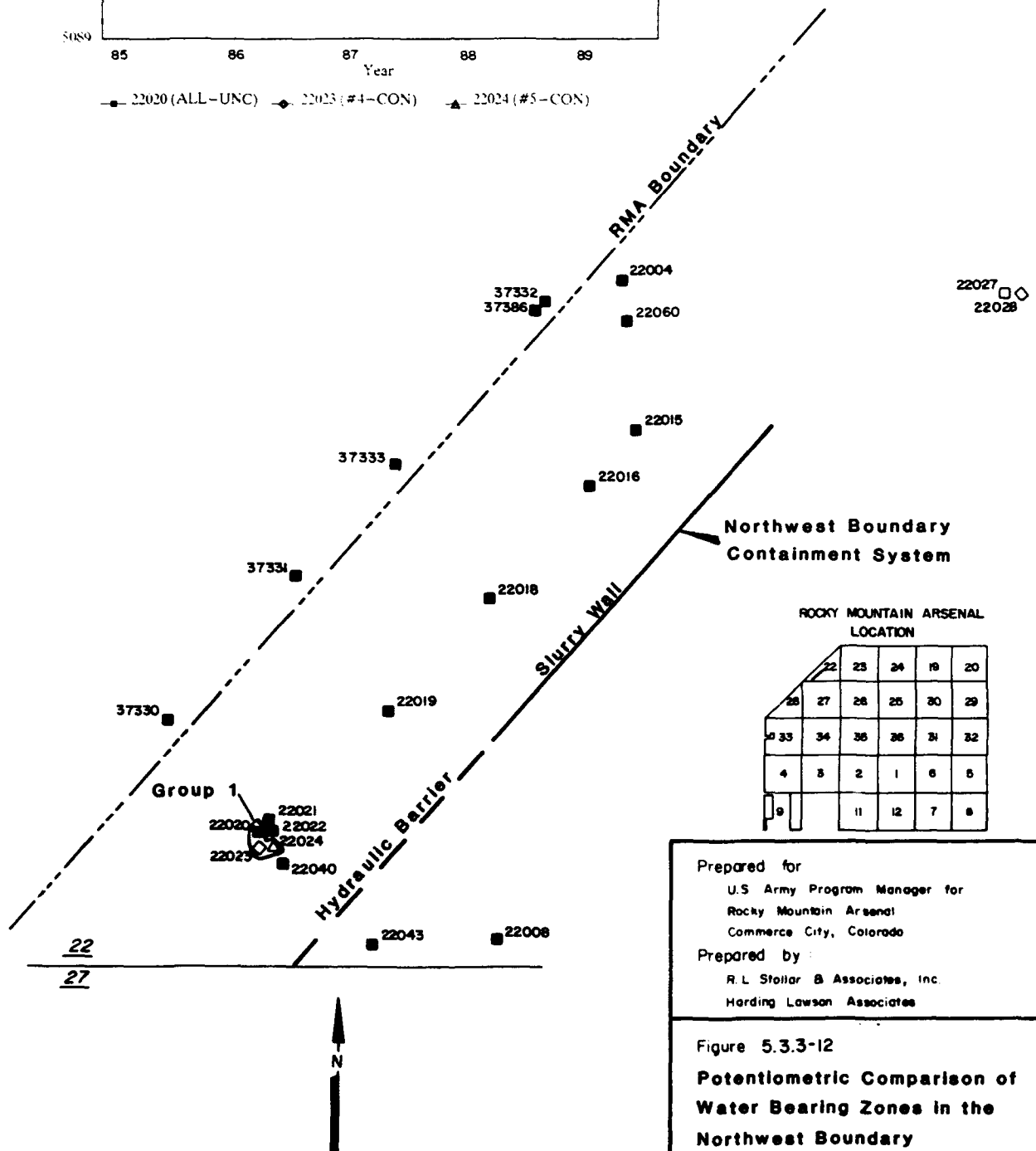
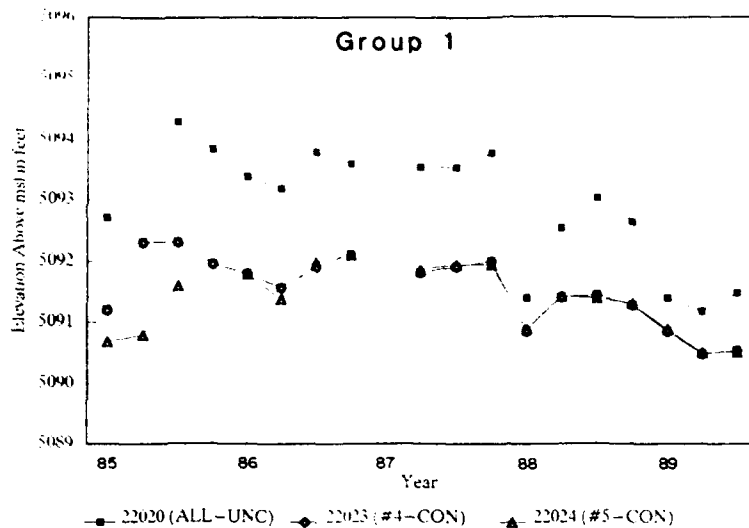
Prepared by :
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Harding Lawson Associates

Figure 5.3.3-II

**Historical DIMP Concentrations
in Wells Downgradient
of the NBCS**

CMP GWAR FY89

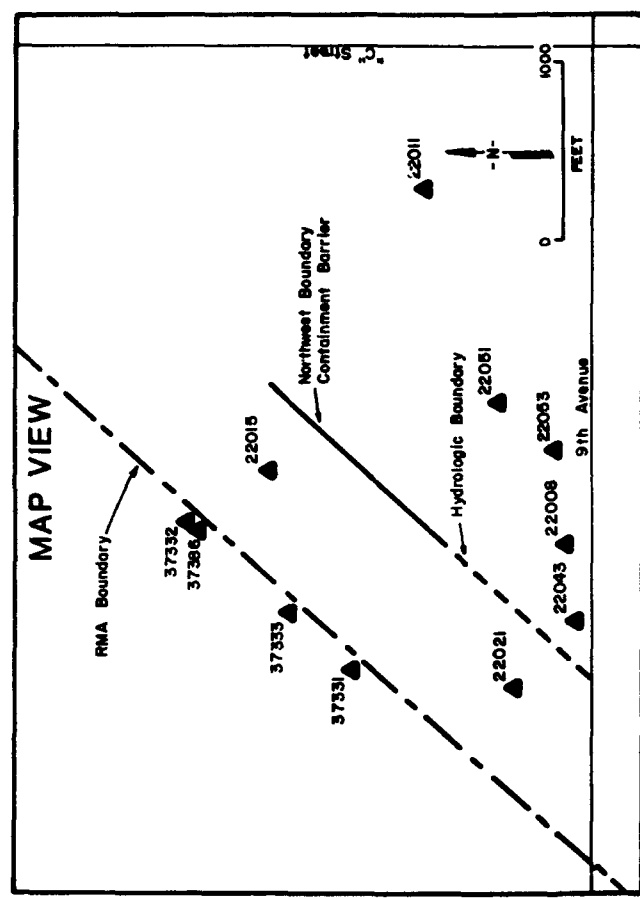
Sources: Ebasco, 1989i
Hunter, 1987c
PMRMA, 1987a

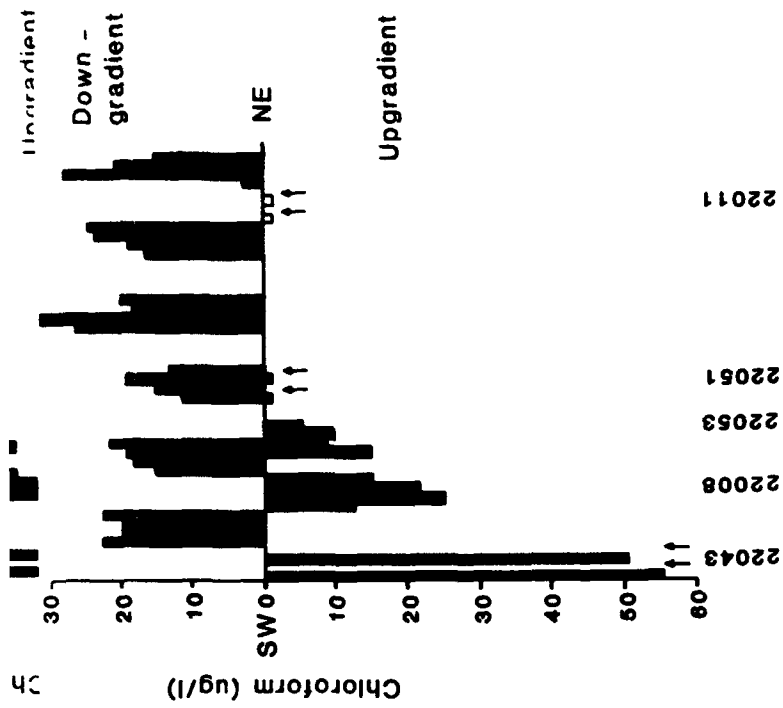
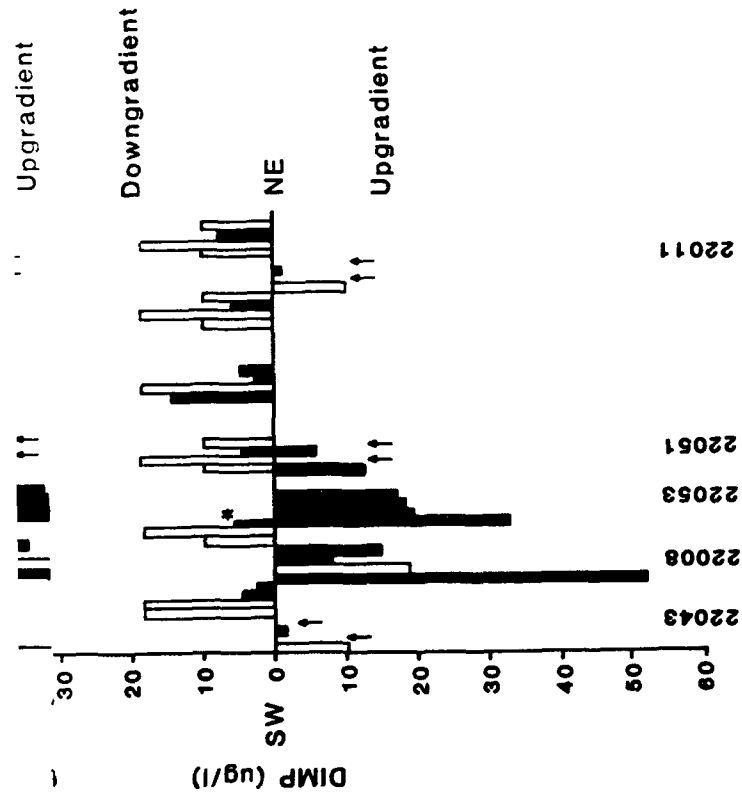


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Figure 5.3.3-12
**Potentiometric Comparison of
Water Bearing Zones in the
Northwest Boundary
Containment System Area**
CMP GWAR FY89





Explanation

The Four Bars (L-R) Correspond to
Winter 87/88, Spring 88, Fall 88,
and Spring 89 Sampling Events
Open Bars are Below the CRL,
Solid Bars are Detections

↑ Sample Not Collected

* Anomalous reading of 33.9 ug/l for Spring 1989.
Prior and subsequent values from both GC
and GC/MS are less and range from 3.39 - 5.67 ug/l.

