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# ROCKY MOUNTAIN ARSENAL NORTHWEST BOUNDARY CONTAINMENT/TREATMENT SYSTEM BASELINE CONDITIONS, SYSTEM STARTUP, AND OPERATIONAL ASSESSMENT

REPORT FOR FY 85/86



VOLUME I
REPORT



by

Program Manager Staff Office
Program Manager Rocky Mountain Arsenal
Contamination Cleanup,
Aberdeen Proving Ground, Maryland 21010-5401

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13. ABSTRACT (*Maximum 200 words*)

THIS REPORT WAS PREPARED TO DOCUMENT AND ASSESS THE STATUS AND OVERALL OPERATIONAL PERFORMANCE OF THE NORTHWEST BOUNDARY CONTAINMENT/TREATMENT (NWBCT) SYSTEM. THE REPORT CONSISTS OF THREE VOLUMES:

1. MAIN TEXT
2. HYDROGEOLOGIC AND CONTAMINANT DISTRIBUTION PLATES
3. DATABASES DEVELOPED TO SUPPORT THE EVALUATIONS AND ASSESSMENTS.

THE REPORT COVERS THE OPERATING PERIOD OF OCTOBER, 1984, TO SEPTEMBER, 1986. THE OBJECTIVES OF THE REPORT INCLUDE:

1. ASSESS THE CONTINUING EFFECTIVENESS OF THE NORTHWEST BOUNDARY SYSTEM IN PREVENTING OFF-POST MIGRATION OF CONTAMINATED GROUND WATER
2. DOCUMENT SYSTEM OPERATING PARAMETERS
3. IDENTIFY AND DOCUMENT SYSTEM IMPROVEMENTS
4. IDENTIFY AND DOCUMENT OPERATIONAL IMPROVEMENTS THAT WILL ENHANCE LONG-TERM SYSTEM EFFECTIVENESS.

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EXECUTIVE SUMMARY

## Introduction

This report was prepared to document and assess the status and overall operational performance of the Northwest Boundary Containment/ Treatment (NWBCT) System. The report consists of three volumes: Volume I is the main text; Volume II contains all of the hydrogeologic and contaminant distribution plates; and Volume III contains the data bases developed to support the evaluations and assessments made during the study. The report covers the operating period from October 1984 to September 1986 (fiscal years (FY85-86)). Data on historical ground-water levels and quality (FY81-84) are also provided prior to startup of the system in FY85. This data base gives an historical baseline setting upon which the current data base was evaluated.

## Monitoring Activities

### Ground Water

The ground-water monitoring programs conducted during FY 81-86 consisted of the collection of water elevation data and water samples for chemical analysis to define water quality. The data were generated as part of a variety of in-house and contracted efforts. Presently, the basic ground water monitoring program for the Program Manager, Rocky Mountain Arsenal Cleanup (PM, RMA) is a combination of a regional program and a system specific program that consists of both on and off-post hydrology and contamination assessments. The chemical analysis and water level data are maintained on the PM, RMA computer system and the Rocky Mountain Arsenal Information Center (RIC) computer. These data bases are the official record and were used as the primary source of information for the ground water assessments.

### Plant Operations

Monitoring of the treatment plant included collection of data on influent and effluent flow quantities, and on quality of water at various points in the treatment system. The program is managed by personnel of the Program Manager Staff Office (PMSO) at RMA. Flow data are collected on a daily basis and a log of plant operations is also maintained daily. Process control is facilitated by weekly chemical analysis of water samples taken from strategic sampling locations within the interior of the treatment plant. Chemical analyses are performed by the analytical laboratory at RMA and the data are maintained in the PM, RMA data base by the RIC.

## Summary of Operational Effectiveness

The NWBCT System was designed to capture and remove organic contaminants, particularly dibromochloropropane (DBCP) from the ground water to below maximum operating levels (see Table 5, page 45), so that ground water down gradient of the system would not contain concentrations of contaminants in excess of acceptable levels (standards and criteria where available). In order to evaluate the system's ability to intercept and control ground-water flow, and to treat the contaminants in this flow to an acceptable level, a system operational assessment was performed.

### Ground-Water Flow and Evaluations

Ground-water contours developed for the study period indicate that the NWBCT System is effectively intercepting ground water moving toward the system in the alluvium. The hydraulic gradients between the recharge and dewatering wells indicate that the system is serving as an effective barrier to alluvial flow. The lack of significant movement of ground-water contours around the system during the last three quarters of FY86 suggests that ground-water levels are starting to stabilize around the system.

### Contamination Control Operations

The NWBCT System is effectively reducing the off-post migration of contaminants in the ground water in the alluvial aquifer, which is consistent with the original design objectives for the system. As indicated by the contaminant distribution maps (Volume II, Plates 25 through 76) prior to construction of the system, the contaminants distributions followed a "dogleg" pattern entering the study area near the southeast corner of Section 27, continuing northwest towards the center of the section, and then turning north and continuing across the boundary. After construction and during operation of the system (FY85 and FY86) the contaminant distribution upgradient of the system has changed little. However, the concentrations of contaminants downgradient of the system have generally decreased to below detectable levels.

Monitoring data obtained for the influent and effluent of the treatment plant indicate that the system is effectively removing organic contaminants to concentrations generally below detectable levels. No concentrations of organic contaminants above their respective maximum operating levels were found in the effluent from the plant. Inorganic contaminants, such as chloride and fluoride, are not treated by the treatment system.

System Reliability

System operating reliability is an important factor in the overall effectiveness of the system. The NWBCT System has, in general, been very reliable. Downtime due to equipment failures has rarely exceeded a few hours. This is due in part to a continuing program of upgrading the system. A number of modifications have been made since the system went on line in January 1985. For example, the addition of bag-type, manually operated filters in the effluent line and installation of centrally-located, pump control switches in the treatment system building have significantly improved the operating reliability and performance of the system.

## Conclusions and Comments

Current assessment of the NWBCT System operating rates (FY86) indicates that the system is effectively intercepting ground water moving toward the system in the alluvium. Contours upgradient of the system indicate that ground-water levels are beginning to stabilize around the system. Also, flow through the system is being effectively prevented as evidenced by the gradients between the recharge wells and dewatering wells. Primary ground-water flow directions are west, northwest, and north with the major flow and contaminant transport occurring in the alluvial sand and gravel aquifer overlying the Denver formation.

Ground-water contaminants are being effectively removed by the NWBCT System prior to exiting the arsenal boundary. The monitoring data show a historical downward trend in organic contaminants downgradient of the system during the operating period (FY85-86). The treatment plant is removing all organic contaminants to levels at or below their detectable levels. Inorganic contaminants (chloride and fluoride) are not treated by the system.

The reliability of the NWBCT System has been improved to its current high standard due to a continual program of system operational improvement and upgrading.

Review of the data bases used in this operational assessment has indicated there was insufficient information to definitively assess the operational characteristics of the NWBCT System upgradient and immediately north of the system in Section 22. Monitoring of existing wells and the addition of new monitoring wells in Section 22 are needed to enhance the data base required to make a more definitive operational assessment in this area.

The Program Manager RMA Contamination Cleanup has maintained a groundwater monitoring program (Task 25 and 44) for the NW Boundary System through 1987. This program has included the installation of new or replacement monitoring wells in areas lacking sufficient geologic, hydrologic and ground water quality data. The PMRMA will continue to maintain a ground water monitoring program in support of the system operation that will include well installation as required.

# PREFACE

This study was conducted from March 1987 to October 1987 as part of a cooperative effort by personnel from the Program Manager Staff Office for Rocky Mountain Arsenal Contamination Cleanup (PMSO) and the U.S. Army Engineer Waterways Experiment Station (WES). Funding for participation by WES was provided by the Program Manager, Rocky Mountain Arsenal Cleanup via Intra-Army Order Nos. 87-D-2 and 87-D-3. Mr. E. Berry served as Project Coordinator for the PMSO. Project management was provided by Messrs. David W. Strang, PMSO, Norman R. Francingues, WES Environmental Laboratory (EL) and James H. May WES Geotechnical Laboratory (GL).

This study is the first operational assessment of the Northwest Boundary Containment/Treatment System at Rocky Mountain Arsenal (RMA). The contributing authors to this report were Messrs. Edwin W. Berry, Brian L. Anderson and Jerry Barbieri (PMSO), Douglas W. Thompson, Jack H. Dildine, Norman R. Francingues (WES-EL) and Paul Miller and William Murphy (WES-GL). The study and report were authorized by the Program Manager, Rocky Mountain Arsenal, COL Wallace N. Quintrell.

The authors acknowledge the support and assistance of the following people and organizations during this study: Mrs. Marsha Darnell, Ms. Darla McVann, and Mr. Bennie Washington, WES, Mr. Jack Pantleo, Mr. Jim Clark and Ms. Dianna Reynolds, D. P. Associates, and personnel of the Rocky Mountain Arsenal Information Center (RIC).

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows.

| Multiply | By | To Obtain |
|---|---|---|
| acre | 4046.873 | square metres |
| cubic feet | 0.02831685 | cubic metres |
| feet | 0.3048 | metres |
| feet per mile (U. S. statute) | 0.1893936 | metres per kilometre |
| gallons (U. S. liquid) | 3.785412 | cubic decimetres |
| horsepower (550 foot-pounds (force) per second) | 745.6999 | watts |
| inches | 2.54 | centimetres |
| miles (U. S. statute) | 1.609347 | kilometres |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| square feet | 0.09290304 | square metres |
| square miles | 2.589998 | square kilometres |

# NORTHWEST BOUNDARY CONTAINMENT/TREATMENT SYSTEM OPERATIONAL ASSESSMENT: BASELINE CONDITIONS, SYSTEM STARTUP, AND FY85/86 ACTIVITIES

## PART I: INTRODUCTION

### Background

1. The Northwest Boundary Containment/Treatment System Operational Assessment described herein has been prepared to document and evaluate the geochemical and hydrologic parameters and treatment process performance related to the boundary system operations. This report covers the system startup and operating periods of FY85 and FY86 and historical ground-water conditions (FY81-84).

2. Ground-water contamination problems have existed in the area of the Northwest boundary since the mid 1950's, when investigations were conducted by the Army Corps of Engineers. In 1975, a ground-water surveillance program for RMA was established as a requirement of a Cease and Desist Order issued by the State of Colorado. This regional surveillance task included the monitoring of wells in the arsenal boundary areas. Since that time several problem definition studies and design investigations have been conducted by RMA and the Corps of Engineers. Subsequently, a ground-water surveillance program was initiated in 1978 specifically for the Northwest boundary.

3. As a result of the ground-water investigations in 1980, several contaminants including DIMP, DBCP, chloride, endrin and dieldrin were detected in a narrow plume of ground-water leaving the arsenal to the north and northwest. Additional studies by RMA and the Corps of Engineers have lead to the design and construction of the Northwest Boundary Containment/Treatment (NWBCT) Facility that was completed in October 1984. This was the third boundary ground-water contamination control system constructed and operated at RMA.

### Containment and Treatment System Description

4. The NWBCT facility is located along the northwest boundary of Rocky Mountain Arsenal (RMA) parallel to Colorado Highway 2 and the South Platte River (see Figure 1). The NWBCT facility was constructed to remove organic contaminants primarily dibromochloropropane (DBCP), from the ground-water

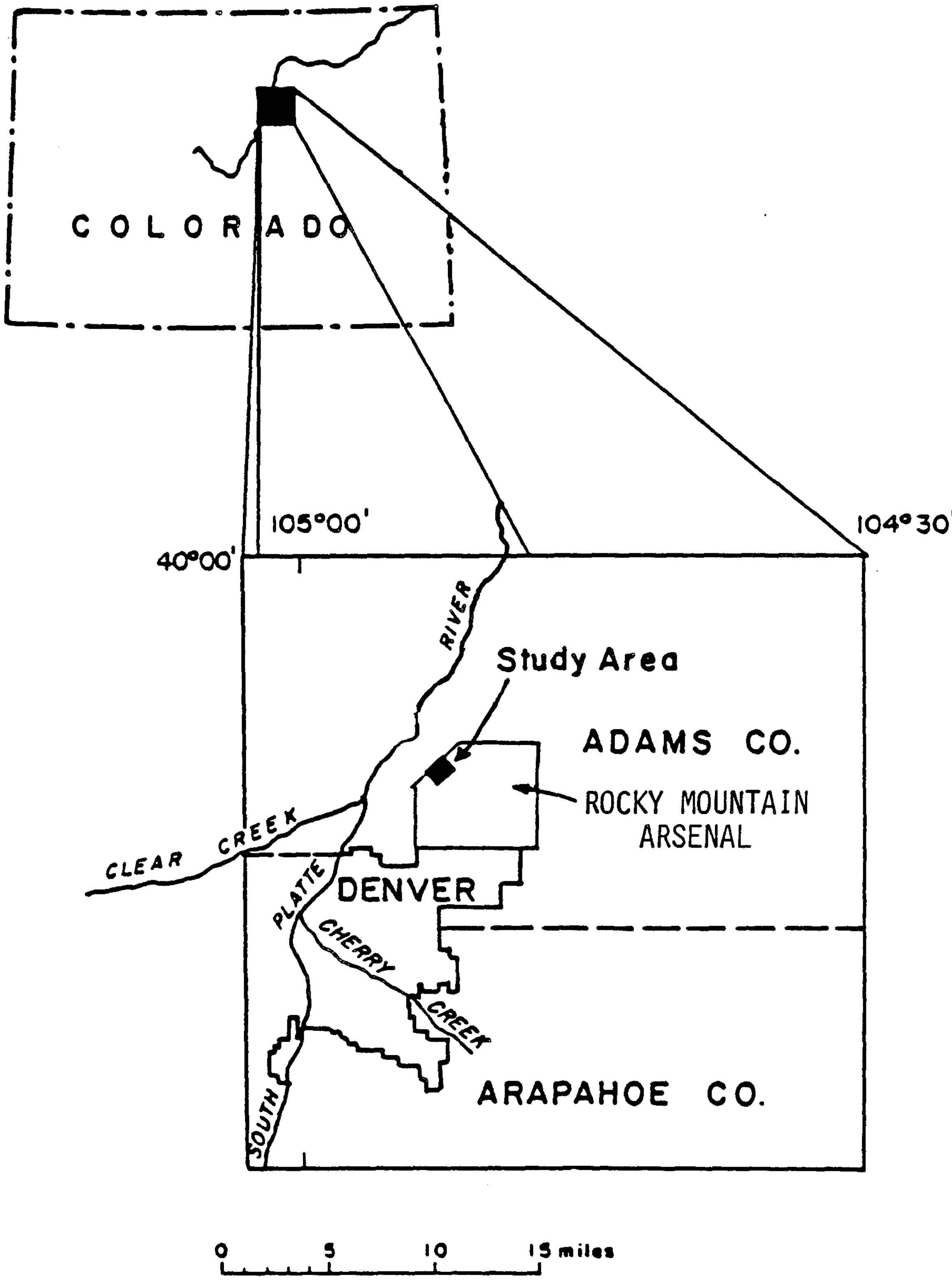



Figure 1. Location of NWB Containment/Treatment System

crossing the Arsenal boundary. A combination of a hydraulic barrier and a 1,425-foot long by 3 foot wide bentonite clay slurry trench cutoff wall were installed along the northwest boundary to intercept the contaminated ground-water flowing across the boundary. (See Figure 2). Ground-water is pumped from a row of dewatering wells on the upstream side of the barrier, treated by carbon adsorption, and returned through recharge wells to the aquifer near the arsenal boundary.

Dewatering Wells

5. A total of 15 dewatering wells are used to remove ground-water. The 10 dewatering wells which form the hydraulic barrier are along the southwest end of the facility alignment and are spaced 100 feet apart. The eleventh dewatering well is spaced 200 feet and the remaining four wells are spaced 250 feet. All of the dewatering wells were drilled 10 feet into the Denver formation. The depth of the Denver formation in this area varies from 54 to 70 Feet below the ground surface.

6. The average design pumping rate for each of the submersible pumps in dewatering wells 1-10 is 100 gpm. The remaining submersible pumps in dewatering wells 11-15 are designed to pump at 25 gpm each. The hydraulic barrier is located in the areas of dewatering wells 1-10 (Figure 3). The bentonite slurry wall is adjacent to the location of dewatering wells 11-15. Water level sensors are located in each well and are used to control the dewatering wells. An additional sensor is used to indicate high water level in the well and is connected to a red indicating light at each well. The dewatering well pumps are remotely controlled from building 810. Flow rate in each well is accomplished via a combination pressure reducing check valve that is manually controlled. A shutoff valve is installed on each well discharge line to isolate the well from the distribution system. Each dewatering well valve pit contains the in-line, totalizing, flow meter, sample valve, and 500 watt space heater to keep the piping from freezing during periods of subfreezing temperatures.

Influent Sump and Pumps

7. The contaminated water that is pumped from the dewatering wells flows through a manifold system to the influent sump adjacent to the treatment building (Figure 3). The influent sump contains four pumps of 500 gpm design capacity each. Depending on the flow rate either two or three of the four sump pumps are in operation at a time. The fourth pump is kept in a stand-by

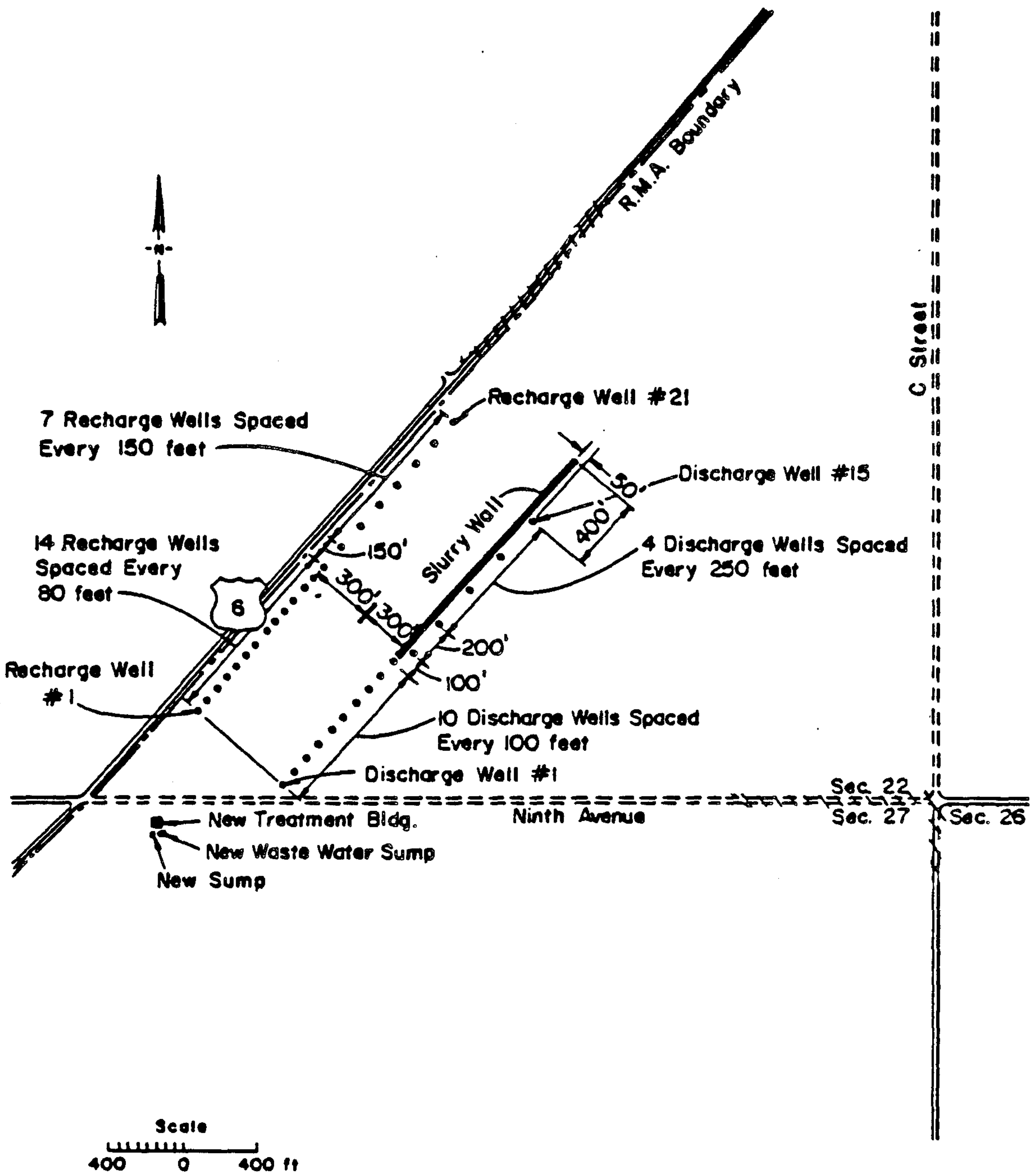



Figure 2. Northwest Boundary Containment/Treatment System layout map

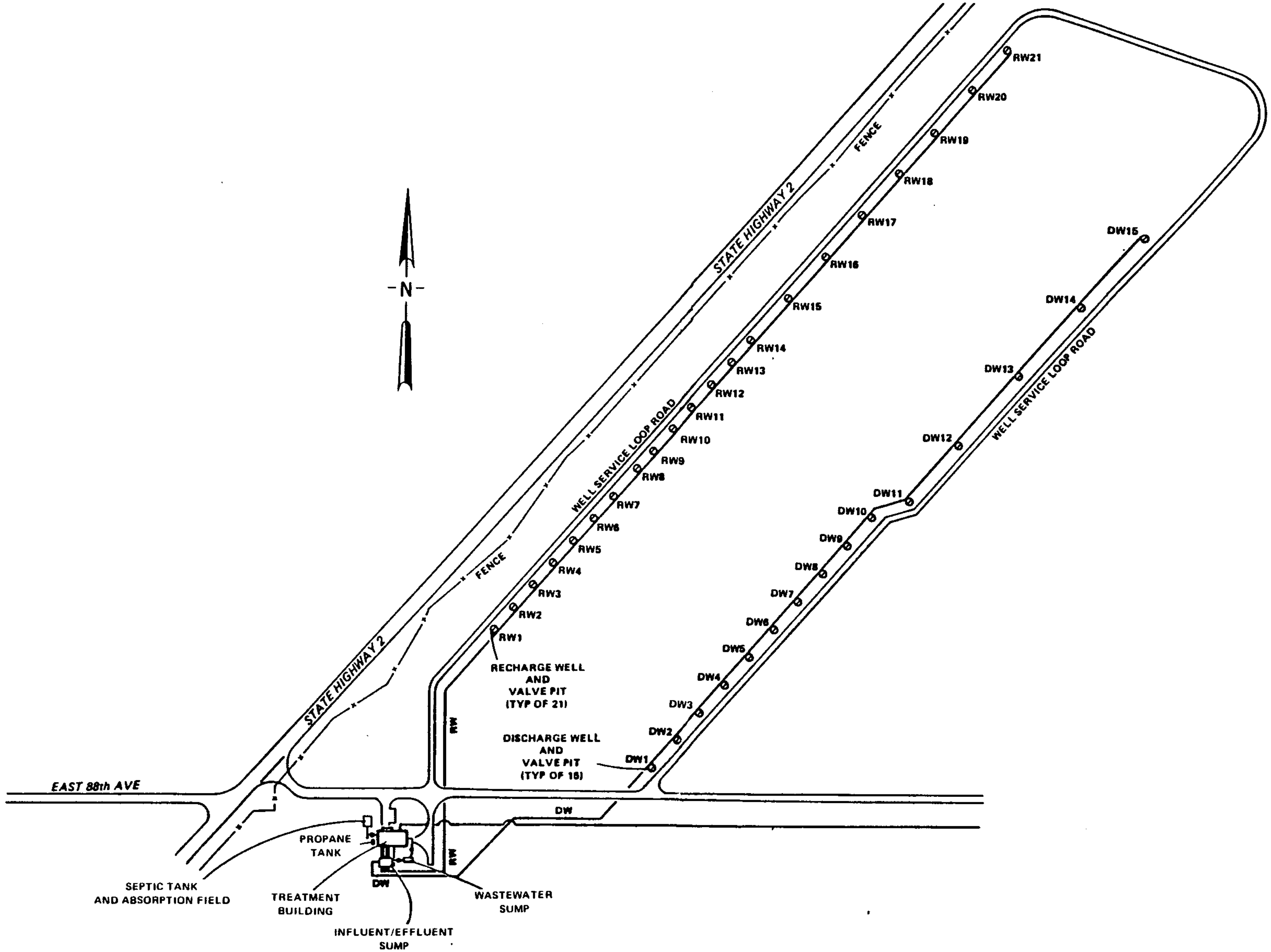



Figure 3. Dewatering wells and manifold collection line

operating position. Control of the sump pumps is by preset water level controls located in the sump. The influent sump also contains a high water level alarm device that activates an alarm light in the treatment building.

