PROGRAM MANAGER RMA CONTAMINATION CLEANUP

U.S. ARMY MATERIEL COMMAND

— COMMITTED TO PROTECTION OF THE ENVIRONMENT —

COMPREHENSIVE MONITORING PROGRAM

Contract Number DAAA15-87-0095

FINAL SURFACE WATER DATA ASSESSMENT REPORT FOR 1990

FEBRUARY 1992

Version 4.1

Volume I

R.L. STOLLAR & ASSOCIATES, INC.
Harding Lawson Associates
Ebasco Services Incorporated
DataChem, Inc.
Enseco-Cal Lab
Midwest Research Institute

REQUESTS FOR COPIES OF THIS DOCUMENT SHOULD BE REFERRED TO THE PROGRAM MANAGER FOR THE ROCKY MOUNTAIN ARSENAL CONTAMINATION CLEANUP AMXRM ABERDEEN PROVING GROUND, MARYLAND

[redacted]

ROCKY MOUNTAIN ARSENAL • COMMERCE CITY, COLORADO • 80022-2180

COMPREHENSIVE MONITORING PROGRAM

Contract Number DAAA15-87-0095

FINAL SURFACE WATER DATA ASSESSMENT REPORT FOR 1990

FEBRUARY 1992

Version 4.1

Volume I

Prepared by:

R. L. STOLLAR & ASSOCIATES INC.
HARDING LAWSON ASSOCIATES
EBASCO SERVICES INC.
DATACHEM LABORATORIES
ENVIRONMENTAL SCIENCE & ENGINEERING, INC.
RIVERSIDE TECHNOLOGY, INC.

Prepared for:

U. S. ARMY PROGRAM MANAGER FOR
ROCKY MOUNTAIN ARSENAL

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
02/00/92

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
COMPREHENSIVE MONITORING PROGRAM, FINAL SURFACE WATER DATA ASSESSMENT REPORT FOR 1990, VERSION 4.1

5. FUNDING NUMBERS
DAAA15 87 0095

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ROBERT L. STOLLAR AND ASSOCIATES
DENVER, CO

8. PERFORMING ORGANIZATION REPORT NUMBER
92093R05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
HARDING LAWSON ASSOCIATES
DENVER, CO

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)
THE FISCAL YEAR 1990 SURFACE WATER REPORT IS DIVIDED INTO SIX SECTIONS AND TWO APPENDICES. SECTION 1 PROVIDES A BRIEF HISTORICAL REVIEW OF THE SURFACE WATER PROGRAM AT THE RMA. SECTION 2 PROVIDES THE GENERAL SETTING, THE DEFINED DRAINAGE BASIN AND SURFACE WATER FEATURES AT RMA. SECTION 3 PROVIDES A DETAILED DISCUSSION OF FY90 SURFACE WATER CMP STRATEGIES AND METHODOLOGIES. SECTION 4 PRESENTS THE WATER QUALITY AND QUANTITY DATA COLLECTED DURING FY90 IN THE MAJOR RMA DRAINAGE BASINS. SECTION 5 PROVIDES AN ASSESSMENT OF THE COLLECTED SURFACE WATER DATA. SECTION 6 PROVIDES CONCLUSIONS AND EXAMINES TRENDS OF FY90 DATA COMPARED TO PREVIOUS YEAR DATA. APPENDIX A INCLUDES INFORMATION RELATED TO SURFACE WATER QUANTITY AND APPENDIX B INCLUDES INFORMATION RELATED TO SURFACE WATER QUALITY.

14. SUBJECT TERMS
CONTAMINANTS, DRAINAGE BASINS, SAMPLING

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

TABLE OF CONTENTS

TABLE OF CONTENTS

Appendix B

EXECUTIVE SUMMARY

The Surface-Water Comprehensive Monitoring Program (CMP) at the Rocky Mountain Arsenal (RMA) during Fiscal Year 1990 (FY90) continued the same program as the Fiscal Year 1989 (FY89). The FY90 surface-water quality program included the acquisition of 66 samples from 32 locations. These samples included 28 spring, 12 fall, 22 high event and 4 Quality Assurance/Quality Control (QA/QC) samples. Sediment samples were also collected throughout RMA for qualitative and quantitative analysis. Surface-water quantity was monitored at 18 locations. This included continuous monitoring of five stream stations throughout the year. Ground-water/surface-water interaction was assessed by Surface-Water CMP along First Creek and in the South Plants Lakes and Havana Pond areas.

During FY90 32 surface-water quality locations were sampled and organic compounds were detected at 15 different sites. The site with the most organic compound detections during the spring was SW36001 (Basin A) with 26 different organic compound detections followed by SW01002 (South Plants Water Tower Pond) with 19 detections from a sample collected during a high event in the spring. The most common organic compounds, listed in order of number of sites detected, were:

- aldrin -- 6 sites
- atrazine -- 6 sites
- hexachlorocyclopentadiene (CL6CP) -- 6 sites
- diisopropylmethylphosphonate (DIMP) -- 5 sites
- chloroform (CHCL3) -- 5 sites
- endrin, chlordane, parathion, TCLEE -- 4 sites
- dieldrin, PPDDT -- 3 sites

Twenty-two high event samples were collected from 12 different locations during FY90. Thirteen of the 22 samples and seven of the 12 locations had organic detections. Atrazine was the most common organic compound and it was detected in eight samples. Organic compounds were detected in South Plants Water Tower Pond, Havana Interceptor, Peoria Interceptor and at the South Uvalda, North First Creek, First Creek Off-Post and Basin F monitoring stations.

During FY90 the most common inorganic detections, listed in order of number of sites detected, were:

- zinc (total) -- 14 sites
- arsenic (total) -- 10 sites
- copper (total) -- 6 sites
- chromium and lead (total) -- 5 sites

During FY90, 86 total suspended sediment samples were obtained from 36 sites on RMA. These samples were acquired under baseflow and high event conditions. The results that were obtained during FY90 indicate five times the amount of total suspended sediments are being deposited in the streams during a high event than during baseflow conditions.

During FY90 sediment quality analysis of stream bottom sediments was performed on 13 samples from nine locations. During FY89 organic compounds were detected in 10 samples from nine sites. In the fall, the site with the most organic detections in sediments was SW02006 (South Plants steam effluent ditch) with eight organic compounds. The most common organic detections in sediments, listed in order of number of sites detected, were:

- dieldrin -- 6 sites
- aldrin -- 5 sites
- chlordane, DBCP, isodrin -- 4 sites

During FY90 *surface-water quantity monitoring* was conducted at 18 stations located in three of five drainage basins defined on RMA. Stream stage data were recorded continuously at 12 stations and lake or pond levels were obtained weekly from five stations. A new control was constructed and continuous recording equipment was installed at Basin F Interim Response Action (IRA). Continuous stage data was recorded throughout the year which included the freezing months of December through April at five monitoring stations (Havana Interceptor, Peoria Interceptor, South Uvalda North First Creek and South First Creek).

Surface-water inflow to RMA through Irondale Gulch drainage basin continued to be measured at four stations: Highline Lateral (SW12007), South Uvalda (SW12005), Peoria Interceptor (SW11001) and Havana Interceptor (SW11002). All these stations monitor surface-water runoff originating from areas south of RMA, except Highline Lateral which monitors irrigation water diverted from the South Platte River. Highline lateral received 57 percent of the total RMA inflow water during FY90. The South Uvalda, Peoria Interceptor, and Havana Interceptor stations measure incoming surface-water from developed commercial, industrial and residential areas. These stations recorded 27 percent of the total RMA inflow water. In addition, stream flow and lake levels within Irondale Gulch drainage basin were measured at eight stations. Flow stations were North Uvalda (SW01001), Ladora Weir (SW02001) and South Plants Ditch (SW01003). These stations monitor surface-water flow to and from the South Plants Lakes. Water levels were measured at Upper Derby Lake (SW01004), Lower Derby Lake (SW01005), Ladora Lake (SW02003), Lake Mary (SW02004) and Havana Pond (SW11003).

Surface-water flow within the First Creek drainage basin along First Creek is monitored at three locations. South First Creek monitoring station (SW08003) measures inflow from southeast off-post sources, North First Creek monitoring station (SW24002) measures stream flow leaving RMA and First

Creek Off-Post monitoring station (SW37001) measures flow between the northern RMA boundary and Highway 2. The South First Creek monitoring station recorded 16 percent of the total RMA inflow. Of this flow less than half was recorded as outflow at the North First Creek monitoring station.

Surface-water was measured in the South Platte drainage basin at Basin A monitoring station (SW36001) and at the new Basin F monitoring station. The Basin A station is used to monitor runoff originating from South Plants area and ground-water seepage. The Basin F monitoring station recorded three separate high event flows during the year.

Surface-water quantity analyses included evaluation of stream flow characteristics and extremes, as well as calculation of mean monthly, maximum daily and minimum daily flows. Stream flow hydrographs were analyzed to describe flow conditions in response to six storms that occurred during FY90.

This report also contains information on ground-water and surface-water interaction in the South Plants Lakes area, Havana Pond area and along First Creek. This study involved the hydrographic analysis of surface-water locations and ground-water wells located in these areas. A gain/loss assessment along First Creek was performed in June and August to determine if there were any seasonal variability in surface-water/ground-water interaction in the creek. The data indicated significant interaction in the South Plants Lakes area, Havana Pond area and along First Creek. The South Plants Lakes and nearby wells indicate similar water levels suggesting interaction as has been suggested in previous years. Havana Pond storage volume infiltrates at a rate of approximately 35 acre-feet within 7 days. First Creek gain/loss data indicates that the creek is influent or effluent at different times of the year and at different locations along the creek.

1.0 INTRODUCTION

The Comprehensive Monitoring Program (CMP) is designed to provide both continual and long-term monitoring of ground water, surface water, air, and biota. Each environmental medium is being monitored within a separate program element. Each element has detailed objectives, outlined in respective technical plans, which establish monitoring guidelines, analytical parameters, and sampling protocol and strategies.

The purpose of the surface-water element of the CMP at Rocky Mountain Arsenal (RMA) is to:

- Monitor surface-water quality and surface-water hydrology for the assessment of rates and potentials of contaminant migration in both on-post and off-post areas;

- Maintain a regional surface-water monitoring program to support and verify the Remedial Investigation/Feasibility Study (RI/FS) program;

- Maintain a regional surface-water monitoring program as part of the surface-water management program at RMA; and

- Characterize and monitor quality and quantity of surface water flowing onto and off of RMA.

The Fiscal Year 1990 (FY90) Surface-Water Report is divided into six sections and two appendices. FY90 is defined as the period from October 1, 1989, to September 30, 1990. The use of Water Year 1990 in this report also corresponds to the same time period as FY90 (October 1, 1989, to September 30, 1990). The two terms are used interchangeably throughout this report. Section 1 provides a brief historical review of the surface-water program at the RMA . The general setting, the defined drainage basins and surface-water features at RMA as well as their general characteristics and interrelationships are presented in Section 2. The positioning of the surface-water quantity monitoring stations and the surface-water quality sampling locations relative to major RMA drainage basins are also discussed in this section. Section 3 provides a detailed discussion of FY90 Surface-Water CMP strategies and methodologies. Section 4 presents the water-quality and-quantity data collected during FY90 in the major RMA drainage basins. An associated assessment of the procedures used while collecting and reviewing some of the data is also included in this section. Section 5 provides an assessment of the collected surface-water data. Surface-water quality and quantity issues are addressed and include a comparison of FY90 program results to Fiscal Year 1988 (FY88) and Fiscal Year 1989 (FY89) results. Section 6 provides conclusions and examines trends of FY90 data compared to previous years' data. Appendix A includes information related to surface-water quantity and Appendix B includes information related to surface-water quality.

1.1 Site Background

The RMA occupies approximately 27 square miles (sq mi) in south Adams County, Colorado, and is located about 6 miles (mi) northeast of downtown Denver (Figure 1.1-1). Before RMA was built in 1942, land in the area was used principally for dry farming, some irrigated farming and cattle grazing. At various times from 1942 to 1946, the U.S. Army produced chemical and incendiary weapons for use in World War II. Chemical agents were also produced from 1953 to 1957. Munitions-filling operations continued at RMA until late 1969 (Ebasco Services, Inc., et al., 1989a). From 1970 to 1982, Army operations at RMA centered on demilitarization of chemical weaponry. Between 1946 and 1982, parts of RMA were leased to private companies involved in chemical manufacturing. The two principal lessees, Julius Hyman and Company and Shell Chemical Company, manufactured a variety of pesticides, insecticides, herbicides and soil fumigants (Ebasco Services, Inc., 1988a).

Land use surrounding RMA is variable. Mixed residential housing and light industrial manufacturing facilities are present along its western and southern borders. A part of Stapleton International Airport's (Stapleton Airport) north-south runway system extends into the southwest part of RMA. Land north and east of RMA is used mainly for farming and ranching. Principal RMA surface-water features are shown on Figure 1.1-2.

1.2 Pre-CMP RMA Surface-Water Programs

A detailed review of the historical development of the RMA surface-water program is presented in the RMA Surface-Water Historical Report. The review consisted both of documenting previous programs' activities and evaluating the reported data. This section provides a brief review of Pre-CMP activities. Table 1.2-1 provides a synopsis of these surface-water programs.

The present surface-water monitoring program has evolved from a series of programs and studies originating in 1975. The first sampling program implemented at RMA used monitoring wells and surface-water sites both within and around the Arsenal. Sampling was initiated because of organic solvents and phthalate esters detected in RMA wells by the Colorado Department of Health. It was believed that sources outside RMA might be contributing to the contamination. This initial program was called the Revision I-360° Monitoring Program (United States Army, 1977). Participants included the U.S. Army, Shell Chemical Company and the Colorado Department of Health. The 360° Monitoring Program was initiated in January 1976 and included a combined total of 124 ground-water monitoring wells and surface-water sites on or adjacent to RMA. Additionally, five off-post surface-water sites and 24 private wells were selected by the Tri-county District Health Department (Environmental Sciences and Engineering (ESE), 1986a). In November 1976 the program was revised, resulting in analyses being conducted quarterly for 12 surface-water locations on RMA and 10 off-post sites. Under this new

Table 1.2-1 Chronology of RMA Surface-Water Monitoring

Date	Organizations Responsible for Monitoring	Program Name and Activities
January 1976 - November 1976	1	Revision I-360° Program . Surface- and ground-water sampling both on- and off-post
November 1976 - 1982	1	Revision II-360° Program . Surface- and ground-water sampling quarterly, both on- and off-post
1983 - 1985	2	Revision II-360° Program . Surface- and ground-water sampling quarterly, both on- and off-post
1981 - 1982	Resource Consultants, Inc.	. Delineate watersheds and major flow paths . Calculate a water balance based on estimated flows

1 - Data collected by Tri-County Health Department; Colorado Department of Health; Shell Chemical Company; RMA Personnel

2 - Data collected by Tri-County Health Department; Colorado Department of Health; RMA Personnel

Table 1.2-1 Chronology of RMA Surface-Water Monitoring (continued)

Date	Organizations Responsible for Monitoring	Program Name and Activities
Spring 1982	Resource Consultants, Inc.	. Install gaging stations at South First Creek, South Uvalda Interceptor, Basin A inflow, Ladora Weir, North Uvalda Interceptor (relocated) and South Plants Ditch . 7 gaging stations in place and being monitored for stage and discharge
October 1982 - September 1983	Resource Consultants, Inc.	. Gaging stations installed on Peoria Interceptor, Havana Interceptor and North First Creek . North Uvalda station moved to present location . Staff gage installed at Havana Pond . 10 gaging stations in place and being monitored for stage and discharge
May - December 1984	Jack Dildine (Waterways Experiment Station); Bill Krupke (subcontractor)	. Installation of concrete control structures at South Uvalda, North Uvalda, South First Creek, North First Creek and Peoria Interceptor

Table 1.2-1 Chronology of RMA Surface-Water Monitoring (continued)

Date	Organizations Responsible for Monitoring	Program Name and Activities
December 1985 - April 1986	ESE	Revision III-360° Program . Surface- and ground-water sampling off-post Task 4 - Water Quantity/Quality Survey Program . Monitoring at 10 gaging stations for stage and discharge . 30 sites designated for sampling . Installation of 2 rain gages on RMA
September 1985 - February 1986	ESE; Resource Consultants, Inc. (subcontractor)	Task 4 - Initial Screening Program . Repair and rehabilitation of existing recording stations . Install staff gage on Lake Mary . Monitor water-surface elevations weekly on Upper and Lower Derby, Ladora Lake and Lake Mary . Monitor 11 gaging stations for stage and discharge . 16 on-post surface-water sites sampled

Table 1.2-1 Chronology of RMA Surface-Water Monitoring (continued)

Date	Organizations Responsible for Monitoring	Program Name and Activities
December 1985 - January 1986	ESE; Resource Consultants, Inc. (subcontractor)	Task 4 - Final Screening Program . Addition of a recording station off-post on North First Creek . 12 recording stations in place and monitored for stage and discharge . Monitor surface-water elevations on Upper and Lower Derby, Ladora Lake and Lake Mary on a weekly basis . 46 on-post sites designated for quarterly sampling . 19 on-post and 11 off-post surface-water sites sampled during 3rd Quarter FY86 . 21 on-post and 9 off-post surface-water sites sampled during 4th Quarter FY86
December 1986 - September 1987	ESE	Task 39 - Off-Post Remedial Investigation/Feasibility Study . 11 off-post surface-water sites designated for sampling

Table 1.2-1 Chronology of RMA Surface-Water Monitoring (continued)

Date	Organizations Responsible for Monitoring	Program Name and Activities
March 1987 - November 1987	ESE Resource Consultants, Inc. (subcontractor)	Task 44 . 12 recording stations in place and monitored for stage and discharge . Monitor water surface elevations on Upper and Lower Derby, Ladora Lake and Lake Mary . 40 sites designated for quarterly sampling on- and off-post
April 1988 - September 1988	R.L. Stollar & Associates, Inc. Harding Lawson Associates (subcontractor)	*Comprehensive Monitoring Program* . Monitor existing 10 recording stations for stage and discharge (North First Creek station destroyed July 1987, First Creek Off-Post station inoperative due to non-functioning control structure) . Monitor water surface elevations on Upper and Lower Derby, Ladora Lake, and Lake Mary . Monitor totalizing flow meter at Sewage Treatment Plant effluent discharge location . 35 sites designated for sampling on- and off-post

Table 1.2-1 Chronology of RMA Surface-Water Monitoring (continued)

Date	Organizations Responsible for Monitoring	Program Name and Activities
October 1988 - September 1989	R.L. Stollar & Associates, Inc. Harding Lawson Associates (subcontractor) Riverside Technology, Inc. (subcontractor)	Comprehensive Monitoring Program (FY89) . Continued FY88 Program . Added new monitoring stations and control at South First Creek, North First Creek, and First Creek Off-Post
October 1989 - September 1990	R.L. Stollar & Associates, Inc. Harding Lawson Associates (subcontractor) Riverside Technology, Inc. (subcontractor)	. Continued FY89 Program . Added new monitoring station at Basin F IRA

program, identified as the Revision II-360° Program, the network of off-post surface-water sites established in the original Revision I-360° Program remained essentially the same (U.S. Army, 1977). With the closing of Shell Chemical Company's facilities at RMA in 1982, Shell's participation in the program was reduced (Ward, 1984). The Revision III-360° Program, implemented in 1985, consisted of 11 off-post surface-water sampling sites (ESE, 1986a).

The first comprehensive monitoring effort directed at understanding surface-water flow conditions at RMA began in 1982 by an Army contractor, Resource Consultants, Inc. (RCI). RCI was responsible for installing the gaging equipment used at most stations being operated at the Arsenal today. During the period from 1982 to 1984, 10 monitoring stations were constructed as shown in Table 1.2-1, although flow control structures had been previously established. Stage and discharge data were collected and rating curves were developed. Flow measurements were obtained at gaging stations with natural channel sections. Flow measurements were not obtained at Highline Lateral and Basin A inflow, where rated structures existed. From 1982 to 1984, while RCI was conducting the surface-water gaging program, surface-water chemical sampling was being carried out concurrently under the Revision II - 360° monitoring program. In 1984 an independent contractor (Bill Krupke), installed concrete control structures at five of the monitoring stations under the direction of U.S. Army Waterways Experimental Station. He also collected stage and discharge data throughout the entire network and installed the Stevens recorders. None of this data was reduced nor was it reported.

Task 4 was initiated in 1985 to provide a coordinated surface-water quality and quantity monitoring program. A main objective of Task 4 was to develop a quality core database for use in RI/FS (ESE, 1988a). ESE managed the program, with RCI providing substantial support in collecting and interpreting surface-water flow and lake level information. Two rain gages were installed on RMA, in Section 24 and in South Plants area. The goals of the surface-water portion of the Task 4 water quality and quantity survey were twofold. Separate efforts were established to determine a surface-water mass balance for RMA and water quality at 30 designated on-post sites (ESE, 1986a). The first phase of Task 4 was conducted under the Initial Screening Program (ISP) from September 1985 through February 1986. Initial efforts pertaining to the surface-water portion of the program were directed at repair and rehabilitation of existing monitoring devices and recording stations. Sixteen on-post surface-water sites were sampled (ESE, 1987).

Surface-water quantity and quality data continued to be gathered during the third and fourth quarters (spring and summer) of FY86 under Task 4. These results were reported in the Final Screening Program report (ESE, 1988a). The Final Screening Program was essentially the same as that developed for the ISP. A core database was maintained as a baseline for future studies which included data on surface-water conditions, ground-water recharge, changes in contaminant migration, and the effects of expanding urbanization (ESE, 1988a). The surface-water quantity monitoring network used during the ISP was expanded by the addition of a station off-post on First Creek near Highway 2. There were 46 potential on-post surface-water sampling sites and 11 potential off-post sites incorporated into the surface-water quality monitoring network (Table 1.2-1).

From December 1986 to September 1987, 11 off-post surface-water sites designated by the Task 4 Final Sampling Program were sampled under the direction of the off-post RI/FS (Task 39). Task 39 was instituted to provide a RI/FS for the area north and northwest of RMA.

Following Tasks 4 and 39, on-post and off-post surface-water monitoring activities continued to be directed by ESE under the new Task 44 contract awarded in March 1987. Task 44 operated under the core objectives of Task 4, but had broadened the scope of the program. The expanded program included monitoring changes in water quality, assessing distribution and concentration levels of contaminants, identifying areas of public exposure, and recommending modifications to the program (ESE, 1988b). The 12 gaging stations established previously during Task 4 were used during this monitoring period. There were 40 potential on-and off-post surface-water sampling locations designated for sampling on a quarterly basis. On-post locations corresponded to the sampling sites used during Task 4. Surface-water quantity and quality data collection was attempted during high flow events if an event had fallen within a designated sampling period, but none were collected.

Recently, as part of the RI program, the Water Remedial Investigation (WRI) Report (Ebasco Services, Inc., et al., 1989a) was created as a summary document of water-related programs at RMA. This report presents data and interpretations related to the surface-water system at RMA that was collected by the Tasks 4, 39 and 44. Included in the document are discussions on water balances, surface-water/ground-water interactions, and historical surface-water quality data from fall 1985 to fall 1987.

Other studies relating to surface-water features at RMA included drainage basin analysis by Wright Water Engineers (1988) and the United States Army Corps of Engineers (USACOE 1983). Wright Water Engineers presented a hydrologic analyses of the First Creek and Irondale Gulch drainage basins. These analyses evaluated the hydrologic characteristics of the watersheds for existing conditions and with or without the proposed new Denver Airport. Flood peaks and volumes were defined for various recurrent storm intervals. The USACOE (1983) prepared a drainage analyses for the upper Irondale Gulch and First Creek watersheds on RMA. Flood Peaks and volumes were defined for future development, analyses were conducted of flooding problems and recommendations were made for solving on-site drainage problems. The USACOE conducted inspections of the lakes and their associated dams. In 1983 the four principal lake impoundments in the South Plants lake area , Havana Pond and Basins C, D, and F were inspected. During this period disposal basins C and D were not in use. Additional inspections of Havana Pond, Ladora Lake, and Lower Derby Lake were performed in 1986, 1987, and 1988. The inspection reports assessed hydraulic, hydrologic, structural, and geotechnical conditions of the dams and impoundments. Hydraulic and hydrologic data incorporated in the reports included spillway elevation and condition, top-of-dam elevation, and lake capacity rating curves.