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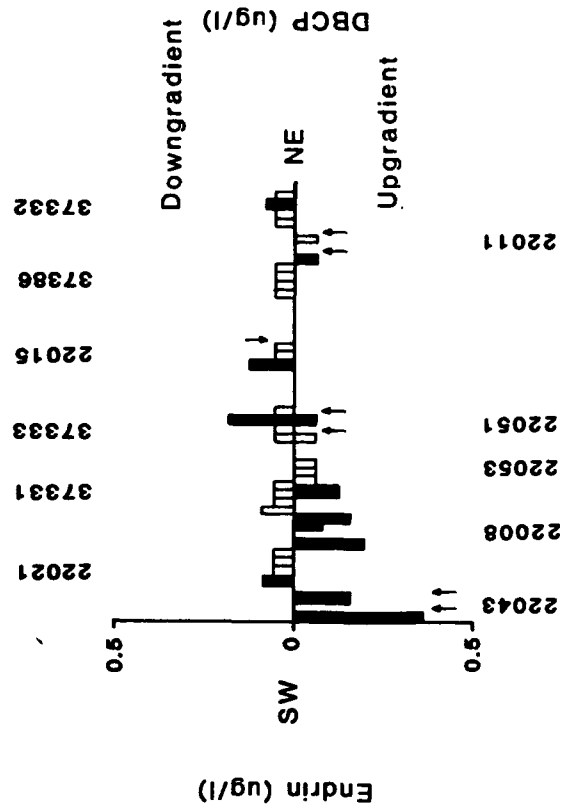
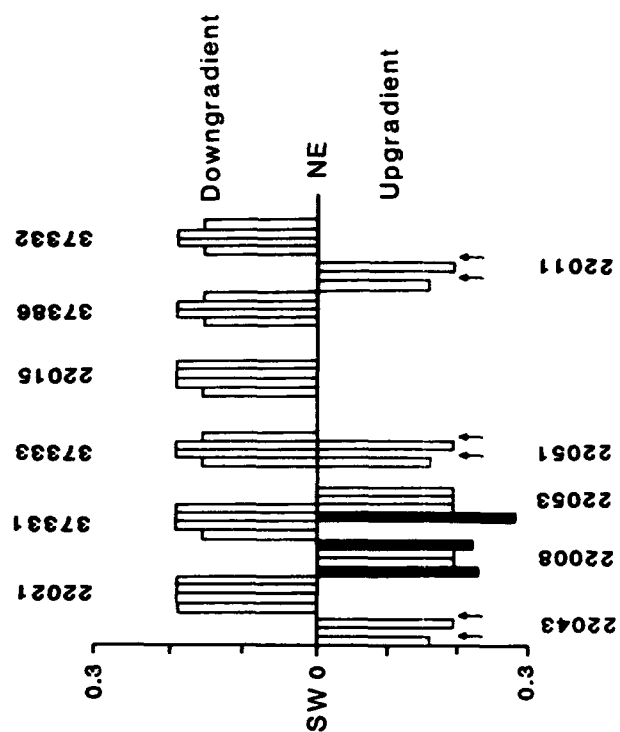
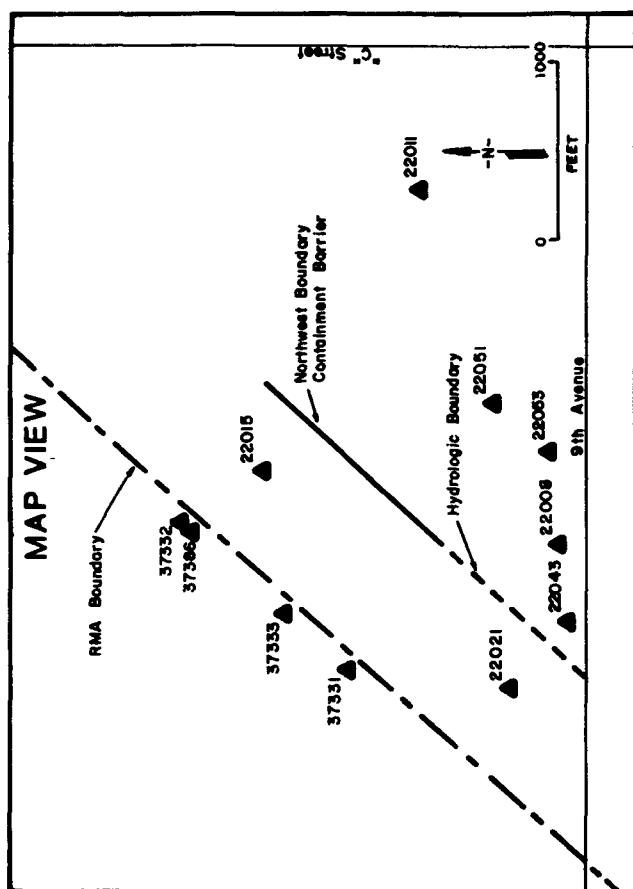
Prepared by

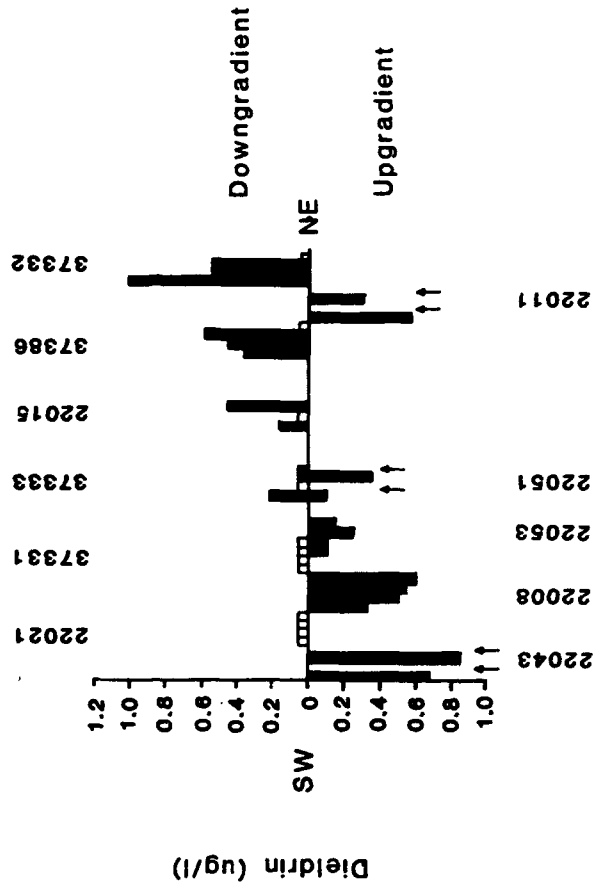
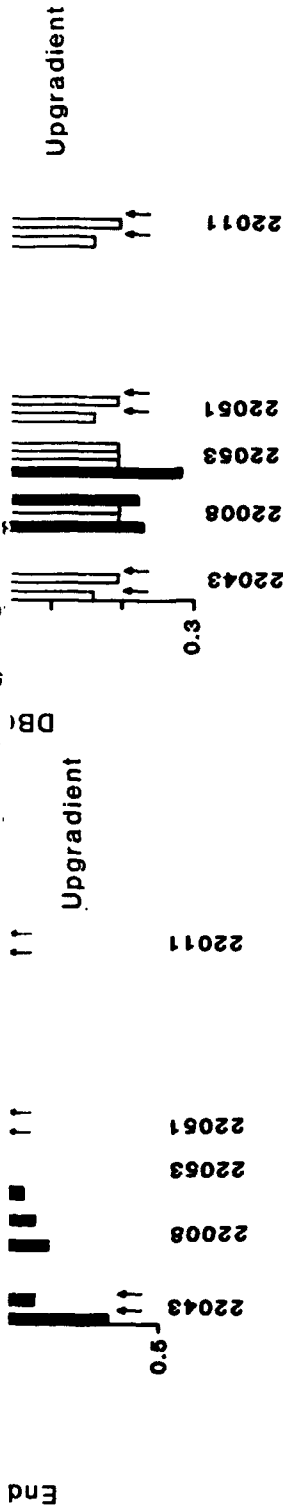
R. L. Stollar & Associates, Inc.
Harding Lawson Associates

Figure 5.3.3-13

**Contaminant Distribution
Histograms for Wells Near the
Northwest Boundary Containment
System**

CMP GVAR FY89





Explanation

The Four Bars (L-R) Correspond to
 Winter 87/88, Spring 88, Fall 88,
 and Spring 89 Sampling Events
 Open Bars are Below the CRL,
 Solid Bars are Detections

↑ Sample Not Collected

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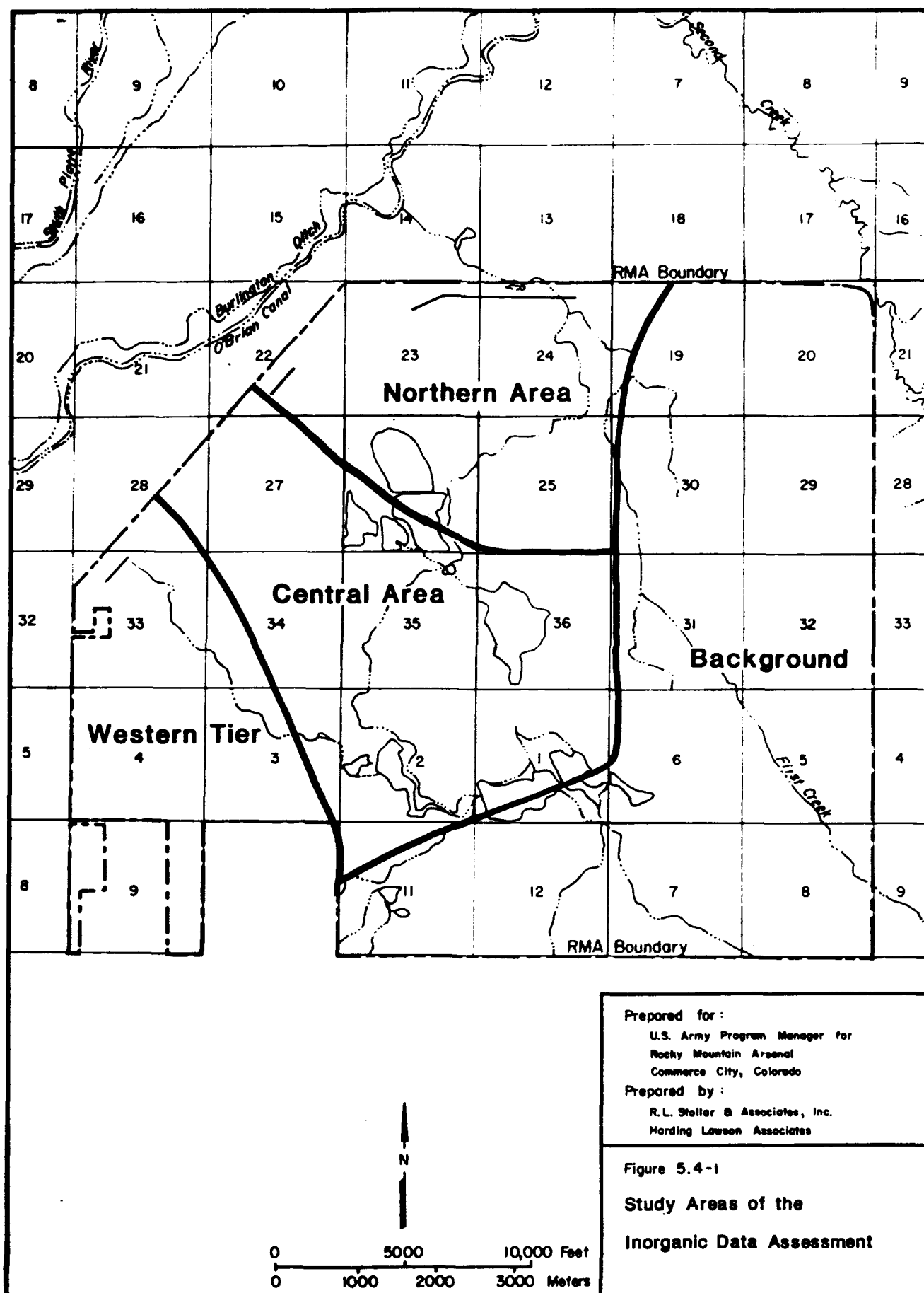
Prepared by :

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 Harding Lawson Associates

Figure 5.3.3-14

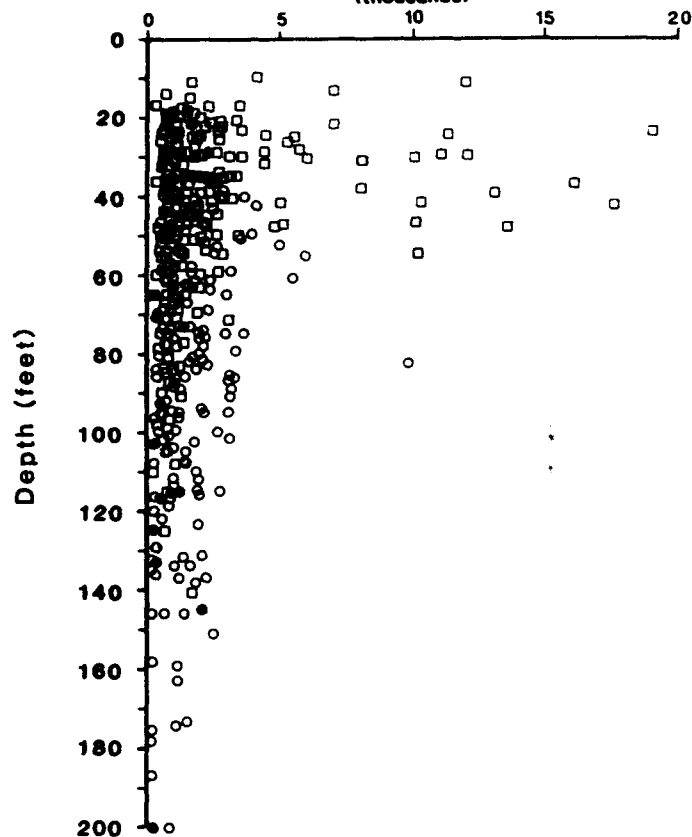
Contaminant Distribution
 Histograms for Wells Near the
 Northwest Boundary Containment
 System