Treatment System

8. The treatment facility consists of three high efficiency carbon adsorption columns designed to remove specific organic contaminants from the influent water. Water from the influent sump is pumped through three tubular prefilters to remove suspended solids larger than 100 microns prior to entering the carbon columns. A flow control valve maintains a constant flow into the adsorber columns. The adsorption units are designed as countercurrent, pulsed-beds using granulated activated carbon as the adsorption medium. Residence time in the units is 22 minutes at the design flow rate of 500 gpm. Effluent from the adsorption units passes through a 10 micron postfilter, where entrained carbon particles are removed. All overflow and backwash streams, that contain suspended solids or carbon, are discharged to the wastewater sump. After settling, the wastewater overflows to the influent sump for reprocessing through the carbon units.

9. Small amounts of carbon are removed periodically from the influent side (bottom) of the adsorption columns and an equal amount of fresh carbon is added at the effluent side (top). The amount of carbon removed and replaced represents approximately 5 percent of the total bed volume. Each adsorber contains approximately 1,400 cubic feet of carbon.

10. Spent carbon is removed by a pulse of slurry water from the adsorber into the spent carbon blowcase. Carbon slurry for removal of spent carbon and the addition of fresh carbon is provided by a subsystem consisting of two blowcases and two storage vessels. The spent carbon is transferred by means of compressed air from the blowcase to the spent carbon storage vessel. Fresh carbon is added to the top of the adsorber in a reverse manner. The 740-cubic foot spent carbon storage vessel is emptied by a truck, that also delivers fresh carbon for the 1,100-cubic foot fresh carbon storage vessel.

Effluent Sump and Pump

11. Treated water from the 10 micron bag postfilters is discharged into the effluent sump. The pumping system consists of four, 500-gpm pumps. Each of the four effluent sump pumps is equipped with a low water cutoff float switch. The four switches trigger at different water levels allowing for increased or decreased pumping capacity depending on the water level in the

sump. The sump is equipped with a high water level alarm and a float switch which triggers an emergency cutoff of all influent pumps should the sump become full. The treated water is pumped from the effluent sump through a recharge header pipe to the recharge wells.

Recharge Wells

12. There are a total of 21 recharge wells (RC). Fourteen of the wells (RC 1-14), which are located along the southwest end of the facility alignment, are spaced 80 feet apart. The other 7 wells (RC 15-21) are spaced at 150-foot intervals. The wells were drilled 5 feet into the Denver formation that varies from 48 to 60 feet below the ground surface in this area. Each of the 21 recharge wells has an enclosed valve pit containing a shutoff valve, a V-port ball valve to control the flow of water, a flow meter, a high water level alarm, and a 500-watt space heater.

## Report Objectives

13. Report objectives include:

a. To assess the continuing effectiveness of the Northwest Boundary System in preventing the offpost migration of contaminated ground-water along the system alignment during eight time periods covering FY85 and FY86.

b. To document system operating parameters.

c. To identify and document system improvements, field studies, and facility alterations conducted during FY85 and FY86.

d. To identify and document operational improvements that will enhance long-term system effectiveness.

## Approach

14. The approach to developing this study incorporates direction of the office of the Program Manager, Rocky Mountain Arsenal Contamination Cleanup and the Program Manager Staff Office (PMSO) at Rocky Mountain Arsenal. The PMSO established and provided the reporting framework and objectives, the data base (Volume III) and general technical guidance. The Waterways Experiment Station, Vicksburg, Mississippi (WES) provided specialized Environmental Engineering and Geotechnical assessments.

15. The study was conducted in three phases. Originally, data were retrieved and organized by the PMSO and Rocky Mountain Arsenal Information Center (RIC). Next, WES and PMSO personnel reviewed the data bases for completeness and then developed geotechnical and water quality assessments along with various system performance evaluations. During the course of study, several in-progress reviews and coordination working sessions were held at the PMSO and at the WES to facilitate exchange of information and to assure continuity and consistency in data interpretations and evaluations. Finally, the report was assembled from individual sections prepared by the various contributing authors.

## Organization of Report

16. This report consists of three volumes. Volume 1 is the main text and consists of five parts. Following this introductory part are four parts dealing with data collection, system operations including facility alterations and modifications, data evaluations for geologic, hydrologic and treatment systems, and finally, conclusions and comments. Volume II contains all of the hydrogeology and contaminant distribution plates referred to in Volume I. The data bases developed to support the evaluations and assessments made during the study are located in Volume III. Volume III will not be distributed with Volumes I and II. Instead, it will be maintained on file at the Rocky Mountain Arsenal Information Center (RIC) reference library at Rocky Mountain Arsenal.

## PART II: DATA COLLECTION

### Ground-Water Monitoring

#### Background

17. Numerous ground-water monitoring programs have been conducted in the Northwest Boundary area between 1979 and the present. Many of the early programs (1979-1983) consisted of hydrogeologic and ground-water contamination investigations that supported the problem definition studies and the design and construction of contamination control systems. Much of the data collected as baseline data for the NWBCT System during late 1982 and 1983 was primarily water quality data. The need for a comprehensive monitoring program was recognized in late 1983 and a plan was prepared and implemented in 1984. The program was initiated prior to final construction and startup of the NWBCT system in 1984. The monitoring program consisted of the collection of water level and water quality data at selected sites on a consistent basis. Annual reviews and modifications were made to the monitoring program to improve data collection efforts. This monitoring program was conducted by the Rocky Mountain Arsenal, Technical Operations Directorate, Environmental Division and continued through FY85.

18. The methods used for ground-water sample collection have been modified over nearly ten years of ground-water monitoring at RMA. Initially the wells were sampled using a simple bailing procedure and water levels taken using steel tapes and/or electric probes. This procedure was considered to be acceptable since the ground-water had fairly high levels of contaminants and the monitoring was being done in shallow alluvial wells with little potential of containing stagnant water. With the installation and monitoring of deep wells a need to improve the procedures was required. Changes were also required to improve the representativeness of the data being collected as a result of the analysis of new contaminants and the development of lower analytical detection levels. Additionally, it was desired to implement a consistent sampling procedure for all the RMA ground-water monitoring programs. A sample collection protocol, a copy of which is contained in RIC document number 86078R01, Appendix A, was developed in 1983 by RMA for the monitoring and investigative programs. This procedure was used from 1983 through 1985 for the Northwest Boundary System monitoring.

19. The FY86 monitoring program was conducted by the Program Manager, Rocky Mountain Arsenal Contamination Cleanup (PM, RMA) as part of the remedial studies being conducted at RMA. The development of the monitoring task technical plans for Task 4, Task 6 and Task 25 and the implementation of the monitoring programs was performed for the PM, RMA by Environmental Science and Engineering, Inc., the task contractor.

FY81 - FY85 Monitoring Programs

20. The RMA ground-water monitoring programs for FY81 through FY85 varied in the number of well sites monitored and the frequency of data collection activities. In the later years the program used 45 well sites for quarterly sampling for water quality. Water level measurements were taken quarterly at these 45 well sites, and at an additional 117 alluvial and Denver formation sites. Water samples were submitted to the RMA Environmental Division Laboratory for the analysis of DIMP, DBCP, the chlorinated pesticides; endrin, isodrin, aldrin and dieldrin; chloride, and fluoride.

FY86 Monitoring Program

21. The FY86 ground-water monitoring program was conducted as part of the PM, RMA remedial program activities at the Arsenal. In addition to these monitoring programs, the RMA Technical Operations Directorate collected some water level and water quality samples from the study area during the first quarter of FY86 using the same procedures as the FY85 program. The data that were developed for the NWBCT system monitoring program, under the PM, RMA, were produced as part of the remedial investigation and feasibility study by three separate tasks: Task 4, "RMA Water Quantity/Quality Survey," and Task 25 "Boundary Systems Monitoring" under contract DAAK11-84-D-0016, and Task Order 6 "Offpost Contamination Assessment" under Contract DAAK11-83-D-0007.

22. The basic ground-water monitoring program during FY86 was the regional program, that consisted of the RMA Water Quantity/Quality Survey and the Off Post Contamination Assessment. These programs were initiated at the beginning of FY86 and consisted of monitoring the water quality at 363 alluvial and Denver formation sites. Forty-three of these 363 wells were located off-post. Water level measurements were also taken at 863 alluvial and Denver Formation wells located both on-post and off-post. Out of this regional monitoring effort, 40 sites consisting of 26 alluvial and 14 Denver Formation wells, were monitored for water quality in the Northwest boundary area. Water

level data from 79 alluvial and Denver Formation sites were also developed for both on-post and off-post wells. During the last quarter of FY86, the Boundary System Monitoring Task (Task 25), was initiated to provide detail site specific data for the operating systems. This monitoring task consolidated the efforts of water quality and water level data collection activities for the NWBCT system. In addition to the regional monitoring outlined above, Task 25 collected 49 samples from 43 alluvial and 6 Denver formation wells for analysis. Water levels were measured at 49 additional alluvial and Denver formation sites. All monitoring done under Tasks 25 in the Northwest boundary area was conducted in sections 22 and 27 on-post and section 22 off-post. A summary of the sampling conducted by each task is included as part of the data summary in Volume III.

23. The above described tasks utilized the same protocols, that were developed specifically for the PM, RMA program at RMA. The sample collection and measurement protocols are presented in the Task 4 and Task 25 technical plans. These plans are available for review at the RIC Center located at RMA under document numbers 87013R01 and 87014R24, respectively.

24. The monitoring was conducted by Environmental Science and Engineering, Inc. (ESE) and their subcontractors. Water samples were submitted to the ESE laboratories in Gainesville, Florida and Denver, Colorado for the analysis of the contaminants listed in Table 1.

25. Data Management. The sample analysis and water level data for the NWBCT area are maintained in special files on the PM, RMA computer system. Laboratory and field data were entered into the data base by the RIC personnel or the task contractors, subjected to the data checking routines, validated and placed into the computer system. Data sets were prepared and then used to construct data tables, maps, graphs, etc. Volume III of this report contains a copy of the water quality and water level data that were used in this report. The data can also be obtained through the RIC at the Rocky Mountain Arsenal or the PM, RMA computer system located at Aberdeen Proving Ground, Edgewood Area, Maryland.

## Plant Operations Monitoring

26. The treatment plant monitoring program was initiated in October 1984 and included collection of data on flow quantities through the system and on

Table 1

Chemical Analysis - Task 25

| Analysis/Analytes | Maximum Hold Time | Level of Certification | Reference Methods | Method |
|---|---|---|---|---|
| Organochlorine Pesticides | | Quantitative | EPA 608 | CAP-GC/ECD |
| Aldrin<br>Endrin<br>Dieldrin<br>Isodrin<br>Hexachlorocyclopentadiene<br>p,p'-DDE<br>p,p'-DDE<br>Chlordane | Extract as quickly as possible. (No more than 7 days). Analyze within 40 days of extraction. | | | |
| Volatile Organohalogens | | Quantitative | EPA 601 | PACK-GC/Hall |
| Chlorobenzene | 14 days | | | |
| Chloroform | 14 days | | | |
| Carbon Tetrachloride | 14 days | | | |
| trans-1,2-Dichloroethylene | 14 days | | | |
| Trichloroethylene (TCE) | 14 days | | | |
| Tetrachloroethylene | 14 days | | | |
| 1,1 Dichloroethylene | 14 days | | | |
| 1,1 Dichloroethane | 14 days | | | |
| 1,2 Dichloroethane | 14 days | | | |
| 1,1,1 Trichloroethane | 14 days | | | |
| 1,1,2 Trichloroethane | 14 days | | | |
| Methylene Chloride | 14 days | | | |
| Organosulfur Compounds | | Quantitative | | PACK-GC/FPD-S |
| P-Chlorophenylmethylsulfone ($PCPMSO_2$)<br>P-Chlorophenylmethylsulfoxide (PCPMSO)<br>P-Chlorophenylmethylsulfide (PCPMS)<br>1,4-Dithiane<br>1,4-Oxathiane<br>Dimethyldisulfide (DMDS) | Extract as quickly as possible. (No more than 7 days). Analyze within 40 days of extraction. | | | |

(Continued)

Table 1 (Concluded)

| Analysis/Analytes | Maximum Hold Time | Level of Certification | Reference Methods | Method |
|---|---|---|---|---|
| DCPD/MIBK | | Quantitative | EPA 608 | CAP-GC/FID |
| Dicyclopentadiene/ Methylisobutylketone | Extract as quickly as possible. (No more than 7 days). Analyze extract within 40 days of extraction. | | | |
| DIMP/DMMP | | Qualitative | EPA 622 | PACK-GC/FPD-P |
| Diisopropylmethylphosphonate/ Dimethylmethylphosphonate | Analyze within 47 days of sampling. | | | |
| DBCP | | Quantitative | | CAP-GC/ECD |
| Dibromochloropropane | 14 days | | | |
| Inorganics | | Quantitative | | |
| Arsenic | 6 months | | EPA 206 | AA-Hydride Furnace |
| Chloride | 28 days | | EPA 300 | Ion Chromatograph |
| Fluoride | 28 days | | | |
| Sulfate | 28 days | | | |
| Volatile Aromatics | | Quantitative | EPA 602 | PACK-GC/PID |
| Toluene | 14 days | | | |
| Benzene | 14 days | | | |
| Xylene (o-, m-, p-) | 14 days | | | |
| Ethylbenzene | 14 days | | | |

Source: ESE, 1985.

the quality of the water entering and leaving the plant. The flow quantities were recorded on a daily basis in the plant operations log. The water quality monitoring was scheduled on a weekly sampling basis in January 1985 when the plant started operating on a 24 hour continuous basis. A list of the analytes included in the sampling and analysis program is shown in Table 2.

27. Samples are taken weekly from the interior of the adsorbers for process control. These data are used in determining when to change carbon within the adsorber. The quality of the plant's influent and effluent was monitored by taking water samples on a weekly basis and analyzing them. Samples were collected also from the dewatering wells on a quarterly basis. These samples were collected from ports located in the well pits.

28. All water samples were collected in previously cleaned, glass containers, sealed, and transported to the analytical laboratory at RMA for analysis. The parameters for which the plant samples were analyzed for during FY85 and FY86 are presented in Table 2. All analyses were performed using standard methods. The sample analysis and flow data were entered into the analytical data base by laboratory personnel, subjected to a quality control routine, validated, and placed into the PM, RMA data base by the RIC. Data sets were prepared for use in developing tables and figures. Copies of the plant analytical and flow data for FY85 and FY86 are contained in Volume III of this report.

Table 2

Chemical Analysis of Treatment Plant Samples

| Analyte | FY85 | FY86 |
|---|---|---|
| Aldrin | X | X |
| Chloride | X | X |
| Dibromochloropropane | X | X |
| Dicyclopentadiene | X | X |
| Diisopropylmethylphosphonate | X | X |
| Dithiane | X | X |
| Dieldrin | X | X |
| Endrin | X | X |
| Fluoride | X | X |
| Isodrin | X | X |

## PART III: SYSTEM OPERATIONS AND FACILITY ALTERATIONS

### Operational Summary

29. The NWBCT System became operational in October 1984, with system testing and final construction continuing into January 1985. A log of plant operations for the system is maintained by RMA plant operations personnel with major events documented on a daily basis. The daily log contains flow meter readings along with comments on the operation, maintenance, and repair of the dewatering and recharge wells, pipes, electrical components, sumps, and treatment equipment. For purposes of this report, daily logs are available for the time period covering November 7, 1985 through September 30, 1986. The log notes various problems during FY86 that affected the normal operation of the system. These problems primarily included equipment malfunctions, pipe breakages, and well plugging. Normal operation of the system was also impacted by scheduled maintenance and repair/construction activities. The log indicates that there was a considerable amount of construction going on during the first and second quarters of FY86. In general, downtime due to equipment failures has rarely exceeded a few hours.

### Alterations and Repairs

30. During operational checkout of the treatment plant between October 1984 and January 1985, it was determined that several modifications to be plant would be necessary. These modifications were required to provide for stable operation of the plant, reduce the manpower required to operate the plant, and reduce equipment maintenance requirements. The major alterations and repairs made to the plant between October 1985 and September 1986 are as follows:

a. Addition of bag-type, manually-operated filters in the effluent line replacing the existing automatic back-wash, multi-media filters. The multi-media filters were not able to handle the migrating carbon fines and were continually back washing.

b. Addition of dewatering well pump control switches in the treatment building. These replaced the old switches located at each well head.

This change provided for control of all the dewatering well pumps from a central location.

c. Addition of a high water-level control switch in the influent sump. This switch shuts off the dewatering well pumps when the water level rises too high in the sump. This change prevents flooding/overflow of the influent sump.

d. Addition of stairs and platforms around the adsorbers to improve the accessibility of the adsorbers for maintenance and repairs. Also, the manually operated valves on top of the adsorbers were replaced with remotely operated ones. This change facilitated operation of the valves without climbing to the top of the adsorbers.

e. Modification of the valve pit covers to reduce a potential safety hazard resulting from the weight of the covers. This change provided for improved access to the flow meters and sampling ports located in the valve pits. It also reduced the potential for injury to the operators from opening and closing the covers. In addition, the sampling valves in each valve pit were modified to simplify and speed-up sample collection.

## System Flow Quantities

31. The quantity of flow through the treatment system is recorded on a daily basis. The flow quantities recorded for FY85 and FY86 are presented in tabular form in Part I, Volume III of this report. Graphs of weekly flow data for each adsorber and the effluent stream have been prepared and are presented in Figures 4 through 11. The treatment plant flow data were accumulated on a weekly (7 day) basis beginning with the first day of the FY and continuing through the end of the FY. Thus, each bar on the flow graph represents data for one week. This graphical presentation may cause some confusion with the monthly labels on the graph. The months are only a guide to show approximately where the weekly flows fall in relation to the months.