1.3 FY88 SURFACE-WATER CMP ACTIVITIES

The major activities of FY88 included:

- Review of previous RMA surface-water quality data and evaluation of its usefulness in trend analyses when compared to current program results;
- Review and comparison of historical instantaneous discharge data to that obtained during the CMP;
- Review, refinement and extension of rating curves developed by previous contractors at selected monitoring stations;
- Monitoring of surface-water quantity and quality;
- Monitoring of sediment quantity and quality;
- Maintenance of the existing monitoring network and a modification analysis of the network; and
- Obtaining surface-water/ground-water interaction data.

All surface-water calculated instantaneous flow data collected since April 1985 were compiled, critically reviewed, and presented in the FY88 report. Procedures used to collect and reduce this information were evaluated. The 1985 to 1987 instantaneous flow data were reviewed to validate historical flow trends and document any changes noted in the natural flow system that may have affected the present monitoring network. Historical surface-water quality data (back to 1979) were also reviewed and were assessed to determine their validity and usefulness as part of a comprehensive database. Surface-water quality data collected from April through October 1988, were compared to that collected during the Tasks 4, 39 and 44 (1985-1987) and the 360° Monitoring Program (1979-1986).

In addition to verifying the results of the RI program, CMP surface-water element results expanded the available database that could be used for the surface-water management program at RMA. The present surface-water program could also be used to monitor the effect of interim response actions (IRA) on the surface-water system. A verifiable historical database has to be maintained in order to judge the effect of future RMA remedial actions on surface-water flow and quality. This database could be used to monitor off-post upgradient activities such as ranching, farming, and urban or industrial activities that can affect the quality and quantity of surface-water entering RMA from the south.

During the first year of CMP operation, the existing stream flow and quality monitoring network employed by the RI (Task 44) was generally maintained (Table 1.2-1). The R.L. Stollar & Associates, Inc. (RLSA) team collected stage data on a continuous basis for FY88 from April 4, 1988, to September 30, 1988. Data collected from October and November 1987 by ESE were also evaluated and included in the FY88 report in order to present as complete a record as possible of conditions for Water Year 1988 (October 1, 1987 - September 30, 1988). Instantaneous discharge data were collected monthly at active stream monitoring stations and when possible during high flow storm events. Old rating curves had to be refined or redeveloped to document Water Year 1988 stage-discharge relationships at many of the active monitoring stations. Staff gage readings were taken on the lakes and converted to elevation to monitor storage changes over time. Water-level measurements from monitoring wells near surface-water features were used to help assess surface-water and ground-water interactions in the lake areas and in other selected areas. To supplement this assessment, ground-water and surface-water samples taken at locations proximate to each other were compared geochemically to document interchange between the two systems.

A network of sites coordinated with sample locations previously used during the RI program were sampled to determine surface-water quality during FY88. Sampling frequency (seasonal and high event) and analytical parameters varied depending on locations. A preliminary assessment of the role of suspended and bed load sediment transport on contaminant migration was also undertaken during FY88.

1.4 FY89 PROGRAM ACTIVITIES

The same surface-water quantity monitoring network established during FY88 was utilized during FY89. The network was expanded by installing new gaging stations in the areas of South First Creek, North First Creek, and First Creek Off-Post (Table 1.2-1). The FY89 surface-water program included the following activities:

- Installation of digital equipment (Datapods and data loggers) for stage level measurements;
- Installation of bubbler systems at five stations in order to obtain stage data throughout the freezing months (December to April);
- Modification and refabrication of controls at First Creek Off-Post, North First Creek, South First Creek, Peoria Interceptor, and Havana Interceptor stations;
- Utilization of long-throated portable flumes for low flow measurements;

- Expansion of Gas Chromatography/Mass Spectrometry (GC/MS) analysis to more internal sampling locations;
- Utilization of automated samplers for obtaining water quality samples during high events;
- Acquisition of more water quality samples during high events than during FY88;
- Obtainment of suspended sediment samples for quantitative analysis;
- Obtainment of bottom sediment samples for qualitative analysis;
- Acquisition of more well water level measurements for use in ground-water/surface-water interaction assessment; and
- Obtainment of gain/loss data for use in ground-water/surface-water interaction assessment.

In addition, the CMP surface-water program during Water Year 1989 collected instantaneous discharge and stage data, lake stage water levels and high event water quality samples. New rating curves were generated for North and South First Creek stations and First Creek Off-Post station, and rating curves were refined for the other stations. Water quality samples were obtained from the surface-water sampling locations that were used during FY88 in the spring and fall. Suspended sediment samples were collected for quantitative analysis along the southern reach of First Creek. Bottom sediment samples were collected throughout RMA for qualitative analysis.

1.5 FY90 SURFACE-WATER CMP ACTIVITIES

The Surface-Water CMP during FY90 maintained, operated and collected surface-water quantity and quality data from the same monitoring and sampling locations that were used during the FY89 program. The monitoring network was expanded by the installation of a new gaging station at the Basin F IRA site (Table 1.2-1).

The FY90 major surface-water activities included the following:

- Obtained surface-water quantity data using CR-10/bubbler systems throughout the water year, including the freezing months (December to April), at South First Creek, North First Creek, Havana Interceptor, Peoria Interceptor, and South Uvalda monitoring stations;

- Reactivated an existing rain gage in the South Plants area;
- Acquired surface-water quality data from the outfall of Eastern Derby Lake as it enters First Creek in Section 6;
- Continued utilizing automated samplers to collect high event samples;
- Acquired a total of 22 high event samples;
- Obtained 86 total suspended samples for quantitative analysis; and
- Obtained 13 bottom sediment samples for qualitative analysis.

In addition, a new rating curve for the new station located at Basin F IRA site was generated. Rating curves were refined for North Uvalda, South Uvalda, Havana Interceptor, Peoria Interceptor, Highline Lateral, Ladora Weir, South First Creek and North First Creek monitoring stations. New sites for controls downstream of Havana Pond in Sand Creek Lateral and in the Ladora Lake Spillway were surveyed this year. This information appears in Appendix A-1.2. Surface-water quality samples were collected at the same locations as in FY89 and were also collected at Eastern Upper Derby Lake outfall to First Creek and the outfall from the United States Army Reserve Center area. Total suspended solids (TSS) samples were collected along First Creek on-post and off-post. Bottom sediment samples were collected for qualitative analysis throughout RMA.

1.6 PRE-CMP SURFACE-WATER QUALITY

This section contains a brief description of surface-water analytical results prior to the CMP. A detailed discussion of pre-CMP procedures and analytical results is presented in the RMA Surface-Water Historical Report (RLSA, 1990). A total of 311 organic compound detections and 89 trace inorganic detections in surface water are reported historically for sites corresponding to CMP surface-water sampling sites. Current CMP sites were not included in the analysis.

Compounds detected historically at three or more current CMP sites are listed as follows, according to the number of sites at which a compound was detected:

Compound	No. of Sites
Dibromochloropropane (DBCP)	11
Chloroform (CHCL3)	10
Dieldrin (DLDRN)	7
Aldrin (ALDRN)	6

Diisopropylmethyl phosphonate (DIMP)	7
Chlorophenyl methylsulfone (CPMSO2)	6
Dicyclopentadiene (DCPD)	6
Benzothiazole (BTZ)	4
Chlorophenyl methylsulfoxide (CPMSO)	4
Hexachlorocyclopentadiene (CL6CP)	4
Benzene (C6H6)	3
Chlorophenyl methylsulfide (CPMS)	3
Endrin (ENDRN)	3

Compounds detected at only two sites included the following:

1,1,1-Trichloroethane (111TCE)
1,1-Dichloroethene (11DCE)
DDE (PPDDE)
DDT (PPDDT)
Isodrin (ISODRN)
Tetrachloroethene (TCLEE)
Toluene (MEC6H5)
Trichloroethene (TRCLE)
Xylene (XYLEN)

Compounds detected at only one site included the following:

1,1,2-Trichloroethane (112TCE)
1,2-Dichloroethane (12DCLE)
1,2-Dichloroethene (12DCE)
Atrazine (ATZ)
Bicycloheptadiene (BCHPD)
Chlorobenzene (CLC6H5)
Dimethyl methyl phosphonate (DMMP)
Dithiane (DITH)
Ethylbenzene (ETC6H5)
Methylene chloride (CH2CL2)
Methylisobutylketone (MIBK)
Oxathiane (OXAT)
Supona (SUPONA)

NOTE: IRDMIS entries are in parentheses

Basin A (SW36001) and the South Plants sedimentation pond site (SW01002) have historical detections of a wide range of compounds, with 31 and 18 compounds detected, respectively. The North Bog (SW24003), First Creek Off-Post monitoring station (SW37001), and South Plants Ditch monitoring station (SW01003) have historical detections of seven compounds each, and the Sewage Treatment Plant effluent site (SW24001) has historical detections of five compounds. The South Uvalda Interceptor monitoring station (SW12005) has historical detections of four compounds. All other sites have historical detections of three or fewer compounds.

Six trace inorganic constituents were detected historically at current CMP surface-water sampling sites. Constituents detected historically at three or more current CMP sites are listed in order of number of sites detected as follows:

Constituent	No. of Sites
Arsenic (As)	16
Zinc (Zn)	11
Mercury (Hg)	6
Chromium (Cr)	3
Lead (Pb)	3
Copper (Cu)	2

Havana Interceptor (SW11002) and First Creek Off-Post monitoring stations (SW37001) had historical detections of a wide range of trace inorganic constituents with five and four constituents detected respectively. All other sites have historical detections of three or fewer constituents.

1.7 SUMMARY OF FY88 AND FY89 CMP SURFACE-WATER QUALITY RESULTS

During FY88 29 surface-water quality locations were sampled and analyzed for 39 organic compounds. During the spring of Water Year 1988 the site with the most organic compound detections was SW36001 (Basin A), which contained 16 detections, followed by SW01002 (South Plants Water Tower Pond) with 11 detections. The most common organic detections during FY88 are listed as follows:

- dieldrin (DLDRN) -- 5 sites
- chloroform (CHCL3) -- 4 sites
- aromatic volatile compounds (BETX) -- 4 sites
- hexachlorocyclopentadiene (CL6CP) -- 4 sites
- dicyclopentadiene (DCPD) -- 3 sites

During FY88 the most inorganic detections, listed in order of sites detected, were:

- zinc (total) -- 33 sites
- mercury (total) -- 31 sites
- lead (total) -- 31 sites

- arsenic (total) -- 29 sites

During FY89 organic compounds were detected at 21 out of 30 sites that were sampled. The site with the most organic compound detections during the spring of Water Year 1989 was SW36001 (Basin A) with 37 different organic compound detections, followed by SW01002 (South Plants Water Tower Pond) with 20 detections. The most common organic compounds, listed in order of number of sites detected, were:

- Vapona -- 7 sites
- dimethylmethylphosphonate (DMMP) -- 6 sites
- endrin -- 6 sites
- dieldrin -- 5 sites
- hexachlorocyclopentadiene (CL6CP) -- 5 sites
- p,p'-DDE (PPDDT) -- 5 sites
- aldrin, DIMP, chlordane, isodrin -- 4 sites

During FY89 the most common inorganic detections, listed in order of number of sites detected, were:

- zinc (total) -- 10 sites
- arsenic (total) -- 10 sites
- mercury (total) -- 4 sites

1.8 SEDIMENT TRANSPORT

Sediment transport is a potential pathway for contaminants in the surface-water system at RMA. Contaminants may be adsorbed onto sediment particles and transported as suspended load or bed load in the drainages. Limited data exist to evaluate the magnitude of the flow of low solubility contaminants such as heavy metals, pesticides, and semi-volatile organics through the surface-water system. Sediment loading in RMA drainages can be a significant factor that influences aquatic habitat and channel evolution.

The WRI Report (Ebasco Services, Inc., et al., 1989a) identified mechanisms for mobilizing contaminants into RMA surface water. Some qualitative or quantitative evaluation was performed during FY88 to ascertain the role of sediment/solid transport in the movement of contaminants in RMA surface water. As part of the 1988 sampling program, bottom sediment and suspended solid samples were collected on First Creek. Preliminary results of the initial sampling effort were presented in the FY88 report. As part of the 1989 sampling program bottom sediment samples were collected at various sampling locations throughout RMA for qualitative analysis. The most common organic compounds that were detected in the sediments were atrazine, dieldrin, CPMSO, endrin, isodrin, and aldrin. During the FY89 sampling program TSS samples were collected on First Creek for quantitative analysis. The results indicated that over 10 times the amount of total suspended solids are being deposited in the streams during high events than during baseflow conditions. During FY90, the Surface-Water CMP collected TSS samples along First Creek, Uvalda Interceptor, Highline Lateral, Havana Interceptor, Peoria Interceptor and at various locations throughout RMA during high events. In addition, bottom sediments were collected throughout RMA for qualitative analysis.

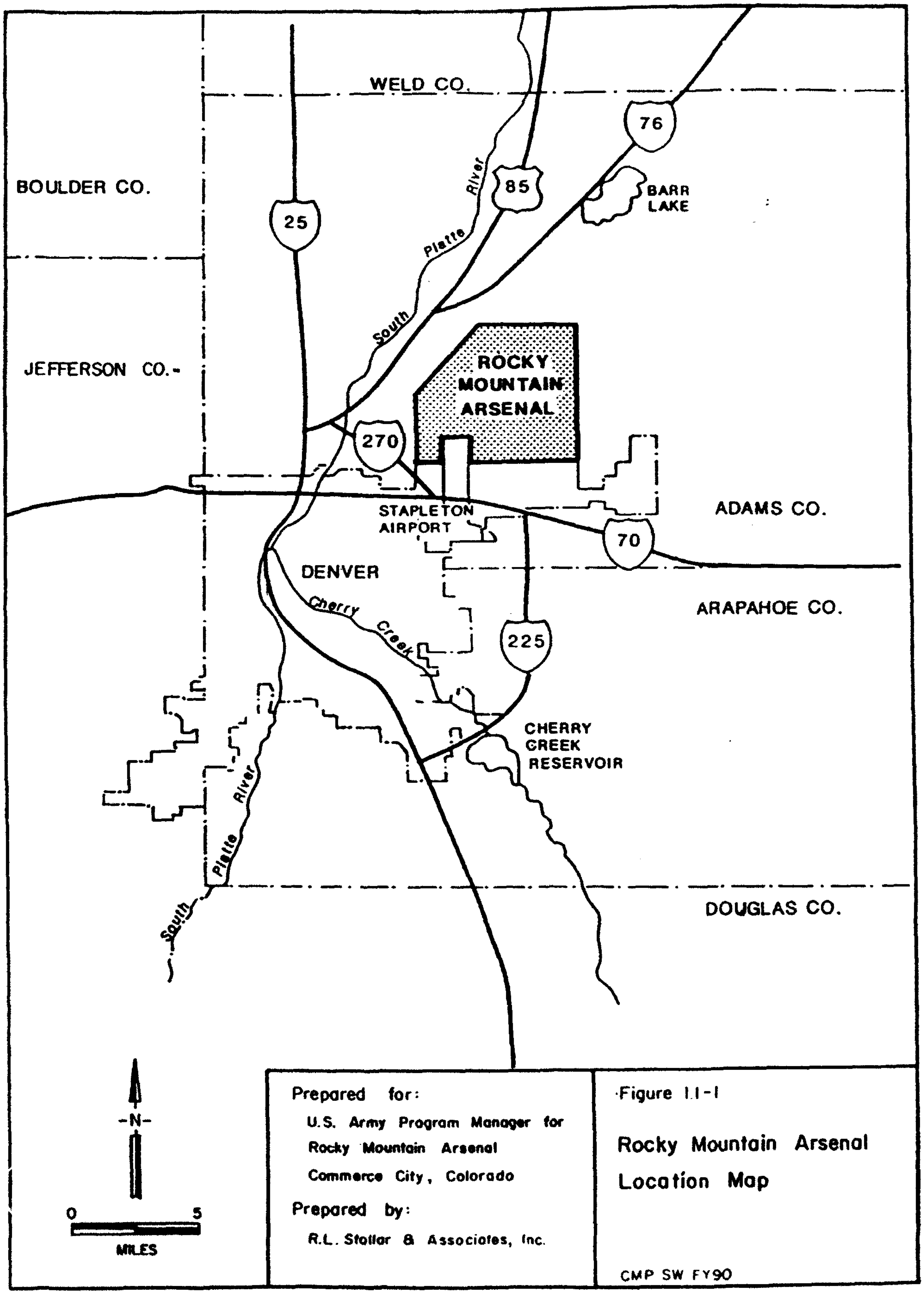
1.9 GROUND-WATER AND SURFACE-WATER RELATIONSHIPS

To monitor the pathways by which contaminants may be entering or moving off RMA, it is important to assess the relationship between the surface-water and ground-water systems, and specifically to assess the potential for discharge of contaminated ground water to surface water.

Previous attempts were made to verify areas of surface- and ground-water interaction. Initial studies which tried to quantify the gain-loss relationship between surface- and ground-water systems were conducted by RCI (1982, 1983, 1984 and 1987). These studies emphasized gain-loss calculations for the South Plants Lakes. In a 1-month water balance calculation for March, 1987 (RCI, 1987), areas of ground-water discharge were identified at Ladora Lake and Lake Mary. Ground water appeared to be recharged by surface water at Havana Pond and along Uvalda Interceptor. Water balance calculations in the lakes area could not be totally substantiated because it was uncertain whether all components had been addressed. It was noted that there were unaccounted inflows, such as potable water releases to and direct precipitation on the lakes. Unmeasured outflow occurred in Lake Mary and Ladora Lake in the form of bank seepage and discharge through overflow outlets. Water balance calculations conducted by RCI were considered preliminary. Further data need to be collected to verify initial computations.

Under the Task 4 and 44 programs conducted by ESE (1988a and 1988b), additional stream flow and ground-water level information was gathered to delineate areas of gain or loss to the surface-water system. The WRI Report (Ebasco Services, Inc., et al., 1989a) interpreted data available up to 1987 and indicated locations and estimated values of recharge and discharge between surface-water bodies and the unconfined ground-water system. Water balance calculations were completed for the lakes area. Gain-loss volumes were considered approximate because of a number of unmeasured variables in the calculations. Water-table contours derived from monitoring wells located near surface-water bodies, compared with comparisons to long-term hydrographs, substantiated recharge-discharge relationships. RMA areas of interest to the Surface-Water CMP that have historically indicated a net discharge from ground water include Ladora Lake, Lake Mary and Upper Derby Lake (when dry). Areas displaying a net loss to the ground-water system include First Creek, Lower Derby Lake, Upper Derby Lake (when filled with water), Havana Pond and Uvalda Interceptor (Ebasco Services, Inc., et al., 1989a).

During the FY88 and FY89 of the Surface-Water CMP, available data were used to evaluate surface-water/ground-water interaction in the South Plants Lakes area, Havana Pond, along Uvalda Interceptor, and along First Creek (RLSA, 1990a). The data presented in the FY88 and FY89 reports suggested that surface water on RMA is interconnected with ground water in several areas. Hydrograph data indicated similar water elevations in the South Plants Lakes and Havana Pond with nearby wells. An ionic comparison of First Creek and nearby wells showed that surface water and ground water is similar in ionic character and proportion. During FY90 the surface-water CMP collected surface-water/ground-water interaction data along First Creek and in the South Plants Lakes and Havana Pond areas. Hydrograph, gain/loss and infiltration data was collected and analyzed for this effort. The data continued to show that surface-water/ground-water interaction was occurring these areas.



Prepared for:

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

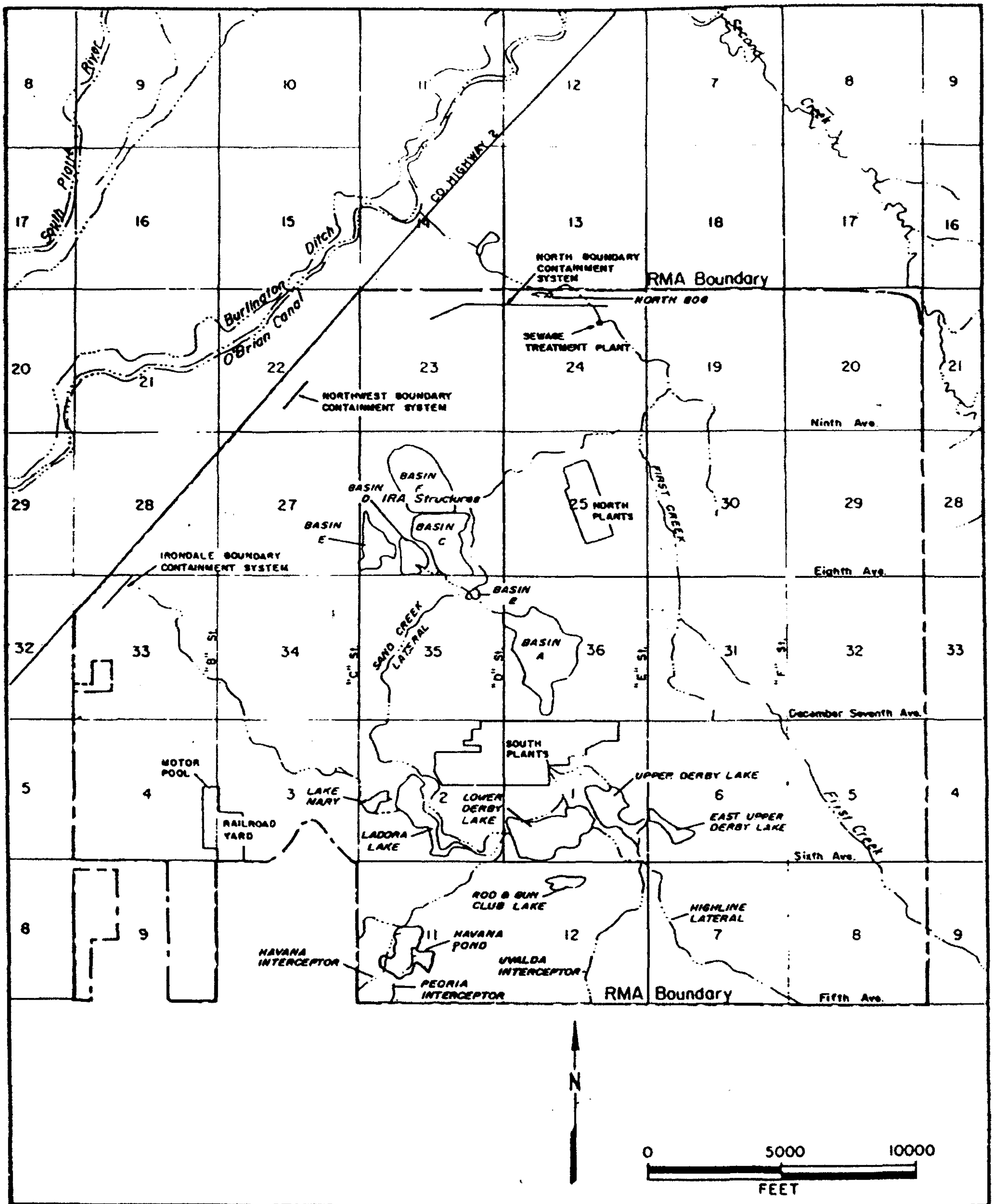
Prepared by:

R.L. Stollar & Associates, Inc.

Figure 1.1-1

Rocky Mountain Arsenal Location Map

CMP SW FY90



Prepared for:

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

Prepared by:

R.L. Stollar & Associates, Inc.

Figure 1.1-2

Rocky Mountain Arsenal Features Map

CMP SW FY90

2.0 ENVIRONMENTAL SETTING

Surface water is only one component in the interacting hydrogeologic system at RMA. Weather, geology, physiography, man-made structures, and man's activities all have varying influences on the characteristics of the surface-water system. Section 2.0 provides a description of these components and some of their influences. A historical review of the development of each of the major surface-water features at RMA and their physical characteristics and interrelationships is provided in the Surface-Water Historical Report and the Surface-Water Data Assessment Report for 1989 (RLSA, 1990b). This section also discusses the major drainage basins that exist on and near the RMA facility. Figure 2.3-1 shows the drainage basins as defined on RMA. Figure 2.3-2 shows the locations of the surface-water monitoring stations with respect to the RMA drainage basins and Table 2.3-1 lists these stations. Figure 2.3-2 shows the surface-water locations that were considered during Water Year 1990 and Table 2.3-2 lists the locations.

2.1 GENERAL SETTING

RMA lies within the High Plains physiographic province. Topography at the Arsenal is characterized by gently rolling hills with intermittent depressions occurring mostly in its west and northwest portion. Surface elevation ranges from approximately 5,340 feet above mean sea level (ft-msl) in the southeast corner of RMA to 5,140 ft-msl along the southwest boundary. The overall topographic surface slopes to the northwest towards the South Platte River. First Creek is the only active stream that transects and flows through the entire Arsenal. The stream drops in elevation about 160 ft along its course at RMA.