CMP GVAR FY89



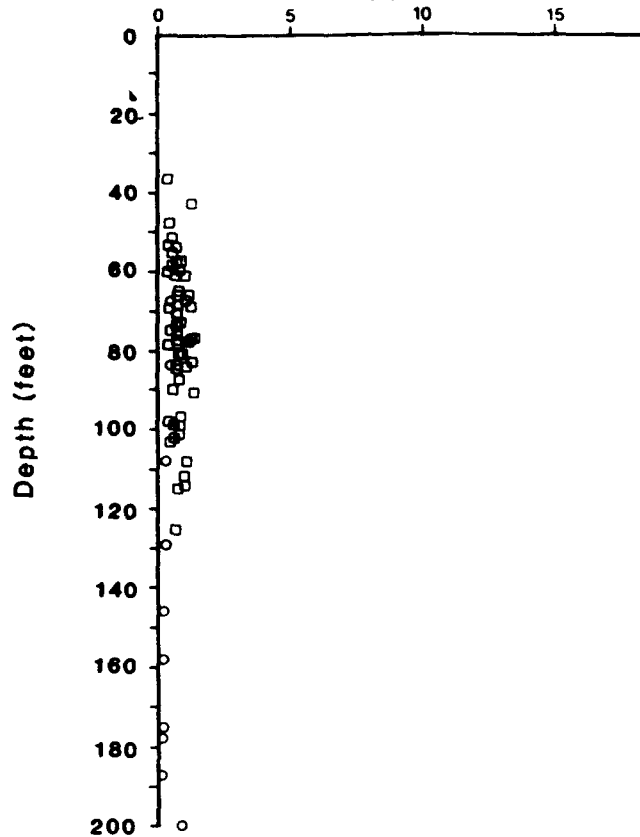
Regional/Background

Specific Conductance ($\mu\text{mhos/cm}$ @ 25°C)
(thousands)



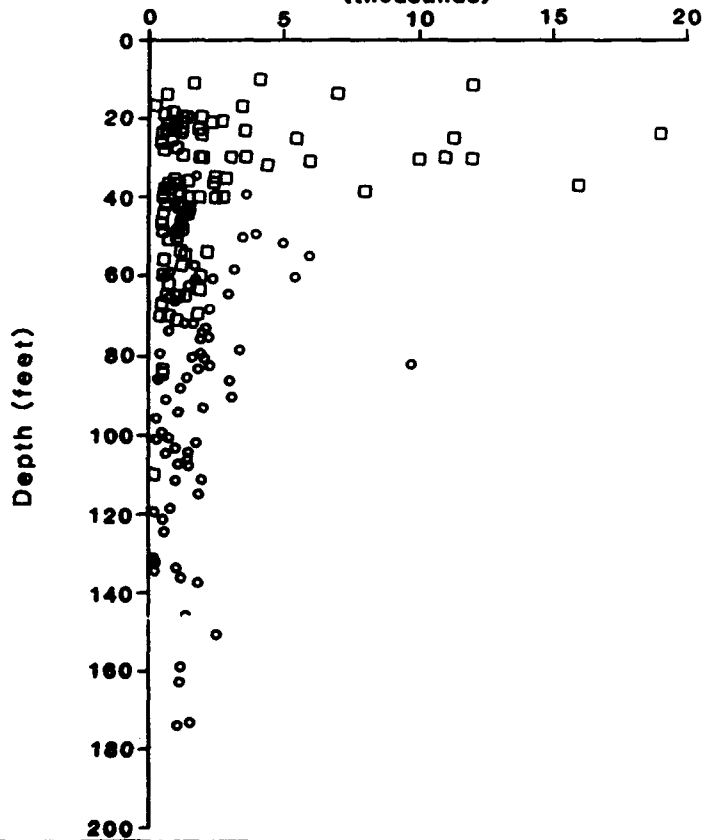
Western Tier

Specific Conductance ($\mu\text{mhos/cm}$ @ 25°C)
(thousands)



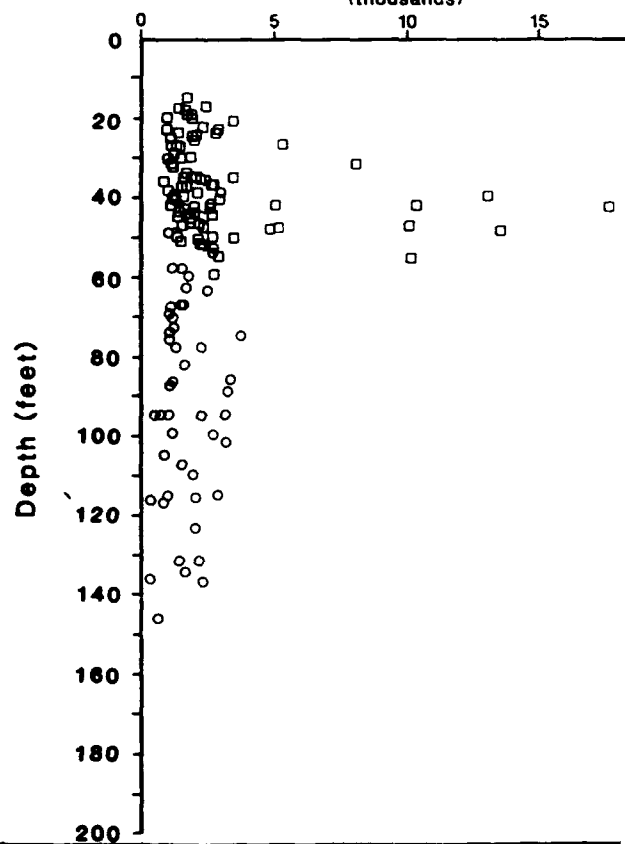
Central Area

Specific Conductance ($\mu\text{mhos/cm}$ @ 25°C)
(thousands)



Northern Area

Specific Conductance ($\mu\text{mhos/cm}$ @ 25°C)
(thousands)

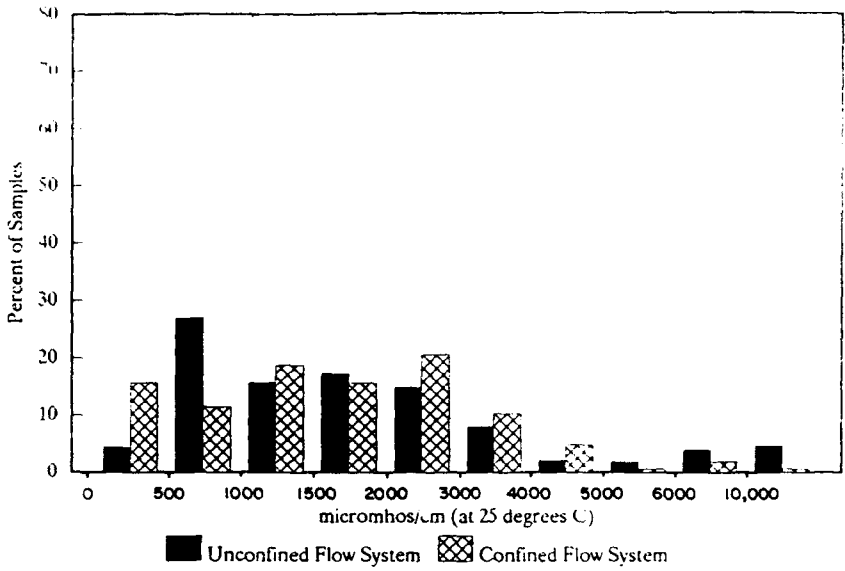


Western Tier

Specific Conductance (μmhos/cm @ 25°C)
(thousands)

10 15 20

Specific Conductance
Frequency Distribution



Northern Area

Specific Conductance (μmhos/cm @ 25°C)
(thousands)

10 15 20

Explanation

- UFS Background
- Confined Denver Formation Background
- UFS
- Confined Denver Formation

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Commerce City, Colorado

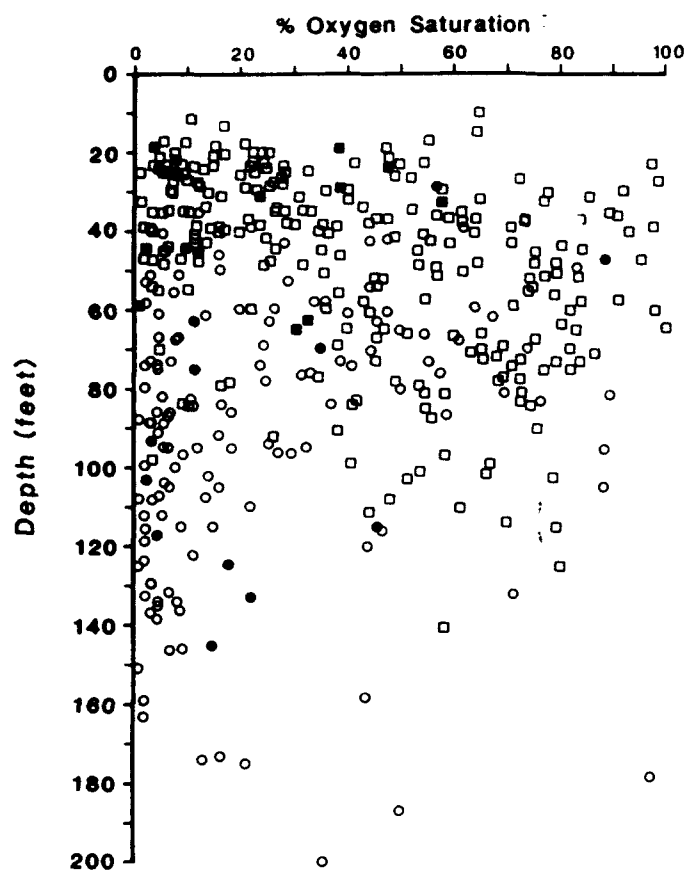
Prepared by :
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Harding Lawson Associates