32. During FY85, the total system flow rate (effluent) ranged from a low of 0 gpm to a high of approximately 1100 gpm. Low or no flow conditions during the first quarter of FY85 are a result of system testing and final construction. During this time the plant was operated only during the day due to unstable operating conditions. The system went into continuous operation in January 1985. The plant was down for approximately 5 days in late January

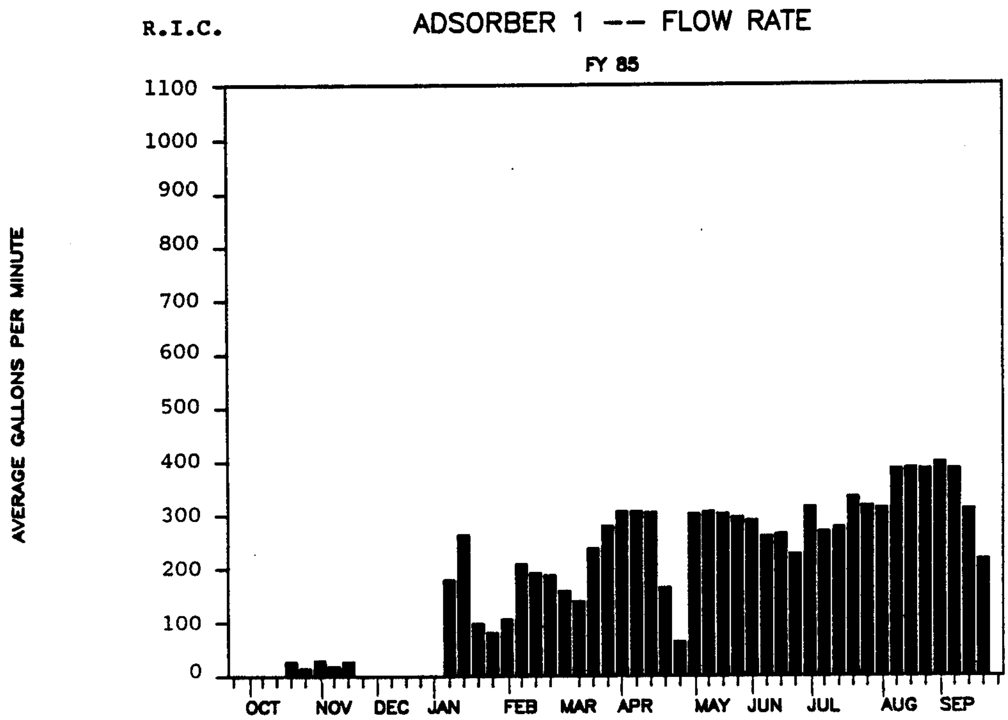



Figure 4. Adsorber 1 flow rate during FY85

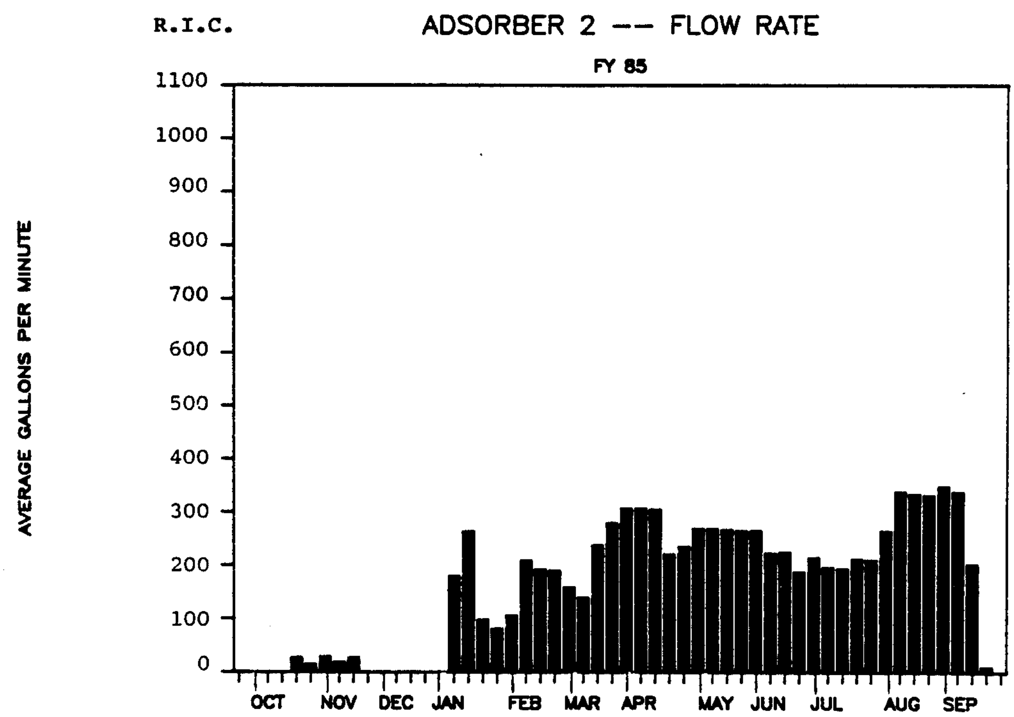



Figure 5. Adsorber 2 flow rate during FY85

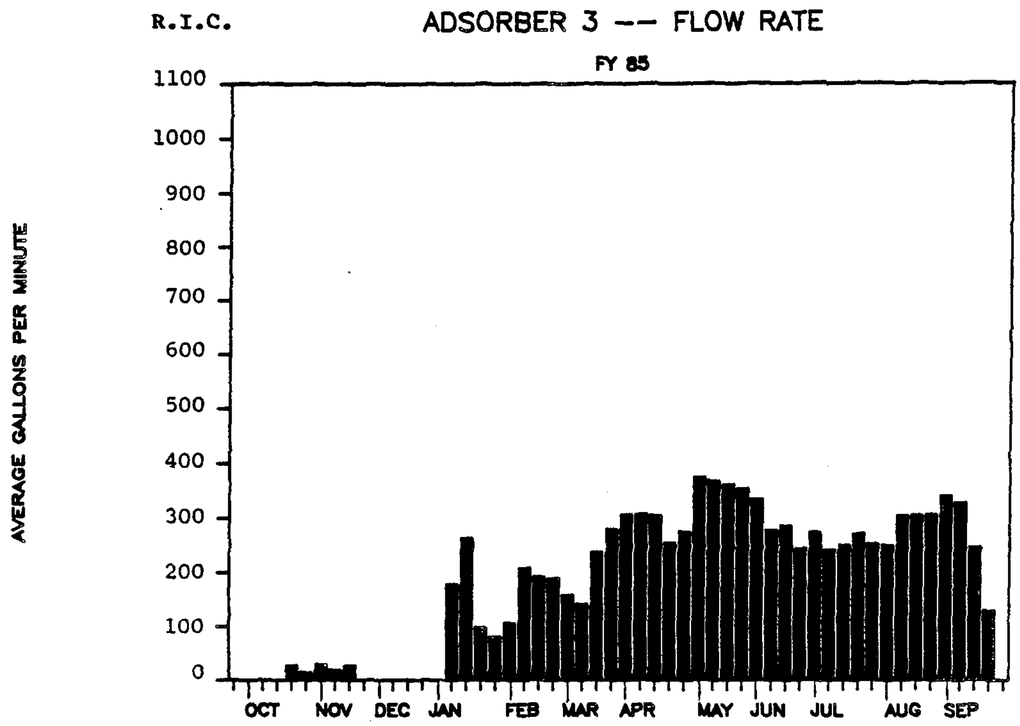



Figure 6. Adsorber 3 flow rate during FY85

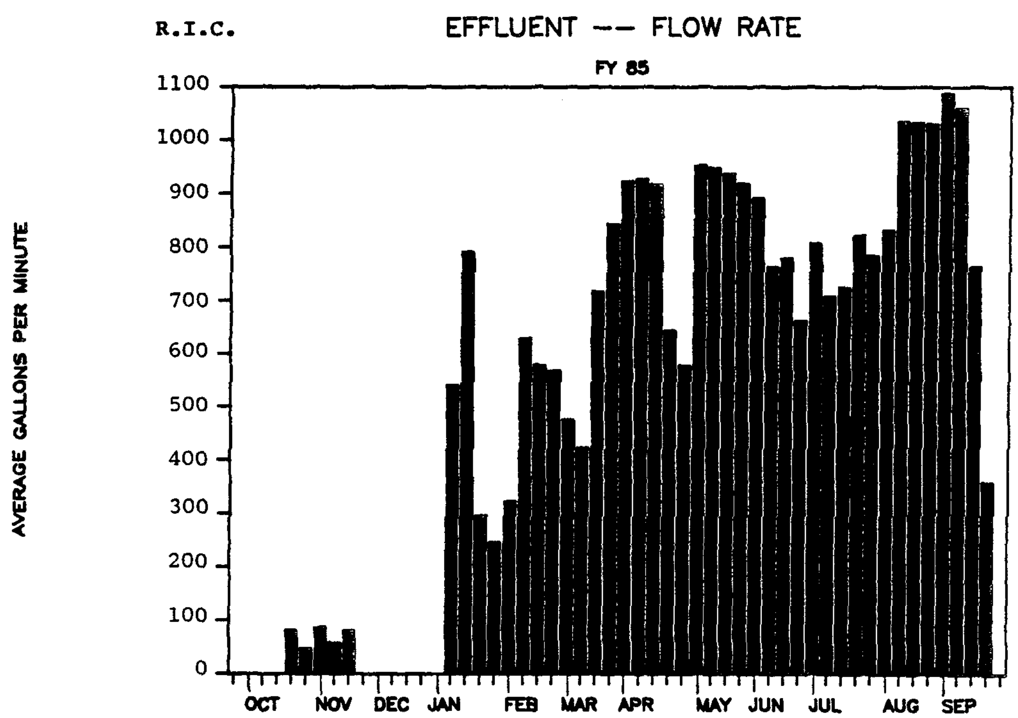



Figure 7. Effluent flow rate during FY85

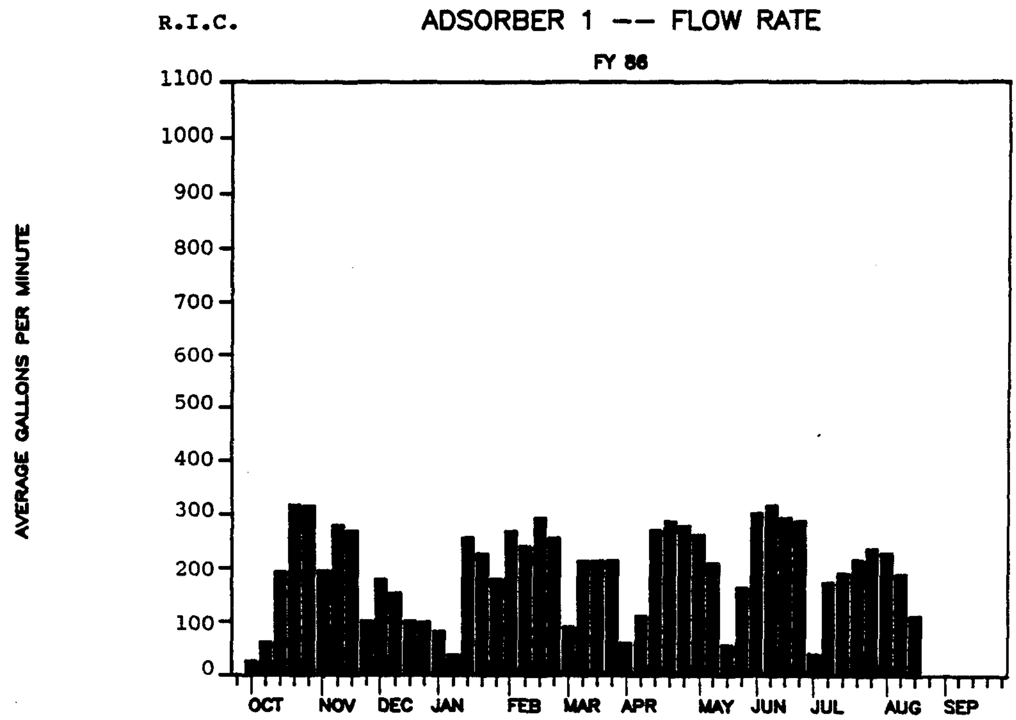



Figure 8. Adsorber 1 flow rate during FY86

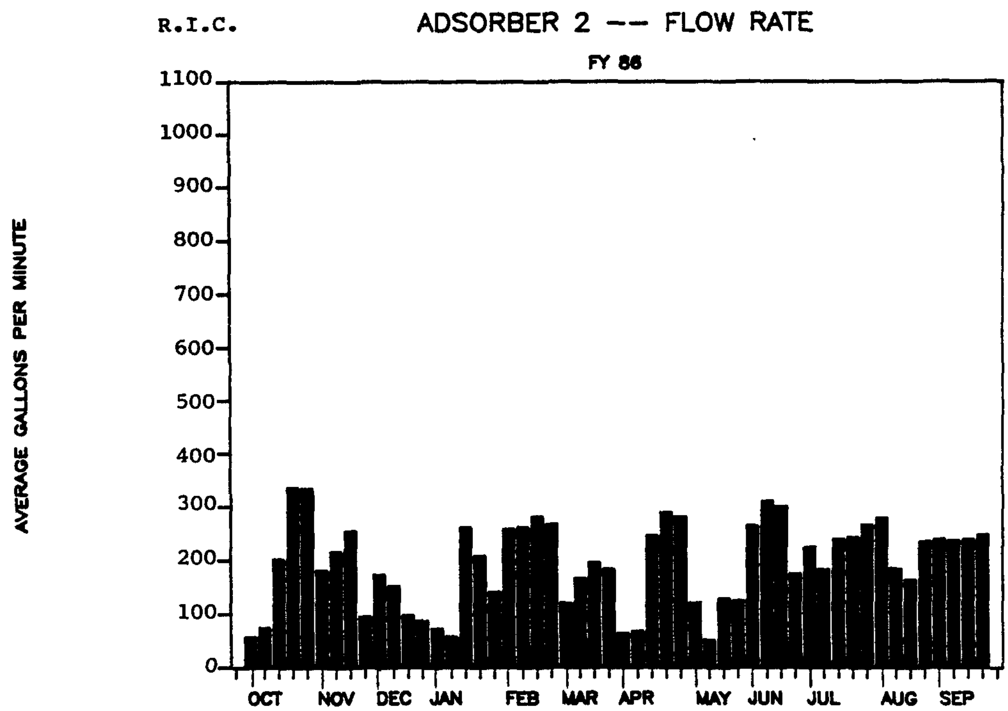



Figure 9. Adsorber 2 flow rate during FY86

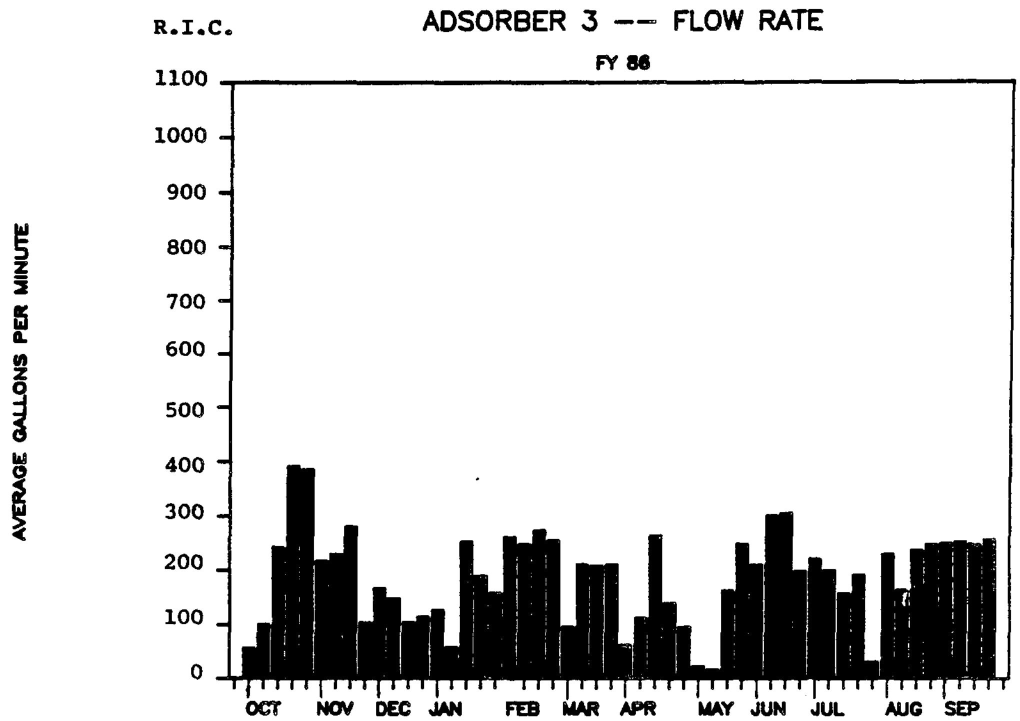



Figure 10. Adsorber 3 flow rate during FY86

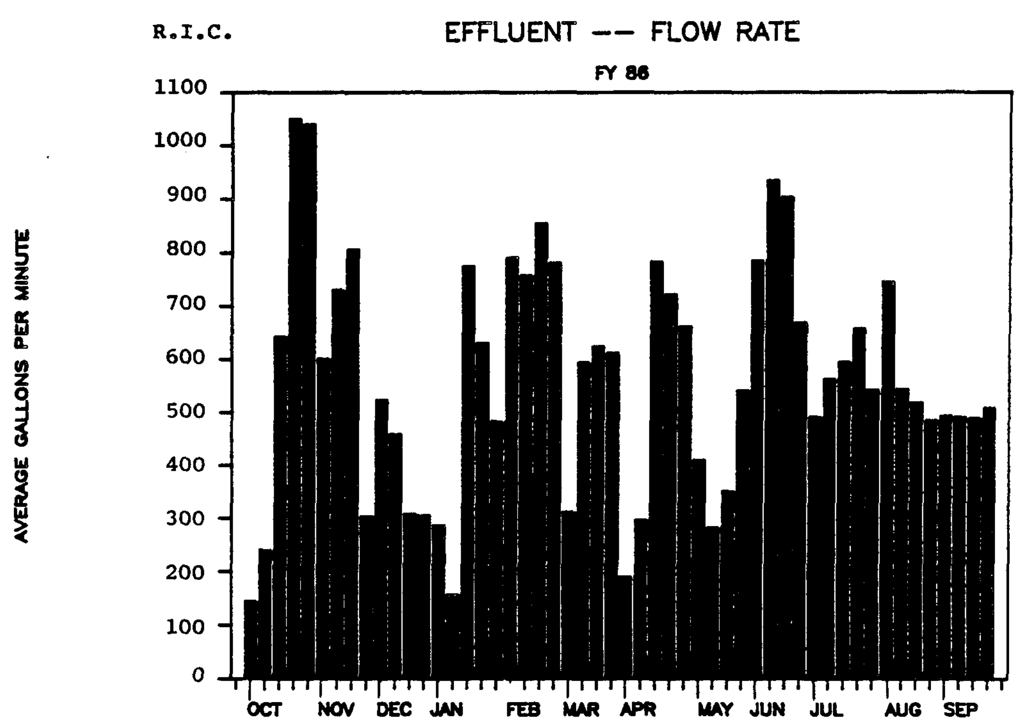



Figure 11. Effluent flow rate during FY86

awaiting repair of the automatic back-wash unit for the effluent filters. The plant was shut down in late September when work started on the plant alterations. Average flow rates and total gallons of water treated during FY85 are presented in Table 3.

33. During FY86, the total system flow rate (effluent) ranged from a low of approximately 145 gpm to a high of approximately 1,050 gpm. During December 1985, the plant was shut down temporarily due to broken valves and leaking pipes. The plant was down in January to complete replacement of the valves on top of the adsorbers. Low flows in early March 1986 are a result of plant shutdown to install bag filters. During April, the plant experienced a shutdown due to loss of electrical power caused by a spring blizzard. Low flows in May were caused by leaks in the newly installed bag filters and required repair of several pumps.

34. The reduction in flow through the plant during August and September was an operations decision. Results of hydrological flow modeling of the Northwest Boundary System indicated that a dewatering/recharge rate of 500 gpm to 600 gpm would achieve an acceptable reverse gradient between the dewatering wells and the recharge wells. During August the system throughput flow rate was reduced to an average flow rate between 500 gpm to 600 gpm. Prior to August 1986, three adsorbers were used in parallel, however with the reduced throughput flow rate, Adsorber 1 was shut down and maintained in a standby status.

35. Average flow rates and total gallons of water treated during FY86 are presented in Table 4. The total volume treated for FY86 was approximately

Table 3

FY85 System Flow Quantities

| Adsorber | Average Flow Rate (gpm) | Total Volume Treated (gal) |
|---|---|---|
| 1 | 193.09 | 101,519,000 |
| 2 | 170.83 | 89,549,000 |
| 3 | 190.23 | 99,888,000 |
| Total Effluent | 554.15 | 290,956,000 |

Table 4

FY86 System Flow Quantities

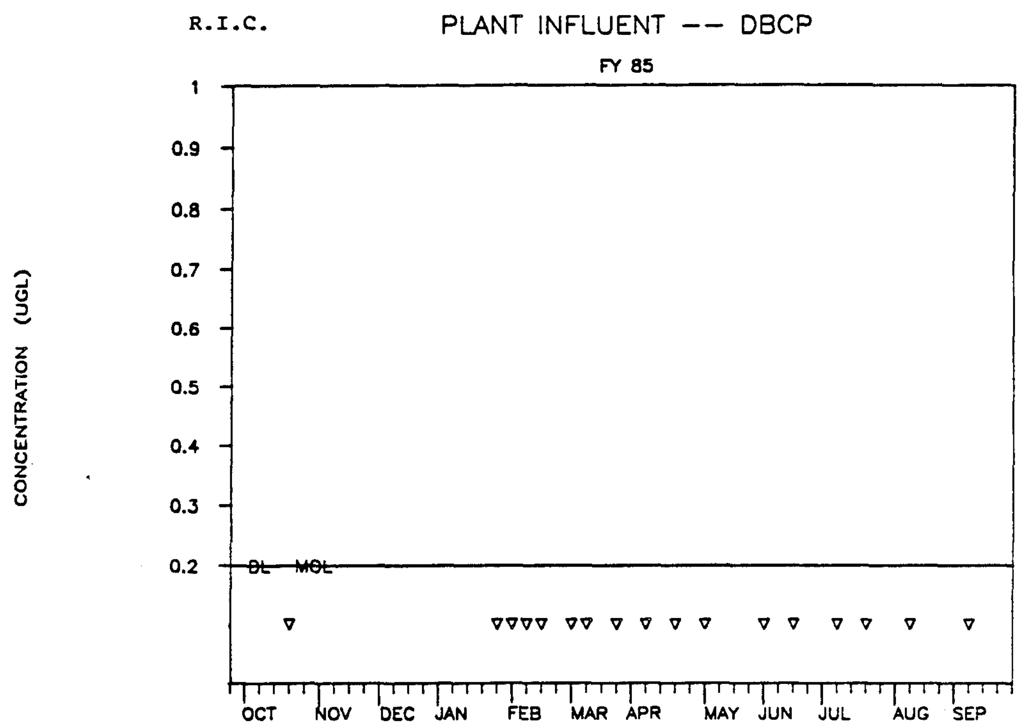
| Adsorber | Average Flow Rate (gpm) | Total Volume Treated (gal) |
|---|---|---|
| 1 | 178.57 | 93,603,000 |
| 2 | 197.42 | 103,857,000 |
| 3 | 192.63 | 101,407,000 |
| Total Effluent | 568.62 | 298,867,000 |

7.9 million gallons higher than that treated for FY85. The average flow rate in FY86 was approximately 14 gpm higher than that for FY85.

## System Influent and Effluent Water Quality

36. The quality of the influent and effluent from the treatment systems is monitored periodically by taking grab samples and analyzing them for the contaminants of concern. A single influent sample is collected from the influent sump to determine the quality of water flowing to the adsorbers. A single effluent sample is collected from the effluent sump after treatment.

37. The results of these analyses for the period October 1984 through September 1986 are presented in tabular form in Volume III, Part II of this report. Data for the first quarter of FY85 is limited since the treatment plant was not in continuous operation until January 1985. Graphs of the concentrations found for DBCP, DIMP, DCPD, aldrin, endrin, dieldrin, isodrin, chloride, and fluoride over this period have been prepared and are presented in Figure 12-29. A separate figure for the plant's influent and the effluent for FY85 and FY86 has been prepared. Each figure contains a plot of the contaminant concentrations found over the particular FY and shows, where applicable, the detectable limit, the maximum operating limit (MOL) permitted, the average concentration over the FY. Average concentrations were calculated only where sufficient data above detectable levels were available. A list of the MOL's used during the FY85 and FY86 operational assessment is presented in Table 5. No MOL was established for chloride and fluoride because these compounds are not treated by the system.