The climate at RMA is similar to that of much of the central Rocky Mountain Region. The area generally experiences low relative humidity, light precipitation and abundant sunshine. Historical climatological records (1960-1990) collected at Stapleton Airport (National Oceanic and Atmospheric Administration (NOAA), 1990) indicate much of the precipitation falls as snow during the months of March and April with a range from 4.1 to 41.8 in and a range of 0.52 to 6.66 in of total precipitation. The month of May historically receives the most total precipitation, averaging 2.48 inches. Summer precipitation falls principally from scattered thunderstorms during the afternoon and evening. Severe thunderstorms with large hail and heavy rain occasionally occur. Autumn is relatively dry with few thunderstorms and abundant sunshine. Historical mean average temperatures range from 29.6°F in January to 73.5°F in July (NOAA, 1990). Large temperature variations can occur in the winter resulting from invasions of cold arctic air from the north or warm Chinook winds from the west.

The two uppermost geologic units underlying RMA consist of Pleistocene to recent alluvial and eolian deposits and the Cretaceous to Tertiary Denver Formation. Unconsolidated Quaternary deposits are composed principally of fluvial sediments deposited by the ancestral South Platte River system,

Table 2.3-1 Water Quantity Monitoring Stations Used During Water Year 1990

<u>Irondale Gulch Drainage Basin</u>

North Uvalda (SW01001)
South Plants Ditch (SW01003)
Upper Derby Lake (SW01004)
Lower Derby Lake (SW01005)
Ladora Weir (SW02001)
Ladora Lake (SW02003)
Lake Mary (SW02004)
Peoria Interceptor (SW11001)
Hanava Interceptor (SW11002)
Havana Pond (SW11003)
South Uvalda (SW12005)
Highline Lateral (SW12007)

<u>First Creek Drainage Basin</u>
South First Creek (SW08003)
Sewage Treatment Plant (SW24001)
North First Creek (SW24002)
First Creek Off-Post (SW37001)

<u>South Platte Drainage Basin</u>
Basin A (SW36001)
Basin F (SW26001)

Table 2.3-2 Sample Locations Considered During Water Year 1990

Irondale Gulch Drainage Basin	First Creek Drainage Basin
North Uvalda (SW01001)	Old South First Creek (SW05001)
South Plants Tower Pond (SW01002)	Eastern Upper Derby Lake (SW06002)
South Plants Ditch (SW021003)	First Creek Southern Boundary (SW08001)
Upper Derby Lake (SW01004)	South First Creek (SW08003)
Lower Derby Lake (SW01005)	South First Creek Retention Pond (SW08004)
Ladora Weir (SW02001)	Sewage Treatment Plant (SW24001)
Sand Creek Lateral (SW02002)	North First Creek (SW24002)
Ladora Lake (SW02003)	North Bog (SW24003)
Lake Mary (SW02004)	First Creek Northern Boundary (SW24004)
Sand Creek Lateral (SW02005)	North Plants (SW30001)
South Plants Steam Effluent (SW02006)	First Creek near North Plants (SW30002)
Uvalda Ditch (SW07001)	First Creek Toxic Yard A (SW31001)
Uvalda Ditch (SW07002)	First Creek Toxic Yard B (SW31002)
Peoria Interceptor (SW11001)	First Creek Off-Post (SW37001)
Havana Interceptor (SW11002)	Off-Post First Creek (SW37010)
Havana Pond (SW11003)	Off-Post First Creek (SW37011)
Uvalda Ditch (SW12001)	Off-Post First Creek (SW37012)
Uvalda Ditch (SW12002)	
Rod and Gun Club Pond (SW12003)	South Platte Drainage Basin
Storm Sewer (SW12004)	Basin A (SW36001)
South Uvalda (SW12005)	Basin F (SW26001)
Army Reserve Storm Sewer (SW12006)	
Highline Lateral (SW12007)	Sand Creek Drainage Basin
	Motor Pool (SW04001)
	Second Creek Drainage Basin
	No Sampling Locations

covered in part by windblown sediments. Eolian material varies in thickness to a maximum of 50 ft and consists of very fine to silty sand, sandy silt and clay (Morrison-Knudsen Engineering (MKE), 1988). Alluvial deposits consist predominantly of sands and gravels, which normally vary in thickness from approximately 50 to 130 feet. Alluvium increases in thickness where deposition has occurred in paleochannels present on the surface of the Denver Formation. Areas with less than 20 ft of alluvial and eolian deposits occur across RMA, mainly in areas overlying bedrock highs (Ebasco Services, Inc., et al., 1989a).

The underlying Denver Formation is composed of interbedded bentonitic claystone, sandstone, siltstone, lignite and volcaniclastic deposits. Many of the beds are rich in plant remains and carbonaceous material. Sandstones are lenticular and laterally discontinuous. Individual sandstone intervals range in thickness from a few inches up to 65 feet. Data suggest the total thickness of the Denver Formation underlying RMA is approximately 200 to 500 ft (MKE, 1988). Denver Formation strata display a regional dip of approximately 1° to the southeast, resulting in relatively older stratigraphic zones subcropping against alluvium in the northwest portion of RMA, and progressively younger zones subcropping in the southeast. Quaternary sediments and the upper permeable portions of the Denver Formation are in hydraulic communication and form the unconfined ground-water system (Ebasco Services, Inc., et al., 1989a).

2.2 GROUND-WATER HYDROLOGY

The ground-water system contributes significantly to the physical and chemical characteristics displayed by surface water at some RMA locations. An evaluation of the interaction occurring between surface water and ground water in certain areas across RMA is provided in Section 4.4 of this report, FY88 and FY89 Surface-Water Data Assessment Reports and Surface-Water Historical Report. The following discussion is a brief synopsis of the general characteristics of the ground-water system at RMA.

Ground water at RMA occurs under both confined and unconfined conditions. Unconfined flow occurs in saturated portions of the eolian and alluvial Quaternary deposits and the uppermost permeable subcropping portion of the underlying Denver Formation. In areas where materials making up the Quaternary deposits are unsaturated, the unconfined flow system consists solely of sandstone and fractured or weathered rock within the upper portion of the Denver Formation. Saturated thickness varies from less than 10 ft to approximately 70 ft (Ebasco Services, Inc., et al., 1989a). The regional unconfined flow direction at RMA is to the north and northwest. Deviations in these flow directions occur in the vicinity of the South Plants manufacturing facility and in the South Plants Lakes area. A ground-water mound underlying South Plants creates divergent radial flow away from the area (RLSA, 1990c). Ground-water flow beneath Ladora Lake and Lake Mary is towards the west, whereas flow directions beneath Upper and Lower Derby Lakes are less well defined but appear to have a predominant westward component (RLSA, 1990a and 1990b).

Water-level fluctuations in the unconfined aquifer at RMA are generally less than 2 ft, although fluctuations as large as 6 ft have been measured beneath South Plants (Ebasco Services, Inc., et al., 1989a). Present-day recharge to the unconfined flow system occurs as infiltration of precipitation, seepage from lakes, streams, canals and buried pipelines, and discharging flow from the Denver Formation. Discharge from the unconfined flow system occurs primarily as seepage into Upper Derby Lake and possibly into portions of First Creek and Uvalda Interceptor(Ebasco Services, Inc., et al., 1989a and RLSA, 1990b).

2.3 RMA Drainage Basins and Surface-Water Features

Surface water at RMA can be discussed in terms of both larger and smaller scale features. Five principal drainage basins occur within the RMA area and are shown on Figure 2.3-1. The general characteristics of the drainages and associated surface-water features that are on RMA are discussed in this section. The locations of the surface-water monitoring stations and sample locations associated with each of the surface-water drainage basins at RMA are also discussed in this section. Section 3.0 discusses the monitoring procedures and equipment utilized in each drainage basin.

RMA lies within the South Platte River drainage basin. Surface water on RMA flows within several smaller drainage basins that are tributaries or subdrainage basins to the South Platte. First Creek, Second Creek, Sand Creek and Irondale Gulch drainage basins (Figure 2.3-1) contain defined flow channels that have a main direction of flow to the north and northwest. The South Platte drainage basin (Figure 2.3-1) on RMA has no well defined main flow channel. The following discussion describes the principal drainage basins and subcatchments on RMA. A more detailed discussion of the drainage basins' upstream land uses, RMA surface-water use, soil infiltration rates and construction histories of dams, diversions, interceptors, lakes and ponds appear in the Surface-Water Historical Report and the FY89 Surface-Water Data Assessment Report.

2.3.1 First Creek Drainage Basin

The First Creek Drainage Basin originates in Arapahoe County, Colorado, about 20 miles (mi) east of downtown Denver. The basin is approximately 26 mi long and varies from 1 to 4 mi in width. The basin drains approximately 27 square miles (sq mi) upstream of RMA and approximately 12 sq mi on RMA (Figure 2.3-1). The topography of the First Creek Basin within RMA is gently undulating with low hills.

A detailed map of the First Creek drainage is presented in the Surface-Water Historical Report and FY89 Surface-Water Data Assessment Report. First Creek flows approximately 26 mi northwesterly from its source to its confluence with O'Brian Canal about 0.5 mi north of the RMA northern boundary. This includes about 5.5 mi of channel on RMA. In dry years, the flow of First Creek on the Arsenal is continuous only during the spring and after major storms. The general persistence of flow along the creek is evidenced by well-developed hydrophytic and phreatophytic vegetation along much of its length (MKE, 1987). Most of the course of First Creek on RMA is straight. Channel meandering is most common in Section 8 where First Creek comes on-post. Channel straightening was done in the northwest portion of Section 5 and on the east side of Section 24 following a major flood in 1973 (USACOE, 1983a). The channel capacity of the creek as it enters RMA is about 250 cubic feet per second (cfs) and downstream of the sewage treatment plant outfall at the north boundary it is about 300 cfs (RCI, 1982).

Storm water drainage is currently being routed into First Creek from the northeast portion of the Green Valley Ranch residential area. The storm runoff is collected in the vicinity of Nepal Street and the westernmost end of 48th Street. The area which directs flow into First Creek from Green Valley Ranch covers approximately 0.177 sq mile.

The Highline Canal also has the potential to add runoff to First Creek. Highline Canal crosses First Creek on the eastern side of Green Valley Ranch. An overflow diversion channel for the Highline Canal is located at this intersection. The overflow channel directs flow from the Highline Canal into First Creek when the overflow level in Highline is surpassed. This occurred during Water Year 1990.

As First Creek traverses RMA, several tributaries have the potential of contributing to its flow (Figure 2.3-1). The first well-defined tributary, an old overflow from Eastern Upper Derby Lake, enters First Creek in Section 6. Under normal flow conditions, this tributary usually does not carry water from Eastern Upper Derby Lake. However, flow did occur in this channel during Water Year 1990 and entered First Creek. First Creek then flows through three breached small detention or retention dams in Section 31. Prior to being breached, the combined available storage behind these dams was approximately 150 acre-feet (ac-ft) (USACOE, 1983a). The next tributaries join First Creek in the northwest corner of Section 31 and drain the old Toxic Storage Yard. The North Plants area is drained by a tributary which joins First Creek in the central-western portion of Section 30. The Sand Creek Lateral enters First Creek near the northeast corner of Section 25; however, the infrequent flows in the lateral have not normally reached the confluence in the past several years although this did occur during Water Year 1989.

Effluent from the Sewage Treatment Plant enters First Creek in the northeast corner of Section 24. The sanitary sewer Interceptor Line originates near the north boundary of Section 1 in South Plants and terminates at the Sewage Treatment Plant in Section 24 (Figure 2.3-1). The sanitary sewer Interceptor Line collects and transmits domestic wastewater from the administration and railroad areas, the North Plants complex and the South Plants manufacturing area (Ebasco Services, Inc., et al., 1988b). At the Sewage Treatment Plant, wastewater is pre-filtered through a sand and gravel sequence before it is treated in a granulated active carbon and in-line ozonation system (Ebasco Services, Inc., et al., 1987a).

Just before First Creek crosses the north boundary, it intercepts a small channel which drains overflow from the North Bog. North Bog is a 2.7 acre (117,000 ft^2) body of water located in the northwest quarter of Section 24. During high flow events, water from First Creek flows into the bog. Since 1983 the North Bog has been used as a natural recharge for treated ground water from the North Boundary Containment System (Ebasco Services, Inc., 1988a).

In the fall of 1988, First Creek was diverted away from a stand of trees near the south-central border of Section 5. A new culvert was placed under Sixth Avenue approximately 300 ft west of the stream's old location. The creek was diverted in this area in order to reduce bank erosion and associated deterioration of the trees along this section of the creek. Preservation of trees along First Creek is important because they have become the seasonal roosting location of a large number of eagles at RMA. This construction also produced a small retention pond just south of Sixth Avenue on First Creek. The primary purpose of this pond is to cultivate a habitat that can be used by eagles and waterfowl. The effect of surface-water ponding at this location on local ground-water conditions has not been determined at this time. There is a potential for creating an area of increased ground-water recharge by restructuring the flow of water along this section of First Creek.

Four surface-water monitoring stations are located in the First Creek Drainage Basin (Figure 2.3-2 and Table 2.3-1). Three of the stations that are located on First Creek monitor the quantity of surface-water flowing on to and off of RMA along First Creek. One station (South First Creek) monitors the amount of surface-water continuously as it enters RMA. A second station, located near the north boundary (North First Creek), monitors the amount of surface-water continuously as it exits RMA. The third station (First Creek Off-Post) monitors the amount of surface-water flow between the North First Creek station and Highway 2. The fourth station monitors water discharging from the Sewage Treatment Plant.

Eleven potential sampling locations have been designated within the First Creek Drainage Basin to monitor surface-water quality (Figure 2.3-3 and Table 2.3-2). Three sample sites are located on First Creek as it enters RMA and are used to determine the surface-water quality of off-post upstream sources. Four stations are located in the middle of RMA on or near First Creek and are used for the determination of surface-water quality that may be affected by ground-water discharge and possible contaminant sources located in this area of RMA. The remaining sample sites are used for the determination of surface-water quality as it leaves RMA.

2.3.2 SECOND CREEK DRAINAGE BASIN

Only a small portion of Second Creek Basin is present in the northeast corner of RMA (Figure 2.3-1). The basin has a total drainage area of 20.6 sq mi, of which only 0.6 sq mi are within RMA. Upstream of RMA, Second Creek Basin is 9.1 mi in length. The width of the basin varies from 1 to nearly 3.5 mi and the main channel length is 12.3 miles. The main stream channel crosses RMA at its very northeast corner, traversing less than 1,000 ft of the Arsenal. Drainage is towards the northwest (RCI, 1982). The portion of Section 20 that lies within Second Creek drainage has been used as a buffer zone for Arsenal operations.

No monitoring stations or sample locations are located in the Second Creek Drainage Basin, because of its limited extent of flow on RMA and its peripheral location in a buffer zone.

2.3.3 Sand Creek Drainage Basin

Sand Creek drainage includes 2.2 sq mi in the southwest area of RMA. The lack of any major channelized flow has been attributed to the high infiltration capacities (2 to 20 in/hr) of the soils in this area (RCI, 1982). Many natural depressions in the basin intercept runoff, so that surface-water flow tends to be local. If an extreme precipitation event would occur, runoff could progress from one depression to another in a northwesterly direction, finally exiting on RMA's western boundary (RCI, 1982, Plate II).

The Sand Creek drainage is interrupted by the Stapleton Airport runways and drainage system, which extend into Section 10 adjacent to RMA. Runoff from the airport and the Sand Creek drainage is partially intercepted by the Havana Interceptor, which returns the flows to RMA within the Irondale Gulch Drainage Basin (Figure 2.3-1). A detailed hydrologic analysis of the drainage in this area was performed as part of the Stapleton Airport expansion studies (Wright-McLaughlin Engineers, 1969).

Monitoring stations are not necessary in the Sand Creek Drainage Basin on RMA. Surface-water impoundments do not exist nor do any channels exhibit flow except during a high event into or exiting this drainage within RMA. One sample location is in a ditch that directs flow towards the north from the motor pool area (Figure 2.3-3 and Table 2.3-2). This sample location is used to delineate surface-water quality as it leaves the motor pool area.

2.3.4 South Platte Drainage Basin

Approximately 6 sq mi in the northwest corner of RMA drain toward the South Platte River. This subcatchment is bounded by the Irondale Gulch drainage to the southwest, the Sand Creek Lateral to the east and southeast, and First Creek drainage to the northeast (Figure 2.3-1). The South Platte drainage on RMA does not contain a distinct channel and is characterized by a large number of natural depressions similar to Sand Creek Basin. Three significant subordinate drainages, Basin A, Basin F and the Sand Creek Lateral Sub-Drainage have been delineated within the South Platte Drainage Basin. Due to the low infiltration rates, more overland flow is expected in the north-northeast area of this subcatchment. The flow would be towards the north and west boundaries of RMA.

Six basins used for the retention of process wastes, wastewater, or storm water runoff were constructed on RMA within the South Platte Drainage Basin (Figure 2.3-1). These basins are natural topographic depressions which have been supplemented by berms and other structures. The topographic depressions associated with the basins have small catchment areas. A historical perspective of the subcatchments is presented in the Surface-Water Historical Report (RLSA, 1991) and FY89 Surface-Water Data Assessment Report.

The Basin A subcatchment has a total area of approximately 240 acres and is located in Sections 1 and 36 (Figure 2.3-1). The subcatchment includes the Basin A disposal area and portions of the South Plants industrial complex. The Basin A disposal area was originally a natural depression that was modified by embankments to provide greater storage for liquid process wastes (United States Army Chemical Warfare Service, 1945). The subcatchment receives runoff that is transported from the northern part of the South Plants industrial complex through the storm water drainage system under December Seventh Avenue (USACOE, 1984). Most runoff within this subcatchment collects in low areas and causes local ponding in the Basin A area, where it either infiltrates, transpires, evaporates or remains in storage. Surface-water discharge from the subcatchment occurs primarily along the small drainage on the northwest portion of Section 36, referred to as the Basin A ditch. Flow is from Basin A to Basin B, and subsequently out to Basins C, D and E (Blackwell, 1973). Runoff is therefore contained within the basins and either evaporates or infiltrates into the soil. Basin A subcatchment runoff does not directly contribute to any of the major surface-water drainages at RMA (RCI, 1982).

Basin B is located in the northeast corner of Section 35 (Figure 2.3-1). The basin covers 1.77 acres and is a modified natural topographic depression. A series of ditches connecting Basin A to Basins B, D and E were constructed in 1946. A Basin A runoff ditch was constructed in 1957 and can carry water into Basin B from the southeast. However, Basin B was observed to be dry in 1985 and contains only a small marsh with limited catchment area since 1986 (Colorado Aerial Photo Service (CAPS), 1986).

Basin C is an unlined basin that was constructed in 1953 (ESE, 1987) in a natural depression in the south-central portion of Section 26 (Figure 2.3-1). The basin was designed as the primary overflow containment basin for Basin A wastes prior to construction of Basin F. Basin C covers approximately 78 acres when it is at a spillway crest storage volume of 620 ac-ft (USACOE, 1983c). The basin has been dry since 1986 (CAPS, 1986).

Basin D is located in south-central Section 26, south of Basin F and southwest of Basin C, and covers approximately 20 acres (Figure 2.3-1). A ditch directs overflow from the basin west into Basin E.

Basin E covers 29.4 acres in the southwest portion of Section 26, southwest of Basin F and west of Basin D (Figure 2.3-1). The storage volume and drainage area of the basin are unknown. Flow is received from Basin D where there is no outflow. By 1980, all the fluids in Basin E had evaporated or infiltrated (ESE, 1986b). Standing water occasionally occurs in the basin.

The Basin F subcatchment was located just north of the Sand Creek Lateral drainage, west of the First Creek drainage, and within the South Platte drainage area. The basin was removed and the area was recontoured and revegetated during the IRA that was completed in 1989. The basin no longer exists and was recontoured into a mound. A clay cap was applied to the surface of the mound and drainage was directed to a small ditch located on the north side of the mound (Figure 2.3-1). The topography of the surrounding area is gently undulating grassland with no well-defined drainage patterns. The basin was a natural topographic depression that was modified to contain liquid wastes generated at RMA. The basin was roughly oval in shape, 2,900 ft wide at the north end and 1,600 ft wide at the south end. The total area was 92.7 acres and could formerly contain a maximum volume of 746 ac-ft (ESE, 1988c).

Two surface-water quantity and quality monitoring stations are located within the South Platte Drainage Basin (Figures 2.3-2 and 2.3-3). One station is located near a drainage pipe in the Basin A drainage ditch and is used to determine the affect on surface-water quantity and quality in the area caused by the storm water runoff and localized ground-water discharge. The other monitoring station is located in the newly constructed drainage ditch west and north of the Basin F IRA and is used for determining surface-water quality and quantity as it leaves the IRA site.

2.3.5 IRONDALE GULCH DRAINAGE BASIN

The Irondale Gulch Drainage Basin originates at the intersection of Interstate 70 and East Colfax Avenue. It drains 11.5 sq mi upstream of RMA and 6.5 sq mi within RMA. Flow is towards the northwest. The drainage on RMA area consists of undulating topography with low rolling hills. Vegetation on RMA is mainly grasses, with some scattered trees along the lakes and channels and in some low areas (USACOE, 1983d).

Four lakes and several other impoundments are located in the Irondale Gulch Basin on RMA. The Havana and Peoria Interceptors, Uvalda Street Interceptor and Highline Lateral all flow from south of RMA towards the lakes (Figure 2.3-1). The surface-water bodies that are located in this drainage area are Upper Derby Lake, Eastern Upper Derby Lake, Lower Derby Lake, Rod and Gun Club Pond, Ladora Lake, Lake Mary and Havana Pond. Upstream drainage patterns (south of RMA) have been modified by the construction of subdivisions, channelizations and storm drains. Upstream development is composed of light industrial development, urban residential development, open range land, and a portion of Stapleton Airport. Urban development covered 32 percent of the basin in 1983 and was expected to increase (USACOE, 1983a).

Flows within the natural drainage basins on RMA have been greatly modified through the construction of a number of diversions (laterals) and drainage channels (interceptors). The principal channels on RMA are located in the Irondale Gulch Drainage Basin - Highline Lateral, Uvalda Interceptor, Peoria Interceptor, and Havana Interceptor - and surface water from these channels enter along its southern border and carry water to the lakes near South Plants or Havana Pond.

Highline Lateral enters RMA near the southwest corner of Section 8 and flows northwest to a diversion box located in the southeast corner of Section 1 (Figure 2.3-1). At this structure flow can be directed north to Upper Derby Lake or merged with the Uvalda Interceptor and emptied into Lower Derby Lake. Since 1942, the Highline Lateral has been used as an intake canal for water delivery to the South Plants Lakes from the South Platte River. Flow is artificially controlled with intake based on seasonal availability and water rights controlled by RMA. Approximately 1.7 mi of Highline Lateral lie on RMA. The lateral has an average bottom width of 8 ft and an average channel depth of 4 feet. Discharge capacity is calculated to be 75 cfs (USACOE, 1983a).

Uvalda Interceptor enters RMA near the center of the southern border of Section 12 and flows north about 1.2 mi to a diversion structure located in the southeast corner of Section 1 (Figure 2.3-1). From this point flow can be directed either to Upper Derby Lake or to Lower Derby Lake, and may be merged with flow from Highline Lateral. Uvalda Interceptor was completed in 1967 to channel runoff from the Montbello subdivision, adjacent commercial industrial areas, and rangeland south of RMA. The drainage basin area for the Uvalda Interceptor is approximately 7.8 sq mi, of which 4.12 sq mi is residential, with an associated storm sewer system. Normally, the Uvalda Interceptor receives storm runoff from the northern portion of Montbello and the undeveloped area directly west of Chambers Road. Storm runoff from the Green Valley Ranch residential area drains into Irondale Gulch drainage via Uvalda Interceptor during a significant rainfall event. The storm sewer discharge area for Green Valley Ranch is a collection basin located west of the development. Overflow from this basin could flow into the Montbello sewer system and eventually into the Uvalda Interceptor. A detailed map of this drainage area is presented in the Surface-Water Historical Report and the FY89 Surface-Water Data Assessment Report. This channel has a discharge capacity of 1,200 cfs at the south RMA boundary and 600 cfs near Sixth Avenue (USACOE, 1983a). The average channel bottom width is 7 ft, and the average depth of the channel is 8 feet (Larsh, 1969).