Figure 5.4-2

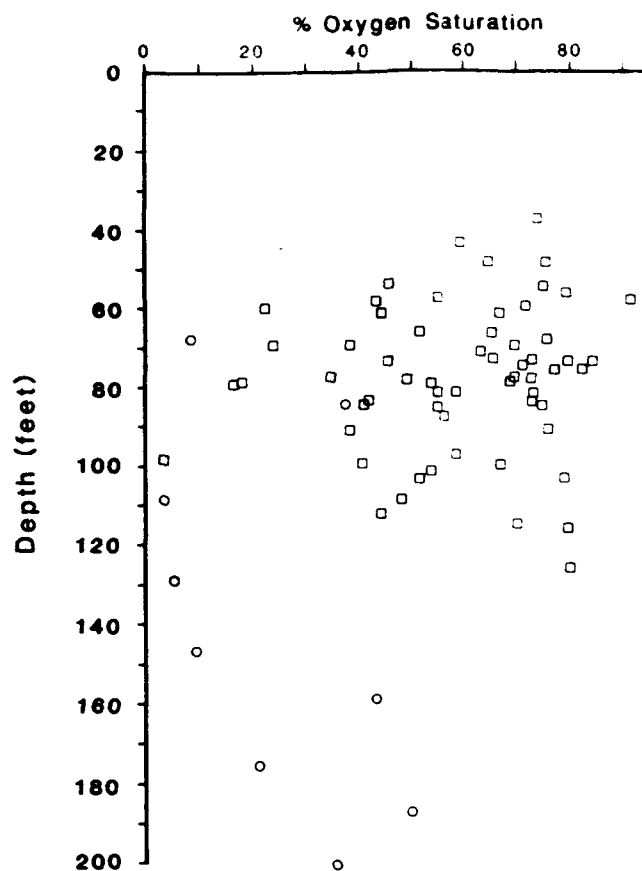
**Specific Conductance
Distribution**

CMP GVAR FY89

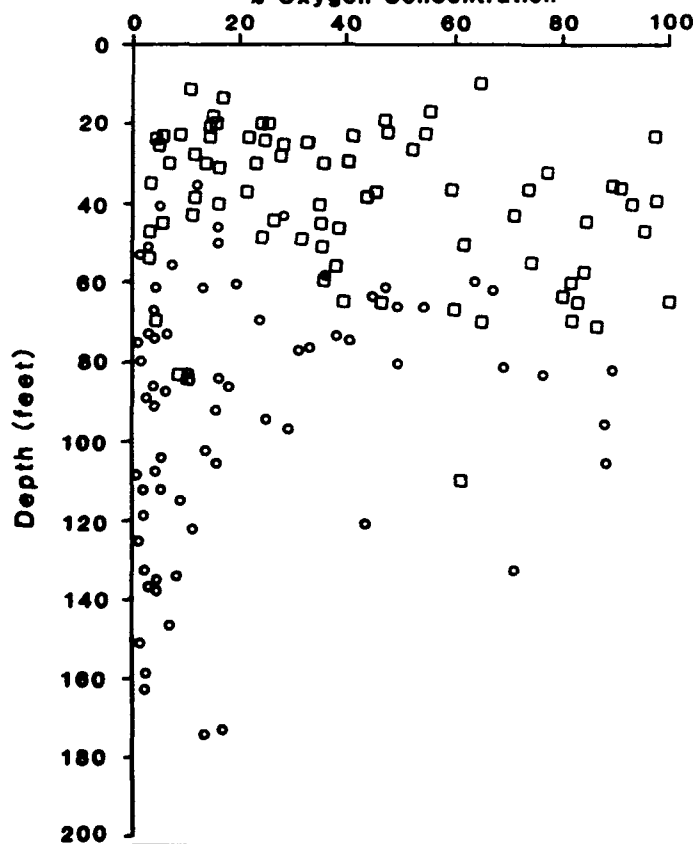
Regional/Background



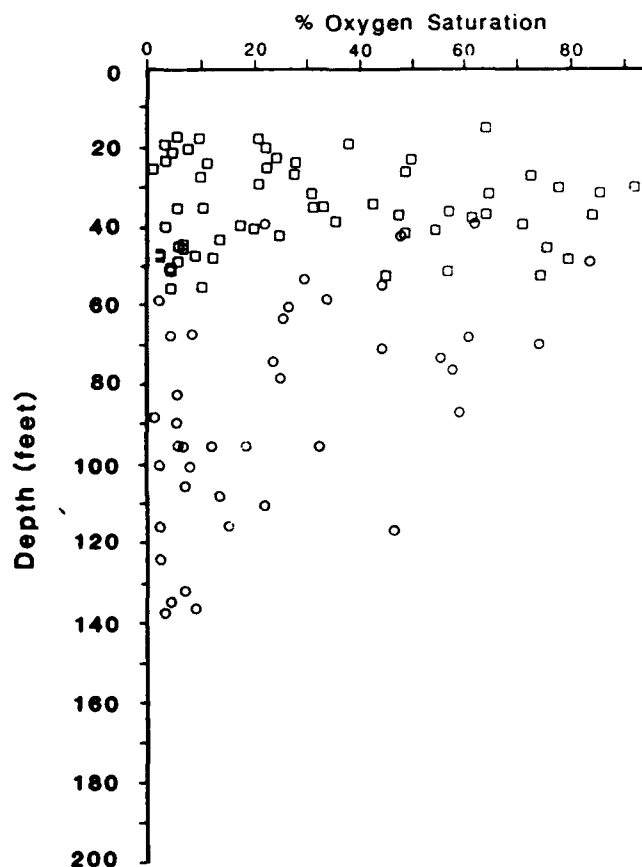
Western Tier



Central Area



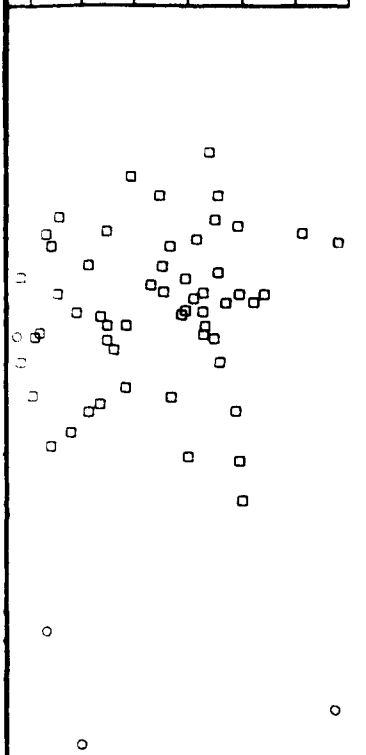
Northern Area



Western Tier

Oxygen Saturation

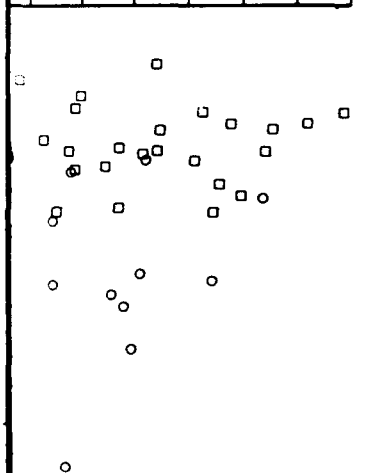
40 60 80 100



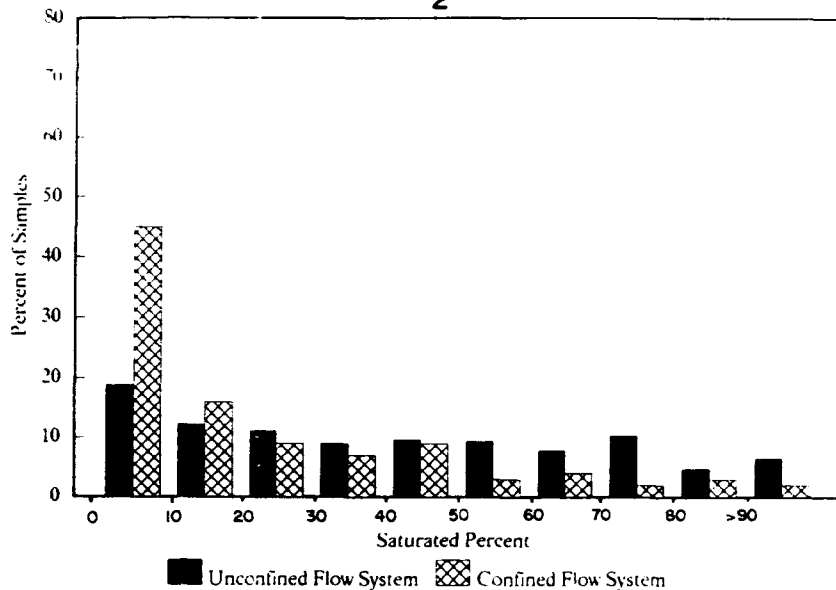
Northern Area

Oxygen Saturation

40 60 80 100



PERCENT O₂ SATURATION



Explanation

- UFS Background
- Confined Denver Formation Background
- UFS
- Confined Denver Formation

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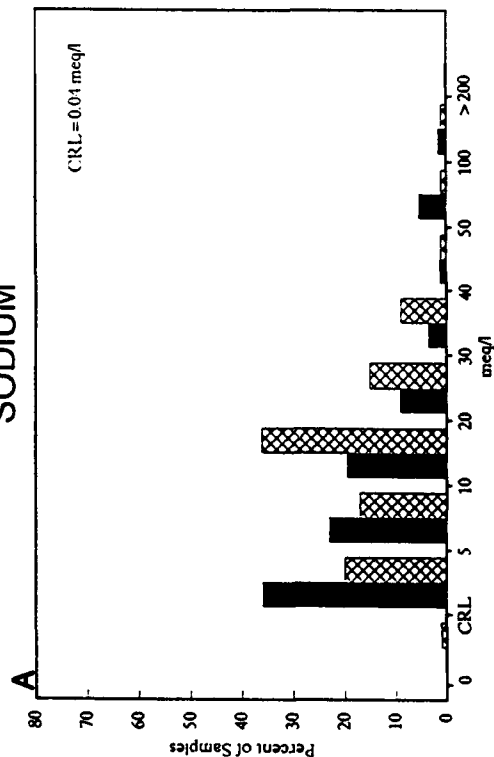
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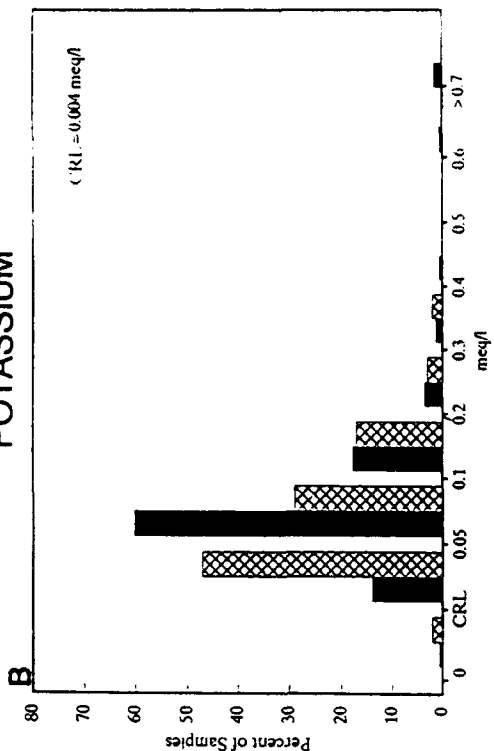
Figure 5.4-3