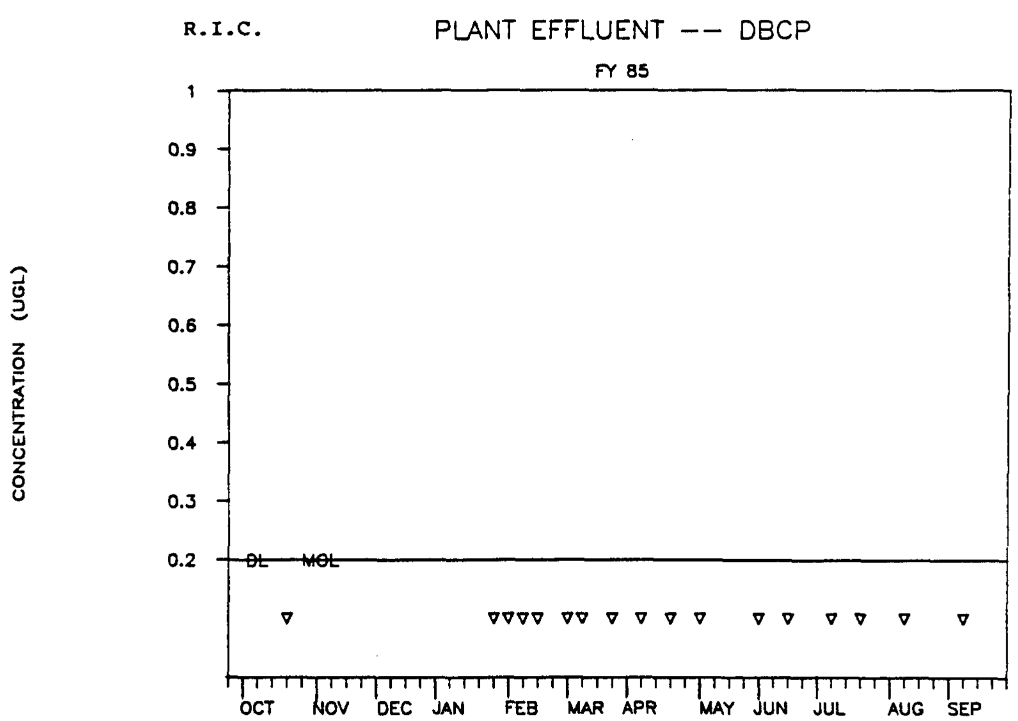
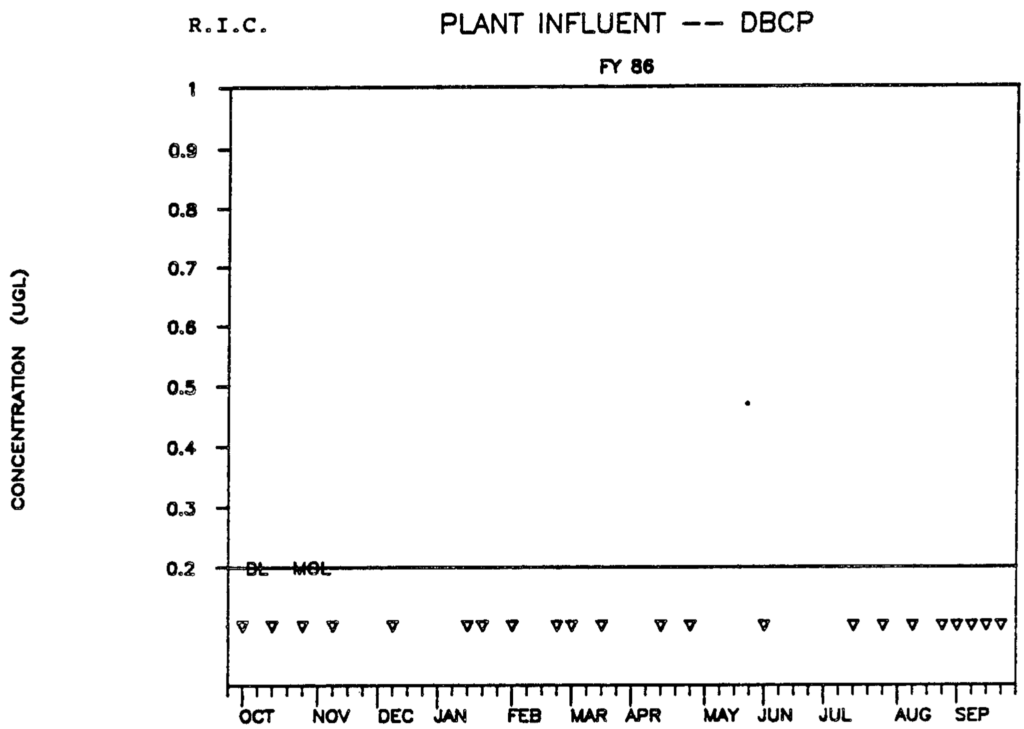




Figure 12. FY85 DBCP



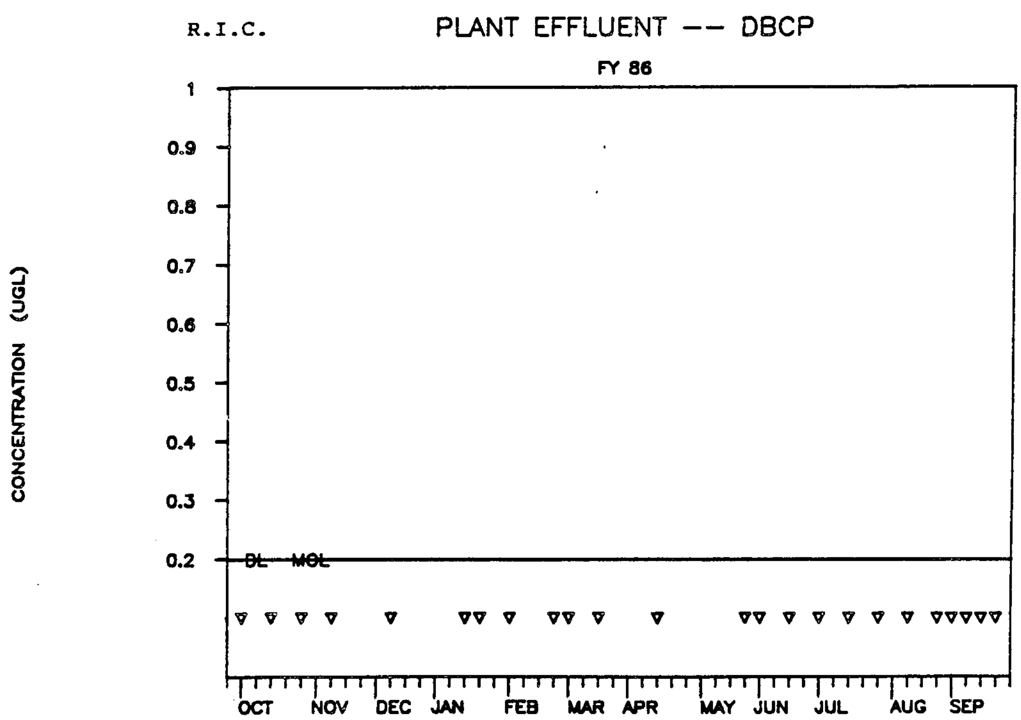
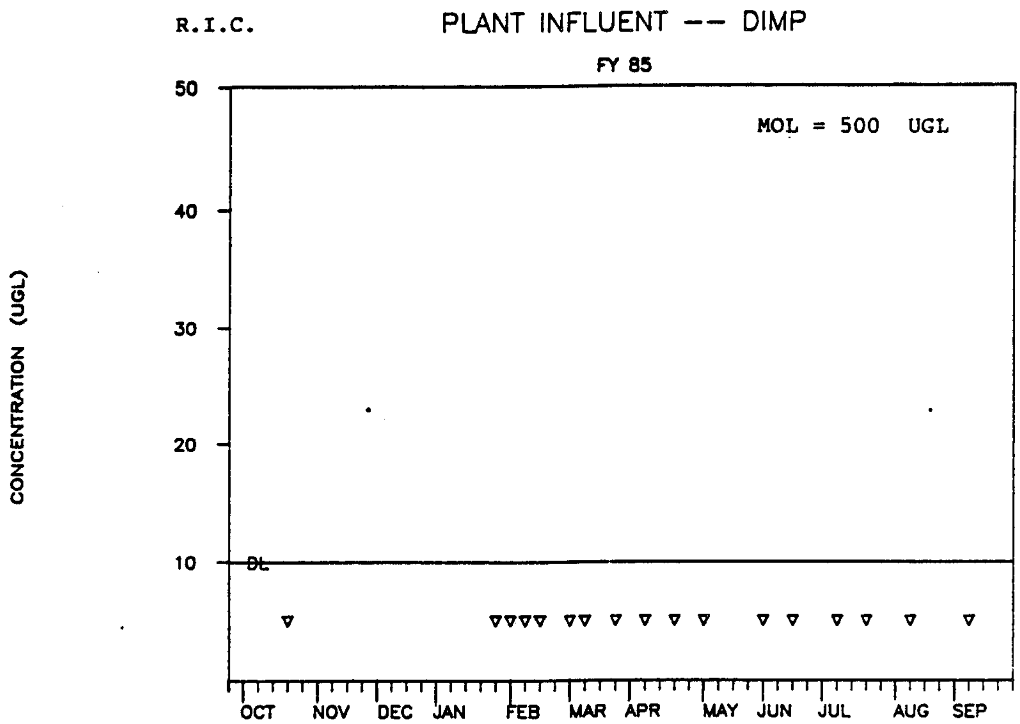




Figure 13. FY86 DBCP



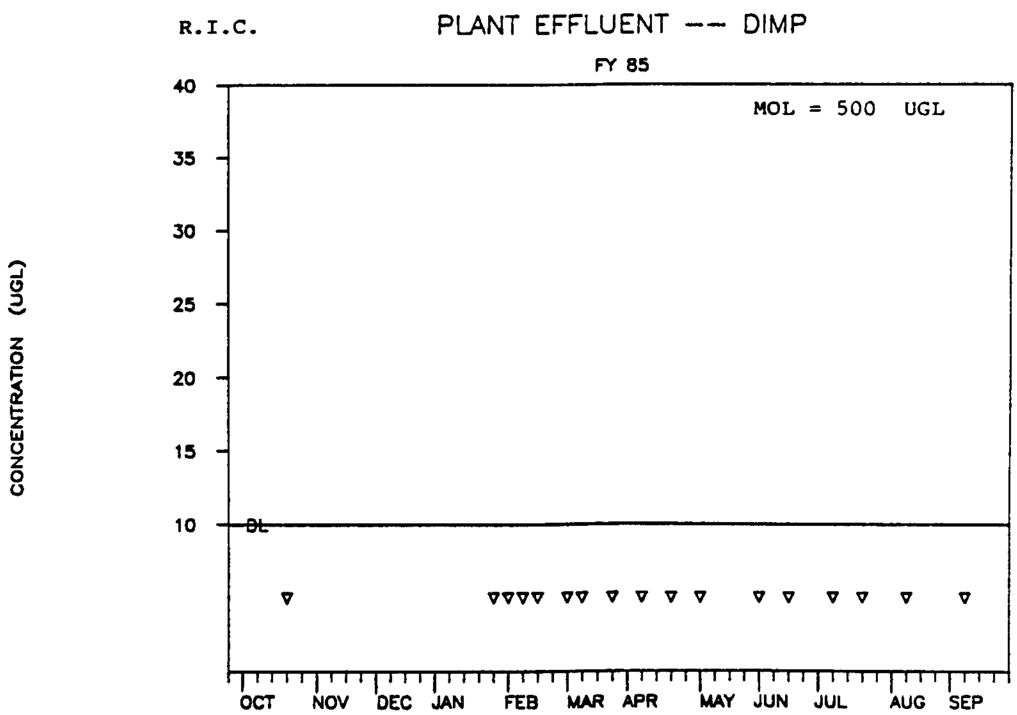
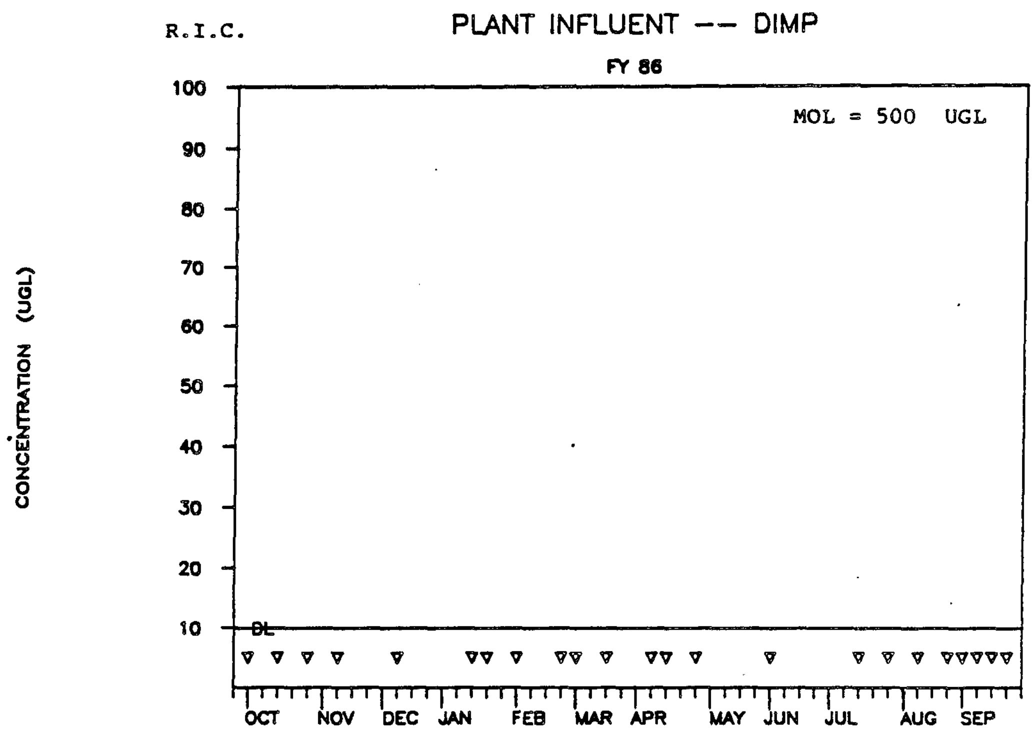




Figure 14. FY85 DIMP



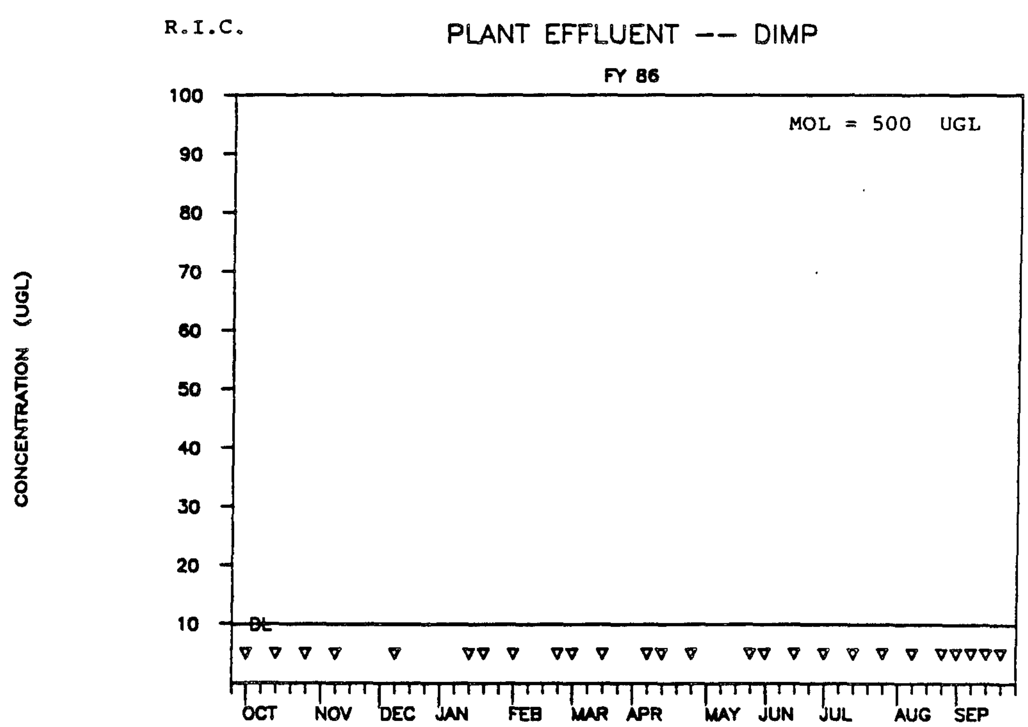
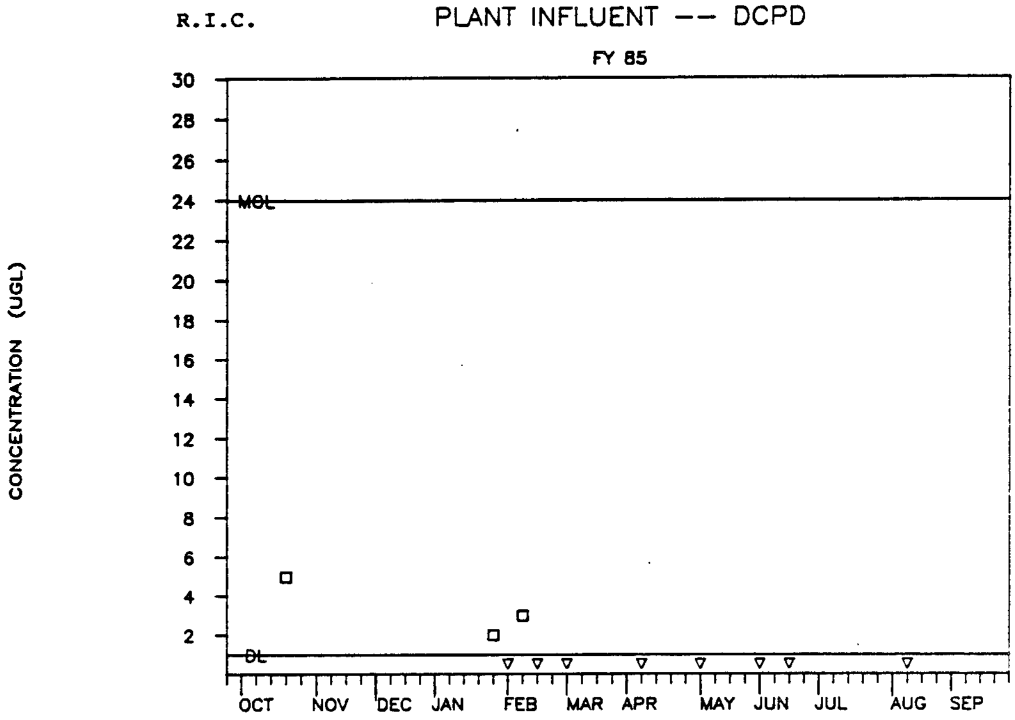




Figure 15. FY86 DIMP



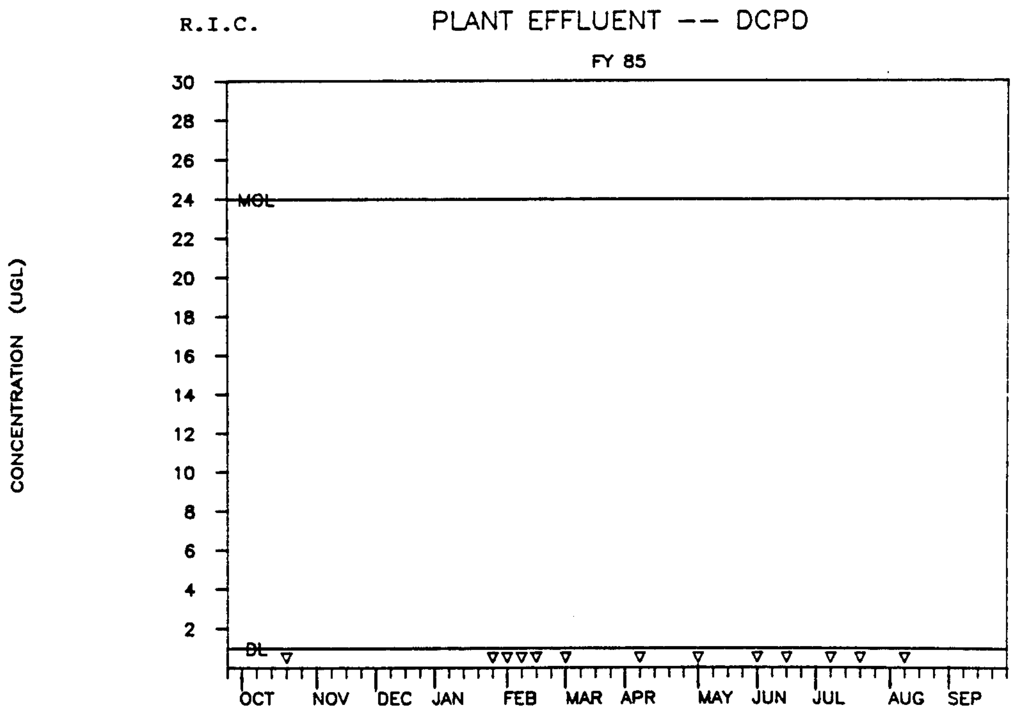
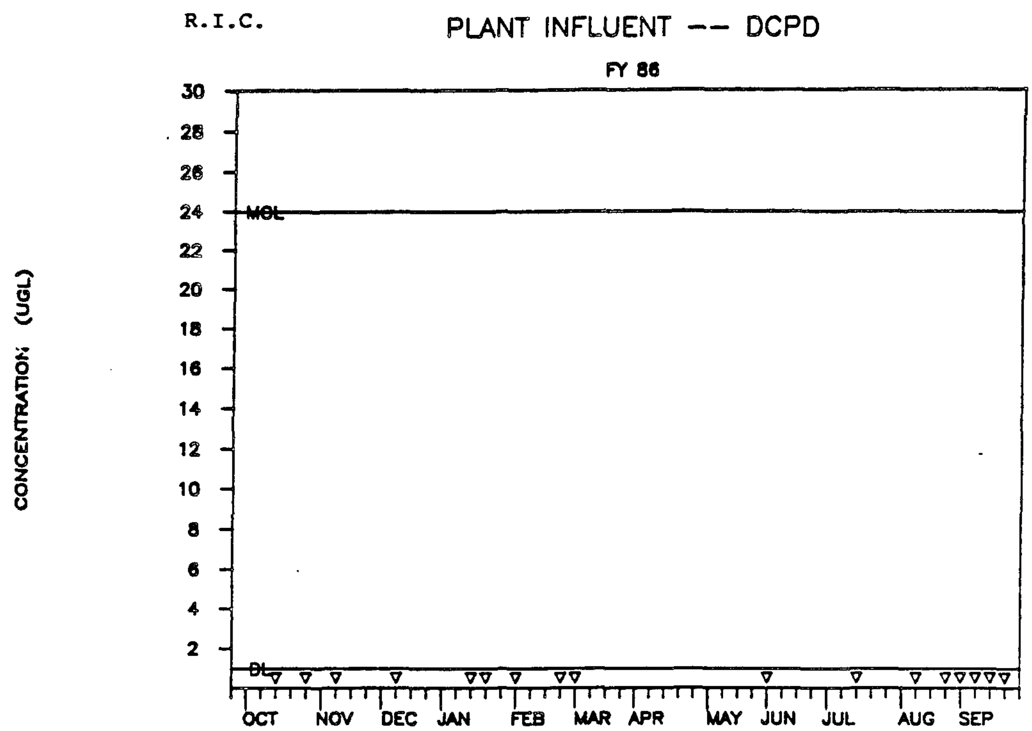