The Havana Interceptor drains industrial and residential areas south of RMA, flows to the north-northeast across Section 11 and terminates in the Havana Pond (Figure 2.3-1). Havana Interceptor drains land with commercial and light industrial development, residential housing and some rangeland (RCI, 1982). Some storm-water runoff from Stapleton Airport is also included in the drainage received by the Havana Interceptor (ESE, 1985). Havana Interceptor is a concrete-lined canal as it enters RMA. The drainage basin for the Havana Interceptor is about 5.22 sq mi, of which 2.6 sq mi is storm sewer drainage. This drainage receives runoff from the southern portion of Montbello and the industrial complex on the south side of the RMA. The drainage subbasin extends in a narrow zone east to approximately Sky Ranch Airport and is bounded on the south by Interstate 70. A detailed map of the Havana Interceptor drainage area is presented in Surface-Water Historical Report and the FY89 Surface-Water Data Assessment Report.

Peoria Interceptor enters RMA along the southern edge of Section 11 and flows about 0.3 mi before joining Havana Interceptor and emptying into Havana Pond (Figure 2.3-1). The Peoria Interceptor drains the northern portion of the industrial complex located on the south side of the Arsenal. Storm water runoff from a small portion of western Montbello is also directed towards the Peoria Interceptor. The drainage basin contains approximately 0.644 sq mi, which is almost entirely urban storm sewer runoff. A detailed map of the Peoria drainage area is presented in the FY90 Surface-Water Historical Report and FY89 Surface-Water Data Assessment Report.

Sand Creek Lateral enters RMA along the western edge of Section 11 just north of Havana Pond (Figure 2.3-1). A short ditch connects the spillway and a valve-controlled discharge point at the north end of Havana Pond to Sand Creek Lateral. This lateral originally was connected to Sand Creek, which flows about 1.2 mi southwest of the Arsenal, and was used to carry irrigation water to farms on land now occupied by RMA (MKE, 1987). Construction of the northern extension of Stapleton Airport filled in a portion of the lateral and disconnected it from Sand Creek. The lateral leaves Irondale Gulch drainage in the southern portion of Section 35, flows northeast through the South Platte drainage, and terminates at First Creek in the First Creek drainage. The Sand Creek Lateral intercepts surface-water flow within the Irondale Gulch and South Platte drainages and is therefore, considered to have a catchment area.

Normally, water from Havana Pond is released to Sand Creek Lateral only after large storm events. The sluice gate used to regulate flow out of the pond to the lateral is fully opened when the water level on the staff gage measures 6 feet. The gate is closed when the staff reading declines to 4 feet. Based on the WRI Report Survey (Ebasco Services, Inc., et al., 1989a) a staff gage reading of 6 ft corresponds to 121.81 ac-ft of water being held in the pond, while 4 ft on the staff gage means that 59.84 ac-ft of water is present in Havana Pond. Flow in Sand Creek Lateral could also originate from the South Plants Lakes (Upper Derby Lake and Lower Derby Lake) if water were released into the lateral from Lower Derby Lake through the Ladora Weir rather than being diverted into Ladora Lake. Surface-water drainage and runoff from the southwestern area of South Plants is intercepted by Sand Creek Lateral downgradient of the diversion structure. Water pumped from three wells located in Section 4, which is used to supplement water in the South Plants Lakes, can also be discharged into Sand Creek Lateral.

Within the South Platte drainage, a channel is located near the eastern boundary of the catchment. The channel originates near the Lime Settling Ponds in Section 36. Water within this channel flows under Sand Creek Lateral and into the South Platte drainage.

The Sand Creek Lateral catchment within the South Platte drainage also contains a reservoir in the eastern side of Section 35 which usually is dry. The reservoir was designed and constructed as a basin to receive caustic waste from the South Plants area, although it was never used for this purpose. The caustic waste basin does not have a formal outlet. Consequently, it is probable that no surface-water flows escape the caustic waste basin, so that all precipitation is either stored, evaporated, transpired or infiltrated. Flow in the Sand Creek Lateral can be diverted to Basin C, and was so diverted from 1953 to 1956.[f] Aqueous waste overflows from Basin B were also diverted to Sand Creek Lateral during that period.

Havana Pond covers about 5 acres in Section 11 during normal pool storage. In the past, water levels were kept low to allow for additional storage capacity during flood events. Two separate mechanisms are in place that can be used to discharge water from Havana Pond to Sand Creek Lateral. A valve-controlled sluice gate on an 18-in pipe is used to regulate flow manually out of the pond. In the fall of 1988, a 56-ft long by 12-ft wide concrete spillway was installed to allow overflow during a 10-year flood event. Based on the WRI (Ebasco Services, Inc., et al., 1989a) storage volume information, an overflow of the pond would occur at a stage of 7.9 ft and the pond would contain 202.6 ac-ft of water.

The South Plants Lakes are important in that they are a significant component in the ground-water/surface-water interaction occurring at the Arsenal. Further discussion concerning the hydraulic communication occurring between these surface-water bodies and the ground-water flow system at RMA is provided in Section 4.4. The history of the lakes construction and water uses is presented in the Surface-Water Historical Report and FY89 Surface-Water Data Assessment Report. Three of the larger impoundments (Upper Derby Lake, Lower Derby Lake and Ladora Lake) were used as part of the process water system from 1942 until 1964. These lakes are connected to a number of diversion channels used to supply or divert water from the lakes. The lakes acted as a cooling system that dissipated heat from water used in the manufacturing processes in South Plants and also provided water for fire protection.

Upper Derby Lake is the uppermost lake that was used in the process water cooling system. The main part of the lake is located in the southwest quarter of Section 1 (Figure 2.3-1). The eastern extension of the lake (Eastern Upper Derby Lake) is located to the East across "E" Street. Upper Derby Lake was created by constructing a dam east of Lower Derby Lake to increase the volume of water in storage for the process water system. Upper Derby Lake can receive inflow both from Highline Lateral and the Uvalda Interceptor. The surface area of the lake at full operating capacity is 83 acres, with a storage capacity of 460 ac-ft of water (Graff & Reilly, 1943).

Eastern Upper Derby Lake has a clay-lined bottom and covers about 15 acres. In the spring and early summer months, the lake can be filled from surface-water inflow through a culvert from Upper Derby Lake when the stage on Upper Derby Lake is 6.8 feet. An overflow ditch exits from the north edge of the lake and flows northeast towards First Creek. Flow towards First Creek can occur when the water level in Upper Derby Lake is at a staff of 9.0 feet. During the late summer, fall and winter months when surface-water runoff is low, the lake is marshy or dry (Ebasco Services, Inc., 1987c). During Water Year 1990 the lake contained water for 4 months.

Lower Derby Lake is located in south-central Section 1 between Upper Derby Lake and Ladora Lake (Figure 2.3-1). The lake is visible on a July 16, 1937, air photograph but is smaller in size. The lake was originally used as an irrigation reservoir at the time RMA was established. In 1942, the lake's storage capacity was increased when the Army modified the existing earthen dam by raising the crest 3 ft, regrading the side slopes, and installing a new drain line (United States Army Chemical Warfare Service, 1945). A ditch was constructed at the northwestern end of Lower Derby Lake to connect with a pipe and drain into Ladora Lake (Donnelly, 1983, cited in Ebasco Services, Inc. 1987c). This diversion controlled outflow from Lower Derby Lake. Because of flooding that occurred in the Irondale Gulch through Lower Derby Lake in May 1973, an emergency overflow ditch was constructed south of the lake to carry overflow water to the Rod and Gun Club Pond. Lower Derby Lake can receive inflow from Upper Derby Lake and both Highline Lateral and Uvalda Interceptor. As of 1982, Lower Derby Lake stored water that is used to maintain the water level in Ladora Lake. Lower Derby Lake is currently used for recreational fishing under a catch-and-release program (Ebasco Services, Inc., 1987c). The normal pool storage volume of the lake is 550 ac-ft with a surface area of 73 acres (USACOE, 1987). A spillway was construoted on the northwest edge of the lake during Water Year 1990.

The Rod and Gun Club Pond located in the north-central part of Section 12 occurs in a natural topographic depression south of Lower Derby Lake (Figure 2.3-1). The shallow ditch that connects the Rod and Gun Club Pond to Lower Derby Lake was constructed during the May 1973 flood to carry overflow from the lake. When water levels are high enough, overflow from Lower Derby Lake can replenish the water in the pond. The Rod and Gun Club Pond can also receive overflow from the Uvalda Interceptor when the stage in the Uvalda Interceptor is high enough for water to flow through a low area or a cut in its bank. This overflow water from the interceptor moves across a field in an undefined channel before reaching the Rod and Gun Club Pond. The surface area of the pond when full has been estimated at approximately 19.3 acres (Ebasco Services, Inc. 1986; cited in MKE 1987). This includes the marshy area around the pond. The actual pond covers about 4.9 acres and has a volume of less than 15 ac-ft.

Ladora Lake, located in the central and south-central portion of Section 2 (Figure 2.3-1), was constructed for use in irrigation by farmers prior to construction of RMA (Donnelly, 1986, cited by Ebasco Services, Inc. 1987c). In 1942 the lake was enlarged to increase its storage capacity for water used in the process water system. Ladora Lake can receive water from many sources. Theses sources include Havana Pond via Sand Creek Lateral, Lower Derby Lake through Ladora Weir, Lake Mary via a pump and from three Section 4 wells. A new spillway was constructed during the summer of 1989. The normal pool storage volume of Ladora Lake is 400 ac-ft with a surface area at that volume of 48 acres (USACOE, 1987). Average water depth is estimated to be 5.6 ft (MKE, 1987).

In 1960 the swampy area directly west of Ladora Lake in Section 2 (Figure 2.3-1) was excavated and a berm was constructed to create a small 7-acre lake (Donnelly, 1986, cited in Ebasco Services, Inc. 1987c). Several years later, parallel earthen mounds were constructed to partition the eastern portion of the lake into three areas for use in minnow-rearing and deepened to an average depth of 15 ft to enhance the quality of the water for the fish (Mullan, 1975; Schmidt, 1975; cited in Ebasco Services, Inc. 1987c). Lake Mary can receive a regulated water supply from several sources: water pumped from three alluvial wells located in Section 4, water pumped from Ladora Lake and potable water discharged from the 1-million gallon storage tank. Lake Mary occupies 9 acres at a normal pool storage volume (spillway crest) of 60 acre-feet (USACOE, 1983b).

The Irondale Gulch Drainage Basin contains the majority of the surface-water monitoring sites operated on RMA with 12 monitoring stations (Figure 2.3-2 and Table 2.3-1) and 22 potential sampling locations (Figure 2.3-3 and Table 2.3-2). The monitoring stations and sampling locations are concentrated in the southeastern portion of this drainage. The monitoring stations and sample sites located in this area are used for measuring surface-water quantity and quality as it enters RMA from the residential, commercial and industrial areas located south of RMA. The lake and pond stations are used for the calculation of storage volumes and assessing the water quality. The monitoring station (South Plants Ditch) and sample sites located north of the South Plants Lakes are used to determine the surface-water quantity and quality as it enters the ground water and the South Plants Lakes.

2.4 SUMMARY OF SURFACE-WATER FLOW ON RMA DURING WATER YEAR 1990

Surface Water was observed to be flowing in three of the drainage basins on RMA (Irondale Gulch, South Platte and First Creek) during Water Year 1990. Surface water entered RMA from the south at several locations. Intermittently, surface water entered RMA along Highline Lateral, Havana Interceptor and Peoria Interceptor. Surface water entered RMA along First Creek and Uvalda Interceptor everyday during Water Year 1990. The water from Uvalda Interceptor and Highline Lateral was directed to Upper Derby Lake and/or Lower Derby Lake. Water from Havana and Peoria Interceptors went directly to Havana Pond. The water in First Creek either continued on past the RMA north boundary or infiltrated on RMA. Surface water exited along First Creek from RMA on 144 days and infiltrated 221 days prior to leaving RMA. In the South Platte drainage basin a high event flow occurred in the Basin F IRA drainage ditch and baseflow conditions were observed in Basin A. Table 2.4-1 summarizes surface-water flow activities on RMA during Water Year 1990.

Table 2.4-1 Summary of Surface-Water Flow During Water Year 1990 on RMA

Monitoring Station	Number of Days	Destination of Flow
First Creek Drainage Basin		
South First Creek	153	North First Creek
	212	infiltration and evapotranspiration
	0	zero flow
North First Creek	144	First Creek Off-Post
	9	infiltration and evapotranspiration
	212	zero flow
First Creek Off-Post	263	O'Brian Canal
	102	zero flow
South Platte Drainage Basin		
Basin A	365'	Basin A Pond
Basin F	8	infiltration and evaportranspiration
	357	zero flow
Irondale Gulch Drainage Basin		
Havana Interceptor	275	Havana Pond
	90	zero flow
Peoria Interceptor	347	Havana Pond
	18	backwater
	18	zero flow
South Uvalda	288	Upper Derby Lake
	77	Lower Derby Lake
	0	zero flow
North Uvalda	90	Lower Derby Lake
	275	zero flow
Highline Lateral	61	Upper Derby Lake
	19	Lower Derby Lake
	285	zero flow
South Plants Ditch	365	zero flow
Havana Pond	365	no releases to Sand Creek Lateral
Upper Derby Lake	118	Eastern Upper Derby Lake
Lower Derby Lake	38	Ladora Lake

Table 2.4-1 Summary of Surface-Water Flow During Water Year 1990 on RMA (continued)

Monitoring Station	Number of Days	Destination of Flow
Irondale Gulch Drainage Basin		
Ladora Lake	3	Ladora Lake Spillway
Lake Mary	365	no releases
Eastern Upper Derby Lake	36	First Creek

Based on mean daily flow .
Approximate days of flow based on weekly observations.

2.4.1 FIRST CREEK DRAINAGE BASIN

Stream flow along First Creek in First Creek Drainage Basin was recorded at the South First Creek monitoring station every day during Water Year 1990. Surface water from Eastern Derby Lake added some sporadic flow to First Creek from July to September. The First Creek stream flow continued past the North First Creek monitoring station and RMA north boundary or infiltrated on RMA (Table 2.4-1). Stream flow was recorded at the North First Creek station on 153 days during the year. This flow continued beyond the RMA north boundary to the First Creek Off-Post station and was recorded on 144 days. This stream flow continued for a short distance to the O'Brian Canal. Stream flow did not reach the North First Creek Station during 212 days, being lost to infiltration and evapotranspiration. Stream flow did not reach the First Creek Off-Post Station for 9 days when flow was recorded at the North First Creek Station. However, stream flow was observed at the First Creek Off-Post station at the same time that no flow was recorded at the North First Creek station on several occasions. The maximum mean daily flows at each of the stations were 3.3 cfs in August at South First Creek station, 2.5 cfs in March at North First Creek station and 1.8 cfs in March at the First Creek Off-Post station.

2.4.2 SAND CREEK DRAINAGE BASIN

Surface-water flow was observed once during Water Year 1990 at the Motor Pool sample location. This flow occurred during a thunderstorm. The maximum rate of flow was 1.0 cfs and the duration was 1 hour.

2.4.3 SOUTH PLATTE DRAINAGE BASIN

In the South Platte drainage on RMA surface-water flow was recorded at Basin F station as a result of high events. Snowmelt accounted for high event flow in March. Thunderstorms caused high event flow twice during the months of July and August. The maximum mean daily flow occurred in March and was 0.02 cfs. Surface-water flow was observed weekly at Basin A with baseflow conditions attributing to flow the majority of the time. Surface water at both locations infiltrated into the ground.

2.4.4 IRONDALE GULCH DRAINAGE BASIN

Surface-water flow was recorded every day entering RMA in Irondale Gulch along Uvalda Interceptor. Controlled flow from Highline Canal entering RMA along Highline Lateral occurred on 70 days during the year. Surface water from both of these sources was directed to either Upper Derby Lake or Lower Derby Lake (Table 2.4-1). The maximum mean daily flows on Highline Lateral and Uvalda Interceptor were 10.0 cfs (June) and 2.3 cfs (August), respectively.

Surface-water flow in Havana Interceptor occurred on 275 days. Peoria Interceptor recorded flow on 347 days. The water in both of the Interceptors was directed to Havana Pond. No water was released from Havana Pond this year. The maximum mean daily flow was 3.6 cfs in May at Havana Interceptor and 0.76 cfs in March at Peoria Interceptor.

Surface-water flow did not occur in South Plants Ditch this year as had occurred in years past. Surface water was observed during the spring and fall sampling events in the South Plants steam effluent ditch.

The total storage volume in the South Plants Lakes remained approximately equal to recent years' storage volumes. Water was only released through the Ladora Lake spillway. Eastern Upper Derby Lake released some low amounts of water to First Creek from July to September. Eastern Derby Lake stored more water than in recent years due to higher water levels in Upper Derby Lake. More water was stored in Upper Derby Lake because water could not be released to Lower Derby Lake. Spillway construction activities on Lower Derby Lake necessitated lower water levels in the lake.

3.0 PROGRAM STRATEGY AND METHODOLOGY

3.1 SURFACE-WATER QUANTITY

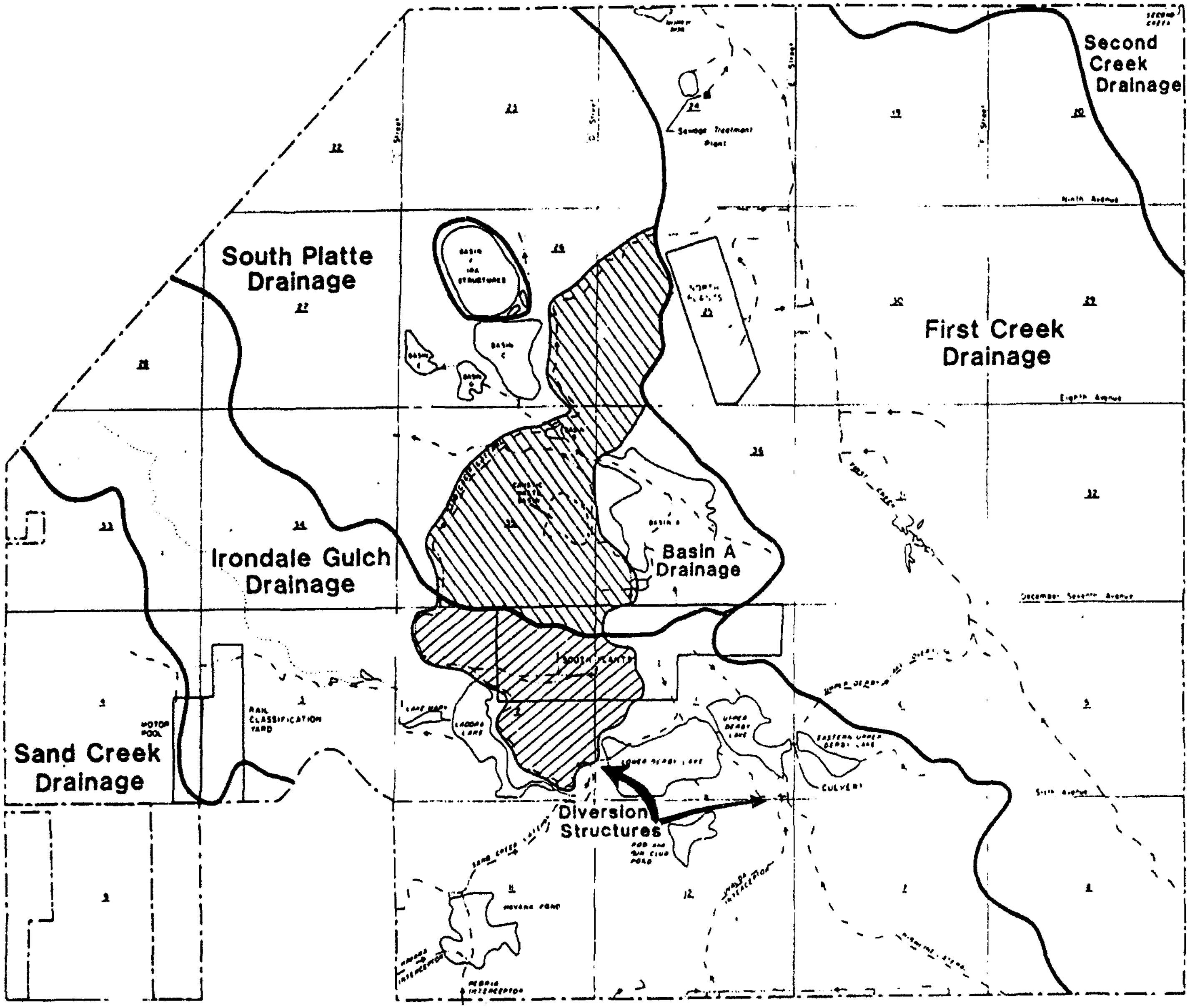
The acquisition of surface-water quantity data in Water Year 1990 resulted predominantly from continuous stage recordings, weekly staff gage observations and monthly instantaneous discharge measurements obtained from several surface-water monitoring stations located on RMA. The stations are strategically located throughout three drainage basins, including one off-post station and are positioned to monitor surface-water flowing on to and off RMA. This section describes the strategies, procedures and equipment employed by the surface-water CMP at each station. Stage and instantaneous discharge data were attained from existing stations that had been constructed for pre-CMP surface-water monitoring programs or stations that were reconstructed or added in 1989 to monitor surface-water flow (Figure 2.3-2). In addition to this, two new stations, Basin F and a rain gage in South Plants, were added to the surface-water monitoring network in Water Year 1990 (Figure 2.3-2). The meteorological stations monitored by the CMP Air Element used in this report are also shown on Figure 2.3-2. The quantity of water entering and exiting RMA in the form of precipitation, surface-water runoff, evaporation and operational use is utilized to determine the effects on ground water at RMA and ultimately to develop plans for surface-water management.

3.1.1 SURFACE-WATER MONITORING NETWORK

The surface-water quantity monitoring stations are located in three major drainage basins on RMA: First Creek Drainage Basin, Irondale Gulch Drainage Basin and South Platte Drainage Basin (Figure 2.3-2). Second Creek Drainage Basin and Sand Creek Drainage Basin do not have surface-water quantity monitoring stations because significant flows do not occur on RMA within these areas.

The stream, lake, pond and diversion monitoring stations that are used for water quantity monitoring were equipped, constructed and strategically located by previous contractors and by RLSA Surface-Water CMP. The purpose was to monitor surface-water volumes for use in water management and remediation efforts. This section describes the equipment and controls used and the surface water that is characteristically monitored at each station within the major drainage basins described in Section 2.