Percent Oxygen Saturation
Distribution

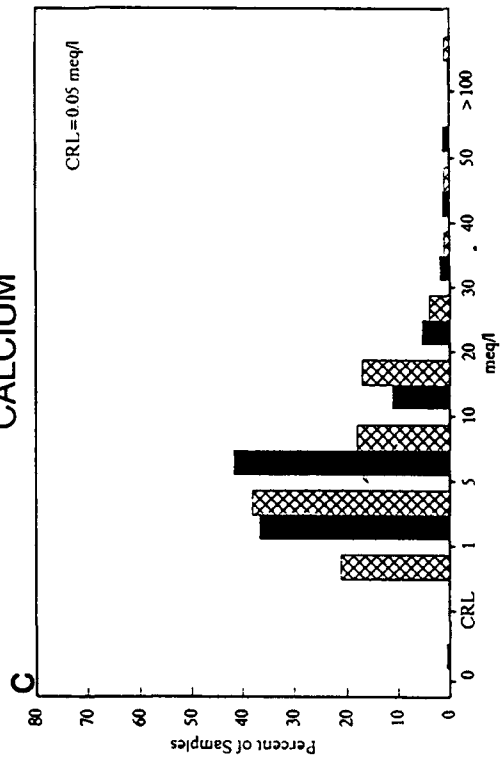
SODIUM



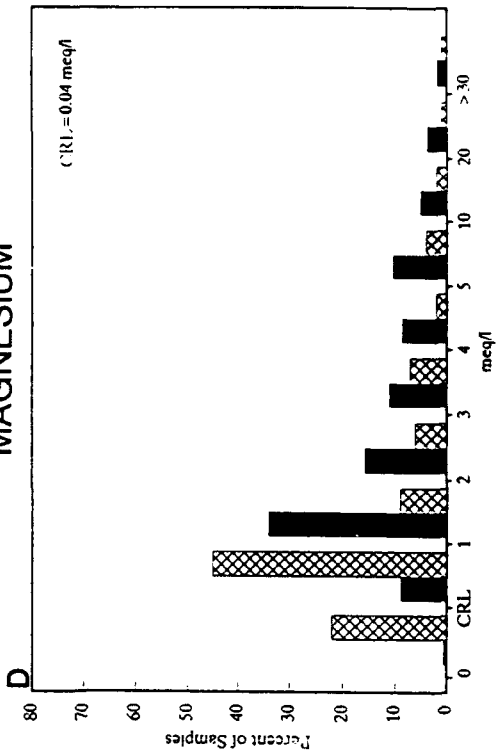
POTASSIUM



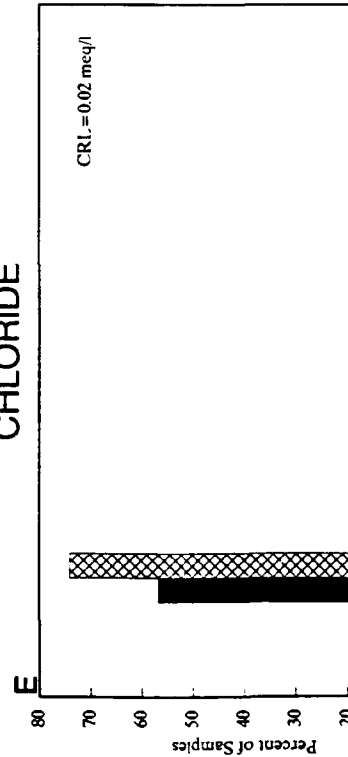
CALCIUM



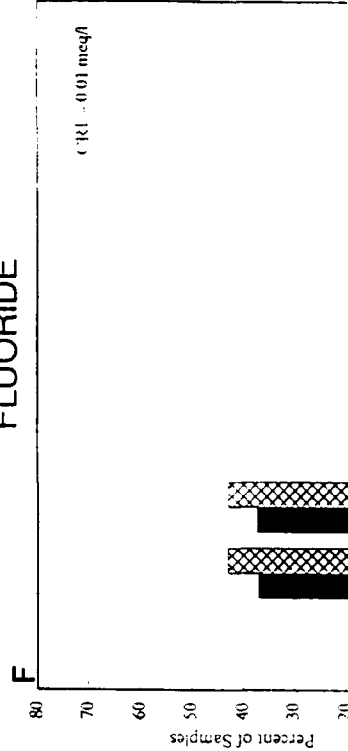
MAGNESIUM

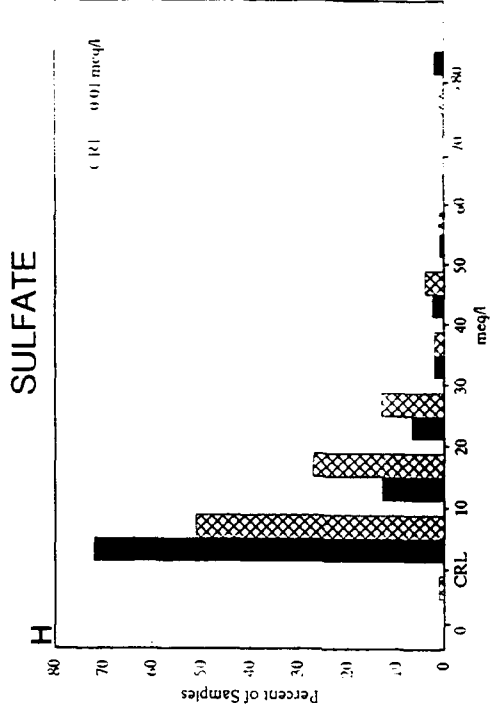
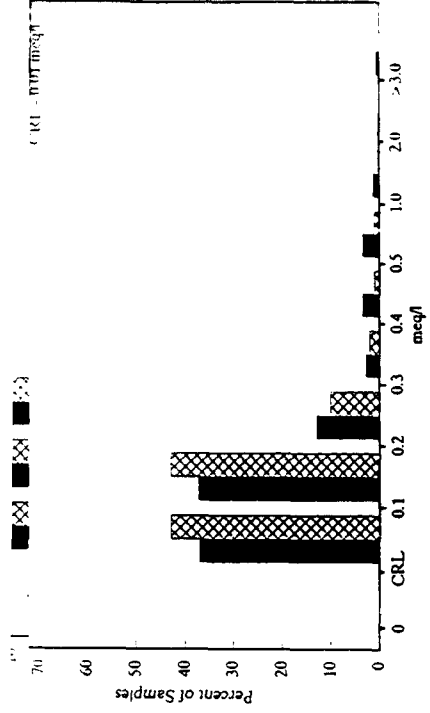
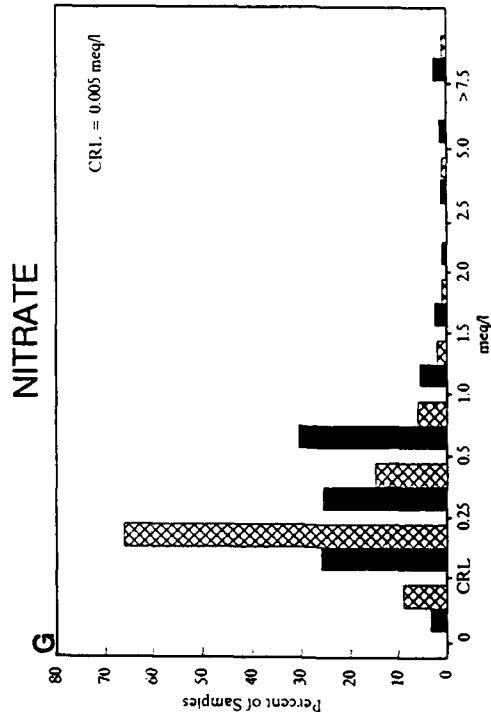
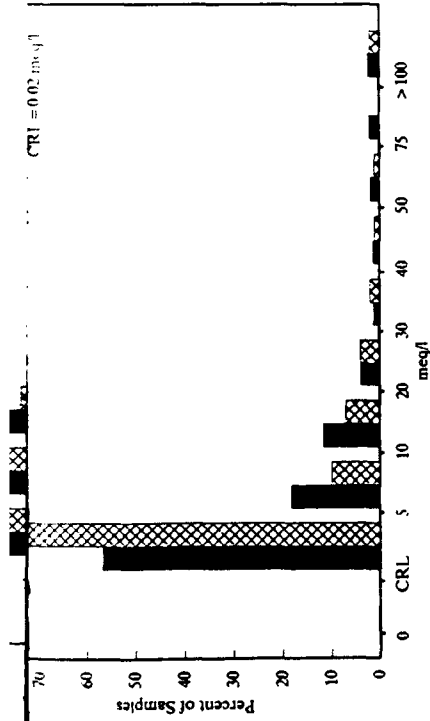


CHLORIDE



FLUORIDE





Explanation

Unconfined Flow System

Confined Flow System

meq/l milliequivalents per liter

CRL Certified Reporting Limit

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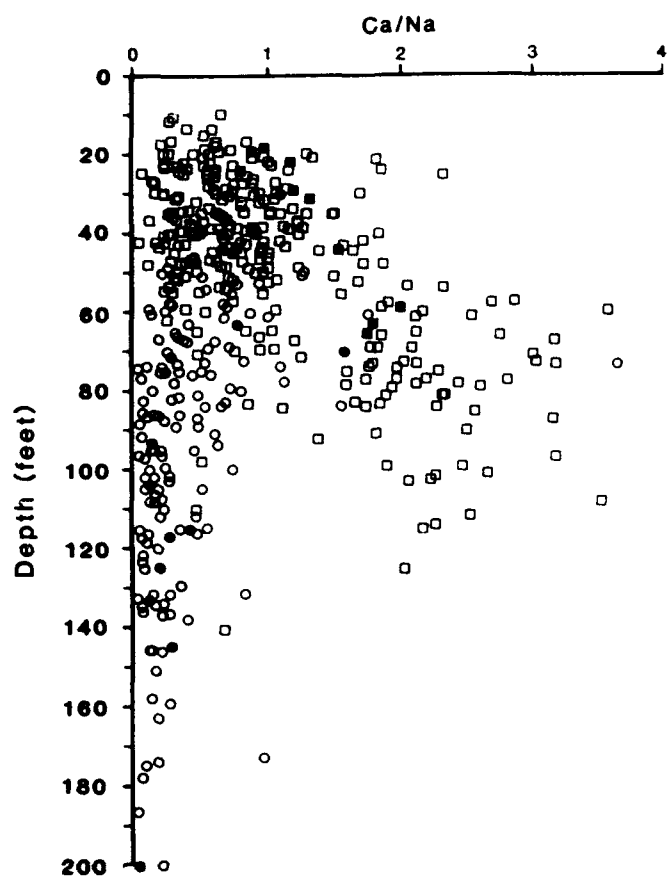
Prepared by :

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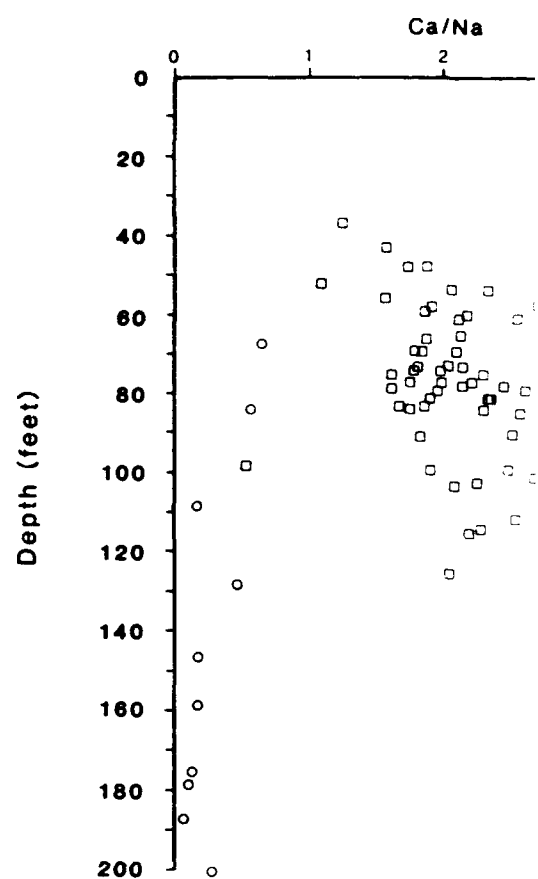
Figure 5.4-4

Inorganic Analyte Frequency
Distribution by Flow System

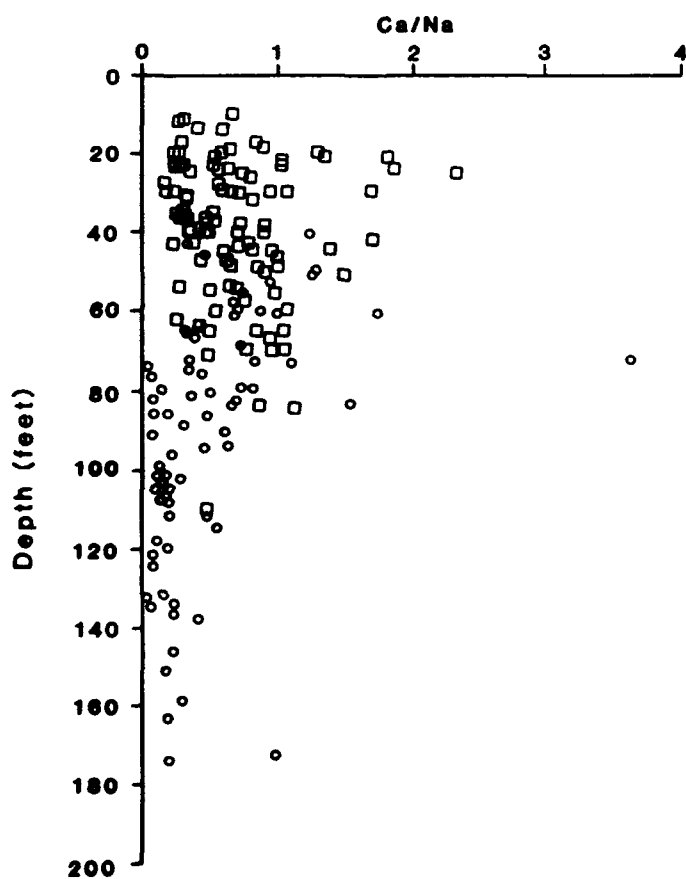
Regional/Background



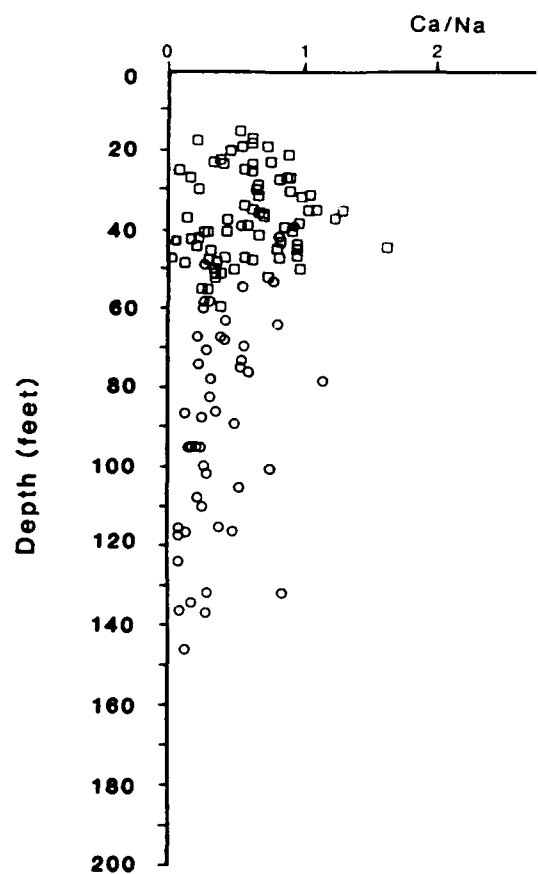
Western Tier



Central Area



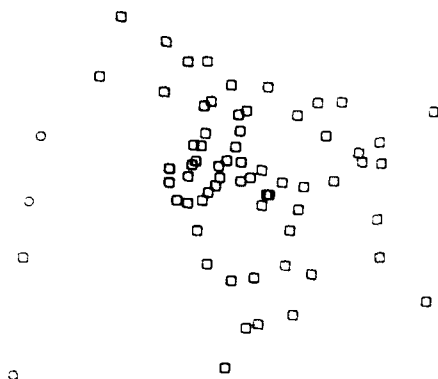
Northern Area



Western Tier

Ca/Na

1 2 3 4



Explanation

- UFS Background
- Confined Denver Formation Background
- UFS
- Confined Denver Formation