Figure 16. FY85 DCPD



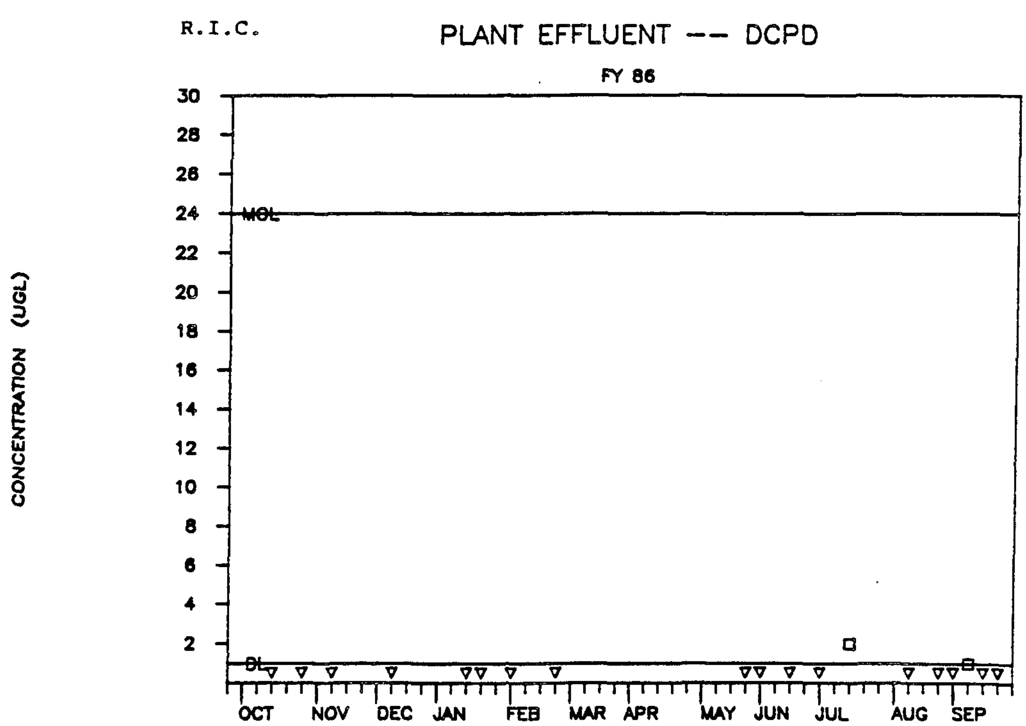
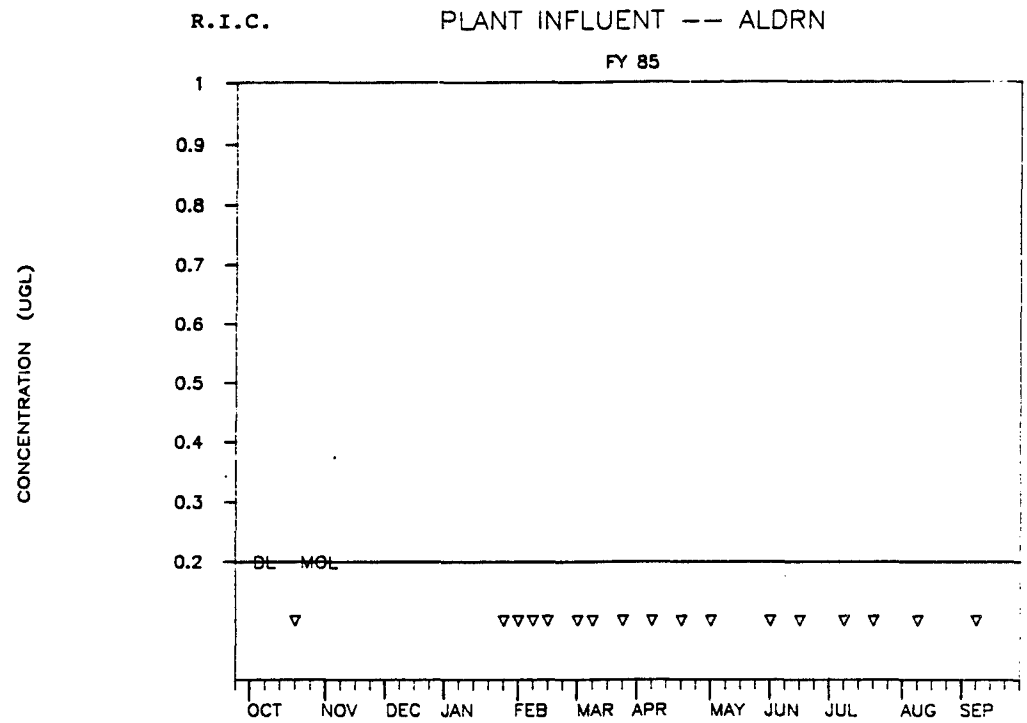




Figure 17. FY86 DCPD



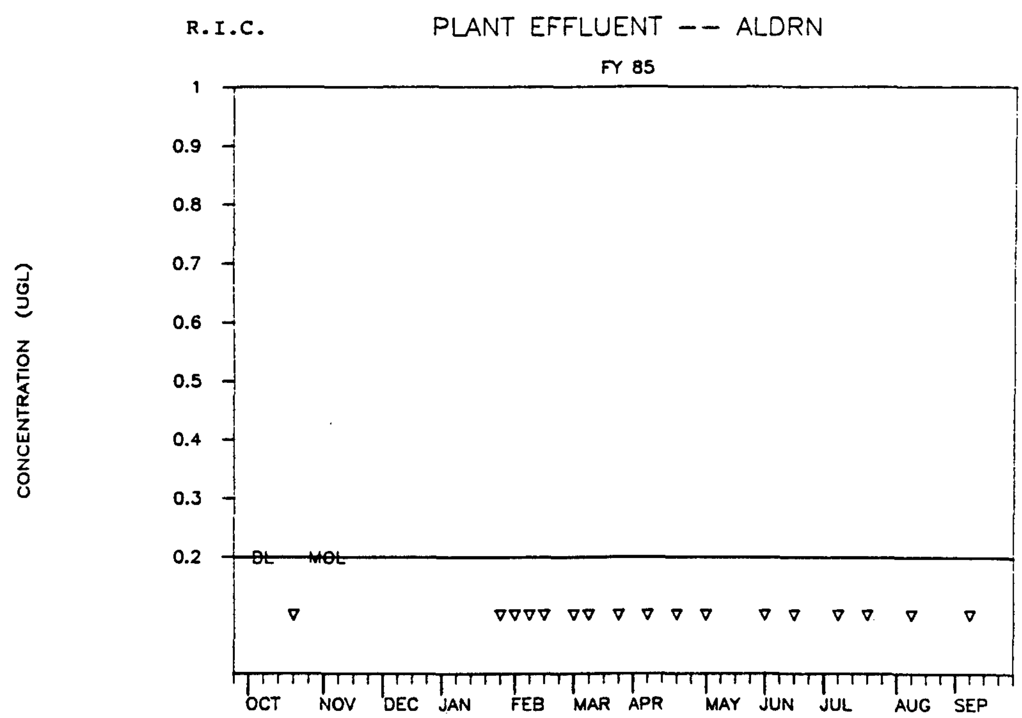




**Figure 18. FY85 Aldrin**

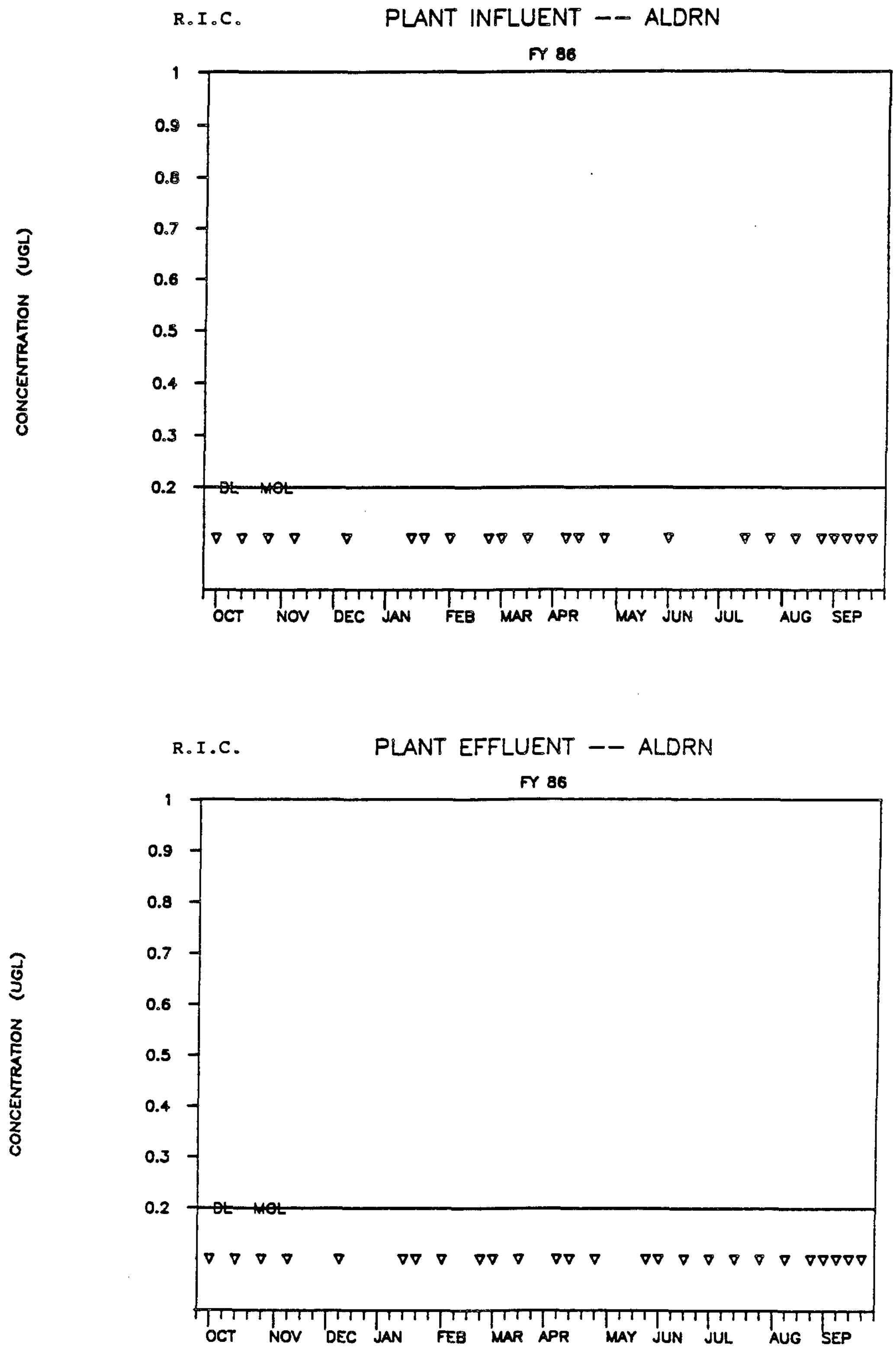
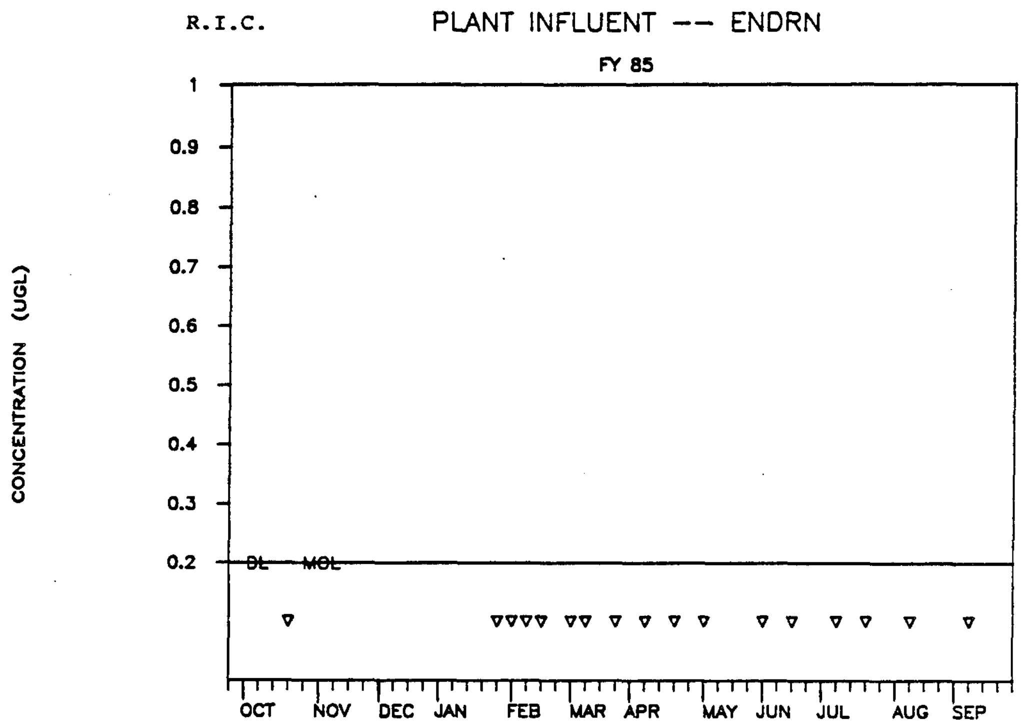



Figure 19. FY86 Aldrin



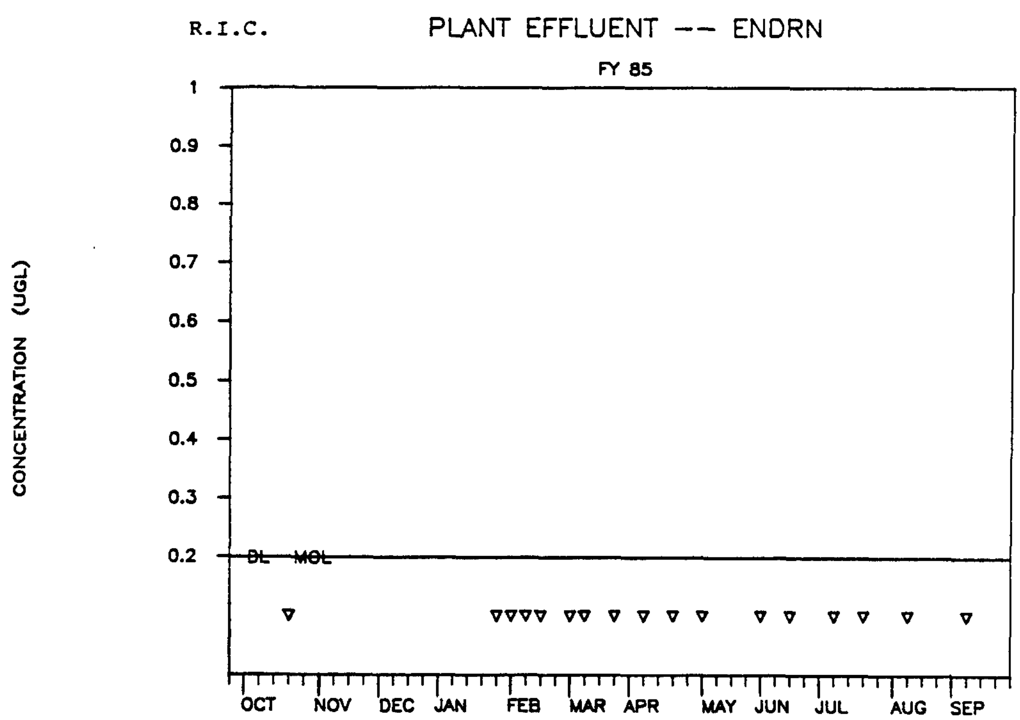
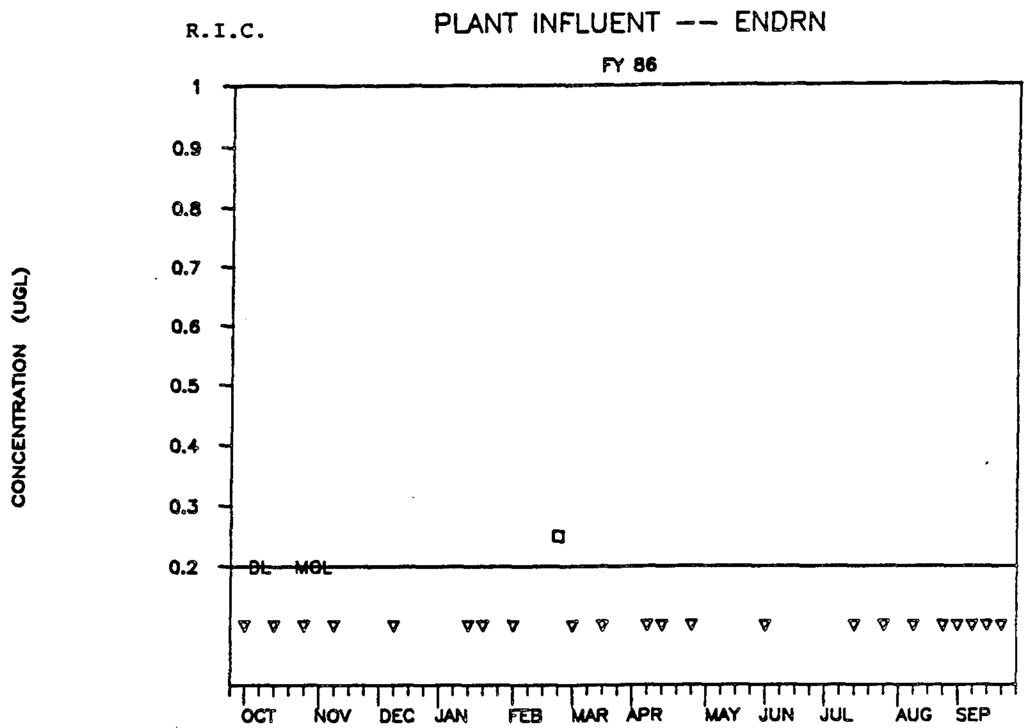




Figure 20. FY85 Endrin



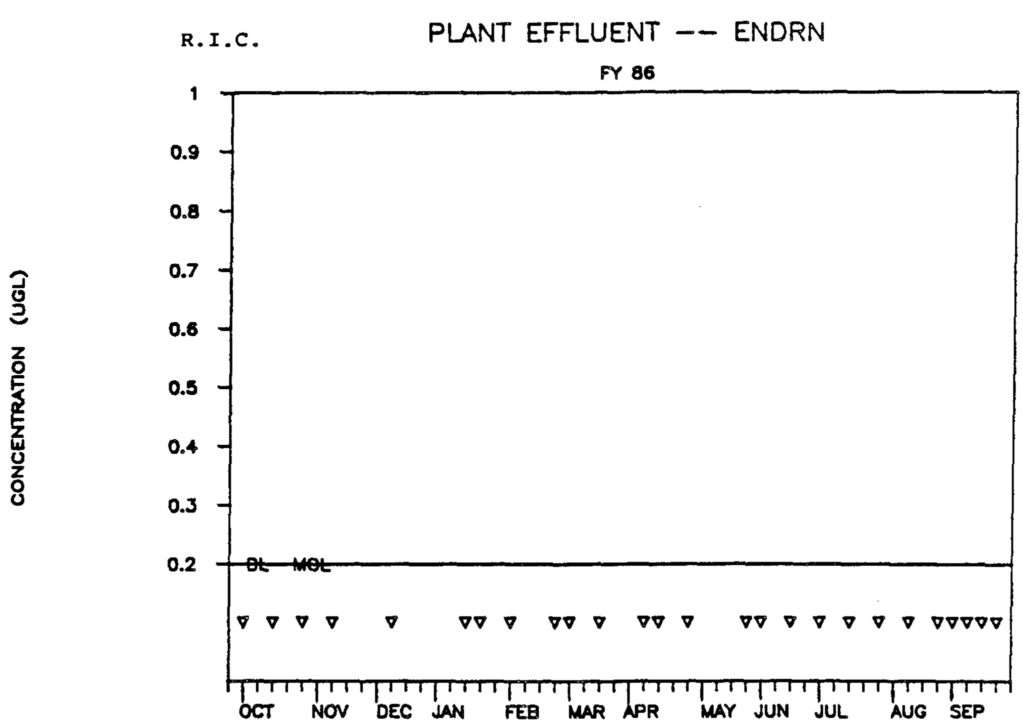
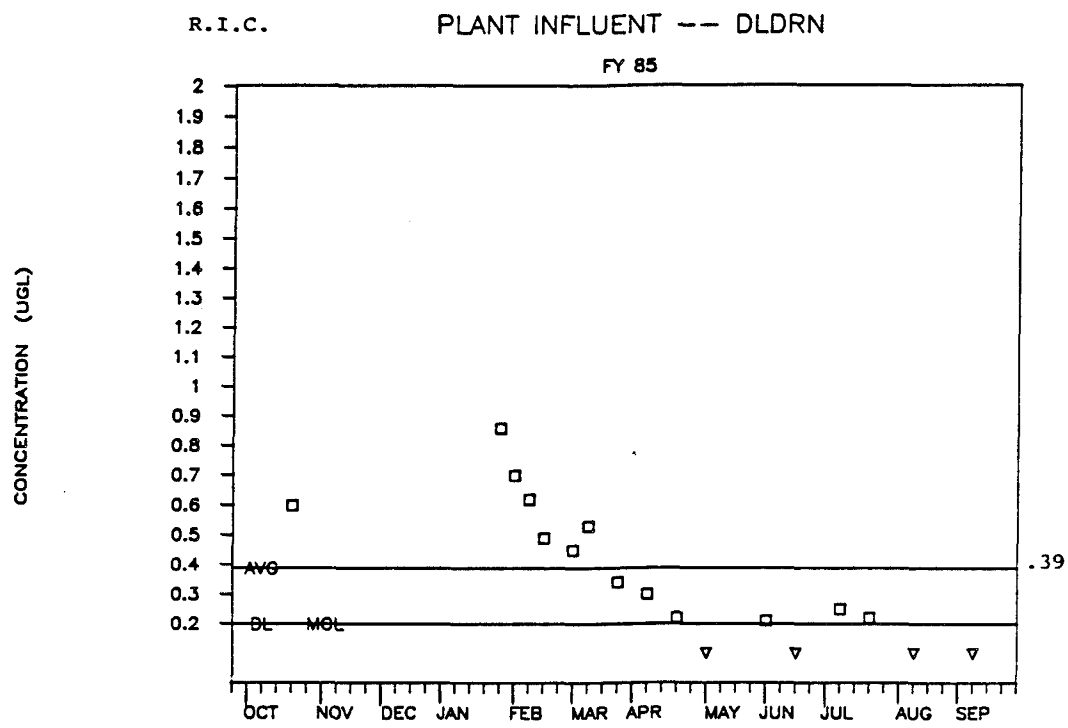