Surface-water quantity monitoring under the CMP during Water Year 1990 was conducted at 17 stations located throughout RMA and one off-post monitoring station. Thirteen of the stations are equipped with Stevens Type F recorders, 10 of which are also equipped with either a CR-10 Datalogger/bubbler system or DP115 Datapod in conjunction with the Stevens Recorder. The Sewage Treatment Plant effluent is monitored by a totalizing flow meter, and the remaining four surface-water monitoring stations are at lakes equipped with staff gages (Table 3.1.1). Section 3.1.2 describes the monitoring equipment. Field activities included weekly maintenance on continuous stage recording systems, weekly logs of observed



Legend

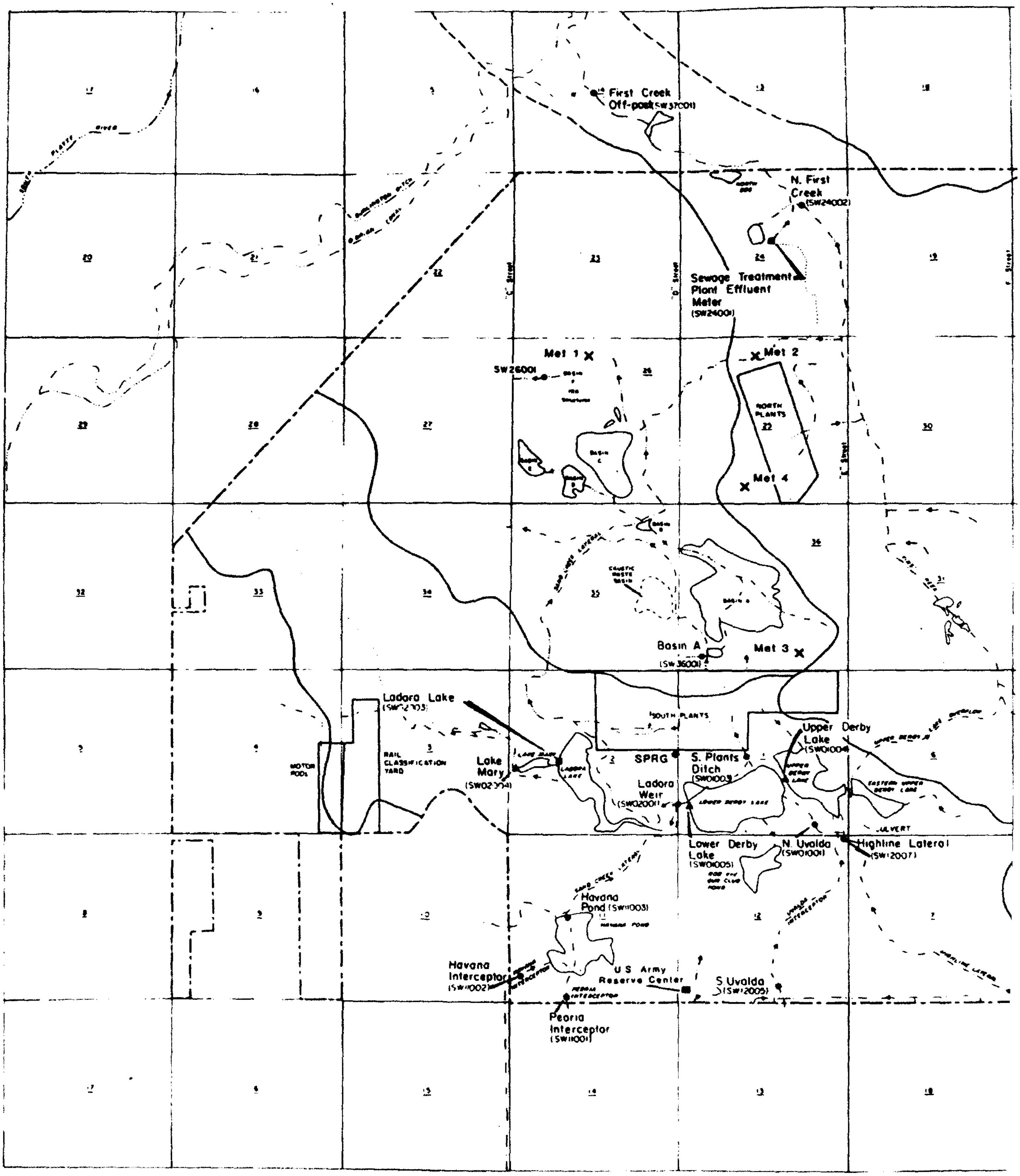
- Section Number
- Lake, Pond or Basin
- Stream or Ditch with Flow Direction
- Abandoned Stream or Ditch
- Drainage Basin
- Sand Creek Lateral drainage within South Platte drainage
- Sand Creek Lateral drainage within Irondale Gulch drainage downgradient of diversion structure
- Arsenal Boundary

0 2000 4000
FEET

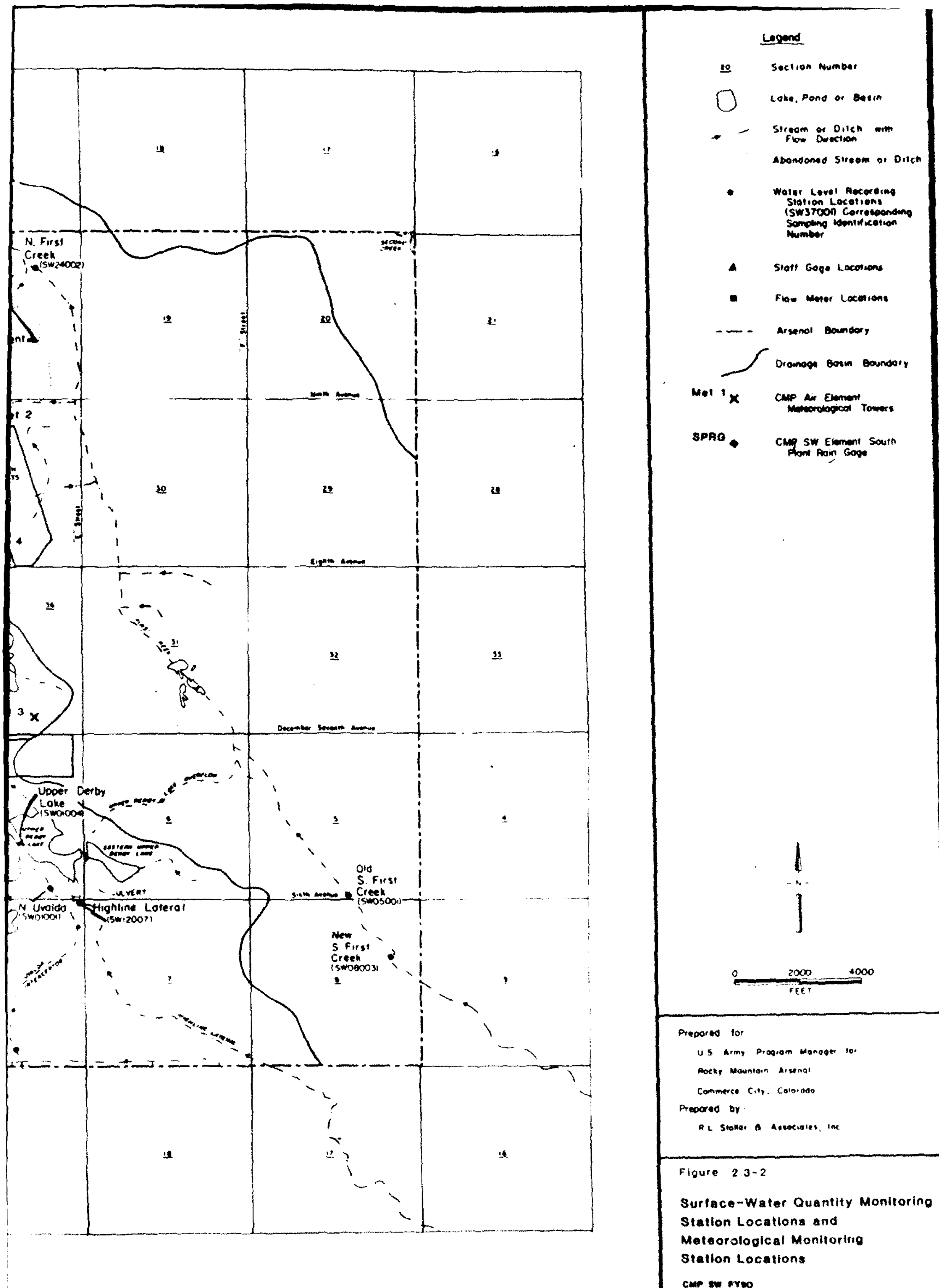
Prepared for
U.S. Army Program Manager ...
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
R.L. Stollar & Associates, Inc.

Figure 2.3-1

Diagram of RMA Surface-Water Features and Drainage Basins



First Creek Off-post (SW37001)
N. First Creek (SW24002)
Sewage Treatment Plant Effluent Meter (SW24001)
Met 1
Met 2
SW26001
NORTH PLANTS
Met 4
Basin A (SW36001)
Met 3
Ladora Lake
SOUTH PLANTS
RAIL CLASSIFICATION YARD
MOTOR POOL
Lake Mary (SW02004)
SPRG
S. Plants Ditch (SW01003)
Ladora Weir (SW02001)
Upper Derby Lake (SW01004)
Lower Derby Lake (SW01005)
N. Uvalda (SW01001)
Highline Lateral (SW12007)
CULVERT
Havana Pond (SW11003)
Havana Interceptor (SW11002)
U.S. Army Reserve Center
S Uvalda (SW12005)
Peoria Interceptor (SW11001)

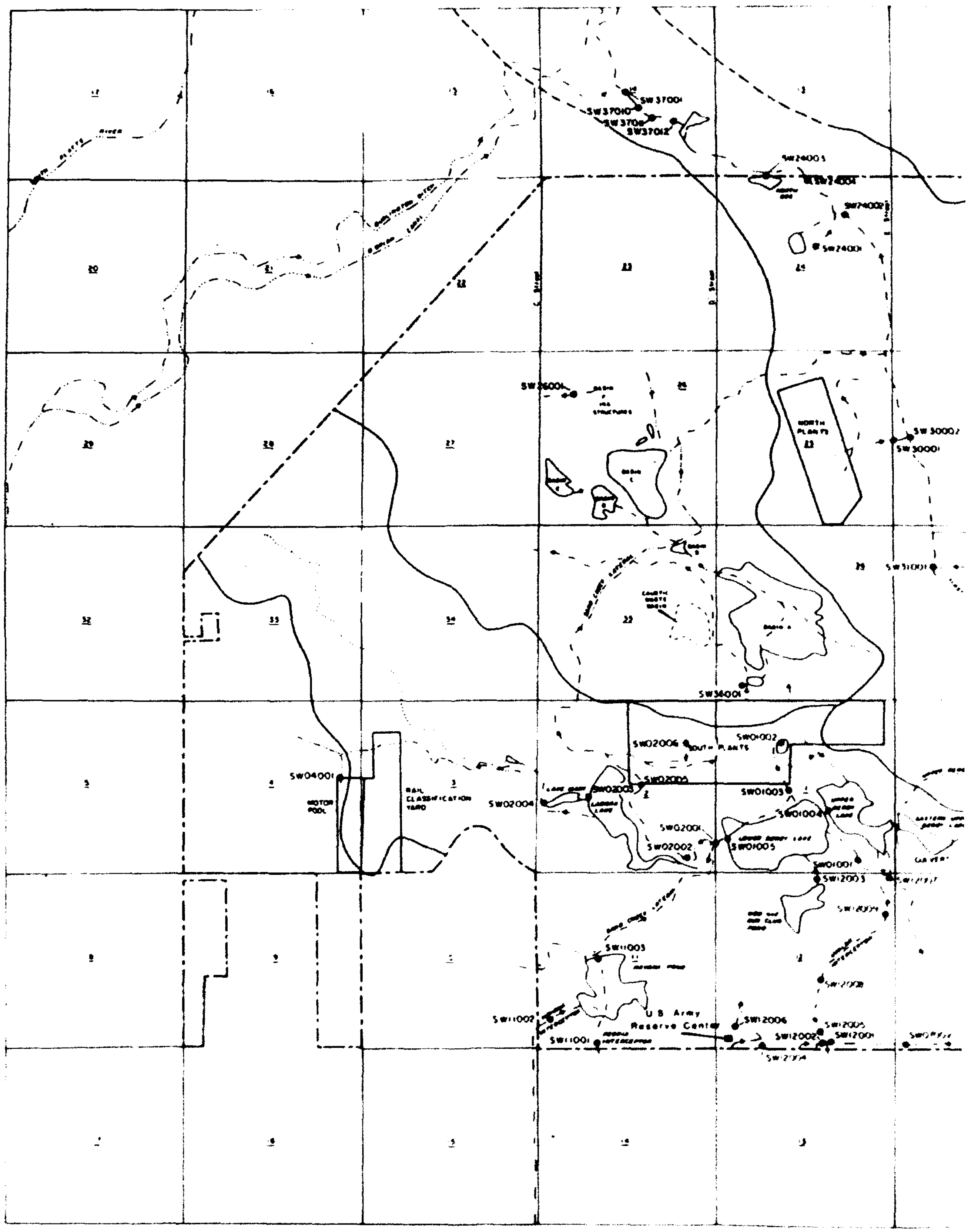


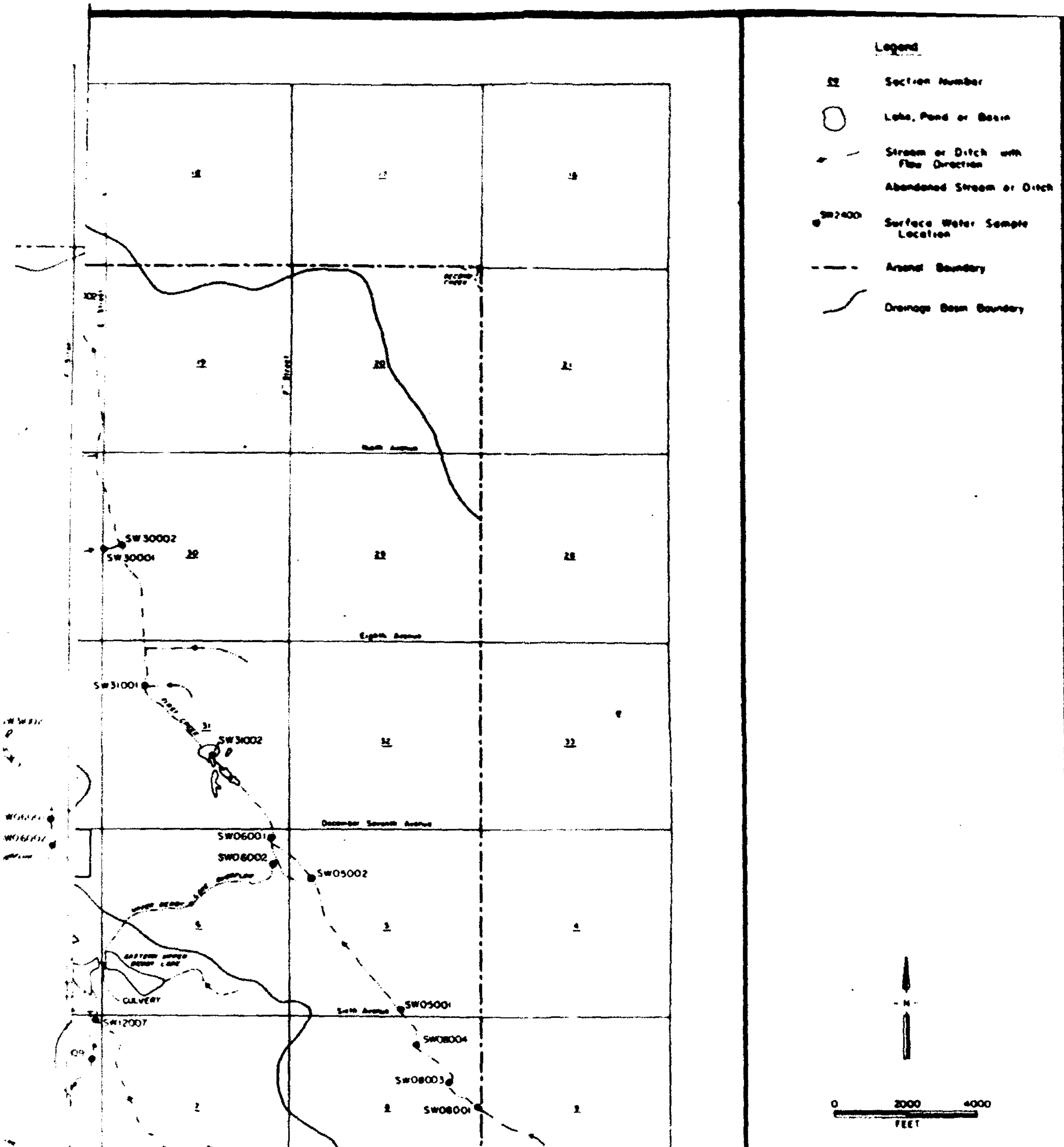
Prepared for
U.S. Army Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by
R.L. Stollar & Associates, Inc.

Figure 2.3-2

Surface-Water Quantity Monitoring Station Locations and Meteorological Monitoring Station Locations

CMP SW FY90


SW37001
SW37010
SW37011
SW37012
SW24003
SW24004
SW74002
SW74001
SW26001
NORTH PLANTS
SW30002
SW30001
SW31001
SW36001
SW02006
SOUTH PLANTS
SW01002
SW04001
MOTOR POOL
RAIL CLASSIFICATION YARD
SW02004
SW02003
SW02005
SW01003
SW01004
SW02001
SW02002
SW01005
SW01001
SW12003
SW12004
SW11003
SW12008
SW11002
U S Army
Reserve Center
SW12006
SW12005
SW11001
SW12002
SW12001
SW12004



Prepared for
U.S. Army, Program Manager for
Rocky Mountain Arsenal
Commerce City, Colorado
Prepared by:
R.L. Stollar & Associates, Inc

Figure 2.3-3

Surface-Water Quality Sampling Locations

CMP SW FY90

Table 3.1-1 *Surface-Water Monitoring Network Equipment*

Monitoring Stations	Monitoring Equipment
<u>Irondale Gulch Drainage Basin</u>	
Havana Interceptor (SW11002)	Concrete Lined Channel Control and CR-10 Data Logger/Bubbler System
Peoria Interceptor Type F Recorder, Style C Staff Gage, CR-	90° V-notch Weir Compound Control, Stevens (SW11001) 10 Data Logger/Bubbler System
Ladora Weir Recorder, Style C Staff Gage, and DP115	Rectangular Weir Section Control, Stevens Type (SW02001) F Datapod
South Uvalda Interceptor Type F Recorder, Style C Staff Gage, and	Concrete V-notch Weir Compound Control, (SW12005) Stevens CR-10 Data Logger/Bubbler System
North Uvalda Interceptor Recorder, Style C Staff Gage, and DP115	Concrete Weir Compound Control, Stevens Type (SW01001) F Datapod
Highline Lateral Recorder, and Style C Staff Gage	Cipolletti Weir Section Control, Stevens Type (SW12007) F
South Plants Ditch Type F Recorder, and Style C Staff Gage	Sharp-crested V-notch Section Control Weirs, (SW01003) Stevens
Havana Pond (SW11003)	Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod
Upper Derby Lake (SW01004)	Staff Gage
Lower Derby Lake (SW01005)	Staff Gage
Ladora Lake (SW02003)	Staff Gage
Lake Mary (SW02004)	Style C Staff Gage

Table 3.1-1 Surface-Water Monitoring Network Equipment (continued)

Monitoring Stations	Monitoring Equipment
First Creek Drainage Basin	
South First Creek F Recorder, Style C Staff Gage, and CR-10	Concrete V-notch Weir Section Control, Stevens (SW08003) Type Data Logger/Bubbler System
North First Creek (SW24002)	Concrete V-notch Weir Section Control, Stevens Type F Recorder, Style C Staff Gage, and CR-10 Data Logger/Bubbler System
First Creek Off-Post (SW37001)	Concrete Triangular-throated Flume Control, Stevens Type F Recorder, DP115 Datapod and Style C Staff Gage
Sewage Treatment Plant (SW24001)	Totalizing Flow Meter
South Platte Drainage Basin	
Basin A Inflow (SW36001)	90° V-notch Weir Section Control, Stevens Type F Recorder, Style C Staff Gage, and DP115 Datapod
Basin F (SW26001)	Galvanized Sheet Metal 200mm Long-throated Flume Control, Side Mounted Style C Staff Gage, Stevens Type F Recorder and DP115 Data Pod

stream, ditch and lake staff gage readings, and monthly instantaneous discharge measurements at sites with active streamflow. Daily flow records were also obtained on effluent from the Sewage Treatment Plant in Section 24. Table 3.1-2 provides a summary of monitoring station activities during Water Year 1990. In December 1990, the Stevens recorders and floats were pulled out of the stations before the stilling wells started freezing. They were reinstalled in March 1990. The stage records for these months without Stevens recorders were based upon weekly observations of the staff gages and the continuous records of CR-10 datalogger/bubbler systems which remained functional throughout the year.

3.1.1.1 Irondale Gulch Drainage Basin

The Irondale Gulch Drainage Basin, located in the southwestern half of RMA, is bordered by the South Platte Drainage Basin and the First Creek Drainage Basin to the northeast and by the Sand Creek Drainage Basin to the southwest (Figure 2.3-1). Irondale Gulch Drainage Basin accepts surface-water flow from Havana Interceptor, Peoria Interceptor, Uvalda Interceptor and Highline Lateral. The surface-water from these sources enter the drainage from the southern border of RMA and is directed to either Havana Pond or the South Plants Lakes.

There are a total of 12 surface-water monitoring stations and one meteorological station located within the Irondale Gulch Drainage Basin (Figure 2.3-2). Stream monitoring stations include Havana Interceptor (SW11002), Peoria Interceptor (SW11001), Ladora Weir (SW02001), South Uvalda (SW12005), North Uvalda (SW01001), Highline Lateral (SW12007) and South Plants Ditch (SW01003). Lake and pond monitoring stations include Havana Pond (SW11003), Upper Derby Lake (SW01004), Lower Derby Lake (SW01005), Ladora Lake (SW02003) and Lake Mary (SW02004). The South Plants rain gage is located just south of the South Plants facility next to "D" Street. Surface-water monitoring equipment that is in service at the gaging stations within Irondale Gulch Drainage Basin is listed in Table 3.1-1.

3.1.1.1.1 Havana Interceptor (SW11002)

The Havana Interceptor gaging station is located near the southern boundary of RMA in the southwest corner of Section 11 (Figure 2.3-2). The purpose of the station is to monitor surface water flowing from the southwest onto RMA. The Interceptor is a concrete-lined channel and is designed to carry surface-water runoff and storm water to Havana Pond from Stapleton Airport and from commercial properties located south of RMA (Figure 2.3-2). The station is equipped with a Campbell Scientific CR-10 data logger/bubbler system and a nitrogen cylinder which is housed inside a wooden storage shed at the station. This system provides continuous records throughout the winter months. Stage measurements are taken by placing a metal tape measure on top of the copper bubbler line in the channel bottom and adding the diameter of the line. FY89 Surface-Water Data Assessment Report, (RLSA, 1990b) contains details on strategies and routine maintenance, which were employed throughout Water Year 1990. The channel control structure at the station is a concrete trapezoidal channel.

Table 3.1-2 Surface-Water Monitoring Station Activities

Monitoring Stations	Type	Activity		
		Weekly	Monthly	High Event
Irondale Gulch Drainage Basin				
Havana Interceptor (SW11002)	Recording Station	Service Recorder & Monitor Stage	Discharge Measurement Monitor Crest Stage	Discharge/Measurement
Peoria Interceptor (SW11001)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
Ladora Weir (SW02001)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement/ When Flow Occurs	
South Uvalda (SW12005)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
North Uvalda (SW01001)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement/ When Flow Occurs	
Highline Lateral (SW12007)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement/ When Flow Occurs	
South Plants Ditch (SW01003)	Recording Station	Service Recorder & Monitor Staff Gage		Discharge Measurement/ Monitor Crest Stage
Havana Pond (SW11003)	Recording Station	Service Recorders & Monitor Staff Gage		
Upper Derby Lake (SW01004)	Staff Gage	Monitor Staff Gage	Monitor Gage	Monitor Gage
Lower Derby Lake (SW01005)	Staff Gage	Monitor Staff Gage	Monitor Gage	Monitor Gage
Ladora Lake (SW02003)	Staff Gage	Monitor Staff Gage	Monitor Gage	Monitor Gage

Table 3.1-2 *Surface-Water Monitoring Station Activities (continued)*

Monitoring Stations	Type	Activity		
		Weekly	Monthly	High Event
<u>Irondale Gulch Drainage Basin</u> (Continued)				
Lake Mary (SW02004)	Staff Gage	Monitor Staff Gage	Monitor Gage	Monitor Gage
<u>First Creek Drainage Basin</u>				
South First Creek (SW08003)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
North First Creek (SW24002)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
First Creek Off-Post (SW37001)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
Sewage Treatment Plant (SW24001)	Flow Meter	Monitor Meter		
<u>South Platte Drainage Basin</u>				
Basin A (SW36001)	Recording Station	Service Recorders & Monitor Staff Gage	Discharge Measurement	Discharge Measurement/ Monitor Crest Stage
Basin F (SW26001)	Recording Station	Service Recorders	Monitor Staff Gage	Discharge Measurement/ Monitor Crest Stage

3.1.1.1.2 Peoria Interceptor (SW11001)

The Peoria Interceptor gaging station is located near the southern boundary of RMA in the southwest quarter of Section 11 (Figure 2.3-2). The purpose of the station is to monitor surface-water flowing from the south onto RMA. It is situated in an unlined ditch designed to carry surface-water and storm-water runoff from the off-post industrial area south of RMA to Havana Pond. The station is equipped with a Stevens Type F recorder on top of a corrugated metal pipe stilling well which is connected hydraulically to the active stream channel by 2-inch intake pipes. A Style C staff gage was remounted to the stilling well and surveyed in July 1990. A CR-10 data logger/bubbler system was installed during December 1989 and is housed in a wooden storage shed with a nitrogen supply tank. This system provides continuous records throughout the winter months. The compound control structure located at the station is a 90° V-notch steel plate weir attached to a narrow plank that is positioned perpendicular to flow and embedded into the banks on both sides of the channel. The weir was refabricated during April 1989 in order to correct leaking underneath and around the old weir, but the structure has developed leaks recently under the V-notch.

Problems that are encountered at this station consist of an accumulation of debris, vegetation overgrowth and a backwater situation. The station collects trash that is removed periodically, and vegetation overgrowth at the station needs to be removed annually. A backwater condition exists at this station when the water stored in the Havana Pond exceeds 3.42 ft. on the Havana Pond staff gage, which occurs during extreme storm events resulting in the loss of some flow data during this period. Additional maintenance includes changing the nitrogen tank for the CR-10 bubbler system when tank pressure drops to less than 400 psi and changing the CR-10 bubbler system batteries when voltage drops to below 12 volts.