Northern Area

Ca/Na

1 2 3 4



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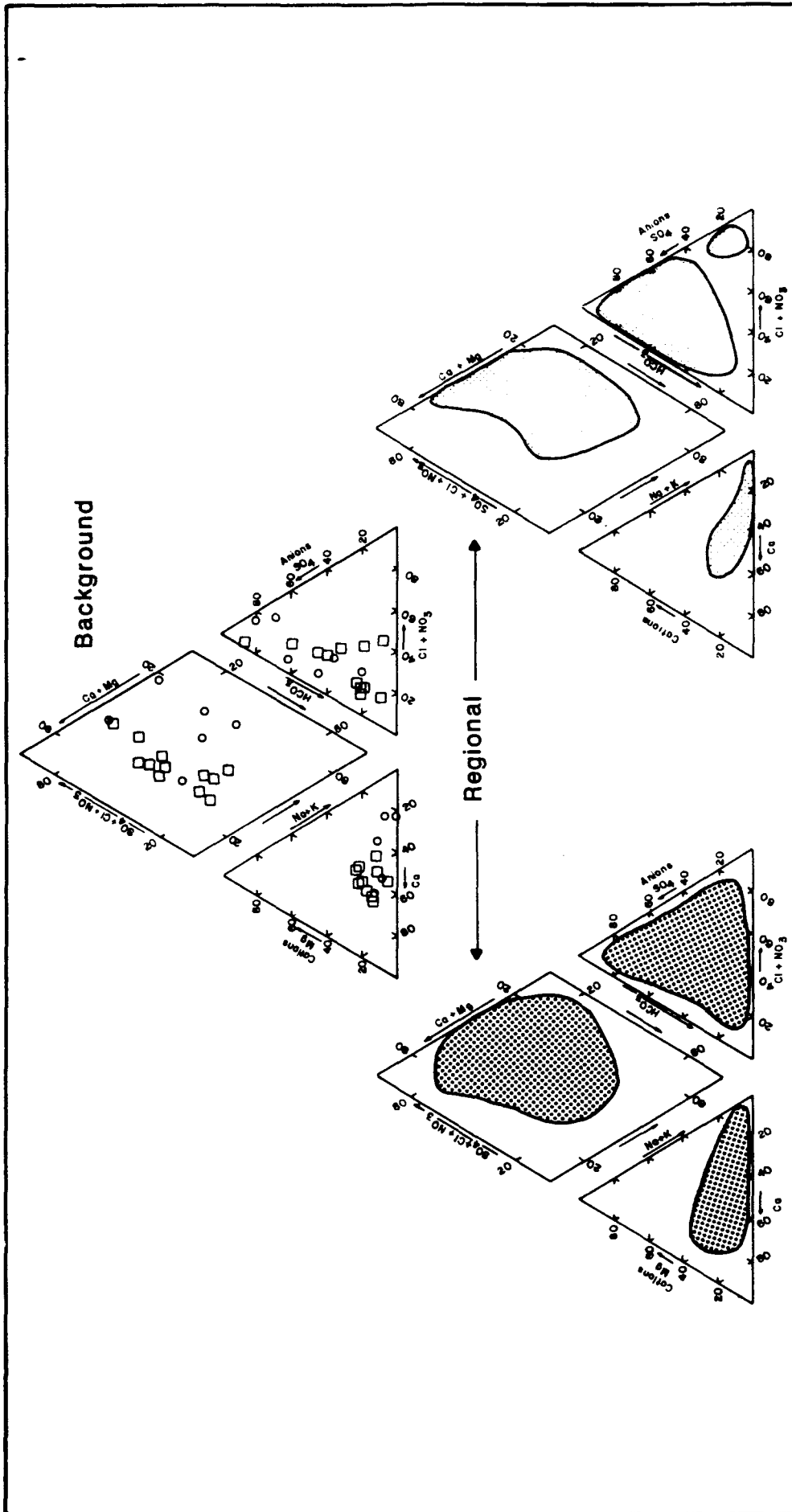
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Figure 5.4-5

**Calcium/Sodium (Ca/Na)
Ratio Distribution**



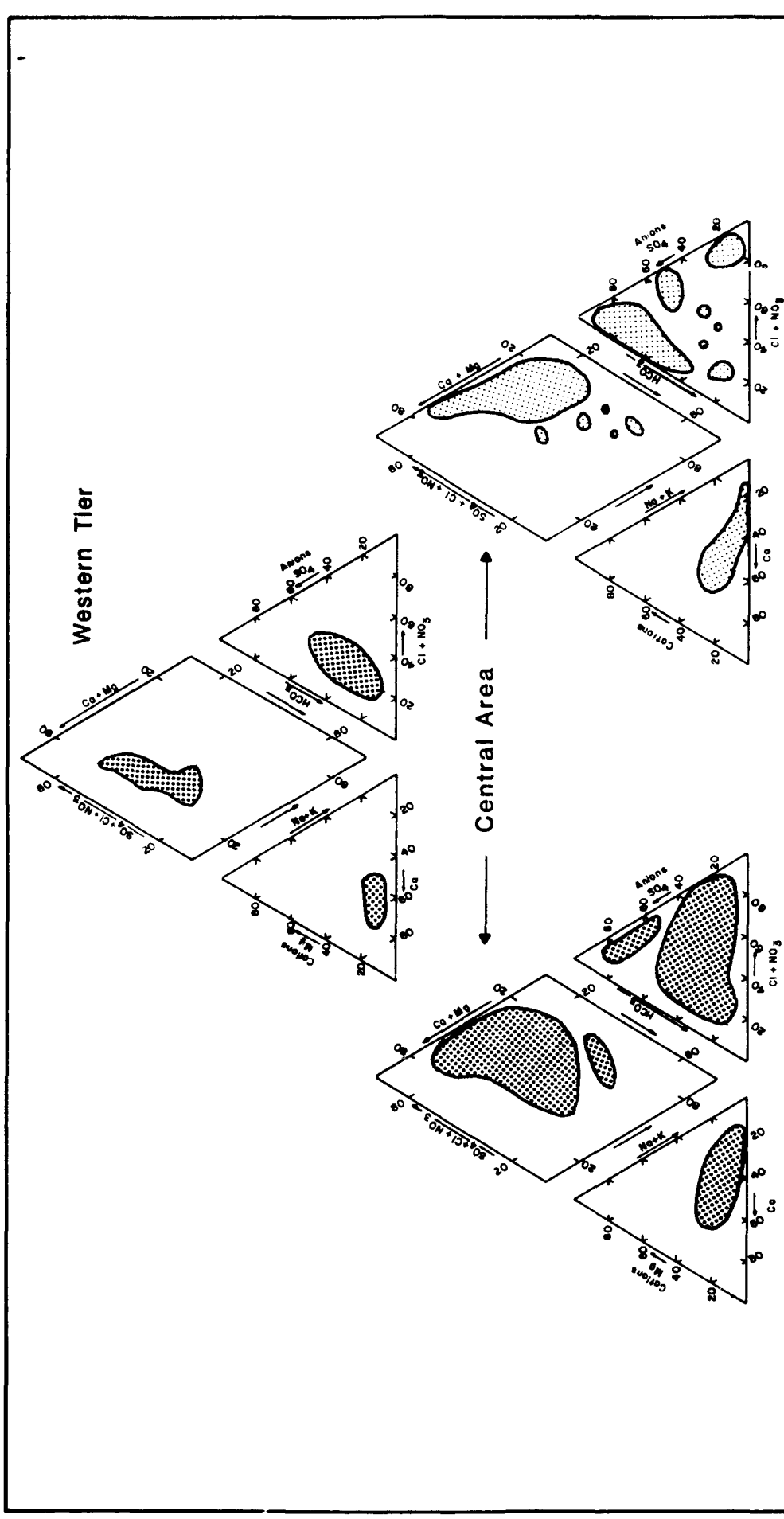
Explanation

- UFS
- Confined Denver Formation
- UFS
- Confined Denver Formation

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Figure 5.4-6
 Regional and Background
 Trilinear Diagrams