Figure 21. FY86 Endrin



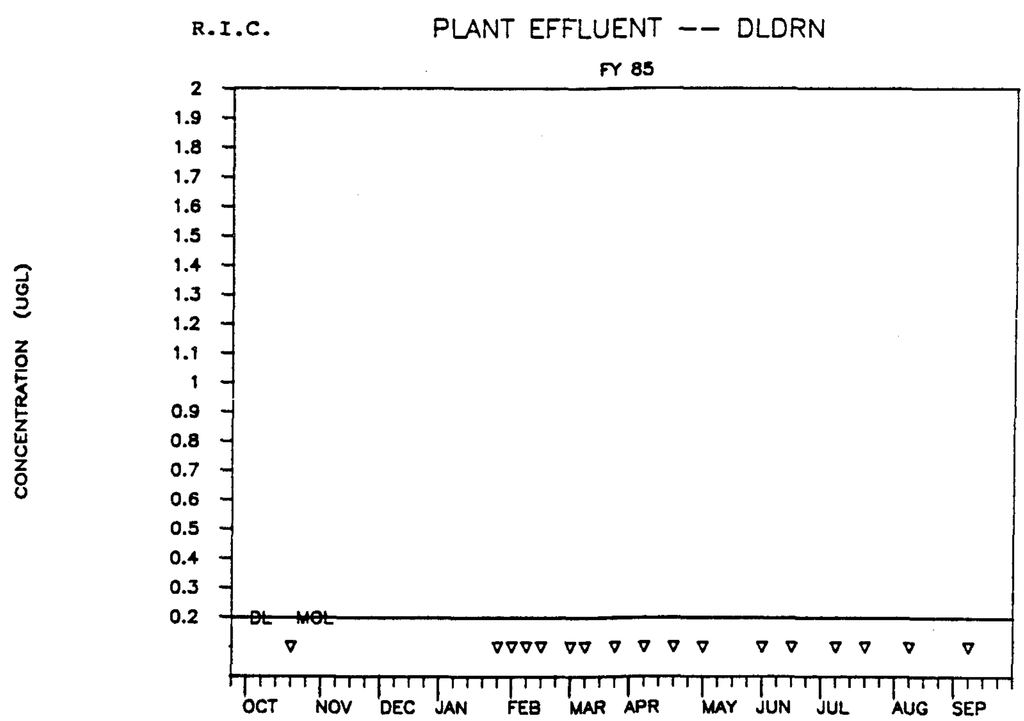
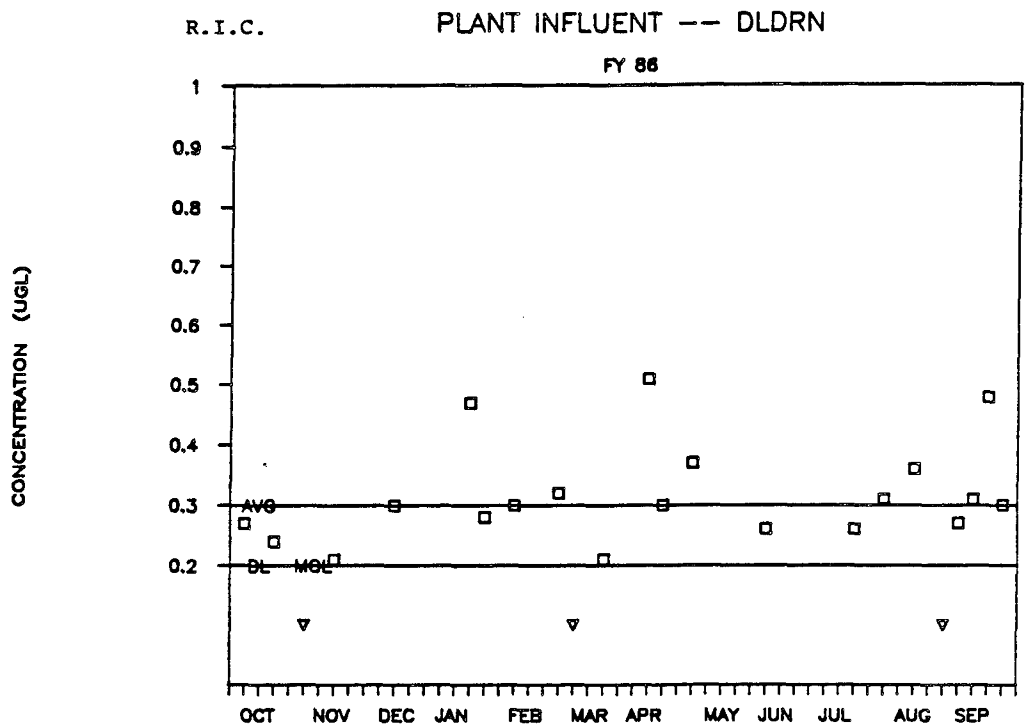




Figure 22. FY86 Dieldrin



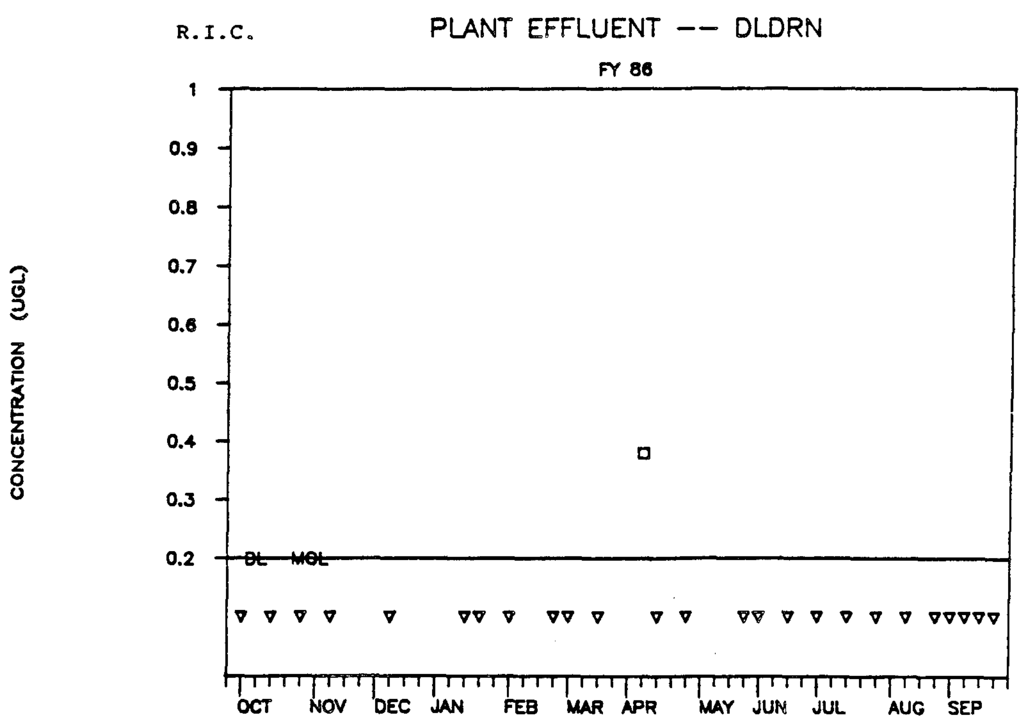
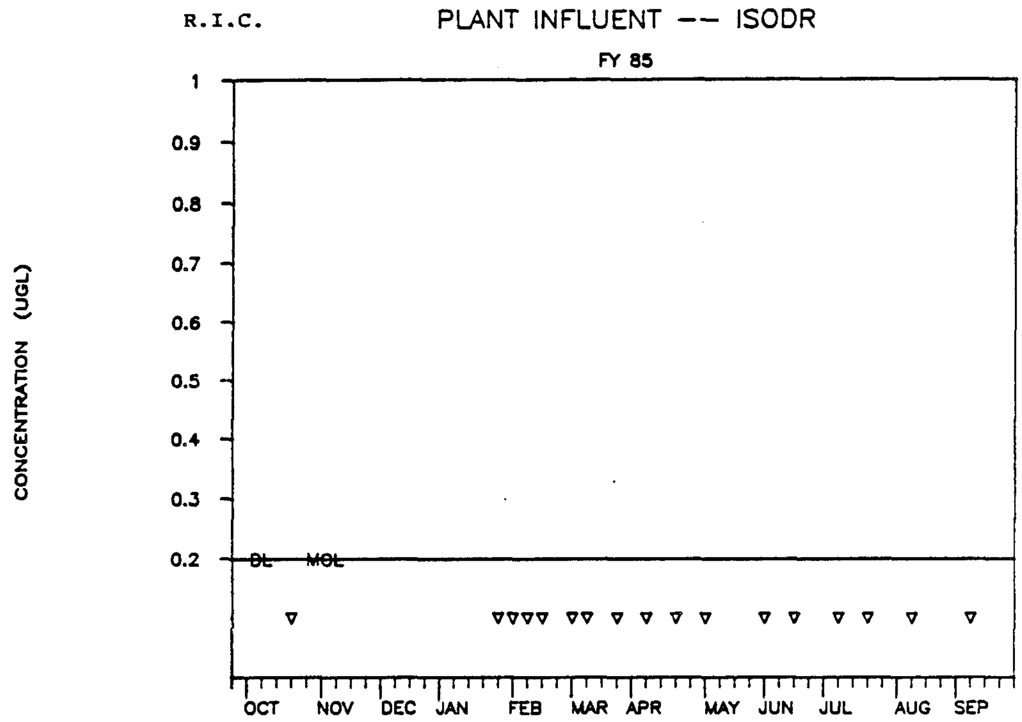




Figure 23. FY86 Dieldrin



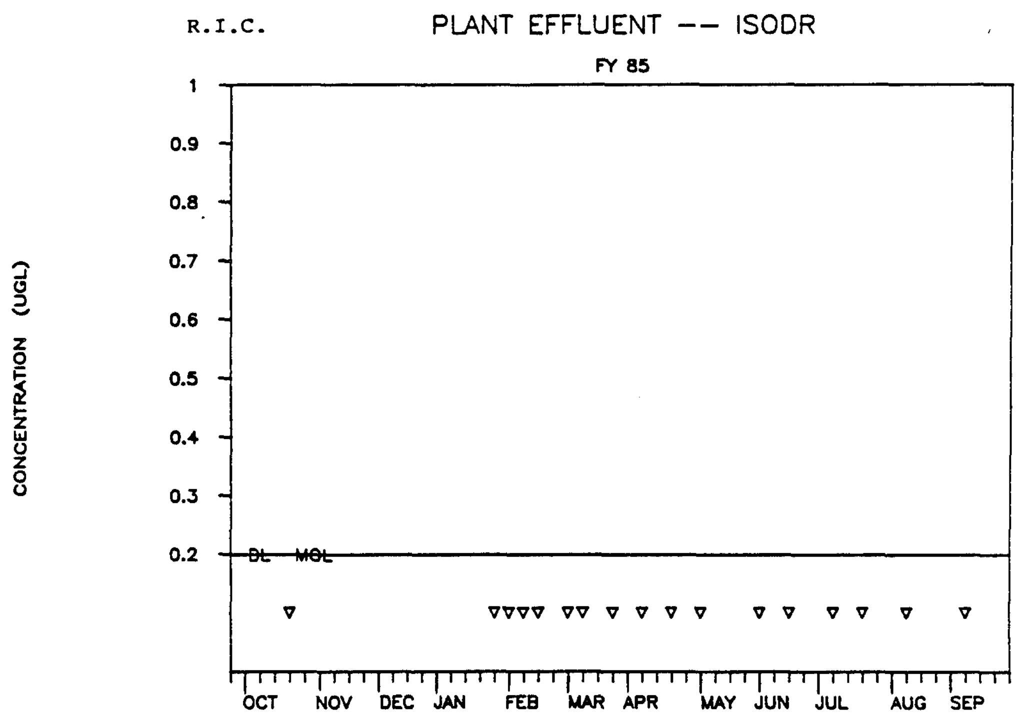
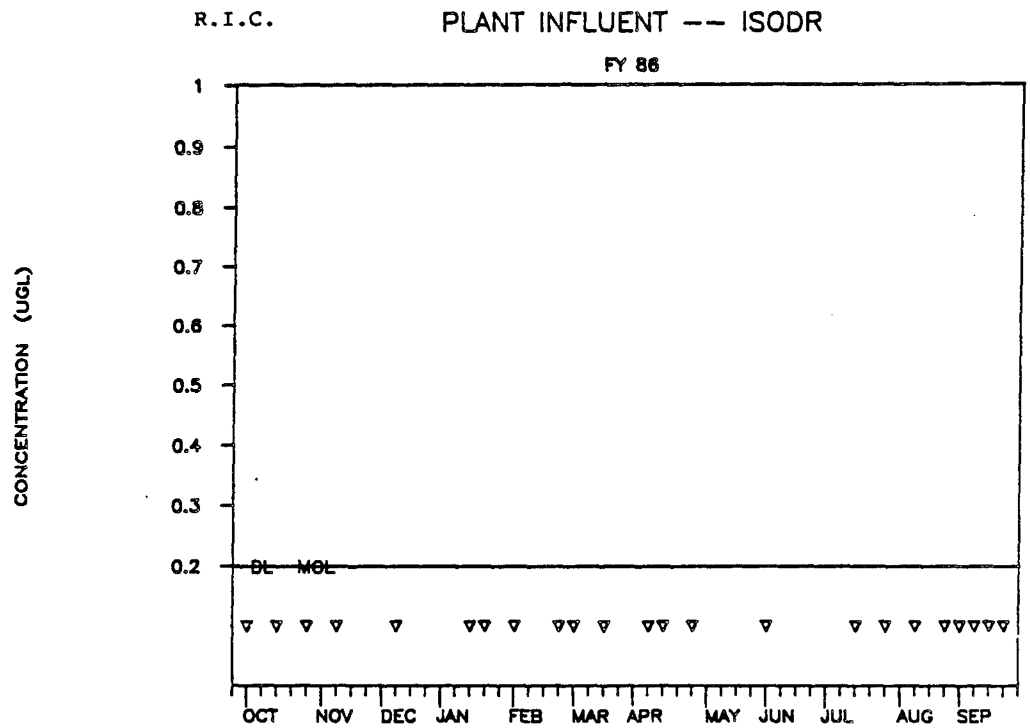




Figure 24. FY85 Isodrin



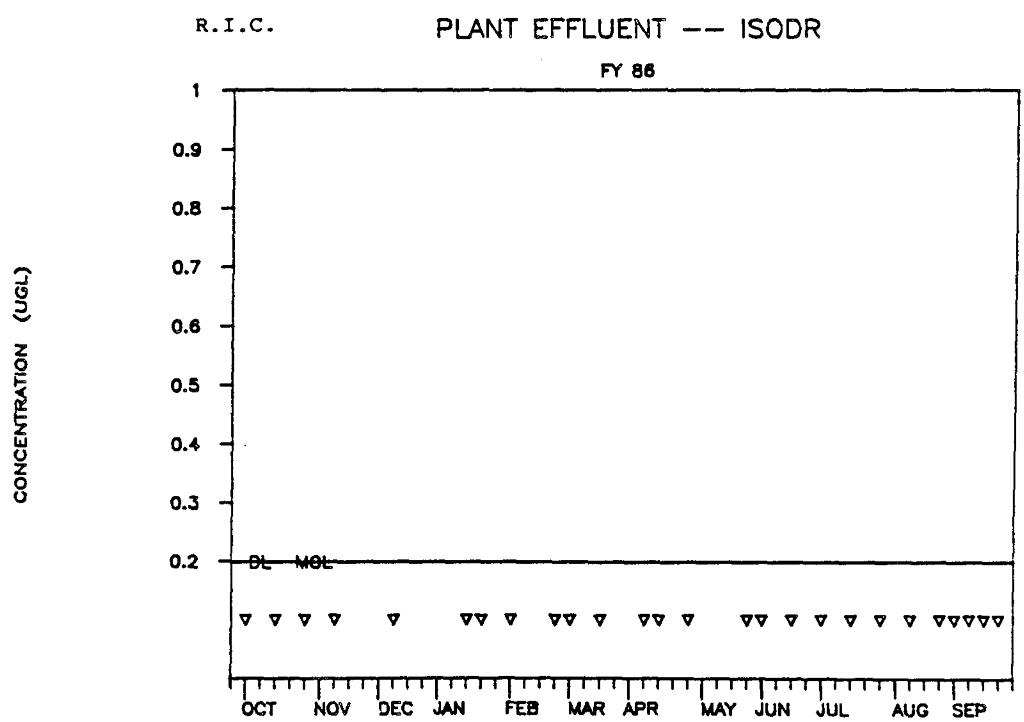
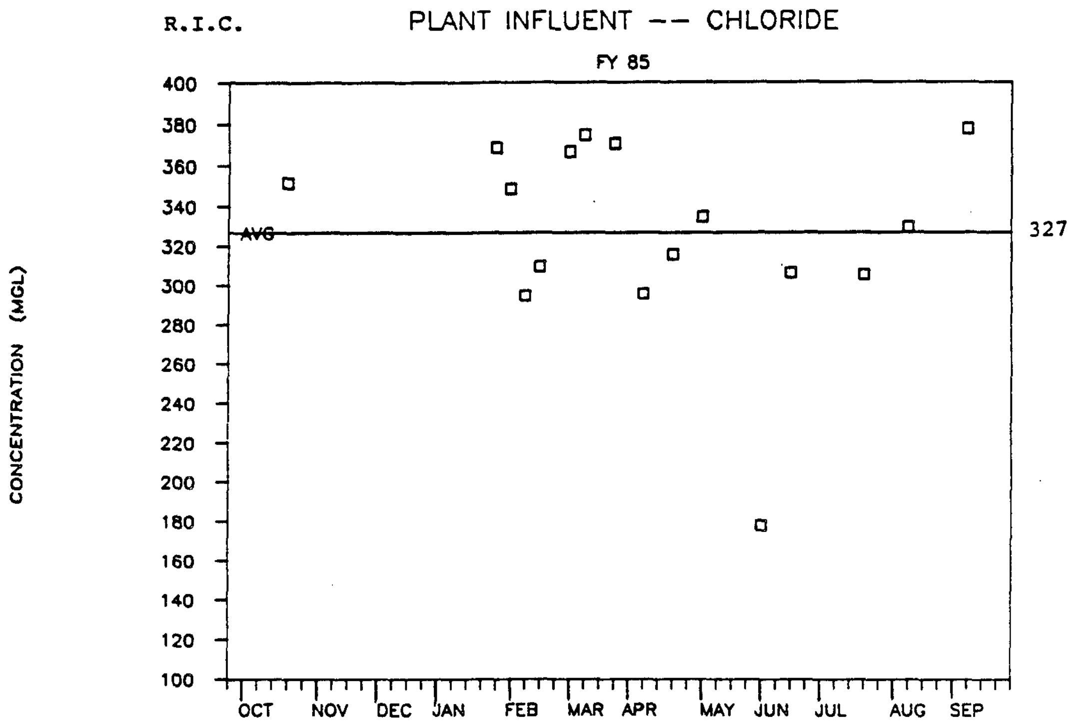




Figure 25. FY86 Isodrin



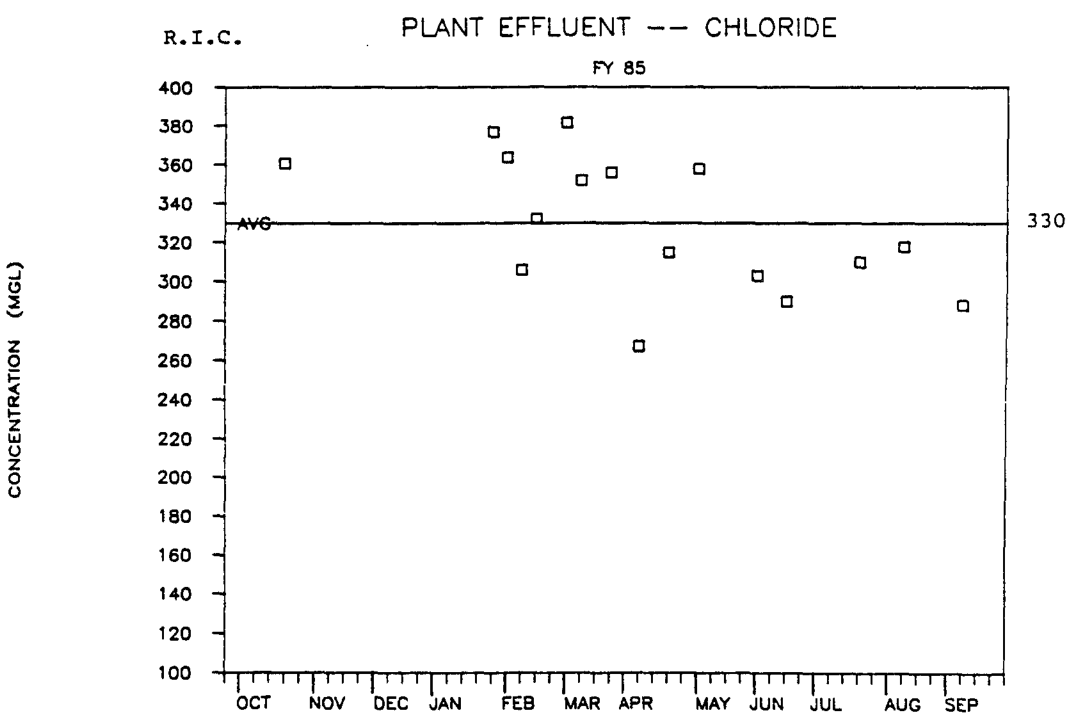
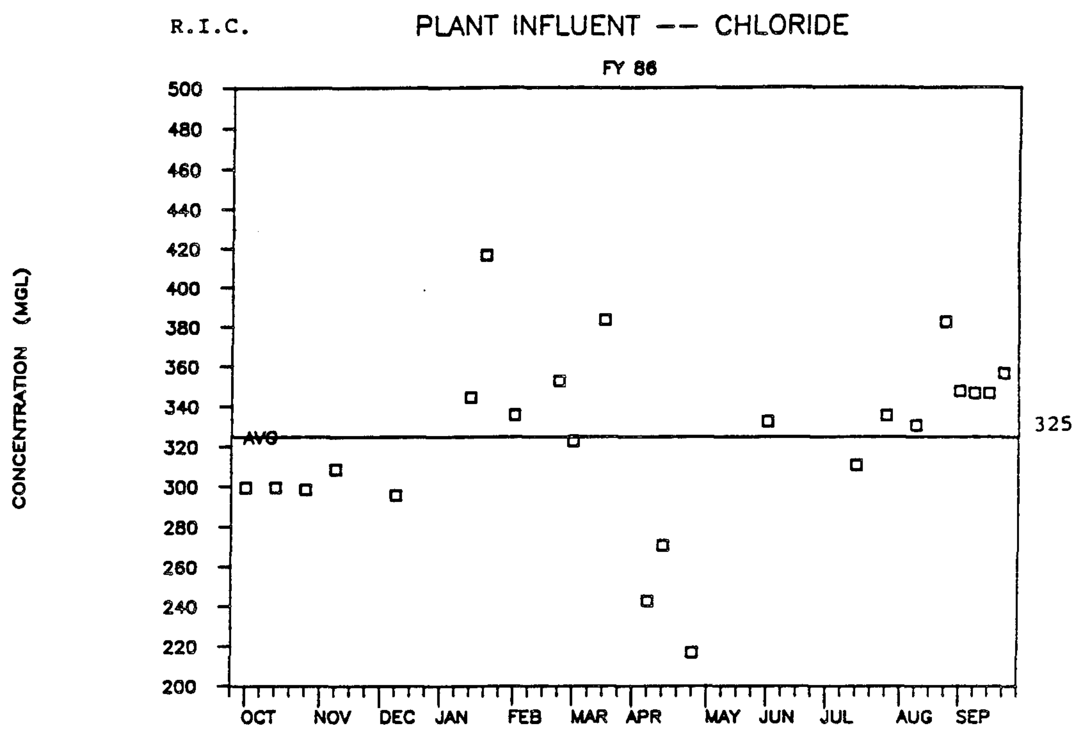