3.1.1.1.3 Havana Pond (SW11003)

The Havana Pond gaging station is located adjacent to the earthen embankment on the north side of Havana Pond near the center of Section 11 (Figure 2.3-2). The pond is used to store surface-water and storm-water runoff from the Havana and Peoria Interceptors. A culvert on the north side of the pond is occasionally used to release water into Sand Creek lateral, but this did not occur in Water Year 1990. The station consists of a Stevens Type F recorder in conjunction with a potentiometer and a DP115 Datapod housed in a protective cover that is mounted on a vertical stilling well. A Style C staff gage is mounted to a vertical post on the walkway leading to the stilling well. The stilling well is positioned near Havana Pond's low stage waterline and is hydraulically connected to the pond.

A significant amount of surface water recharges the ground water at Havana Pond, especially after storm events. Infiltration rates calculated after an August storm indicated a 46 percent decrease in storage volume to the ground water in 10 days.

Water levels in the pond go below the stilling well and staff gage at a stage of about 1.00 foot. To eliminate the problem, a trench is excavated to hydraulically connect the pond with the stilling well and staff gage. The stilling well also accumulates sediment which must be periodically removed to keep the Stevens Type F recorder's float in water. For information about Havana Pond's outflow structure and spillway refer to RLSA, 1990b.

3.1.1.1.4 Ladora Weir (SW02001)

The Ladora Weir gaging station is located in the southeast corner of Section 2 (Figure 2.3-2). A new rectangular concrete weir was constructed in July and August 1990 which included an upper and lower weir with energy dissipators immediately upstream from the lower weir. After construction, a metal grate was installed on top of the upper weir to prevent fish and debris from entering the channel. Holes were drilled in the lower weir to provide drainage for water trapped between the two weirs after periods of flow. Accurate discharge measurements have been difficult to obtain since the new weir was constructed. The dissipators and the grate prohibit a smooth uniform flow within the weir structure. Downstream of the weir, the channel consists of large angular cobbles, making it difficult to obtain reliable discharge measurements.

The station monitors flow from Lower Derby Lake as it enters Ladora Lake or Sand Creek Lateral. Ladora Weir does not monitor flows originating from Havana Pond. The gaging station consists of a Stevens Type F recorder in conjunction with a potentiometer and a DP115 Datapod in a protective cover over a wooden deck. Beneath the deck is a concrete basin that serves as a stilling well. During the construction of the weir in July and August 1990, the Stevens Type F recorder and the DP115 Datapod remained at the stations. The recorders indicate when flow occurs, but not the amount of flow. There were no recorded flows from Lower Derby Lake between July 24 and August 29.

The station's Datapod requires monthly changing of the data storage module (DSM) and batteries. Ladora Weir does not accumulate trash and vegetative debris, but at times can accumulate dead fish in the stilling well structure.

3.1.1.1.5 South Uvalda (SW12005)

The South Uvalda gaging station is located on the southern portion of Uvalda Interceptor in south central Section 12 (Figure 2.3-2). It is situated in an unlined ditch and monitors surface water and storm water originating from off-post residential and industrial properties flowing onto RMA. Stream flow can be directed to either of the Derby Lakes. The station is equipped with a CR-10 data logger and bubbler system and a Stevens Type F recorder. The CR-10 bubbler system provides a stage record for the entire year, which is needed here because the station displays base flow even during the winter months. An ISCO automated sampler was installed at the station in March 1990, thus allowing for samples to be collected during the early stages (rising limbs) of high events. The compound control structure located at the station consists of a V-notch in a 12-in. wide concrete weir. A Style C staff gage was remounted and surveyed in July 1990 in the active channel near the intake pipes. Routine and periodic maintenance at the station remained the same in Water Year 1990 and is detailed in RLSA, 1990b.

3.1.1.1.6 North Uvalda (SW01001)

The North Uvalda gaging station is located on the original Highline Lateral ditch in the southeast corner of Section 1, approximately 1,500 ft upstream of the inlet to Lower Derby Lake (Figure 2.3-2). It is positioned on the segment of the ditch so that surface water delivered to Lower Derby Lake can be monitored. This surface water originates from an area south of RMA, either from Highline Lateral and/or from Uvalda Interceptor. The station consists of a Stevens Type F recorder in conjunction with a potentiometer and DP115 datapod housed in a protective box that is mounted on a corrugated metal pipe stilling well. The stilling well is situated adjacent to the active stream channel and is hydraulically connected to the stream with 2-inch intake pipes. Silt accumulates in the stilling well and needs to be flushed once a year. A Style C staff gage is positioned in the active channel at the stilling well's intake pipes. The compound control structure located at the station is a broad-crested concrete weir.

The station's Datapod requires monthly changing of the DSM and batteries. Significant accumulation of trash or debris does not occur here.

3.1.1.1.7 Highline Lateral (SW12007)

The Highline Lateral gaging station is located on the Highline Lateral, 20 ft south of Sixth Avenue in the northeast corner of Section 12 (Figure 2.3-2). It is situated along the unlined Highline Lateral irrigation ditch, which delivers Army-owned shares of irrigation water from the South Platte River to the Derby Lakes. The station is equipped with a Stevens Type F recorder in a protective cover mounted on an open-ended wooden-cased feeder channel. The wooden feeder channel is hydraulically connected to the main channel and is located approximately 10 ft upstream from the control. The section control for the station is a Cipolletti weir.

3.1.1.1.8 South Plants Ditch (SW01003)

The South Plants Ditch gaging station is located near the center of Section 1 (Figure 2.3-2) at a diversion structure that can monitor flow from the South Plants area, to either the east or to the west end of Lower Derby Lake. The station consists of a Stevens Type F recorder in a protective box that is mounted on a corrugated metal pipe stilling well which is hydraulically connected to the ditch with two 2-inch intake pipes. A Style C staff gage is positioned in the active ditch. The compound control structures located at the station are sharp-crested, 90° V-notch weirs. These are mounted on wooden planks attached to the outflow sides of the diversion structure. Flow can pass over both weirs at the same time, to either the upper or lower end of Lower Derby Lake. This station did not have a measurable flow during Water Year 1990.

3.1.1.1.9 Lake Monitoring Stations

Staff gages that monitor lake levels are located at observation points on each of the lake dams. The lakes currently being monitored are Upper Derby Lake, Lower Derby Lake, Ladora Lake and Lake Mary. Figure 2.3-2 shows the location of each lake observation point.

The Upper Derby Lake staff gage is located on the west shore of the lake near the outflow to Lower Derby Lake. The station number is SW01004. This staff gage is divided into increments of 0.1 ft and has a range of 0 to 10.0 feet. The lake spills over into Eastern Upper Derby Lake at a gage reading of approximately 6.8 ft, which in turn will outflow towards First Creek at an Upper Derby Lake gage reading of approximately 9.0 feet.

The Lower Derby Lake staff gage is located on the west end of the lake near its outfall to Ladora Weir. The station number is SW01005. The staff gage is divided into increments of 0.1 ft and has a range of 3.0 to 21.0 feet. This lake will begin to spill over to a new spillway at a gage reading of 16.8 feet (Stearns-Roger Engineering, 1989, Personal Communication).

The Ladora Lake staff gage is located on the west end of the lake near the pump station. The number for this station is SW02003. A new staff gage was installed in September 1989. The staff gage has of 0.1 ft increments and spans a vertical distance from 0 to 13.0 ft. Overflow will occur at 12.8 ft into a spillway constructed in summer of 1989.

Water elevation at Lake Mary is monitored by a staff gage located on the west end of the lake. The designated number for this station is SW02004. A Style C staff gage with 0.01 ft increments and a range from 0 to 2.00 ft is used to monitor the lake levels. Overflow of the Lake Mary occurs at 1.34 ft.

3.1.1.2 First Creek Drainage Basin

The First Creek Drainage Basin is located predominantly on the eastern half of RMA and is bordered by the Second Creek Drainage Basin to the northeast and by the South Platte Drainage Basin and the Irondale Gulch Drainage Basin to the west and southwest (Figure 2.3-1). The primary source of stream flow in First Creek Drainage Basin is from First Creek, but the drainage can also receive added flow from Eastern Upper Derby Lake Overflow, Sand Creek Lateral, Highline Canal and the Sewage Treatment Plant (Figure 2.3-1). Surface water that exits RMA in the First Creek Drainage Basin is confined to First Creek where it flows off-post at the northern border.

There are four monitoring stations located within the First Creek Drainage Basin; South First Creek (SW08003), North First Creek (SW24002), First Creek Off-Post (SW37001) and the Sewage Treatment Plant (SW24001). Monitoring equipment that is employed at these stations is listed in Table 3.1-1.

3.1.1.2.1 South First Creek (SW08003)

South First Creek monitoring station is located in the northeast quarter of Section 8 (Figure 2.3-2) and is used to monitor flow coming onto RMA. The station is equipped with a Stevens Type F recorder housed in a protective box and is mounted to a corrugated metal pipe stilling well that is hydraulically connected to the active stream with two 2-inch intake pipes. The station is equipped with a CR-10 data logger/bubbler system, which is housed inside a wooden storage shed with a nitrogen supply tank. The CR-10 provides stage data for the entire year, because it remains functional during the freezing months of winter. An ISCO automated sampler was installed in March 1990. The purpose of the ISCO is to collect samples coming from off-post locations during a rising limb of a high event period. The staff gage is a Style C gage and is located in the active stream channel. The compound control structure located at the station is a concrete V-notch weir. The compound control structure at the station is a concrete V-notch weir. Maintenance information at this station remained the same in Water Year 1990 as in Water Year 1989 and is detailed in RLSA, 1990b.

3.1.1.2.2 North First Creek (SW24002)

The North First Creek monitoring station is located in the northeast quarter of Section 24 (Figure 2.3-2). This station monitors surface-water flows that leave RMA via First Creek. The station is equipped with a Stevens Type F recorder housed in a protective box and is mounted to a corrugated metal pipe stilling well that is hydraulically connected to the stream channel with two 2-inch intake pipes. A CR-10 data logger/bubbler system is housed in a wooden storage shed with a nitrogen supply tank. The CR-10 provides stage data for the entire year, because it remains functional during the freezing months of winter. An ISCO automated sampler was installed at this station in April 1990 in order to collect samples during rising limbs of storm events. A Style C staff gage is positioned in the active stream channel opposite to the stilling well's intake pipes. The compound control structure located at the station is a concrete V-notch weir. Maintenance information at this station remained the same in Water Year 1990 as in Water Year 1989 and is detailed in RLSA, 1990b.

3.1.1.2.3 First Creek Off-Post (SW37001)

The First Creek Off-Post monitoring station is located approximately one-half mile north of RMA's northern boundary and directly southeast of Highway 2 (Figure 2.3-2). This station is used to monitor surface-water flow that exists between the North First Creek station and First Creek Off-Post. A concrete triangular-throated flume was constructed in July 1989 to provide the station with section control. The station is equipped with a Stevens Type F recorder, and a Style C staff gage located inside the stilling well. The gaging house serves as the station's stilling well, which is hydraulically connected to the concrete flume by a 2-inch intake pipe.

Accumulation of trash or debris does not occur here. Occasionally the concrete flume is scrubbed free of algae that grows on the structure.

3.1.1.2.4 Sewage Treatment Plant (SW24001)

A totalizing flow meter records flow from the Sewage Treatment Plant in Section 24 towards First Creek (Figure 2.3-2). The Sewage Treatment Plant processes on-post sanitary sewer effluents and discharges treated water to a lined ditch that becomes unlined as it enters First Creek. The flow meter measures flow in hundreds of gallons and flow meter data was converted into gallons per minute, gallons per day, gallons per month and acre-feet per month. The meter is inside the building adjacent to the outfall and is read by Army personnel on a daily basis. Flow is monitored by CMP surface-water personnel weekly.

3.1.1.3 South Platte Drainage Basin

The South Platte drainage basin is located in the northwestern half of RMA, and is bordered by the First Creek drainage basin to the east and by the Irondale Gulch drainage basin to the southwest (Figure 2.3-1). The Basin A subdrainage basin, a portion of the Sand Creek Lateral subdrainage basin and Basin F IRA drainage are located within the South Platte drainage basin (Figure 2.3-1). There is not a defined stream channel that exits RMA within the South Platte drainage basin. Stream flow from the Basin A Inflow terminates in the Basin A lime pond. Surface flows in the northwest corner of Section 26 near Basin F IRA occur after periods of heavy rain or rapid snowmelt. The flow follows a small ditch for several hundred feet before fanning out and infiltrating in a field west of the station.

There are two monitoring stations located within the South Platte drainage basin; Basin A (SW36001) and Basin F (SW26001). Monitoring equipment employed at these stations is listed in Table 3.1-1.

3.1.1.3.1 Basin A (SW36001)

The Basin A gaging station is located in a drainage ditch in the southwest corner of Section 36 (Figure 2.3-2). It is used to monitor storm-water runoff and South Plants area ground water which is discharging into the ditch. The station consists of a Stevens Type F recorder in conjunction with a potentiometer and DP115 Datapod in a protective box mounted on a metal pipe stilling well in the center of the ditch. The section control structure at the station is a steel 90° V-notch weir with a style C staff gage attached to it. Surface water flows past the stilling well into a concrete-lined channel that transports flow to the Basin A pond. In November 1989 a concrete containment wall was undercut and collapsed 15 ft upstream from the station. The flow was diverted from the station, turning north where it discharged into the Basin A pond. These conditions existed up until June 1990 when some fill material was deposited in the area which redirected the flow back to the station. In July 1990 a heavy rainstorm caused the channel wall to breach again. This time the diversion was about 30 ft upstream from the station. The flow by-passed the station throughout the end of the water year. The only full record at this station in Water Year 1990, was recorded in October 1989.

3.1.1.3.2 Basin F (SW26001)

The Basin F monitoring station is located in a drainage area in the northwest corner of Section 26 (Figure 2.3-2). The station is new for Water Year 1990 and construction was completed in October 1989. The Basin F station monitors flow derived from surface-water runoff in the former Basin F IRA area (Figure 2.3-2). The station is equipped with a Stevens Type F recorder in conjunction with a potentiometer and DP115 Datapod in a protective box mounted on top of a corrugated metal stilling well adjacent to the ditch. The section control consists of a galvanized sheet metal 200 mm long-throated flume with a side-mounted Style C staff gage. Maintenance that is required at the station consists of monthly changing of the data storage module and batteries in the Datapod. Additionally, sunflowers have to be removed periodically from the upstream and downstream side of the flume. The washing action from storm events occasionally undercuts the flume. This problem was corrected by packing in rip rap downstream from the flume.

3.1.2 SURFACE-WATER QUANTITY DATA ACQUISITION

A variety of equipment and procedures are used to obtain and calculate surface-water quantity data from RMA. Surface-water continuous stage data are collected using staff gages, Stevens Type F recorders, Omnidata DP115 Datapods and Campbell Scientific CR-10 data loggers. Instantaneous discharge measurements are collected in the field using portable 100 mm and 200 mm long-throated flumes or a Marsh-McBirney Model 201 current meter. Stage data are reduced to mean daily discharges based upon the stage-discharge relationships that have been developed for each surface-water monitoring station. The procedures required for the collection of stage data and the reduction of stage data to mean daily discharges, rating curve development, and computation of discharge during Water Year 1990 are discussed in the following sections.

3.1.2.1 Stevens Recorders

Stevens Type F recorders collect stage data in a continuous analog format, provide a visual record of stream stage and are used as a back-up to digital recorders at RMA. The recording unit consists of a Stevens Type F recorder attached to a pulley, beaded wire and float. The Stevens recorders are located at monitoring stations described in Table 3.1-1. Weekly monitoring includes collecting and replacing strip charts, checking recorder operation, calibrating strip charts to the outside observed stage and initial time. Each strip chart that was produced during Water Year 1990 was reviewed for completeness and accuracy.

The review included the following steps:

- general check on station-by-station consistency with discharge information;
- station-by-station review of outside gage height settings to ensure that they were consistent and in agreement with strip chart information and data logger information;
- review and comparison of Datapod data with strip chart information;
- review of applied pen correction on a station-by-station basis; and
- correction and substantiation of observed stage information.

Following the review, stripcharts were digitized and the resultant digital stage record was reduced to computed instantaneous discharges.

The majority of recorders were taken out of service from late December 1989 through February 1990, due to freezing conditions inside the stilling wells.

3.1.2.2 Datapod Recorders

Six surface-water monitoring stations at RMA (North Uvalda, Ladora Weir, Havana Pond, Basin F, Basin A and First Creek Off-Post) are equipped with Omnidata International, Inc. model DP115 Datapod digital recorders (Table 3.1-1). The DP115 Datapod is a battery-operated, single channel recorder. The Datapod is coupled to a Stevens Type F recorder with a 10-turn potentiometer. The potentiometer receives electrical current from the datapod's battery power source. Movement of the Stevens Type F recorder's pulley system varies the resistance of the potentiometer and is recorded as a change in potential by the Datapod. These changes in potential correlate to changes in stream stage. The resultant digital stage record was compared to stripcharts for accuracy and was then converted to computed instantaneous discharge values for each of the stage values.

The DP115 Datapod recorder automatically records the date, time and corresponding gage height on a nonvolatile solid state memory DSM. The DSM stores at least 1 month of stage data. Detailed specifications and operating procedures are located in Appendix A-6.2.

The continuous monitoring stations equipped with DP115 Datapods were visited weekly to obtain instrument status readouts (short dumps). Data storage modules and batteries were changed at approximately 1-month intervals.

3.1.2.3 Data Logger Recorders

Five RMA surface-water stations (Havana Interceptor, Peoria Interceptor, South Uvalda, South First Creek and North First Creek) are equipped with Campbell Scientific CR-10 data loggers and bubbler systems (Table 3.1-1). CR-10 data loggers were installed at these stations because they can record stage data throughout the year. In the past, collection of stage data at these stations during the freezing months has been difficult because the float and pulley system used with the Stevens recorders freezes inside the stilling wells. The CR-10 data logger/bubbler system is used as the primary source of initial stream stage data; however, strip chart data are used to fill gaps in the data logger's record during nonfreezing months when necessary. The stage information is then used in conjunction with the established rating curves to produce daily discharge records.

The CR-10 data logger/bubbler system is a multiple channel recording instrument that can handle both analog and digital input. The bubbler system consists of a tube and an orifice through which nitrogen is fed. It operates on the principle that the pressure in the tube corresponds to the hydrostatic head of the water above the orifice. A transducer is used to sense the pressure in the bubbler tube. The system calibrates itself based on two different pressure measurements made at a known distance apart in a reference cylinder located in the gage house. These measurements are used to correct the measured pressure value of the station's bubbler line in the stream. The data logger records all information on a 720K random access memory (RAM) pack storage module at 15-minute intervals. The information stored in the module includes Julian day, time, stage data, reference cylinder data and ambient temperature.

Weekly activities at the five monitoring stations equipped with the data loggers included reading staff gage water levels, measuring water depths over bubbler lines, recording instrument status readouts, and checking the bubbler system's nitrogen supply tanks. Other periodic maintenance involved monthly changing of the RAM pack storage modules and changing of the nitrogen cylinder and battery as needed. Detailed specifications and operational procedures for the CR-10 data logger/bubbler system are described in Appendix A-6.3.

3.1.2.4 Discharge Measurements

Field measurement of stream discharge was executed in order to develop and or refine stage-discharge ratings for each RMA water quantity monitoring station. Discharge is defined as the volume rate of water flow and is expressed in cfs. Discharge measurements were made on a monthly basis at active stations for the seasonal surface-water quantity monitoring, with additional measurements taken during high surface-water flow events and during the spring and fall sampling events. In addition to the scheduled monthly measurements, instantaneous discharge measurements were obtained whenever unusual flow conditions were observed. Discharge measurements were made using standard U.S. Geological Survey (USGS) monitoring techniques (Rantz, 1982). Low to moderate flow measurements were made with either 100 mm or 200 mm long-throated flumes (Appendix A-2.2). Higher flows were measured with a Marsh-McBirney Model 201 current meter with a top-setting wading rod (Appendix A-2.2). All meter measurements were wading measurements, i.e., the hydrographer waded into the stream to collect the flow observations.

Each measurement was taken at the most desirable stream cross section. The stream cross section was chosen according to the following criteria:

- a straight reach where flow components parallel each other (laminar flow);
- a stable stream bed, free of large rocks, weeds and protruding obstructions, such as piers and posts, which cause turbulence;
- a flat stream bed profile to eliminate vertical components of velocity; and
- a section having uniform velocity distribution (i.e., avoiding ponded areas), where flow would be similar across the entire section (for meter measurements).

For the shallow streams typically found at RMA, stream depths and flows were generally low enough to collect instantaneous discharge measurements with either the 100 mm long-throated flume or the 200 mm long-throated flume. Discharges ranging from 0.0078 cfs to 0.3099 cfs are obtained with the 100 mm flume and discharges of 0.0367 cfs to 1.762 cfs are measured with the 200 mm flume. A Marsh-McBirney flow meter and top-setting wading rod were used when higher flows exceeded the capacity of the portable flumes. As a safety measure, if the depth of flow multiplied by the velocity exceeded 10 ft/sec, then wading techniques were not undertaken.

Field procedures implemented to measure and calculate current meter instantaneous discharge are detailed in Appendix A-2.2. The procedures that were followed to measure discharge rates using the portable flumes are also detailed in Appendix A-2.2.

3.1.2.5 Stage Data Reduction

The Stevens recorder was the primary source of stage data at Highline Lateral and South Plants Ditch in Water Year 1990 and at other RMA recording stations when Datapods or data loggers malfunctioned. The strip chart analog stage data were reduced to a digital format using either the computer program

CPS/PC (Radian Corp., 1989, Version 4.1) or custom Riverside Technology, Inc. (RTI, 1986) software. Both of the digitizing software were used in conjunction with a digitizer. Operation of the software differs in that CPS/PC digitizes in a "point mode" where X-Y coordinates are recorded each time the button on the digitizing mouse is pressed, whereas the RTI software is operated in a "stream mode" where the digitizing mouse button is held down continually and approximately three sets of X-Y coordinates per second are generated. Redundant X-Y coordinates are discarded by the RTI software. This approach results in the number of points saved being proportional to the length of the strip chart trace. Hence, flat traces generate fewer points than changing traces. Once digitizing is complete, the stored X-Y coordinate points are used to compute a gage height and corresponding time. Details of the digitizing process are outlined in the RLSA, 1990b.

The DP115 Datapod was the primary source of stage data at five stream stage monitoring stations in Water Year 1990 and included Ladora Weir, North Uvalda, Basin A , Basin F and First Creek Off-Post. Digital stage data from the Datapod's data storage module (DSM) are run through software (Riverside Technology, 1986) that formats the raw data and produces a columnar record containing date, time and stage. Strip chart records were used to verify the continuity and accuracy of the datapod's digital record. Errors and inaccuracies in the datapod record were corrected by changing erroneous stages to the values recorded on strip charts or by inserting a digitized portion of record from the strip chart. Stage records from datapods and/or the digitized strip chart records are then used in conjunction with the established rating curves to produce daily discharge records.

Campbell Scientific CR-10 data loggers are the primary source of stage data at five RMA surface-water monitoring stations (Havana Interceptor, Peoria Interceptor, South Uvalda, South First Creek and North First Creek). Digital stage data from the CR-10 data logger are downloaded from the RAM pack storage module to a computer. The stage data is compared to weekly staff gage observations and run through a linear interpolation program (Riverside Technology Inc., 1986) to adjust portions of the record that do not reflect field measurements of stage. Missing portions of data or erroneous data are replaced with digitized strip chart stage records. The resultant stage record is reduced further based on the current stage-discharge relationship established at the station. Details of the stage data process are in Appendix A-6.

3.1.2.6 Rating Curve Development

Continuous records of discharge at the RMA gaging stations are computed by applying a discharge rating for each stream location to records of stage. Discharge ratings for the RMA stations are typically curves plotted on logarithmic paper that relate stage to discharge (Appendix A-3.2). These curves are also described mathematically by the use of rating equations (Appendix A-4). The stage-discharge relationships (rating curves) for the RMA gaging stations were determined empirically by means of periodic measurements of discharge and stage and theoretically using information on channel geometry

(Appendix A-3.1) in conjunction with Hydrologic Engineering Center (HEC-2) computer analyses (USACOE, 1982). HEC-2 analysis was used to extend the upper and lower limits of the rating curves. The discharge measurements were made with a current meter, portable flume or volumetrically (Section 3.1.2.4). Periodic measurements of instantaneous discharge and stage were used to confirm the permanence of the rating and/or to apply adjustments to better define each rating.