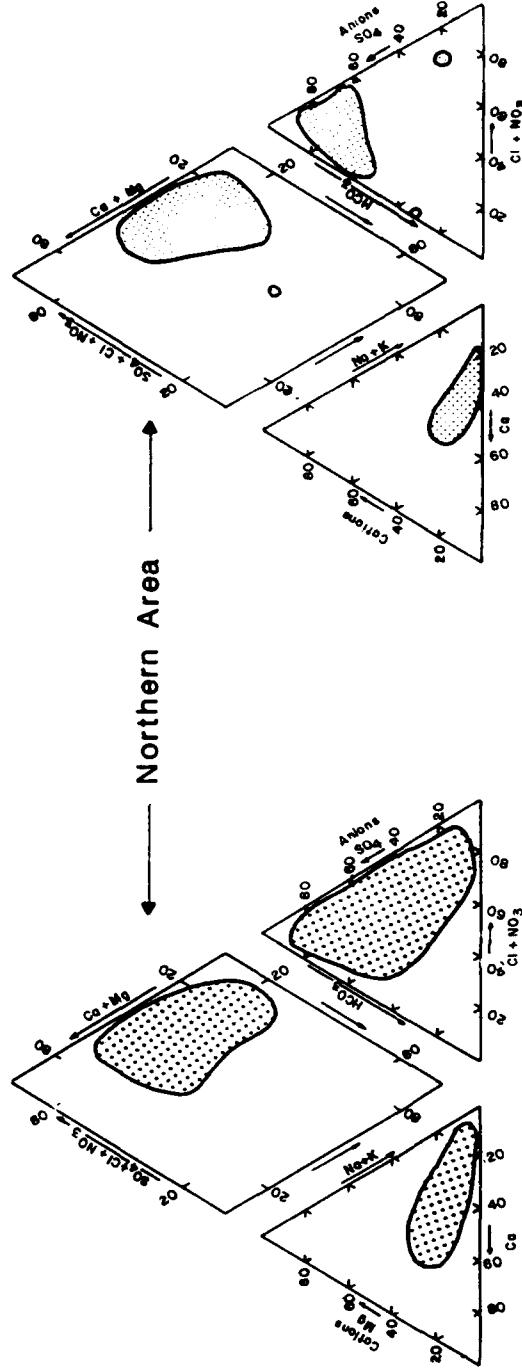
Explanation

- UFS
- Confined Denver Formation

Figure 5.4-7

Western Tier and
Central Area Trilinear
Diagrams

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Explanation

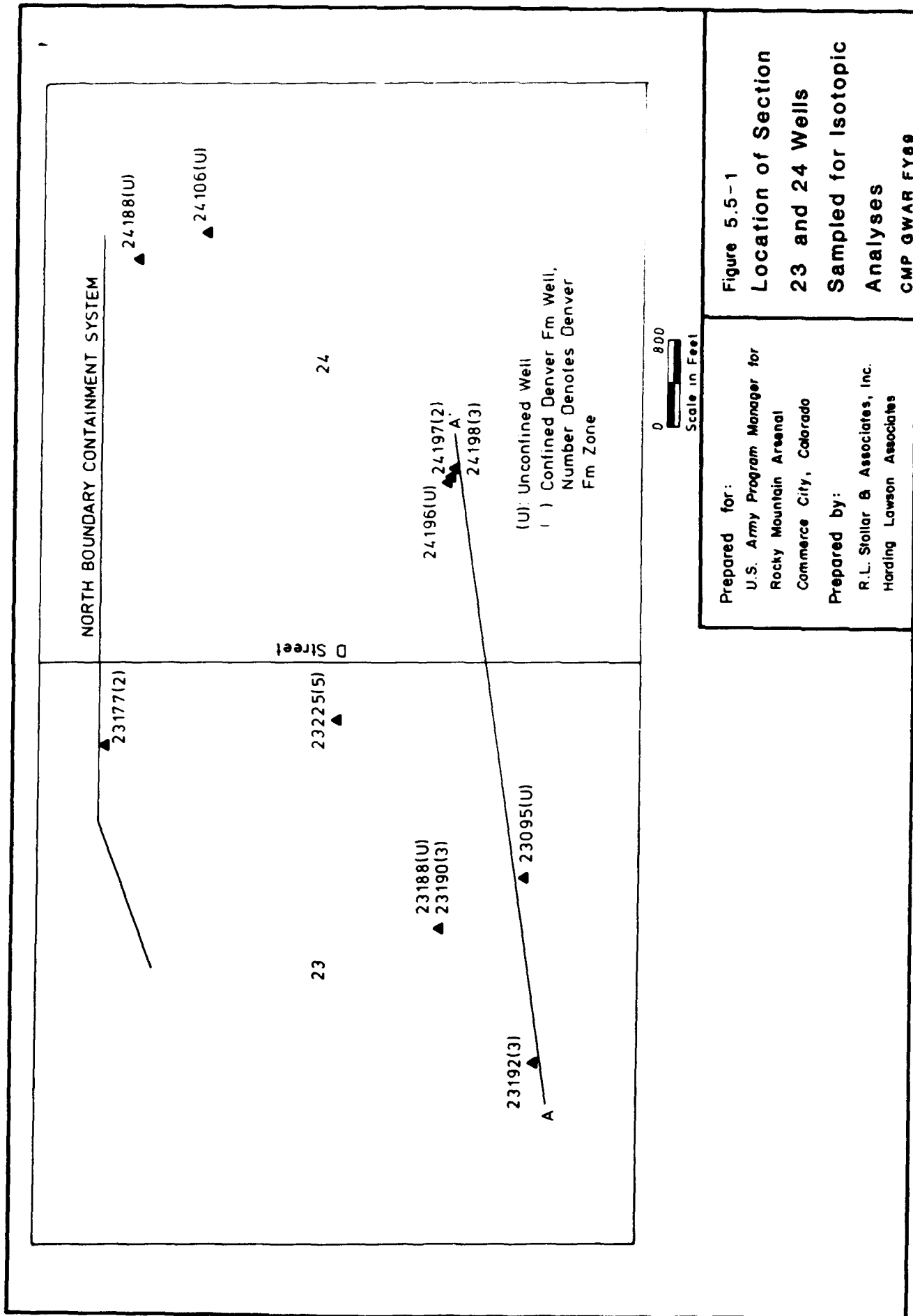
- UFS
- Confined Denver Formation

Figure 5.4-8

Northern Area
Trilinear Diagrams

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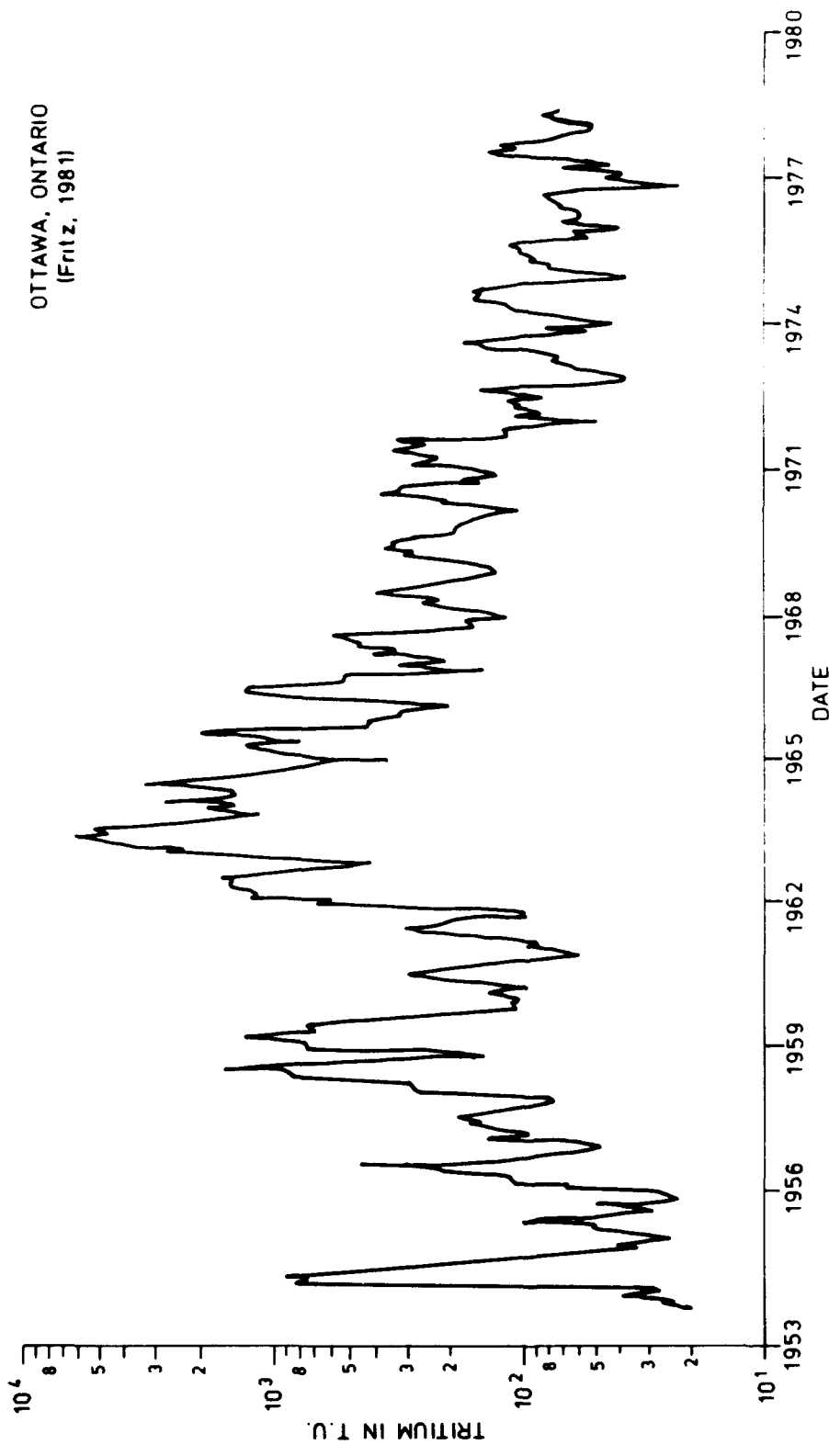


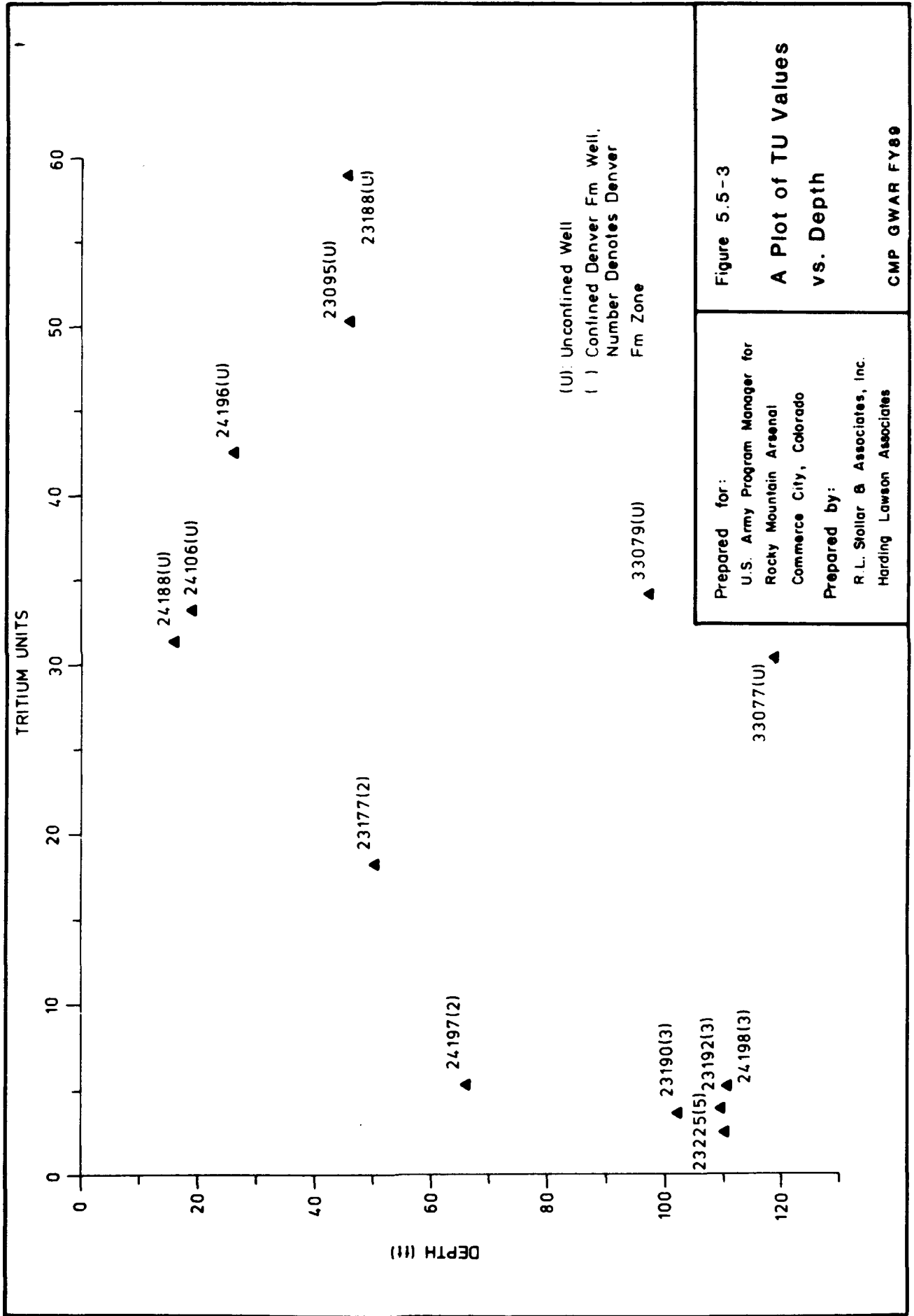
Figure 5.5-2

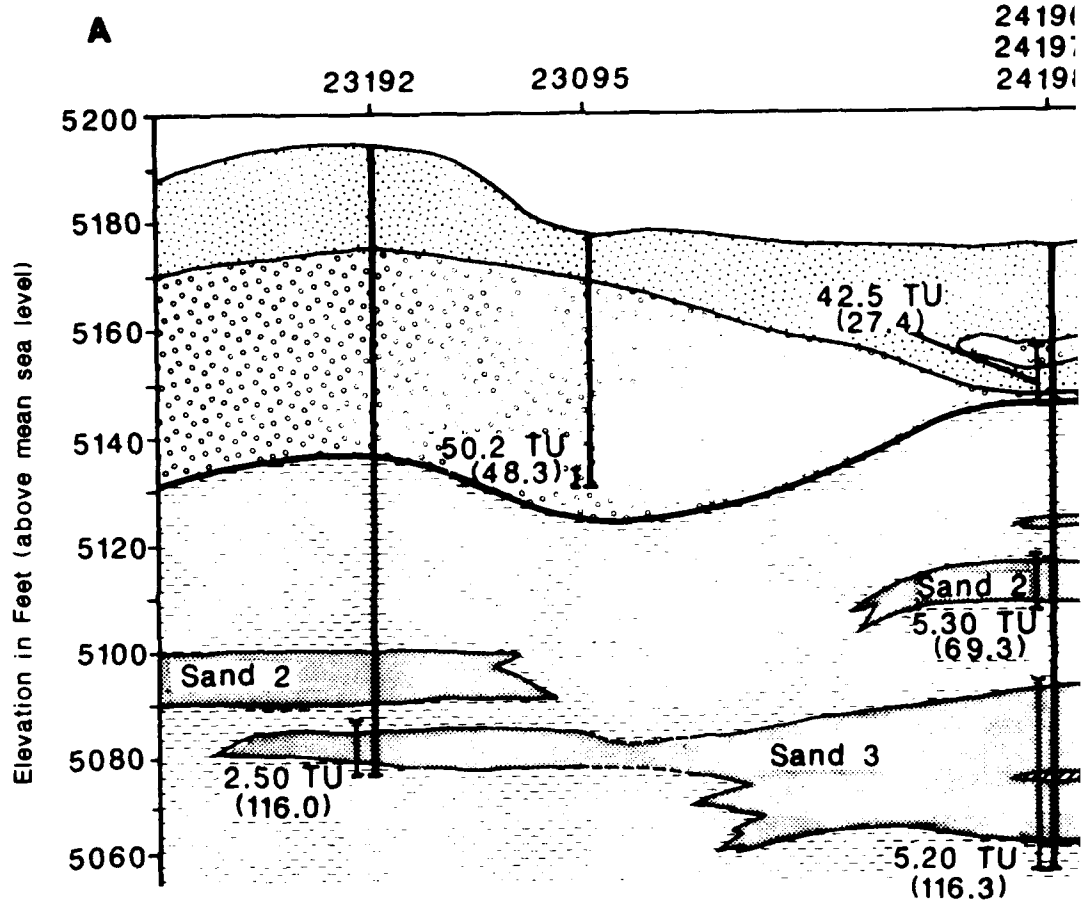
Historic Tritium Data Values

CMP GVAR FY89

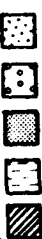
Prepared for:
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Commerce City, Colorado

Prepared by:
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Qal
Eolian And
Alluvial Deposits