Figure 26. FY85 Chloride



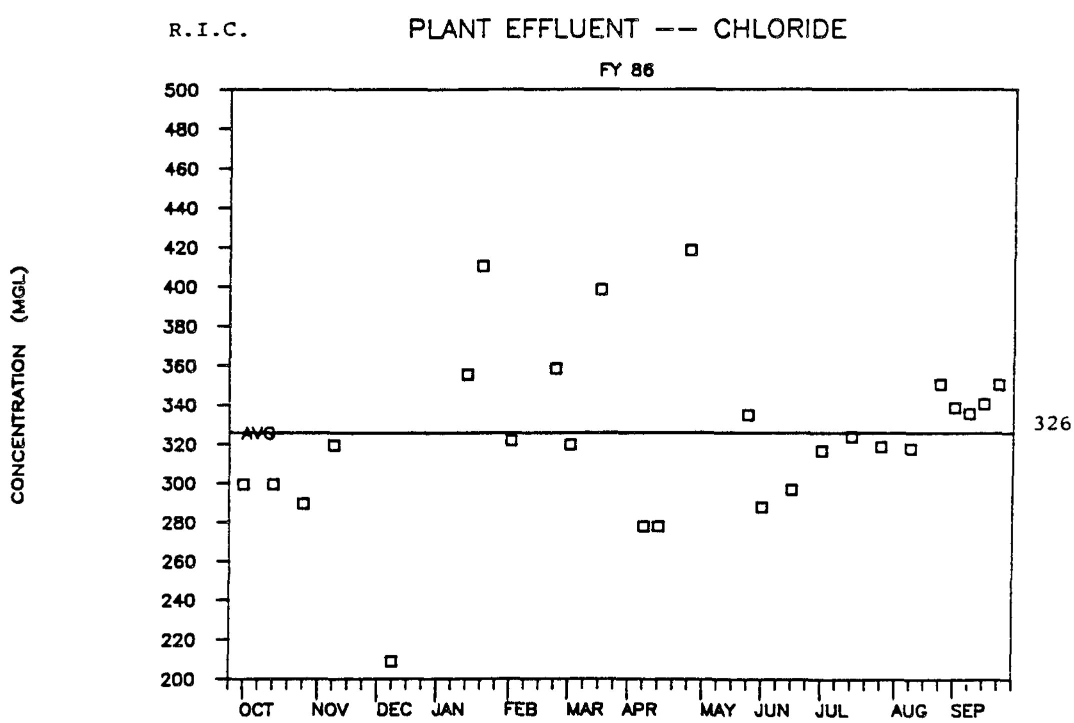
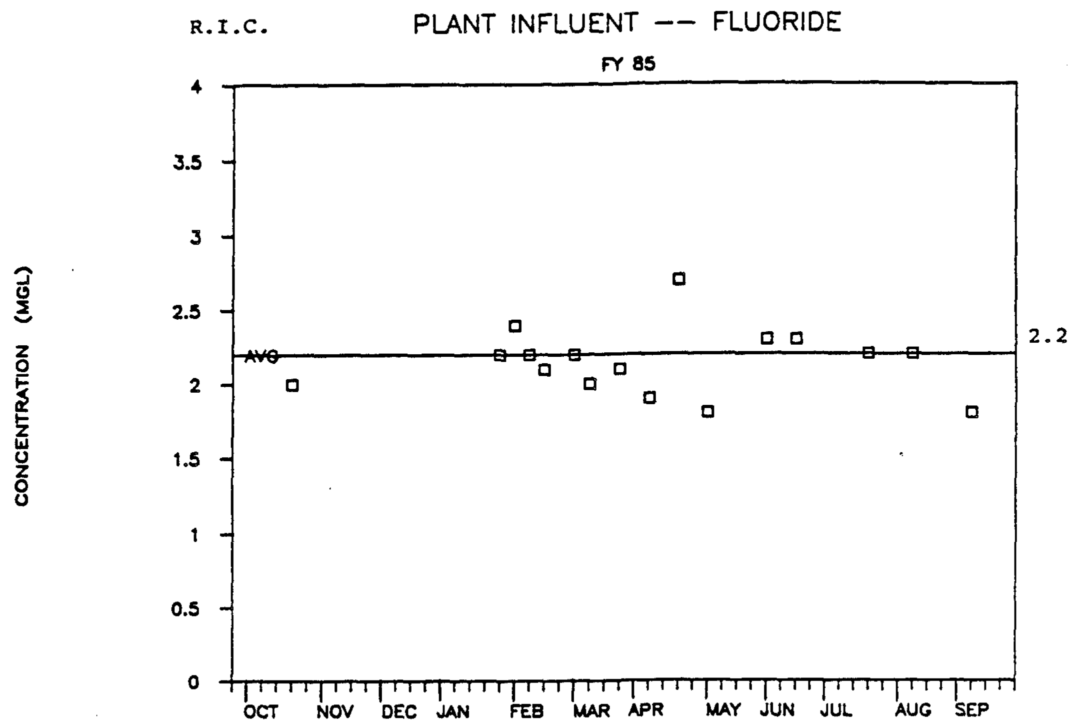




Figure 27. FY86 Chloride



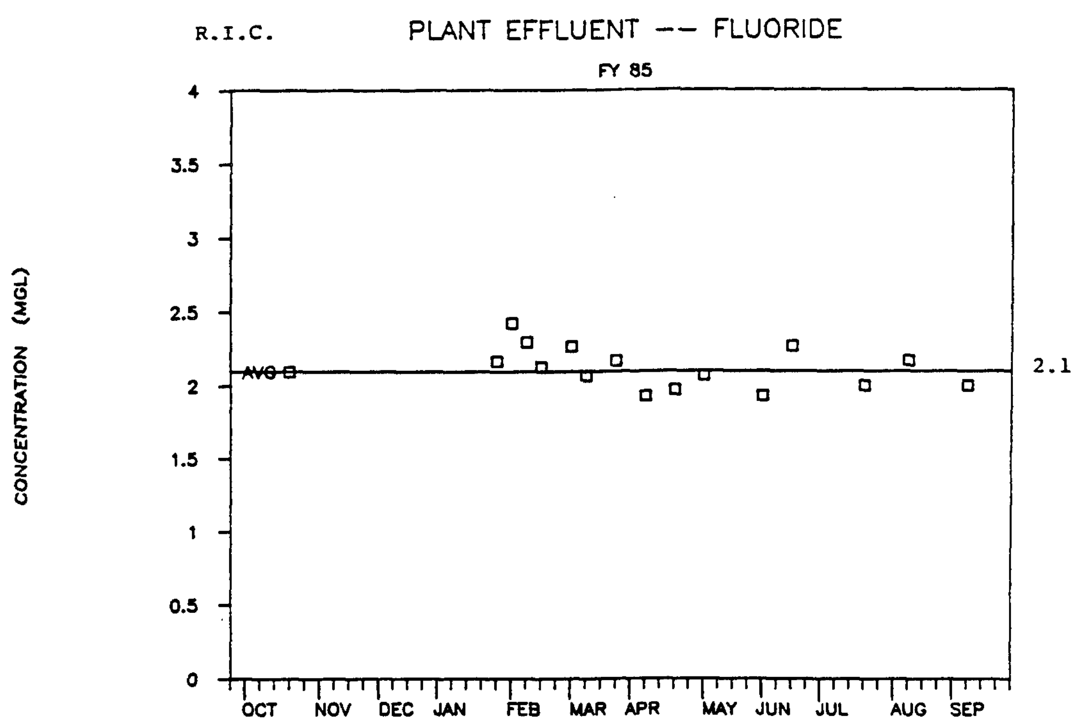
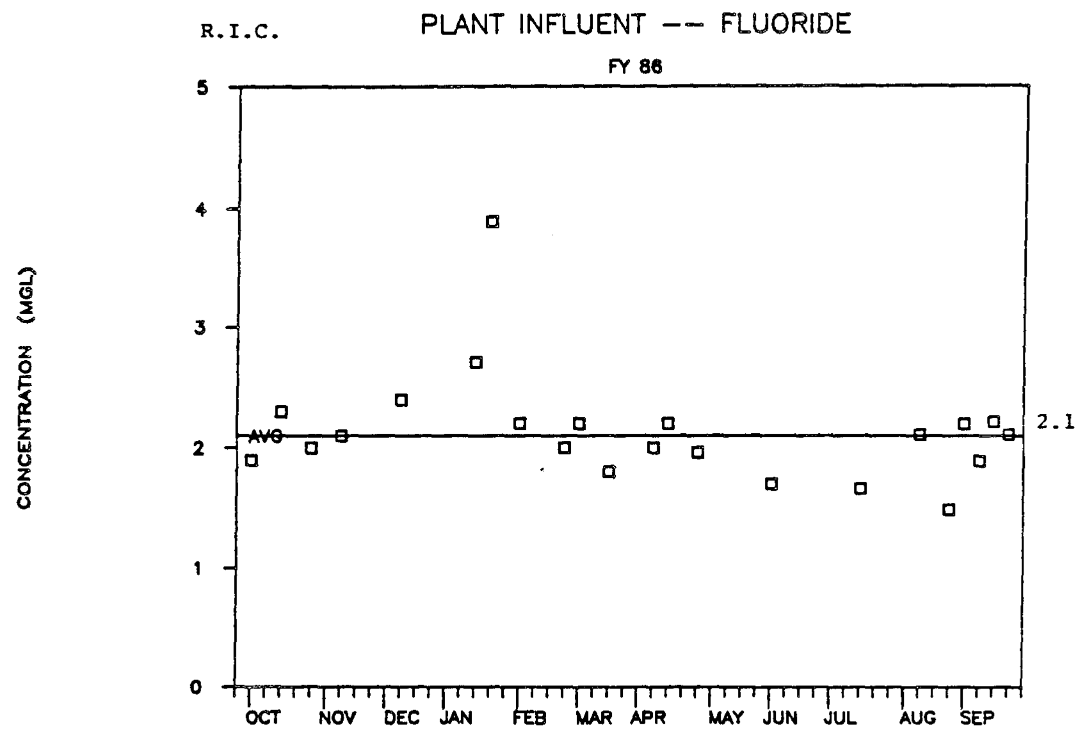




Figure 28. FY85 Fluoride



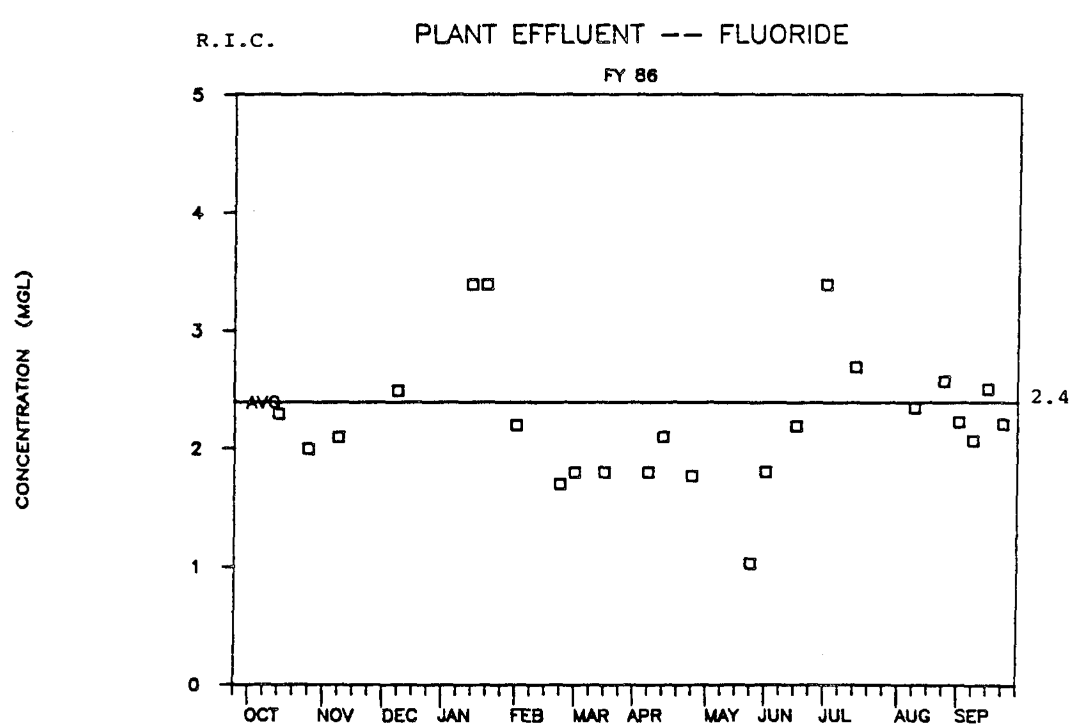




Figure 29. FY86 Fluoride

Table 5

Maximum Operating Limits for Northwest Boundary System

| Parameter | Maximum Operating Limit MOL) | Source* |
|---|---|---|
| Aldrin | 0.2 ug/l | Guidance from OTSG (Army) until standards are developed (Analytical Detection Limit) |
| Chloride | N.A. | EPA Secondary Drinking Water Regulation standard is 250 mg/l |
| Dibromochloropropane (DBCP) | 0.2 ug/l | State of Colorado Department of Health limit per letter to Commander, RMA, 26 June 79. Army's position for Source Areas |
| Dicyclopentadiene (DCPD) | 24.0 ug/l | These criteria are recommended by the US Medical Bioengineering Research & Development Lab (26 Aug 76) and are based on toxicology studies (26 Aug 76) conducted by the Army. The National Academy of Sciences Committee on Military Environmental Research has reviewed the procedures and results of toxicology studies and concurred in the drinking water levels (1 Feb 77). The State of Colorado has requested the Army to meet a limit of 24 ug/l of DCPD based on an odor threshold value. |
| Diisoproplymethyl-phosphonate (DIMP) | 500 ug/l | |
| Dieldrin | 0.2 ug/l | Guidance from OTSG (Army) until standards are developed (Analytical Detection Limit) |
| Endrin | 0.2 ug/l | EPA National Primary Drinking Water Regulation |
| Fluoride | N.A. | EPA Final Rule on Fluoride, National Primary and Secondary Drinking Water Standards, 40 CFR Parts 141, 142 and 143, maximum concentration limit is 0.4 mg/l |

* Source: After Rocky Mountain Arsenal Contamination Control Program Management Team (1983)

N.A. = Not Applicable

38. An inspection of the graphs presented in Figures 12-29 indicates that organic contaminant concentrations in the influent are generally below detectable limits. The contaminants, particularly DBCP, were originally found in a very narrow plume approaching the Northwest Boundary in this area. The ground-water associated with this contamination represented only a small portion of the overall flow intercepted by the barrier. The hydraulic barrier has associated with it a certain amount of ground-water recycle. That is, a portion of the recharged treated water flows towards the dewatering wells, is removed, and, thus is recycled through the system. The end result of these factors is that the contaminant concentrations in the plant influent are significantly reduced due to dilution. The actual concentrations of contaminants in the ground-water approaching the system are presented and discussed in Part IV of this report.

DBCP

39. No concentrations of DBCP in excess of the detectable level of 0.2 ppb were found in the influent or effluent of the treatment plant in either FY85 or FY86. The concentrations of DBCP found in this area prior to construction of the barrier system was approximately 1 to 2 ppb. These concentrations are being diluted to below detectable levels as a result of recycling of water along the hydraulic dewatering system and from the quantity of relatively clean water intercepted by the dewatering wells adjacent to the slurry wall.

DIMP

40. No concentrations of DIMP in excess of the detectable level of 10 ppb were found in the influent or effluent of the treatment plant in either FY85 or FY86.

DCPD

41. During the first half of FY85, three influent samples were found to contain concentrations of DCPD in excess of the detectable level of 1 ppb with the highest concentration found being approximately 5 ppb. No influent samples from the last half of FY85 were found to contain DCPD above the detection level. No concentrations of DCPD in excess of the detection level were found in the effluent from treatment plant in FY86.

42. During FY86, no concentrations of DCPD above the detection level were found in the plant effluent. One sample of effluent was found to have a concentration of DCPD over the detection level at approximately 2 ppb. However, based on the absence of DCPD in the influent, this data point is probable anomalous.

Aldrin

43. No concentrations of aldrin in excess of the detectable level of 0.2 ppb were found in the influent or effluent of the treatment plant in either FY85 or FY86.

Endrin

44. During FY85, no concentrations of endrin in excess of the detectable level of 0.2 ppb were found in the influent or effluent of the treatment plant. During FY86, one influent sample was found to contain a concentration of approximately 0.25 ppb while the rest were below the detection level. No endrin concentrations above the detection level were found in the treatment plant effluent.

Dieldrin

45. The highest concentration of dieldrin found in FY85 in the treatment plant influent was approximately 0.85 ppb. The average concentrations for the year was 0.39 ppb, however, the concentrations tended to decrease over the year. No concentrations in excess of the detection level were found in the treatment plant effluent during FY85.

46. The highest concentration of dieldrin found in FY86 in the treatment plant influent was approximately 0.5 ppb. The average concentration for the year was 0.3 ppb. Only one effluent sample was found to contain dieldrin in excess of the detection level at approximately 0.4 ppb.

Isodrin

47. No concentrations of isodrin in excess of the detectable level of 0.2 ppb were found in the influent or effluent of the treatment plant in either FY85 or FY86.

Chloride

48. The highest concentrations of chloride found in the treatment plant influent and effluent for FY85 were approximately 380 ppm. The influent and effluent averages for the year were 327 ppm and 330 ppm, respectively. Some differences in the influent and effluent concentrations are to be expected due

to the storage effects of the sumps in the system. All effluent samples were found to contain chloride concentrations in excess of 250 ppm.

49. During FY86, the highest chloride concentrations found in the influent and effluent were approximately 420 ppm. The influent and effluent averages for the year were 325 ppm and 326 ppm, respectively. These concentrations were essentially the same as the previous year. All effluent samples except for one were found to contain chloride concentrations greater than 250 ppm.

Fluoride

50. During FY85, the highest fluoride concentrations found in the treatment plant influent was approximately 2.7 ppm. The average influent concentration for the year was 2.2 ppm. The average effluent concentration for the year was 2.1 ppm. Only one effluent sample with a concentration above the then maximum operating level of 2.4 ppm was found.

51. During FY86, the highest fluoride concentration found in the influent was approximately 4.0 ppm. The influent average for the year was 2.1 ppm. The average effluent concentration for the year was 2.4 ppm. As with chloride, some differences in the influent and effluent concentrations are to be expected to lead/lag effects from the sumps. During FY86, the maximum concentration limit (MCL) for secondary drinking water standards was increased from 2.4 ppm to 4.0 ppm. Only one effluent sample was found with a concentration above 4.0 ppm. This sample was collected at the beginning of FY86 and appears anomalous since the corresponding sample from the influent during that sample period was found to have a concentration of less than 2 ppm.

## PART IV: DATA EVALUATIONS

### Geology and Hydrogeology

#### Geologic Setting.

52. Regional Geology. The Rocky Mountain Arsenal lies within the Denver Basin, a structural depression occupying a 6,700 square mile area bounded by Greeley, Colorado on the north, Colorado Springs on the south, the Rocky Mountain Front Range on the west, and near Limon on the east (Figure 30). The oval basin is filled with approximately 15,000 ft of sediments composed of limestone, sandstone, shales, and conglomerates of Tertiary and older age, and clays, silts, sands and gravels of Quaternary age. The regional geology of the Rocky Mountain Arsenal was discussed in an earlier report, (Robson and Romero 1981). The Northwest Boundary study area is in the northwest corner of RMA northwest of Basin F in Sections 21, 22, 23, 26, 27, and 28. The geologic units of interest to the Northwest Boundary evaluation are the Tertiary aged Denver formation and the overlying Quaternary sediments.

53. Regional Geologic Units. The Denver formation consists of 250-400 ft of interbedded clay shale, claystone, siltstone, sand, and sandstone. Water-bearing zones within the Denver formation are generally weakly cemented sandstones or compact fine- to medium-grained sands. Many of the sandy units are deltaic channel deposits which grade laterally and vertically into silts and clay shales. The sand units are commonly lens-shaped and are from several inches to as much as 60 ft thick. The Denver formation aquifer is a complex system of interconnected units of sands and relatively impermeable clays and clay shales with a high variability in transmissivity and storativity from one area to another. The top of the Denver formation in the Northwest Boundary study area ranges from 10 to about 70 ft below the ground surface.