Following the review, verification and validation of instantaneous discharge measurements (Appendix A-3.1), valid measurements were plotted to determine if the rating used for the previous water year was applicable for part or all of the present water year. Discharges computed from the previous rating were compared to Water Year 1990 instantaneous discharge measurements. Percentage differences between measured and computed discharges were calculated. As long as the departures were random and within ±5 percent, the previous rating was kept in effect and used to convert Water Year 1990 continuous stage data to discharge. For low-flow measurements, the ±5 percent criteria is sometimes too stringent because of station control insensitivity; therefore, stage departures were calculated for low flow measurements using the same methodology as used to calculate discharge departures. If the indicated departures in stage did not exceed ±0.02 feet, the previous rating was kept in effect (Rantz, 1982). Rating curves were revised if stage and discharge departures exceeded these criteria limits.

Previously defined stage-discharge relationships were reevaluated for Water Year 1990 at the following RMA gaging stations:

- Havana Interceptor (SW11002)
- Peoria Interceptor (SW11001)
- Ladora Weir (SW02001)
- South Uvalda (SW12005)
- North Uvalda (SW01001)
- Highline Lateral (SW12007)
- South Plants Ditch (SW01003)
- South First Creek (SW08003)
- North First Creek (SW24002)
- First Creek Off-Post (SW37001)
- Basin A (SW36001)

The new gaging station, Basin F (SW26001), required a stage-discharge relationship to be developed this year.

The datum plane at North First Creek and Peoria Interceptor was originally referenced to zero on the staff gage. To eliminate the possibility of minus values of gage height, the datum was changed to an elevation of zero flow over the artificial control. A permanent datum was selected so that only one datum for the gage-height record will be used for the remainder of the life of the station.

The confirmation of the permanence of the rating curves for Havana Interceptor, Ladora Weir, South Uvalda, North Uvalda, Highline Lateral, South First Creek, North First Creek and First Creek Off-Post was based on verified instantaneous discharge measurements collected during Water Year 1990.

3.1.2.7 Computation of Discharge

Data acquired through the collection of instantaneous discharge and continuous stream stage are ultimately used in the production of the yearly RMA surface-water discharge summaries. Once rating curves are developed by empirical and theoretical means, the resultant curve is described mathematically and a set of rating equations are made for each station. Each rating equation applies to a straight line segment on the rating curve and a specific range of stages. The appropriate rating equation is applied to each continuous stage value acquired and results in an instantaneous discharge value for a given stage. Once all of the continuous stage values have been converted to computed instantaneous discharge values, via stage-discharge conversion software (Riverside Technology, Inc., 1986), the record is compiled and mean daily discharges in units of cfs are calculated. The mean daily discharges are summed and averaged for each month. Mean monthly flow, maximum daily flow, minimum daily flow and total water volume are identified and presented at the bottom of the water discharge records in Appendix A-8.

3.1.2.8 Related Surface-Water Data Acquisition

Sources of other surface-water related data acquisition include the lakes and ponds located on RMA, the Sewage Treatment Plant in Section 24 and meteorological equipment located in both on-post and off-post areas.

3.1.2.8.1 Lakes and Ponds

Water levels on the lakes were collected by direct measurement of staff gages and were recorded on a weekly basis. The weekly observed staff gage readings of the South Plants Lakes and Havana Pond were converted to elevation in feet above mean sea level (ft-msl). Lake/pond volumes were calculated using this elevation information and were based on previously defined elevation-volume relationships as determined from earlier surveys (Ebasco Services, Inc., 1989b). Additionally, Havana Pond data were also collected by a Stevens Type F recorder in conjunction with a potentiometer and DP115 Datapod; however, the continuous record was considered unreliable and was not utilized in stage-volume relationships.

3.1.2.8.2 Sewage Treatment Plant

The Sewage Treatment Plant processes RMA sanitary sewer effluents and discharges the treated water into a lined ditch that directs the discharged water north to its confluence with First Creek. A Hersey totalizing flow meter installed at the plant is read daily by Army personnel. Flow is measured in gallons and recorded values are converted to gallons per day, gallons per week and gallons per month. These are presented in Section 4.1 and Appendix A-10 for Water Year 90.

3.1.2.8.3 Meteorological Data

Compilations of meteorological data, including precipitation, temperature and evaporation, were acquired from four sources during the year. Precipitation and temperature data for Water Year 1990 were obtained from Stapleton Airport by the NOAA for Stapleton Airport, from the CMP Air Element and from the South Plants Rain Gage. Evaporation data were compiled as a monthly average based on information collected at Cherry Creek Reservoir by the USACOE. Figure 2.3-2 shows the locations of the South Plant Rain Gage and the CMP Air Element Meteorological Stations.

3.2 SURFACE-WATER QUALITY

Surface-water quality was monitored at numerous locations on RMA and off-post during Water Year 1990. The monitoring network and monitoring strategies that were utilized during the spring, fall and storm sampling events are discussed in the following sections. Also outlined in the following sections are the sampling procedures, analytical procedures, and quality assurance/quality control procedures that are conducted in accordance with Program Manager of Rocky Mountain Arsenal/U.S. Toxic and Hazardous Materials Agency (PMRMA)/(USATHAMA) requirements.

3.2.1 SURFACE-WATER QUALITY MONITORING

In order to maintain a verifiable water quality baseline, monitoring of surface-water quality at RMA is generally conducted according to the network that was established by the Task 44 study. The evolvement of the surface-water quality monitoring network is described in the Surface-Water Historical Report (RLSA, 1991). Sample locations that were considered for sampling during Water Year 1990 are presented in Table 2.3-2 and shown in Figure 2.3-3. Surface-water quality sampling was conducted at 41 locations during Water Year 1990 and included: 21 locations within the Irondale Gulch drainage basin; 17 locations within the First Creek drainage basin; two locations within the South Platte drainage basin; and one location within the Sand Creek drainage basin (Table 3.2-1). The CMP sample locations relative to these respective drainage basins are illustrated in Figure 2.3-3. Sampling sites located at surface-water gaging stations are described in Section 3.1 and the sampling sites without gaging stations are described

Table 3.2-1 Surface-Water Sampling Activities Water Year 1990

Sample Location	Location Name	Site Type	Sample Event	Sample Date	Analysis: Surface Water Target	Surface Water GC/MS	Bottom Sediments Target	Bottom Sediments GC/MS	Quality Assurance	TSS
Irondale Gulch Drainage Basin										
SW01001	North Uvalda Interceptor	Ditch	Spring	04/17/90	1					1
			Fall	09/06/90	1					2
SW01002	South Plants Water Tower Pond	Pond	Hi Ev	03/13/90	1					
			Annual	04/19/90	1		1	1		1
SW01003	South Plants Ditch	Ditch	Spring	Dry						
			Fall	Dry						
SW01004	Upper Derby Lake	Lake	Annual	04/12/90	1					1
SW01005	Lower Derby Lake	Lake	Annual	04/12/90	1 (dupe)					1 (dupe)
SW02001	Ladora Weir	Ditch	Annual	09/05/90	1					2
SW02002	Sand Creek Lateral East	Ditch	Annual	Dry						
SW02003	Ladora Lake	Lake	Annual	04/12/90	1					1
SW02004	Lake Mary	Lake	Annual	04/12/90	1					1
SW02005	Sand Creek Lateral West	Ditch	Annual	Dry						
SW02006	South Plants Steam Effluent	Ditch	Spring	04/19/90	1	1	1 (dupe)	1		1
			Fall	09/04/90	1		1			2
SW07001	Uvalda Ditch A	Ditch	Annual	04/13/90	1					1
SW07002	Uvalda Ditch B	Ditch	Annual	04/13/90	1					1

Table 3.2-1 Surface-Water Sampling Activities Water Year 1990 (continued)

Sample Location	Location Name	Site Type	Sample Event	Sample Date	Analysis: Surface Water Target	Surface Water GC/MS	Bottom Sediments Target	Bottom Sediments GC/MS	Quality Assurance	TSS
Irondale Gulch Drainage Basin (continued)										
SW11001	Peoria Interceptor	Ditch	Hi Ev1	03/06/90	1					1
			Hi Ev2	03/13/90	1					1
			Spring	04/16/90	1		1		1 (trip)	1
			Fall	09/04/90	1 (dupe)		1 (dupe)			2 (dupe)
SW11002	Havana Interceptor	Ditch	Hi Ev1	03/06/90	1					1
			Hi Ev2	03/13/90	1					1
			Spring	04/16/90	1	1				1
			Hi Ev3	07/09/90	1					1
			Fall	09/05/90	1					2
SW11003	Havana Pond	Pond	Annual	04/17/90	1					1
SW12001	Uvalda Ditch C	Ditch	Spring	04/13/90	1					1
			Fall	09/06/90	1					2
SW12004	Storm Sewer	Stsw	Hi Ev	03/08/90	1					1
			Spring	04/13/90	1					1
			Fall	09/04/90	1		1			2
SW12005	South Uvalda	Stream	Hi Ev1	03/08/90	1					1
			Hi Ev2	03/13/90	1					1
			Hi Ev3	03/28/90	1					1
			Spring	04/16/90	1 (dupe)	1 (dupe)	1			1 (dupe)
			Fall	09/06/90	1	1				2
SW12006	Army Reserve Storm Sewer	Stsw	Hi Ev	07/21/90	1					1
			Annual	Dry						
SW12007	Highline Lateral	Ditch	Annual	05/16/90	1					1

Table 3.2-1 Surface-Water Sampling Activities Water Year 1990 (continued)

Sample Location	Location Name	Site Type	Sample Event	Sample Date	Analysis: Surface Water Target	Surface Water GC/MS	Bottom Sediments Target	Bottom Sediments GC/MS	Quality Assurance	TSS
First Creek Drainage Basin										
SW05001	South First Creek (old)	Stream	G/L	06/27/90						1
SW06002	Eastern Upper Derby Lake Ditch	Ditch	Hi Ev1	07/18/90	1					1
			Hi Ev2	07/27/90	1					1
SW08001	South First Creek Boundary	Stream	Annual	04/18/90	1					1
			G/L	06/27/90						1
SW08003	South First Creek	Stream	Hi Ev1	03/09/90	1					1
			Spring	04/18/90	1	1	1		1(field/ GC/MS)	1
			Hi Ev2	05/30/90	1					1
			G/L	06/27/90						1
			Hi Ev3	07/10/90	1					2
			Fall	09/07/90	1				2(field, trip)	2
SW08004	South First Creek Retention Pond	Stream	G/L	06/27/90						1
SW24001	Sewage Treatment Plant	STP	Spring	04/17/90	1	1				1
			Fall	09/06/90	1					
SW24002	North First Creek	Stream	Hi Ev	03/09/90	1					1
			Spring	04/18/90	1	1	1			1
			Fall	09/07/90	1					2
SW24003	North Bog	Pond	Annual	04/17/90	1					1
SW24004	First Creek North Boundary	Stream	Annual	04/17/90	1					1

Table 3.2-1 Surface-Water Sampling Activities Water Year 1990 (continued)

Sample Location	Location Name	Site Type	Sample Event	Sample Date	Analysis: Surface Water Target	Surface Water GC/MS	Bottom Sediments Target	Bottom Sediments GC/MS	Quality Assurance	TSS
First Creek Drainage Basin (continued)										
SW30001	North Plants	Ditch	Annual	Dry						
SW30002	First Creek Near North Plant	Stream	Annual	04/19/90	1					1
			G/L	06/28/90						1
SW31001	First Creek Toxic Yard A	Stream	Annual	04/17/90	1					1
SW31002	First Creek Toxic Yard B	Pond	Annual	04/19/90	1					1
SW37001	First Creek Off-Post	Stream	Hi Ev1	11/29/89	1	1				
			Hi Ev2	03/09/90	1					1
			Spring	04/18/90	1		1	1	1(field)	1
			G/L	06/28/90						1
			Fall	09/07/90	1	1				2
SW37010	Off-Post First Creek	Stream	G/L	06/28/90						1
SW37011	Off-Post First Creek	Stream	G/L	06/28/90						1
SW37012	Off-Post First Creek	Stream	G/L	06/28/90						1
South Platte Drainage Basin										
SW26001	Basin F	Ditch	Annual	Dry						
			Hi Ev1	03/13/90	1					1
			Hi Ev2	08/19/90	1					2
SW36001	Basin A	Ditch	Spring	04/19/90	1 (dupe)	1 (dupe)	1	1		1(dupe)
			Fall	09/05/90	1	1				2

Table 3.2-1 Surface-Water Sampling Activities Water Year 1990 (continued)

Sample Location	Location Name	Site Type	Sample Event	Sample Date	Analysis: Surface Water Target	Surface Water GC/MS	Bottom Sediments Target	Bottom Sediments GC/MS	Quality Assurance	TSS
Sand Creek Drainage Basin										
SW04001	Motor Pool	Ditch	Annual Hi Ev	Dry 07/09/90	1					1
			Annual Total		16	0	1	1	0	17
			Spring Total		12	7	7	3	3Field	12
			Hi Ev Total		22	1	0	0	0	21
			Fall Total 12		3	3	0	2Trip	22	
			Dupe Total		4	2	2	0	0	5
			G/L Total		0	0	0	0	0	9
			TOTAL		66	13	13	4	5	86

Hi Ev = High Event
G/L = Gain-Loss Interaction Study
GC/MS = Gas Chromatograph/Mass Spectrometer
TSS = Total Suspended Solids
Dupe = Duplicate sample taken
Field = Field Blank sample
Trip = Trip Blank sample
Stsw = Storm Sewer
STP = Sewage Treatment Plant

in Section 2.3. Samples collected during annual, spring, fall, and high event sampling rounds are summarized in Table 3.2-1.

3.2.2 SURFACE-WATER QUALITY MONITORING STRATEGY

Surface-water quality samples were analyzed for the parameters listed in Tables 3.2-2 and 3.2-3 for this third year of the Surface-Water CMP. The majority of water samples were analyzed for the target analytical suite of parameters because of the uncertain characterization of surface-water quality at RMA and for use in a comparison to the ground-water quality.

Data collected during previous surface-water monitoring programs indicated that organic contaminants may have been derived from off-post sources south of RMA that moved onto and across RMA through surface-water pathways (RLSA, 1991). The suite of target analytes listed in Tables 3.2-2 and 3.2-3 may not be sufficiently comprehensive to include such contaminants. Consequently, the target analyte list was supplemented by gas chromatography and mass spectroscopy (GC/MS) analysis of selected samples. The analytical procedures employed in this program are discussed in more detail below.

Table 3.2-1 summarizes the frequency and type of sampling activity that was conducted during annual, spring, fall, high event and gain/loss monitoring rounds. Most of the surface-water sampling activities were conducted in conjunction with discharge measurements.

3.2.3 SURFACE-WATER QUALITY MONITORING FIELD METHODS

Specific collection or monitoring methods are described in the Stollar "Surface-Water Field Procedures Manual II" (RLSA, 1988). The manual contains certification procedures and laboratory data forms. All collection procedures and analytical methods complied with the USATHAMA Quality Assurance Program (U.S. Army, Chemical QA Plan, 1989).

Surface-water samples were collected directly with the sample bottle. Samples for organic analysis (volatile organic compounds (VOC), dichlorobromopropane (DBCP), dicyclopentadiene (DCPD), organochlorines and organosulfurs) were collected in amber glass bottles with Teflon (R) - lined caps. Samples for inorganic analysis (chloride and fluoride, total metals and nitrates) were collected in polyethylene containers. Metals samples were not filtered in the field during the Water Year 1990 sampling rounds. Metals fractions were fixed with dilute nitric acid to a pH of 2. The nitrates fraction was fixed with dilute sulfuric acid to a pH of 2. All sample bottles were placed on ice in a sample cooler immediately upon filling.

Table 3.2-2 DataChem Laboratory Analytical Methods for Water and Sediment Samples

Analyte Suite	Parameters	Method Number	Water (µg/l) Reporting Limit (min.)	Water (µg/l) Reporting Limit (max.)	Method Number	Soil (µg/g) Reporting Limits (min.)	Soil (µg/g) Reporting Limits (max.)
Volatile Aromatics	Benzene	AV8	1.05	40.2			
	Toluene		1.47	39.7			
	Chlorobenzene		1.39	39.8			
	Ethylbenzene		1.37	39.7			
	m-Xylene		1.32	39.9			
	o,p-Xylene		1.336	39.6			
Volatile Halocarbons	1,1-Dichloroethane	N8	0.730	200			
	1,1-Dichloroethene		1.70	200			
	1,2-Dichloroethane		1.10	200			
	Chloroform		0.500	200			
	t-1,2-Dichloroethene		0.760	200			
	1,1,1-Trichlorethane		0.760	200			
	Carbon Tetrachloride		0.990	200			
	1,1,2-Trichloroethane		0.780	200			
	Tetrachloroethene		0.750	200			
	Chlorobenzene		0.820	200			
	Methylene Chloride		7.40	200			
	Trichloroethene		0.560	200			
Phosphonates	Diisopropylmethyl Phosphonate	AT8	0.392	31.3			
	Dimethylmethyl Phosphonate		0.188	62.5			
DBCP	1,2-Dibrommo-3-chloropropane	AY8	0.195	10.0	S9	0.005	0.100
Organosulfur compounds	Dimethyldisulfide	AAA8	0.55	15.0			
	1,4-Oxathiane		2.38	25.0			
	1,4-Dithiane		1.34	25.0			
	Benzothiazole		5.00	50.0			
	p-Chlorophenylmethyl sulfide		5.69	50.0			
	p-Chlorophenylmethyl sulfoxide		11.5	75.0			
	p-Chlorophenylmethyl sulfone		7.46	100			

Table 3.2-2 DataChem Laboratory Analytical Methods for Water and Sediment Samples (continued)

Analyte Suite	Parameters	Method Number	Water (µg/l) Reporting Limit (min.)	(max.)	Method Number	Soil (µg/g) Reporting Limits (min.)	(max.)
Organochlorine Pesticide	Hexachlorocyclopentadiene	KK8	0.0480	0.990	KK9B	0.00137	0.1000
	Aldrin		0.0500	1.00		0.00211	0.1000
	Isodrin		0.0510	1.10		0.00188	0.1000
	PPDDE		0.0540	1.00		0.00466	0.1000
	Dieldrin		0.0500	1.00		0.00181	0.1000
	Endrin		0.0500	1.00		0.00471	0.1000
	PPDDT		0.0490	1.00		0.00277	0.1000
	Chlordane		0.0950	1.00		0.02300	0.1000
	DBCP		-----	----		0.005	0.100
Hydrocarbons	Bicycloheptadiene	P8	5.90	104	PP9	1.10	10.2
	Dicyclopentadiene		5.00	99.6		0.45	9.00
	Methylisobutyl Ketone		4.90	98.0		0.640	10.0
Anions	Chloride	TT09	278	10,000			
	Fluoride		153	5,000			
	Sulfate		175	10,000			
Nitrate	Nitrate	LL8	10.0	200			
Arsenic	Arsenic	AX8	2.36	121	B9	2.50	50
Mercury	Mercury	CC8	0.100	2.0	Y9	0.050	1.00
ICP Metals	Cadmium	SS12	6.78	12,500			
	Chromium		16.0	1,000			
	Copper		18.8	10,000			
	Lead		43.4	10,000			
	Zinc		18.0	1,000			
	Magnesium		135	250,000			
	Calcium		105	200,000			
	Sodium		279	50,000			
	Potassium		1,240	250,000			

Table 3.2-2 DataChem Laboratory Analytical Methods for Water and Sediment Samples (continued)

Analyte Suite	Parameters	Method Number	Water (μg/l) Reporting Limit (min.)	(max.)	Method Number	Soil (μg/g) Reporting Limits (min.)	(max.)
Volatiles	1,1,1-Trichloroethane	UM21	1.0	100			
	1,1,2-Trichloroethane		1.0	100			
	1,1-Dichloroethane		1.0	150			
	1,1-Dichloroethene		1.0	150			
	1,2-Dichloroethane		1.0	150			
	1,2-Dichloroethene		5.0	150			
	Benzene		1.0	150			
	Carbon Tetrachloride		1.0	100			
	Chlorobenzene		1.0	150			
	Chloroform		1.0	150			
	Ethyl Benzene		1.0	150			
	Methylene Chloride		1.0	150			
	Tetrachloroethene		1.0	150			
	Toluene		1.0	150			
	Trichloroethane		1.0	150			
	1,3-Dimethylbenzene		1.0	150			
	Xylene		2.0	300			
	Methylisobutyl Ketone		1.4	100			
Semi-volatiles	Aldrin	UM25	13	300			
	Atrazine		5.9	300			
	Hexachlorocyclopentadiene		54	300			
	Chlordane		37	300			
	p-Chlorophenylmethyl sulfide		10	300			
	p-Chlorophenylmethyl sulfoxide		5.3	300			
	p-Chlorophenylmethyl sulfone		15	300			
	Dibromochloropropane		12	300			
	Dicyclopentadiene		5.5	300			
	Vapona		8.5	300			
	Diisopropylmethyl Phosphonate		21	200			
	Dithiane		3.3	100			
	Dieldrin		26	100			
	Dimethylmethyl Phosphonate		130	200			
	Endrin		18	200			

Table 3.2-2 DataChem Laboratory Analytical Methods for Water and Sediment Samples (continued)

Analyte Suite	Parameters	Method Number	Water (μg/l) Reporting Limit (min.)	Water (μg/l) Reporting Limit (max.)	Method Number	Soil (μg/g) Reporting Limits (min.)	Soil (μg/g) Reporting Limits (max.)
Semi-volatiles	Isodrin		7.8	300			
	Malathion		21	300			
	Oxathiane		27	300			
	PPDDE		14	300			
	PDDT		18	100			
	Parathion		37	300			
Nitrogen/ Phosphate Pesticides	Atrazine	UH11	4.03	100			
	Parathion		0.647	50.0			
	Malathion		0.373	50.0			
	Supona		0.787	50.0			
	Vapona		0.384	50.0			

Table 3.2-3 ESE Denver and Gainsville Laboratories Analytical Methods for Water and Sediment Samples

Analyte Suite	Parameters	Method Number	Water (μg/l) Reporting Limit (min.)	Water (μg/l) Reporting Limit (max.)	Method Number	Soil (μg/g) Reporting Limits (min.)	Soil (μg/g) Reporting Limits (max.)
Volatile Aromatics	Benzene	SS8	1.92	10.50			
	Toluene		2.10	11.19			
	Ethylbenzene		0.62	11.32			
	m-Xylene		1.04	11.17			
	o,p-Xylene		1.34	21.72			
Volatile Halocarbons	1,1-Dichloroethane	TT8	1.90	204	LM19*	-----	-----
	1,1-Dichloroethene		1.80	222		0.0039	0.100
	1,2-Dichloroethane		2.10	202		0.0030	0.100
	1,2-Dichloroethene		----	----		0.0039	0.100
	Chloroform		1.90	214		0.0087	0.200
	t-1,2-Dichloroethene		1.80	200		------	-----
	1,1,1-Trichlorethane		1.10	196		0.0044	0.200
	Carbon Tetrachloride		1.70	210		0.0070	0.200
	1,1,2-Trichloroethane		1.60	204		0.0054	0.200
	Tetrachloroethene		2.80	196		0.0028	0.200
	Chlorobenzene		1.40	99		0.00086	0.200
	Methylene Chloride		2.50	88		0.012	0.200
	Trichloroethene		1.30	198		------	------
	Toluene		----	----		0.00078	0.200
	Benzene		----	----		0.0015	0.200
	Ethylbenzene		----	----		0.0017	0.200
	Xylene		----	----		0.0015	0.200
Phosphonates	Diisopropylmethyl Phosphonate	QQ8	10.1	202	TT9*	0.114	4.57
	Dimethylmethyl Phosphonate		16.3	214		0.133	4.18
DBCP	1,2-Dibrommo-3-chloropropane	Q8	0.13	2.20	QQ9	0.005	0.098
Organosulfur compounds	Dimethyldisulfide	PP8A	1.20	42.2	LLO3*	0.692	13.8
	1,4-Oxathiane		1.40	43.6		0.856	17.1
	1,4-Dithiane		3.34	40.6		1.47	11.4
	Benzothiazole		1.20	45.0		1.08	13.2

* ESE Gainsville Laboratory

SWAR-90.TB2

Table 3.2-3 ESE Denver and Gainsville Laboratories Analytical Methods for Water and Sediment Samples (continued)