Fine Alluvium

Coarse Alluvium

Sandstone Zone

Shale

Lignitic Interval

Includes: Sandstone,
Shaly Sandstone, Sandy
Siltstone, Siltstone

Includes: Shale,
Claystone, Silty Shale

SAND 1

Denver Fm
Sandstone Zone

Contact Between
Alluvium And
Denver Formation

Contact Between
Sandy Zone And
Shale In Denver
Formation

Screens

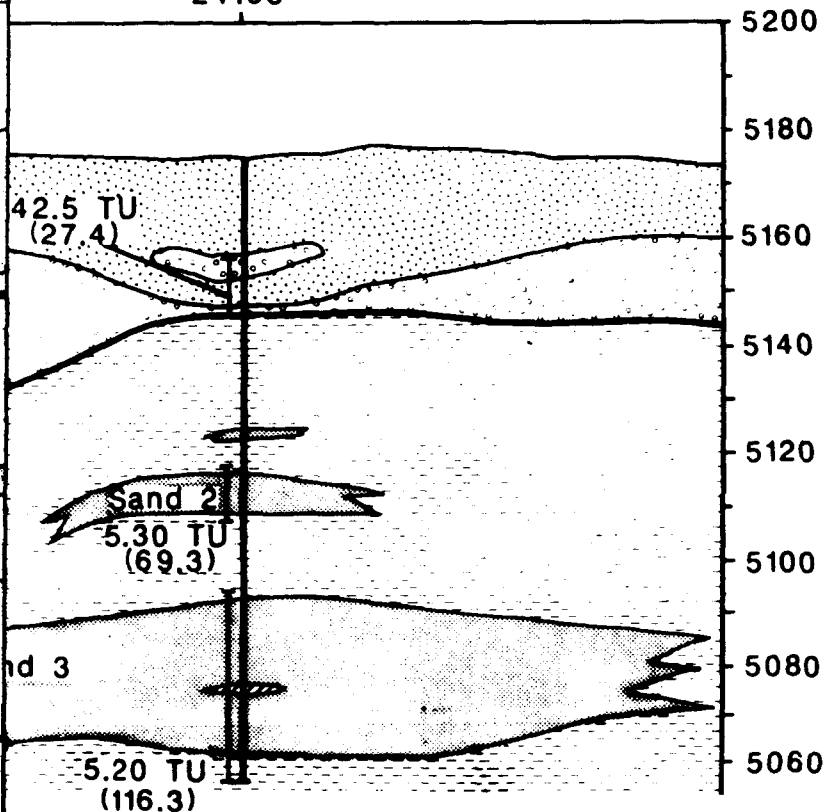
Tritium - 5.20 TU
(Depth In Feet) (116.0)

241

241

24196,
24197,
24198

A'



Well Numbers
Listed Sequentially
Down From The
Surface

0 880

Horizontal
Scale In Feet

Vertical Exaggeration
Equals 44 x

Screens

Tritium-5.20 TU
Depth In Feet) (116.0)

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Commerce City, Colorado

Prepared by :

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Figure 5.5-4

Schematic Cross Section A-A'

CMP GWAR FY89

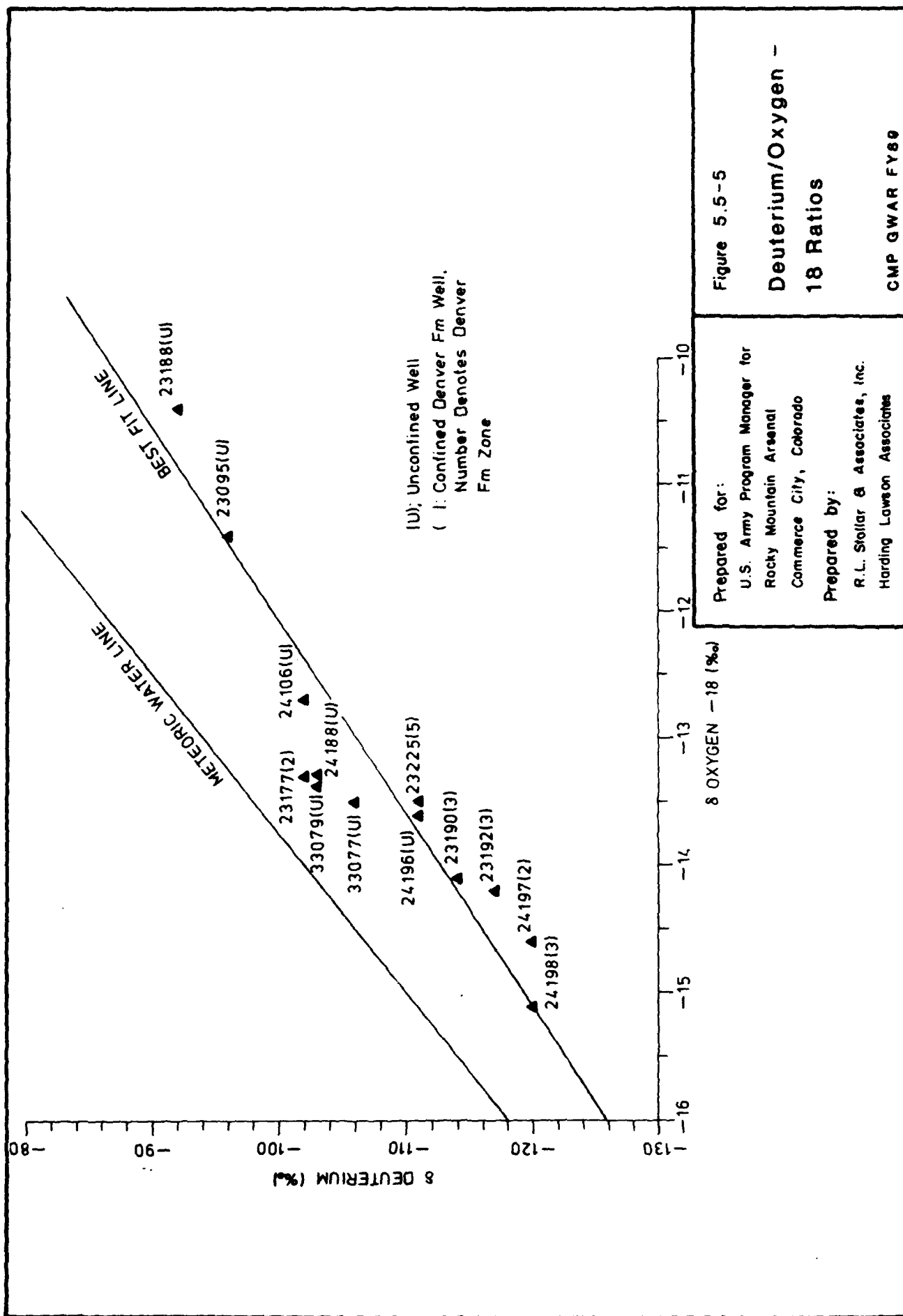


Figure 5.5-5

Deuterium/Oxygen -
18 Ratios

CMP GEAR FY80

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Prepared by:
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 Harding Lawson Associates

6.0 REFERENCES

- Ebasco Services, Inc., March, 1989a. Draft Final Report, Regional Ground-water Flow Modelling at RMA. Prepared for Program Manager, Rocky Mountain Arsenal, Commerce City, Colorado.
RIC#89144R02
- Ebasco Services, Inc., May, 1989b. Final Remedial Investigation Report, Volume XII, Western Study Area. Version 3.3.
RIC#89166R03
- Ebasco Services, Inc., June, 1989c. Final Remedial Investigation Report, Volume VI, Southern Study Area. Version 3.3.
RIC#89166R01
- Ebasco Services, Inc., June, 1989d. Final Remedial Investigation Report, Volume VII, Eastern Study Area. Version 3.3.
RIC#89166R02
- Ebasco Services, Inc., July, 1989e. Final Remedial Investigation Report, Volume VIII, South Plants Study Area. Version 3.3.
RIC#89166R04
- Ebasco Services, Inc., July, 1989f. Final Remedial Investigation Report, Volume IX, North Plants Study Area. Version 3.3.
RIC#89166R05
- Ebasco Services, Inc., July, 1989g. Final Remedial Investigation Report, Volume X, Central Study Area. Version 3.3.
RIC#89166R06
- Ebasco Services, Inc., July, 1989h. Final Remedial Investigation Report, Volume XI, North Central Study Area. Version 3.3.
RIC#89166R07
- Ebasco Services, Inc., July, 1989i. Final Water Remedial Investigation Report, Version 3.3. Prepared for U.S. Army Rocky Mountain Arsenal Program Manager, Commerce City, Colorado.
RIC#89186R01
- Environmental Science Engineering (ESE), December 1988. Boundary Control System Assessment Remedial Investigations, Draft Final Report, Version 2.1, superceded by Draft Final Report Boundary Control System Assessment Remedial Investigations, Version 2.2.
RIC#90114R01
- Environmental Science and Engineering (ESE), February, 1989. North Boundary System Component Response Action Assessment Final Report, Version 3.1, Task 36.
RIC#89103R01
- Fritz, P., April, 1981. Environmental Isotope Hydrology - Tools to Complement the Classical Techniques of Physical Hydrology and Geochemistry, University of Waterloo, Waterloo, Ontario.

REFERENCES (continued)

- Geraghty & Miller, Inc., April 1986. "Rocky Mountain Arsenal Chemical Indexes." Draft Final Report, 2 Vols. RIC#86107R01, superceded by Ebasco, Inc., May 1988. Chemical Index, 3 Vols. Prepared for U.S. Army, Rocky Mountain Arsenal Program Manager. RIC#88357R01
- Harding Lawson Associates, March 1989. Regional Ground-Water Flow modeling at the Rocky Mountain Arsenal, Denver, Colorado. Draft Final Report, Version 2.1. RIC#89144R02
- Hem, J.D., 1989. Study and Interpretation of the Chemical Characteristics of Natural Water. U.S. Geological Survey Water-Supply Paper #2254. U.S. Geological Survey.
- Hunter/Environmental Science and Engineering, Inc., 1987. RMA Analytical Results (Ground Water) for Wells Sampled October 1985 to December 1986 (unpublished). Denver: Hunter/ESE.
- Lindvall, R. M., 1980. Geological Map of the Commerce City Quadrangle, Adams and Denver Counties, Colorado. U.S. Geological Survey Map GQ-1567. Reston, Virginia: U.S. Geological Survey.
- Lutton, R.J., August, 1989. Start-Up Performance of Ground Water Recharge Trenches, Rocky Mountain Arsenal, Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi. Prepared for Program Manager, Rocky Mountain Arsenal, Commerce City, Colorado. RIC#8927701
- Program Manager, Rocky Mountain Arsenal, June 1987a, RMA North Boundary Containment/Treatment System Operational Assessment Report FY85/86. RIC#87320R01
- Program Manager, Rocky Mountain Arsenal, December 1987b, RMA Northwest Boundary Containment/Treatment System Baseline Conditions, System Startup, and Operational Assessment, FY85/86. RIC#88054R01
- Program Manager, Rocky Mountain Arsenal, July, 1989a. Chemical Quality Assurance Plan. Version 1.0. RIC#89233R01
- Program Manager, Rocky Mountain Arsenal, December, 1989b, North Boundary Containment/Treatment System Operational Assessment Report, FY88 Final Report. RIC#90061R01
- Program Manager, Rocky Mountain Arsenal, December 1989c. Northwest Boundary Containment/Treatment System Operational Assessment Report, FY88 Final Report. RIC#90061R02
- Robson, S. G., and Romero, J. C., 1981. Geologic Structure, Hydrology, and Water Quality of the Denver Aquifer in the Denver Basin, Colorado. Prepared for the Geological Survey and the Colorado Division of Water Resources.

REFERENCES (continued)

- Romero, J.C., 1976. Groundwater Resources of the Bedrock Aquifers of the Denver Basin, Colorado. Colorado Department of Natural Resources.
RIC#81266R69
- Stollar, R.L. & Associates, Inc., et al., 1989a. Comprehensive Monitoring Program Ground Water Final Technical Plan. Prepared for Program Manager, Rocky Mountain Arsenal.
RIC#89213R02
- Stollar, R.L. & Associates, Inc., et al., 1989b. Comprehensive Monitoring Program Annual Ground Water Report for 1988. Prepared for Program Manager, Rocky Mountain Arsenal.
RIC#89213R01
- Stollar, R.L. & Associates, Inc., et al., 1987. Draft Final Technical Plan Transition Monitoring Program, Ground Water. Prepared for USATHAMA.
RIC#88340R04
- USEPA Data Review Work Group, February 1988. Laboratory Data Validation - Functional Guidelines for Evaluating Organics Analyses, Prepared for U.S. Environmental Protection Agency, Hazardous Site Evaluation Division.