Analyte Suite	Parameters	Method Number	Water (µg/l) Reporting Limit (min.)	Water (µg/l) Reporting Limit (max.)	Method Number	Soil (µg/g) Reporting Limits (min.)	Soil (µg/g) Reporting Limits (max.)
Organosulfur compounds	p-Chlorophenylmethyl sulfide		1.10	45.6		1.08	21.6
	p-Chlorophenylmethyl sulfoxide		1.98	49.0		2.25	45.0
	p-Chlorophenylmethyl sulfone		2.24	51.4		2.37	47.4
Organochlorine Pesticide	Hexachlorocyclopentadiene	MM8A	0.083	1.67	MK9	-----	-----
	Aldrin		0.083	2.40		0.00259	0.0200
	Isodrin		0.056	2.24		0.00169	0.0200
	PPDDE		0.046	1.85		0.00215	0.0200
	Dieldrin		0.054	2.10		0.00193	0.0200
	Endrin		0.060	2.40		0.00200	0.0200
	PPDDT		0.059	2.36		0.00225	0.0200
	Chlordane		0.152	6.08		0.0139	0.200
Hydrocarbons	Dicyclopentadiene	R8	9.31	132	RR9	4.27	95.3
	Methylisobutyl Ketone		12.9	104		4.61	92.2
Anions	Chloride	NN8	1,590	30,000			
	Fluoride		1,000	10,000			
	Sulfate		5,000	300,000			
Nitrate	Nitrate/Nitrite	TF22*	10.0	200			
Arsenic	Arsenic	VV8	2.50	50.0	AS9	0.91	10.0
Mercury	Mercury	WW8	0.50	5.00	HG9	0.0269	0.300
ICP Metals	Cadmium	R9D	5.0	5,000	JS11*	3.05	20.0
	Chromium		22.4	7,500		12.7	5,000
	Copper		10.0	7,500		58.6	5,000
	Lead		51.6	10,000		6.62	500
	Zinc		20.0	5,000		30.2	5,000
	Magnesium		89.2	7,500		----	----
	Calcium		50.0	5,000		----	----

* ESE Gainsville Laboratory

SWAR-90.TB2

Table 3.2-3 ESE Denver and Gainsville Laboratories Analytical Methods for Water and Sediment Samples (continued)

Analyte Suite	Parameters	Method Number	Water (µg/l) Reporting Limit (min.)	Water (µg/l) Reporting Limit (max.)	Method Number	Soil (µg/g) Reporting Limits (min.)	Soil (µg/g) Reporting Limits (max.)
ICP Metals	Sodium		251	10,000		----	----
	Potassium		1,075	10,000		----	----
Semi-volatiles	Aldrin				SV9	0.665	6.660
	Atrazine					1.857	10.70
	Hexachlorocyclopentadiene					0.704	6.660
	Chlordane					0.666	6.660
	p-Chlorophenylmethyl sulfide					0.266	6.660
	p-Chlorophenylmethyl sulfoxide					1.107	10.70
	p-Chlorophenylmethyl sulfone					0.666	6.660
	Dibromochloropropane					0.363	6.660
	Dicyclopentadiene					0.450	10.70
	Vapona					0.266	10.70
	Diisopropylmethyl Phosphonate					0.266	6.660
	Dithiane					0.889	10.70
	Dieldrin					0.562	6.660
	Endrin					0.266	6.660
	Isodrin					0.266	6.660
	Malathion					0.884	6.660
	Oxathiane					1.213	10.70
	PPDDE					0.513	6.660
	PPDDT					0.584	6.660
	Parathion					0.543	6.660
Cyanide	Cyanide	CN1	8.9	200	KYO1*	0.92	10.00
Nitrogen/ Phosphate Pesticides	Atrazine				LNO5*	0.25	2.0
	Malathion					0.58	5.0
	Parathion					0.733	5.0
	Supona					0.25	5.0
	Vapona					0.452	5.0
Parathion	Parathion	UNO7*	0.25	5.0			

* ESE Gainsville Laboratory

SWAR-90.TB2

Grab samples of stream water were collected from the center of the channel just below the stream surface, at a depth of 1 to 4 inches. Lake or pond samples were collected as grab samples from near the shoreline, also at a depth of 1 to 4 inches. Parameters measured in the field included pH, temperature, electrical conductivity and alkalinity. Field instruments were calibrated using chemical standards of known values.

In order to characterize the influence of contaminants originating at RMA on water chemistry, it was necessary to determine the quality of water entering RMA. For this reason, gas chromatography-mass spectroscopy (GC/MS) analyses were performed (in addition to analyses for target parameters) on surface-water samples collected on several inflows near the southern and southeastern boundaries of the Arsenal, on the single outflow of First Creek near the northern boundary and at Basin A (Table 3.2-1). The GC/MS method confirms contaminant levels detected by other methods and is capable of indicating the presence of nontarget compounds. GC/MS analysis was performed on approximately 29 percent of all water samples collected during the annual, spring and fall sampling rounds. Samples were selected for GC/MS analysis based on historical monitoring and field conditions.

3.2.3.1 High Event Sampling Methods and Procedures

During Water Year 1990, high event samples were collected in the same manner as annual, spring and fall sampling events. The previous section describes the manual collection methods that were utilized in high event sampling. A total of 22 high event samples (snowmelt or rain) were collected this year, 19 high event samples were collected using grab sampling techniques during Water Year 1990. Discharge measurements were generally obtained during these high events.

High event sample collection ideally takes place during the rising limb of a storm event. Since it is often difficult to acquire a sample during this time period, ISCO automated samplers were sometimes employed for high event sampling. The ISCO samplers were deployed at stations that had CR-10 data loggers. This allowed the samplers to be programmed to collect a water sample at a pre-determined rise in stream stage. When a high event increases stage to the level that activates the automated sampler pump, a 5-gal sample container is filled with stream water through Teflon tubing. The water sample is retrieved by RLSA personnel and sample bottles for the required analytical suite are filled. Once sample bottles are filled, preservatives are added and sample parameters are recorded as described previously. Three high event samples were collected by the ISCO automated sampler during Water Year 1990.

3.2.4 Laboratory Analytical Procedures

DataChem and ESE Laboratories Denver and Gainsville were used for the chemical analysis of surface water and stream sediment samples. Tables 3.2-2 and 3.2-3 presents method names with corresponding method numbers and reporting limits for the analyzed parameters.

3.2.5 ANALYTICAL QUALITY CONTROL AND ASSURANCE PROCEDURES

Accuracy and precision of the analytical measurement process is continually monitored by analyzing spikes and surrogates with each sa ole lot. Accuracy is assessed by statistically evaluating recovery data from analyses of the spikes and surrogates. A 3-day moving mean is calculated and plotted on the control charts for each spike or surrogate. Out-of-control situations may be indicated by:

- a value outside the control limits;
- a value classified as an outlier by statistical testing;
- a series of seven consecutive points on one side of the mean;
- a series of five successive points going in the same direction; and
- two consecutive points between the upper warning limit and upper control limit, or the lower warning limit and lower control limit.

When one of the above conditions is indicated on the control chart, an investigation is conducted to determine the cause and provide corrective action. This investigation may indicate that control analysis, reanalysis or resampling may be required for part of all analyses associated with that quality control sample. If the quality control data are within control, the data are reported to the database and accuracy corrections applied.

Precision is assessed by developing range control charts from the difference between the recovery percentages for the two spiked quality control samples in each lot. Out-of-control situations may be indicated by:

- a value above control limit;
- a value considered as an outlier by statistical testing;
- a series of five consecutive points going in an upward direction;
- a cyclical pattern of control values; or
- two consecutive points between the upper warning limit and upper control limit.

Laboratory investigations are conducted as described in the discussion of accuracy control charts, if indicated by the above conditions. Quality Control results are presented in Section 4.5.

Method blanks are analyzed with each lot of samples to monitor potential sample contamination from laboratory sources. Method blank results greater than two times the analyte detection limit are subtracted from the sample results.

The quality assurance and quality control procedures for total suspended sediments analysis are implemented in the following manner. Daily calibration checks are performed for each balance used for weighing. Records for these checks are maintained in a logbook kept with the balance. If the calibration check results vary from the standard weight of 100 mg, the balance is recalibrated. Periodic recalibrations are also performed by the manufacturer. Duplicate analysis was conducted on one of the sediment samples. Identical weights were obtained from the sample and duplicate.

3.3 SEDIMENT TRANSPORT

Contaminants at RMA could possibly migrate in the surface-water through sediment transport. Sediment loading in the RMA drainages influence both the aquatic habitat and channel evolution of the streams. As a result of construction and remedial activities, increased loading of the streams has significantly modified the characteristics of the drainages (e.g., silting) and resulted in sediments deposited on to and downstream of RMA. TSS quantity and bottom sediment quality were monitored at numerous locations on RMA and off-post during Water Year 1990 (Table 3.2-1). This section presents the methods and procedures used to obtain sediment quantity and quality data during Water Year 1990. The purpose of this exercise was to:

- evaluate sampling equipment and methodology;
- evaluate the bottom sediment quality; and
- assess suspended sediment quantity along RMA drainages.

3.3.1 SCOPE OF INVESTIGATION

Contaminants may be transported through the surface-water system by adsorption onto sediment particles that move in the drainages as suspended or bottom sediment particles. The potential for transportation of sediment containing low solubility contaminants such as heavy metals, pesticides and semi-volatile organics warranted further investigation; therefore, a program was developed and initiated during Water Year 1988. This program continued through Water Year 1990 and now encompasses all RMA surface-water quality sampling locations with flowing water (Figure 2.3-3). Four off-post sites downstream of RMA on First Creek are also included in the study. The various surface-water sites where TSS and bottom sediments were collected are listed in Table 3.2-1 and shown in Figure 2.3-3.

3.3.1.1 Sediment Quantity

The CMP surface-water element collected 72 TSS samples from 29 sites during Water Year 1990. Samples were accompanied by instantaneous discharge measurements and staff gage readings at the sites where this was possible. The TSS samples were collected during the spring, fall and high event sampling periods in addition to the surface-water/ground-water interaction study in June. Observations of flow characteristics, such as rising or falling limbs and peak periods within high cycle events, were recorded at the time the samples were obtained. TSS were not qualitatively analyzed because sufficient sample volumes could not be obtained.

3.3.1.2 Sediment Quality

A second objective of this program was to evaluate the significance of bottom sediments as a mechanism for the transport of adsorbed contaminants. Bottom sediment samples were collected from nine locations during Water Year 1990. Eight samples and one duplicate were collected in the spring, and three samples and one duplicate were collected in the fall. Eleven bottom sediment samples were retained for chemical analysis of target organics and four samples were retained for GC/MS analysis. Bottom sediment sample locations are shown in Figure 2.3-3. The methods and target analytes that were used are detailed in Tables 3.2-2 and 3.2-3.

3.3.2 SEDIMENT STRATEGY AND METHODS

Suspended sediment samples were collected in Water Year 1990 by using three sampling techniques: the grab method, the DH-48 hand held sampler and the ISCO automated sampler. The grab method of collection consisted of holding a container 2 to 3 in. below the water surface. DH-48 samples were collected from the middle of the drainage over a period of 5 minutes. The inlet to the DH-48 was always pointed upstream, slightly tilted upward, about 2 to 3 in. below the water surface. The ISCO automated sampler was programmed to collect a sample whenever the stream stage exceeded a programmed depth over the bubble line. When this occurred, the ISCO pump turned on, drawing sample water into a Teflon line.

Bottom sediments were collected directly into the sample container. The sample containers were scooped into the bottom sediment at a depth of no more than 6 inches. Bottom sediment samples were collected at locations outlined in Table 3.2-1 and were analyzed for the parameters listed in Table 3.2-2.

3.4 GROUND-WATER AND SURFACE-WATER INTERACTION

In a surface-water monitoring study, ground-water discharge and recharge were evaluated so that ground-water/surface-water interactions could be characterized. This information is used to assess contaminant migration on and off RMA. From the current understanding of ground-water and surface-water relationships, three areas have been identified for monitoring: First Creek, Havana Pond and the South Plants Lakes area.

3.4.1 Scope of Investigation

Streams and lakes located in the Irondale Gulch Drainage Basin and First Creek Drainage Basins (Figure 2.3-1) were monitored to evaluate ground-water and surface-water interaction. The following three areas were studied to assist in the understanding of ground-water and surface-water interaction at RMA.

3.4.1.1 First Creek

First Creek crosses RMA from the southeast in Section 8 and leaves the RMA in Section 24 (Figure 2.3-1). Occasionally, First Creek receives surface-water runoff from Eastern Upper Derby Lake outflow and North Plants. It may also, at times, be receiving treated effluent from the Sewage Treatment Plant located in Section 24. Its drainage area overlies many contaminated aquifer units. First Creek is the primary route for surface water leaving RMA. Previous studies have suggested that both recharge and discharge of ground water occur in the First Creek drainage; therefore, this is a possible path of migration of contaminants off RMA.

3.4.1.2 South Plants Lakes

The lakes area, which is in the southern region of RMA, just south of South Plants (Figure 2.3-1), includes Eastern Upper Derby Lake, Upper Derby Lake, Lower Derby Lake, Ladora Lake and Lake Mary. Water flows in a southerly direction from South Plants to Upper and Lower Derby Lakes. From Eastern Upper Derby Lake to Lake Mary, water flows from east to west. Water also flows from the south from Uvalda Interceptor to either Lower or Upper Derby Lakes. Surface water in the lakes is also derived from Havana Pond and the Sand Creek Lateral. This water is usually placed in Ladora Lake. Much of the RMA contamination was derived from South Plants; thus it is important to assess the ground-water/surface-water interaction and monitor any contamination in the area.

3.4.1.3 Havana Pond

Havana Pond is located in Section 11 near the southwest entrance of RMA. Surface water flows into Havana Pond from Havana Interceptor and Peoria Interceptor (Figure 2.3-2). Mass balance calculations and water-level data (Ebasco Services, Inc., et al., 1989a) strongly suggest that the water in the pond discharges to ground water. At high flood stages, water flows from Havana Pond to the lakes area via Sand Creek Lateral.

3.4.2 Strategy and Methods

Water levels from the lakes, Havana Pond and First Creek were compared to water levels from adjacent wells. Surface-water levels were measured using staff gages and recorders in conjunction with water level data collected from the wells during February, March, April, June, July, August and September. Ionic and organic data from the surface-water sites were not compared to ground water during Water Year 1990 because the CMP ground-water element did not sample wells in this area at the same time that surface-water samples were collected. The ground-water wells used to help delineate ground-water/surface-water interaction were chosen on the basis of proximity to surface-water monitoring and sampling stations and are listed in Table 3.4-1. Figure 3.4-1 shows the wells chosen for this study in Water Year 1990. A gain-loss study was conducted in April and June 1990 in which several discharge measurements were obtained along First Creek in conjunction with static water levels from nearby ground-water wells.

Table 3.4-1 Wells Used to Delineate Ground-Water/Surface-Water Interaction

Hydrograph Data

01001, 01024, 01028(D), 01044, 01047(D), 01049, 01069, 01070, 01073, 01074, 01075, 01076(D), 02001, ,02008, 02026, 02034, 02050, 02052, 02055, 02056, 02059, 02060(D), 11002, 11007

Water Level Data

19001(D), 24095(D), 24096(D); 24106(D), 24107(D), 24183(D), 30001, 30009(D), 31005(D), 37369

(D) - Well completed in the Denver Formation.

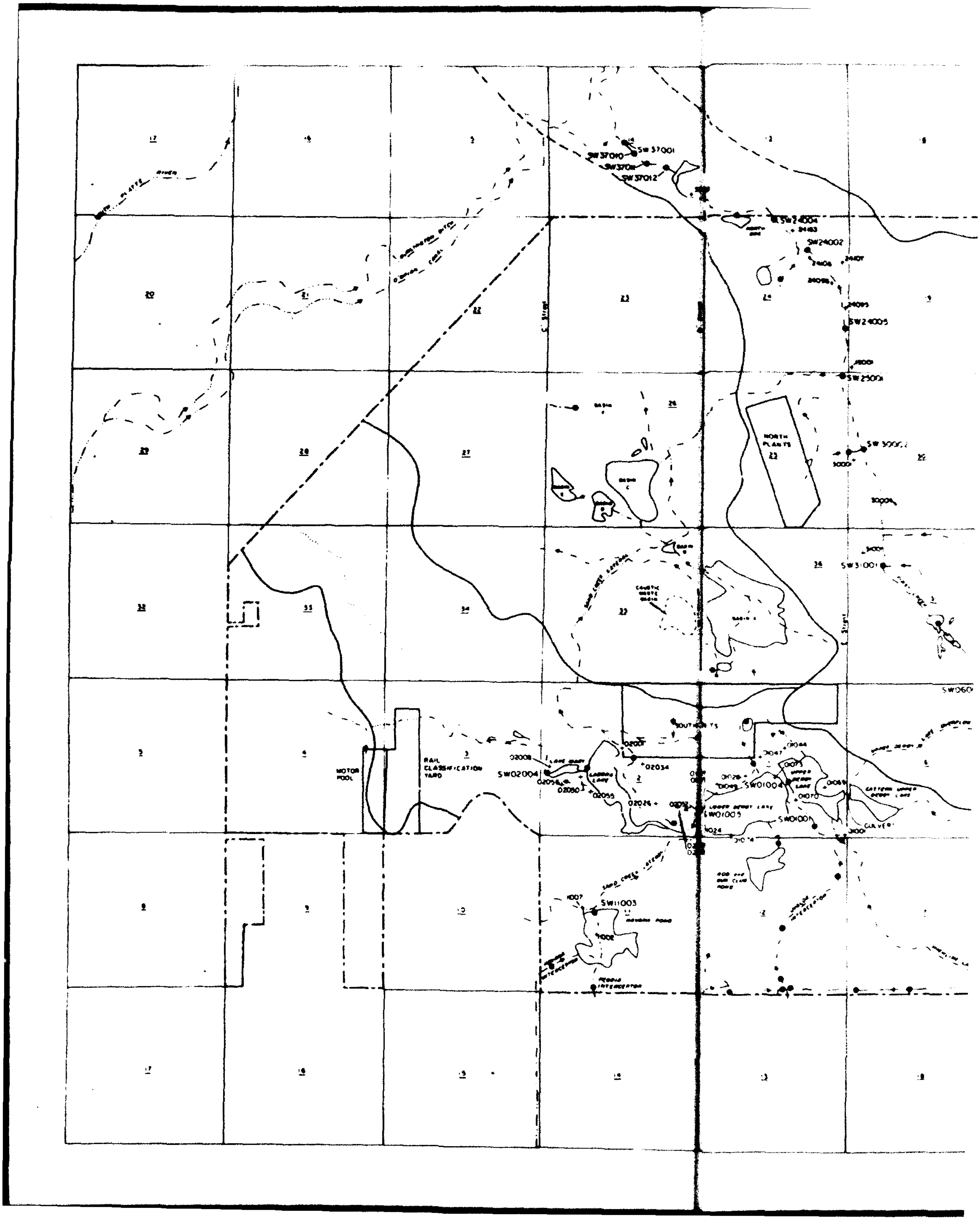
3.4.2.1 Comparison of Hydrographic Data

Water level measurements in 34 wells were used in Water Year 1990 to assess ground-water/surface-water interaction (Table 3.4-1). Ground-water levels in several cluster wells, completed in alluvial and Denver zones, were measured in order to further characterize ground-water/surface-water interaction. Wells completed in the Denver Formation are indicated on Table 3.4-1.

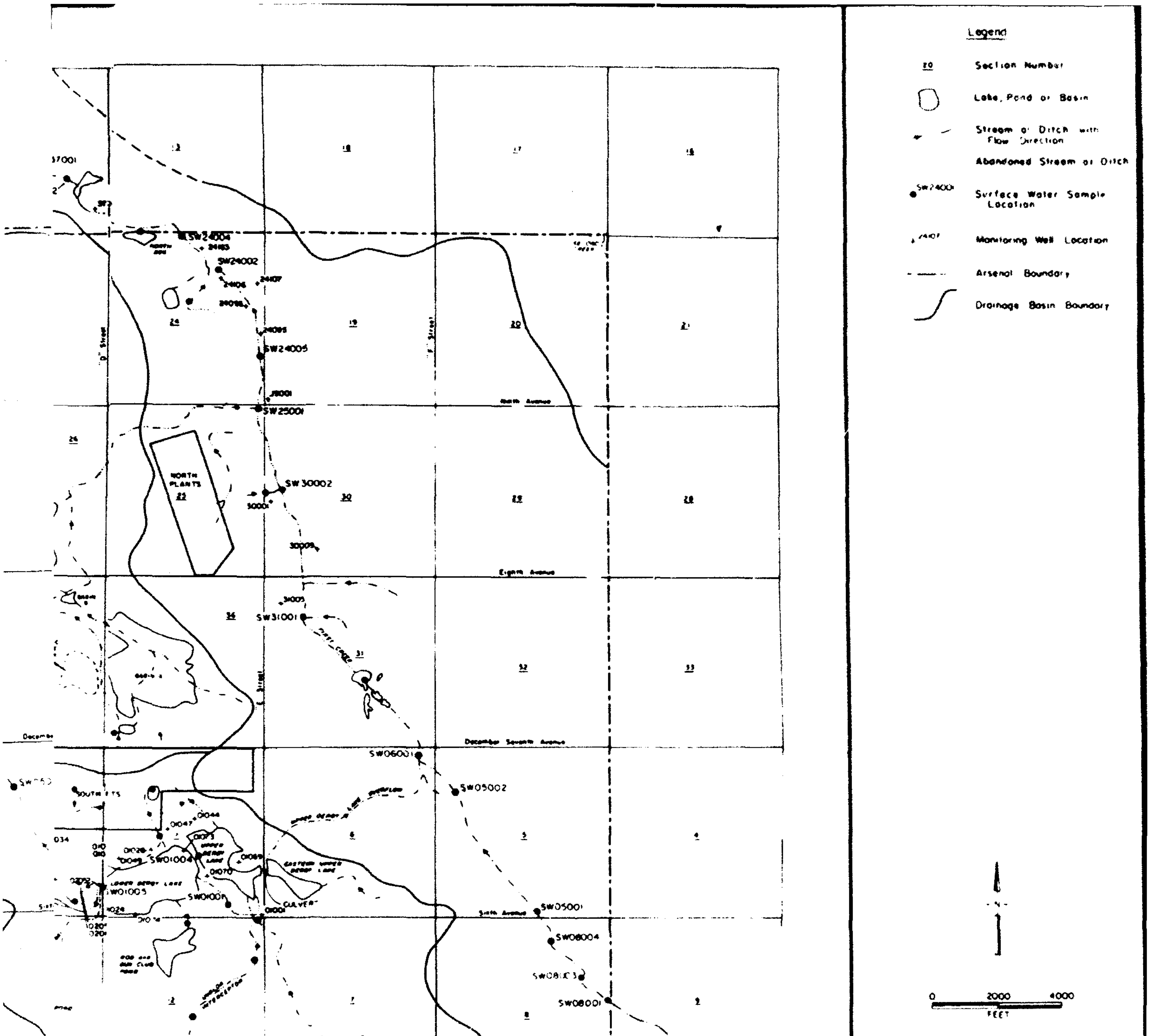
Available water-level data from these wells were compared to data from adjacent surface-water monitoring stations. Hydrograph data for the South Plants Lakes, Havana Pond and corresponding adjacent wells were used to analyze communication between surface water and ground water. The water-level data were used to delineate areas of discharge and recharge.

3.4.2.2 Gain-Loss Study

A gain-loss study was conducted on First Creek to help determine the degree and seasonal variability of ground-water/surface-water interaction in this area. Discharge measurements were taken at several locations along the channel in April and June 1990 and were used to determine if the stream was either effluent (gaining) or influent (losing). Discharge measurements collected from nine on-post sites and one off-post site in April included SW08001, SW08003, SW08004, SW05002, SW06001, SW31001, SW30002, SW24002, SW24004 and SW37001. Discharge measurements collected at 15 on-post sites and four off-post sites in June included SW08001, SW08003, SW08004, SW05001, SW30002, SW37001, SW37010, SW37011 and SW37012. All of the discharge measurements were taken using either a 100 mm or 200 mm long-throated flume with the exception of one Marsh McBirney meter reading from SW24004 in April.



SW37001
SW37010
SW37011
SW37012
SW24004
24183
SW24002
24106
24107
24095
SW24005
SW25001
NORTH PLANTS
SW30002
30001
30004
SW31001
CAUSTIC WASTE BASIN
SOUTH PLANTS
02001
02034
02008
SW02004
02056
02060
02055
02026
SW01004
SW01005
SW01001
MOTOR POOL
RAIL CLASSIFICATION YARD
CULVERT
SW11003
11007
11002
20
21
22
23
24
29
28
27
26
25
32
33
34
35
36



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 3.4-1

Location Map of Surface-Water Sampling Sites and Monitoring Wells used for Ground-Water/Surface-Water Interaction Study