54. The Quaternary age surficial deposits overlying the Denver formation consist of windblown (eolian) and stream-deposited (alluvial) materials of clay to gravel size. The surficial deposits are referred to in this report as "the alluvium" distinct from the underlying Denver formation sediments, although some of the Denver sediments were also deposited in alluvial environments and some of the surficial materials are eolian and not alluvial. Saturated zones in the alluvium of the surficial deposits comprise the second component of the ground-water regime at RMA. The surficial deposits are

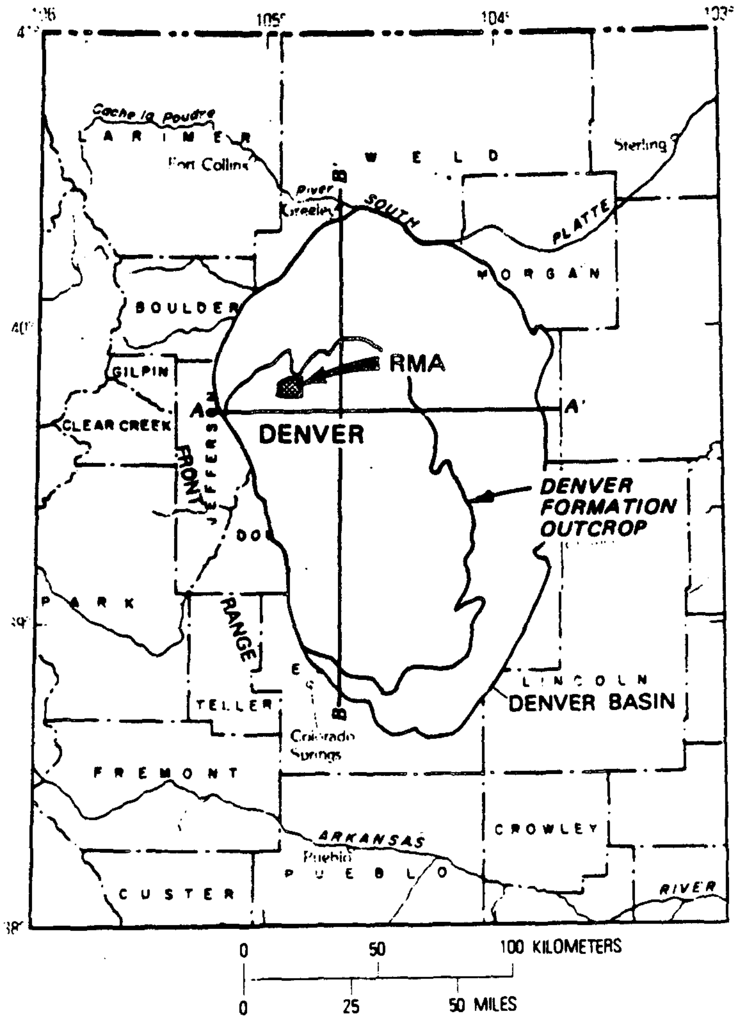



Figure 30. Rocky Mountain Arsenal in relation to the Denver Basin and outcrop pattern of Denver formation (Robson and Romero 1981)

Pleistocene and Recent in age. The Pleistocene deposits contain alluvial silts, sands, and gravels deposited as glacial outwash from the Front Range. Recent alluvial and eolian deposits have masked the older sediments over most of the Arsenal. In the Northwest Boundary study area the surficial deposits are 10 to 70 ft thick. The greatest thickness of surficial deposits penetrated in borings in the study area was 69.7 ft in Well 27002, in which approximately 37 ft of silty clay and fine sand overlie 33 ft of gravelly sand. The gravelly sand of well 27002 is typical of the sediments comprising the alluvial aquifer of the Northwest Boundary study area.

55. Regional Hydrology. The Denver and alluvial aquifers are interconnected and act as a single aquifer regionally (Robson and Romero 1981), but because of local variations in geology and the generally greater transmissivity of the alluvium emphasis is placed in this report on the alluvial aquifer as the primary conduit for ground water movement. Much of the recharge to the Denver formation aquifer occurs in areas of Denver surface exposure that are topographically higher than the Denver formation at RMA. An artesian condition is thereby set up causing ground water in the Denver to flow laterally updip in some areas and to act as recharge to the overlying alluvium locally. In other areas where the water table in the alluvial aquifers is above the piezometric surface of the Denver aquifer the local artesian conditions do not exist.

56. Primary flow components in the alluvium at RMA are from south-southeast to north-northwest (Figure 31), toward the South Platte River, a local base level. The thickness of the arrows indicates relative quantities of flow. The general flow direction for the Northwest Boundary study area is to the northwest, as will be shown by ground-water level maps later in this report. This study has shown that a large component of ground-water flow approaches the Northwest Boundary System in a northernly direction along a paleochannel in the Denver Formation. The arrow crossing the northwest arsenal boundary in Figure 31 has been split to indicate this northerly component of flow. Flow in the alluvial aquifers of RMA varies from artesian to semi-confined to unconfined. Three multi-piezometer pumping tests conducted in the Northwest Boundary study area prior to installation of the barrier and treatment system provided information on the alluvial aquifer parameters there. Test NW-11 (May 1982) responded under artesian conditions with an average transmissivity (T) of 405,000 gpd/sq ft, an average permeability (K)

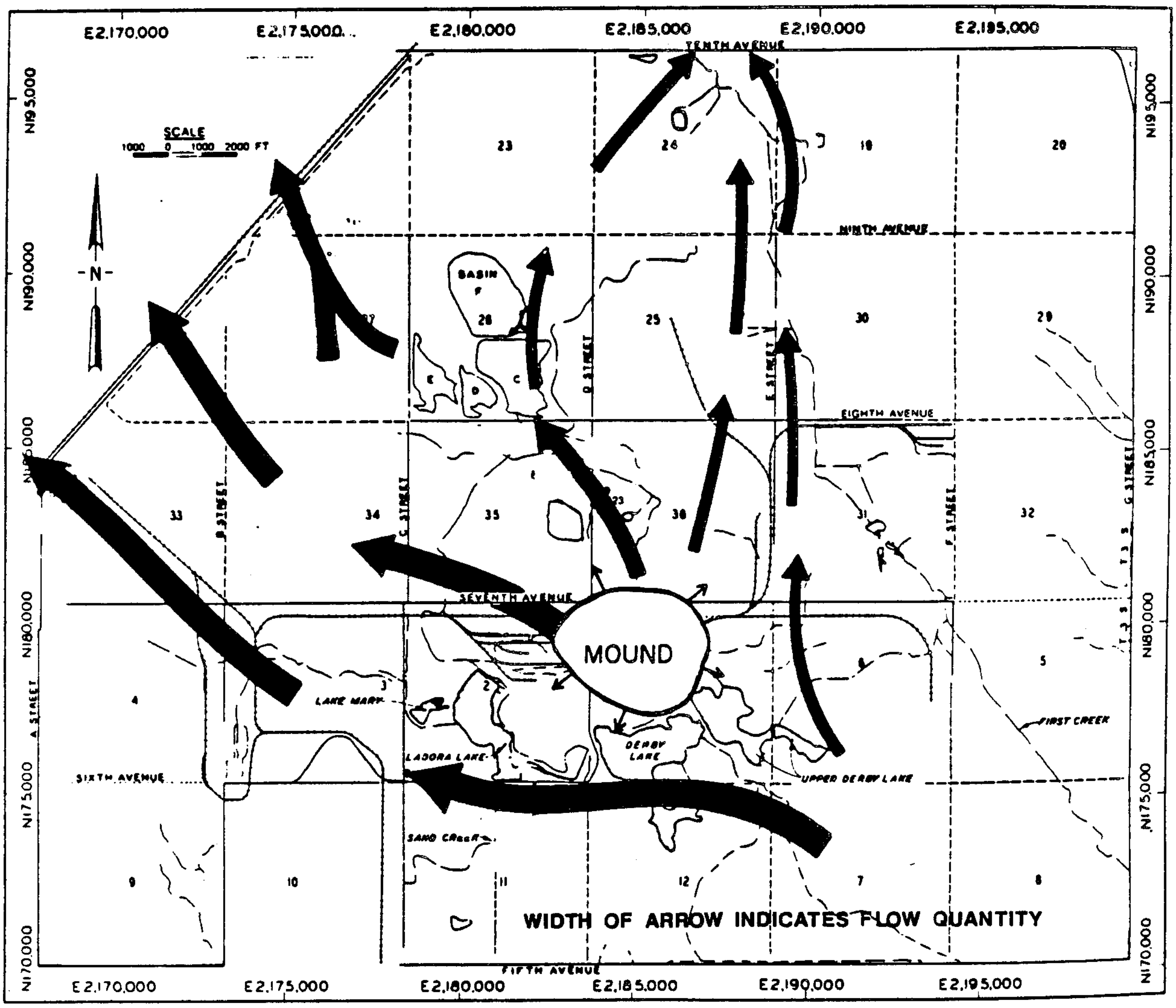



Figure 31. Primary flow components at RMA (May 1982, modified)

of 2,365 ft/day, and storage coefficient (S) of 3.5 X 10(-6) to 4.8 X 10(-4). Test W-4 (USACE 1986 and USACE 1983) responded under water table conditions with a T of 210,228 gpd/sq ft, a K of 1,144 ft/day, and S of 0.085. Tests NW-11 and W-4 were conducted in the alluvial aquifer. Pump test W-5 (USACE 1986 and USACE 1983) responded under water table conditions with a T of 33,213 gpd/sq ft, a K of 587 ft/day, and S of 0.25. A slug test conducted in the lower portion of W-5 in a Denver formation sand lens indicated a value of K=4 to 5 X 10(-5) cm/sec (approximately 0.14 ft/day) for the Denver aquifer. Pumping test locations are shown on Plate 1. The tests reflect saturated thicknesses for the Northwest Boundary area of 7 to 25 ft.

Geology of the Northwest Boundary.

57. Sources of geological information. Approximately 305 exploratory borings and wells have been emplaced in the Northwest Boundary study area. Logs of the borings and wells were the primary data used to evaluate and describe the subsurface geology of the area. Boring and well locations and location of cross sections are shown on Plate 1 (Volume II). An additional source were samples obtained from the base of the barrier slurry trench during construction. Geologic cross-sections were constructed along lines of borings and are presented as Plates 2 through 10. Other working cross-sections were constructed for all available lines of borings and wells for analysis of the subsurface geology but are not formally presented in this report.

58. The Denver formation. The Denver formation in the Northwest Boundary study area consists primarily of clays, clay shales and claystones with occasional lenses or beds of sandstone. Boring and well logs indicate that the top of the Denver formation in the Northwest Boundary study area is usually clay shale or claystone, sediments of low permeability. Few of the borings and wells penetrated the Denver formation more than a few feet. Therefore little is known of the extent, occurrence, and continuity of the permeable sandstone units of the Denver in the study area. Examination of the Denver formation exposed in the trench excavation revealed cracks in the shales and claystones which were attributed to jointing and desiccation (USACE 1986). The zone of weathering and fracturing in the Denver frequently required extending the trenching operations to 3 to 5 ft below the minimum excavation line (USACE 1986) to intact rock to provide a low-permeability key for the slurry wall.

59. The surface of the buried Denver formation slopes generally to the west and exhibits considerable relief in the form of erosional channels incised into the formation prior to deposition of the overlying alluvium. A top-of-rock contour map was constructed for the study area from boring and well data and is presented as Plate 11. To assist in visualizing the top of the rock in the study area a three dimensional diagram is presented as Figure 32. The view of the highly vertically exaggerated rock surface is from the southwest. The buried rock surface shown in Plate 11 (Volume II) and Figure 32 slopes approximately 75 to 80 ft/mile with local steepening to about 265 ft/mile on the terrace fore-slopes. The occurrence of anomalous knobs in some areas of the rock surface indicate that slumping may have been an important process in the development of the top-of-rock topography (USACE 1983). The top-of-rock surface is regularly incised by channels trending northwest-southeast. The dominant feature is a large, deep channel entering from the south and exiting the Arsenal to the northwest near the south end of the line of extraction wells in Section 22. The channel is filled with over 20 ft of saturated sand and gravel alluvium. Erosional gullies entering the study area from the east-southeast apparently persists down-slope to connect with the large channel. Another persistent gully or paleo-valley trending NW-SE from near well 27077 to near well 26088 is an apparent conduit for contaminant plumes, see paragraphs 100 and 106. The slurry wall of the extraction system was emplaced on an erosional terrace where top-of-rock is relatively shallow. Where the rock surface falls off into the large channel to the southwest, the hydraulic barrier replaces the slurry trench barrier.

60. The top of rock (the Denver formation) depicted on the geologic cross sections (Plates 2 through 10) was defined primarily from boring and well logs. The configuration of the rock surface has been enhanced by extracting top-of-rock elevations from the rock contour map (Plate 11) for segments between the boring and well positions. A more detailed and informative rock surface, and a better representation of alluvial aquifer thickness along section lines, has been produced in this way. Three sections (AA', BB', and CC') were constructed parallel to the barrier, or roughly perpendicular to flow; four sections (FF', GG', HH', and JJ') are perpendicular to the barrier, or parallel to flow from the southeast; and two sections (DD and EE) are roughly parallel to a component of flow from the east-northeast. The east-northeast to west-southwest flow component results from a change in the trend of the

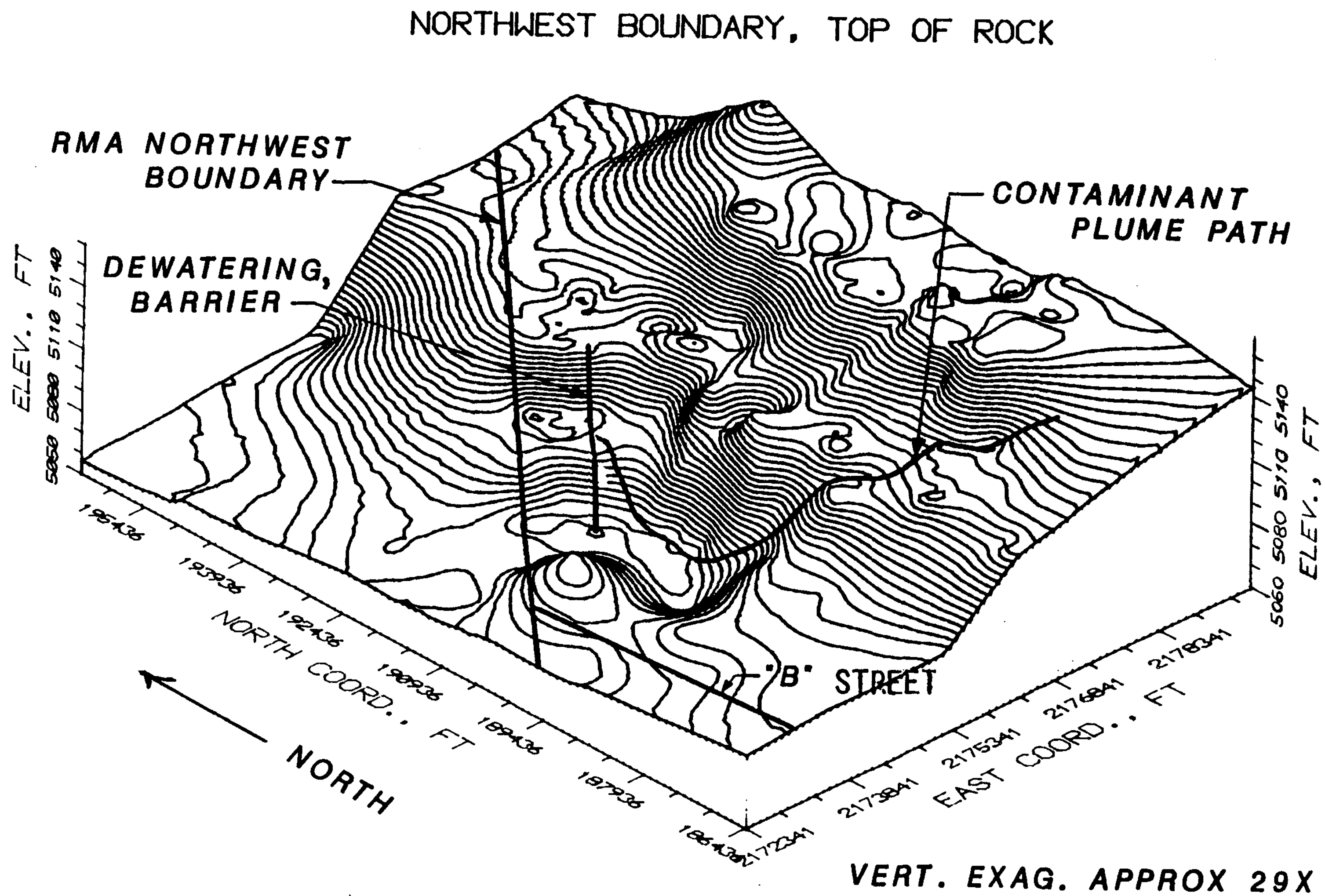



Figure 32. Three-dimensional image of surface of Denver formation (top-of-rock) Northwest Boundary, looking northeast

rock-cut terraces to the northwest as shown on the rock contour map (Plate 11).

61. The alluvium. The surficial deposits (the alluvium) overlying the Denver formation in the study area were described briefly in paragraph 51. The geologic cross sections (Plates 2 through 10) further illustrate the composition and stratigraphy of the alluvial deposits. For this report, the lower portion of the alluvium containing primarily sands and gravels and which serves as the aquifer of the alluvium (the water-producing strata) is designated the "sand and gravel" unit on the sections. The top of the unit is shown as a dashed line on the sections to distinguish it from the overlying finer-grained materials. The sand and gravel unit can be mapped over most of the Northwest Boundary study area. Furthermore, analysis of the boring data for the study area indicates that at least three distinct sub-units of the lower sand and gravel alluvium can be distinguished. The sub-units are designated lower, middle and upper sands and their positions have been mapped on Plate 12. The positions of the sub-unit sands in the study area indicate that each sub-unit is a depositional body distinct (deposited at a different time and at a different elevation) from the other sub-units.

62. Plate 12 shows the positions of the downslope and upslope limits of each sand sub-unit. The positions were mapped from stratigraphic cross sections constructed along the lines of borings and wells. The sand sub-units are interpreted to be depositional terraces with the younger terraces deposited at lower levels than the older terraces during succeeding cycles of erosion and deposition by streams (with the top of the Denver formation the erosional surface). The sub-units are approximately horizontal and show continuity parallel to the trend of the cut-terrace surface of the Denver formation (roughly north-south, see Plates 11 and 12 and Figure 32). Each sub-unit (lower, middle and upper) is limited up-slope and down-slope, normal to the trend of the cut terrace. Careful examination of all available boring and well logs supports the interpretation of the sub-units as separate terraces. The significance to analysis of the ground water system in the study area is that the relatively permeable sand units are not continuous in a downslope direction, but are separated by as much as 600 ft horizontally by fine-grained sediments of correspondingly lower permeability (see Plates 10 and 12).

63. Cross-sections GG', HH', and JJ'; Plates 8, 9, and 10; illustrate the stratigraphy of the sub-unit terrace sands. Section JJ' depicts the lower, middle and upper sands and shows the erosional gaps between the upslope and downslope limits created by successive stages of downcutting. Other sections generally show the lower and middle sand units (for example, Section BB, along the barrier alignment, shows the position of the lower sand and its separation from the middle sand to the north by the steep cut-terrace slope between borings DH82-8 and DH82-8A.) From analysis of sixteen cross sections constructed through the borings and wells, the lower sand lies between elevation (ft) 5066 and 5107, the middle sand between 5104 and 5136, and the upper sand is at elevation 5140 and above. The picture presented here of distinct lower, middle and upper sand and gravel units is believed to portray the character of the alluvial aquifer in the Northwest Boundary study area more accurately than previous representations of the sand and gravel as a continuous blanket overlying the Denver formation.

64. An isopachous (equal thickness) map was constructed for the saturated alluvium in the Northwest Boundary study area for first quarter FY 86 and is presented as Plate 13. The isopach, contoured at 5-ft thickness intervals, readily shows the predominance of saturated alluvium in the deep channel on the western side of the study area. East of approximately the 2,176,000 E coordinate the saturated alluvium is less than 5 ft thick. In the axis of the deep channel the alluvium is as much as 30 ft thick. The slurry wall portion of the extraction system is emplaced in 5 to 10 ft of saturated alluvium and the hydraulic barrier portion in 10 to 25 of saturated alluvium. The mapped thickness of saturated alluvium in some areas includes part of the overlying fine-grained sediments not normally classified as aquifer materials.

Hydrogeology.

65. Contour maps of water levels, Plates 14-24, were constructed for selected quarters of several years for the study area. Analysis of water levels is presented below in paragraphs 65 through 93. Comparison of the water table maps and the top-of-rock contour map (Plate 11) shows that the potentiometric surface is strongly influenced by the shape of the rock surface (the paleodrainage) and by the thickness and character of the alluvial deposits filling the paleo-valleys. The potentiometric lines roughly parallel the rock surface contour lines. Locally higher gradients in the potentiometric surface reflect local steepening of the rock-cut terraces and fining

of the overlying alluvium in the gaps between the sand and gravel sub-units of the alluvium between the terraces as discussed above in paragraphs 58 and 59. Low gradients with a northerly flow in the west half of Section 27 and the southwest portion of Section 22 reflect less restricted flow through the thick section of saturated alluvium (the lower sand of Plate 12) in the large alluvium-filled valley in that part of the study area. All westward components of flow from Section 26 are directed toward the extraction system by the shape of the potentiometric surface in the Northwest Boundary study area. Ground-water gradients in the alluvial aquifer range from about 0.04 in the northeast corner of Section 27 to about 0.0024 in the thick aquifer sands in the western half of Section 27.

66. An occurrence within the alluvial aquifer of a low-permeability zone, which apparently serves as an aquitard to lateral movement of ground water through the alluvium, was inferred from water level contours and from vertical cross-sections constructed through the recharge and dewatering lines (sections BB and CC, Plates 3 and 4). Section CC along the recharge line shows the position of the low-permeability material in wells RW-15 and RW-15A, which were abandoned after unsuitable, predominantly clayey soils were encountered at usual aquifer depth. Well 15B was subsequently emplaced (see Section CC) to serve as the recharge well. The water table contour maps show a locally steep gradient in the area of wells 415 and 416 on the recharge line, between wells 22010 and 22018, and to some extent between 22064 and 22066-067 on the dewatering line. Section BB shows that there is a reduced thickness of aquifer sands and gravels, replaced by an increased thickness of clays, in well 22046 between wells 22064 and 066-067.

67. An interpretation of the water levels and lithology is that the zone of clayey soil in the aquifer is a clay-filled channel that has incised and cut out the normal sequence of sands and gravels. The clay-filled channel trends NNW, is approximately 100-200 ft wide, and deters the flow of water through the aquifer from the southwest to the northeast. The presence of the clay-filled channel helps explain the difference between water levels in the same aquifer on opposite sides of the interpreted channel down-gradient of the barrier, as noted below in the discussion of water levels and the water level contour maps.

Ground-Water Hydrology of the NWBCT System Study Area.

68. Ground-water contour maps and ground-water profiles define the areal ground-water regime, document effects of the system on ground-water flow, and illustrate the ability of the system to intercept contaminated ground water.

69. Contour maps of water levels in the alluvial aquifer, Plates 14-24, were constructed for FYs 1981 (4th Qtr), 1983 (3rd Qtr), 1984 (3rd Qtr), 1985 (1st, 2nd, and 4th Qtrs), and 1986 (all quarters). The FY 81, 83 and 84 maps were constructed for comparison of pre- and post-system water levels. The FY 85 and 86 maps were constructed for analysis of system performance. Quarters were selected on the basis of available data. Insufficient data were available for construction of water level maps for 3rd quarter FY 81 and 3rd quarter FY 1985, though a map showing water levels available for the 3rd quarter FY85 is provided, Plate 19.

70. Data for the water level maps were quarterly readings from study area wells screened in the alluvium. Data for wells described as Denver wells, but whose screens were in contact with the alluvium, were also included in compiling the water level maps. Multiple readings for a well sometimes occurred for a given quarter. In such cases, the readings for the most common date for the quarter were used. If a common date was not available, the average of the multiple readings was used. The water levels were contoured on 1-ft intervals.

71. Three water level profiles along alignments shown on Plate 1, Profiles I, II, and III, were selected along lines of indicator wells for the same quarters as ground-water contour maps.

72. Influences on ground-water levels. System construction, system operation (flow rates), and precipitation were the major influences on ground-water levels in the area of the system during FY 85 and 86. This section summarizes the construction sequence, system flow rates, and precipitation for the study period.

73. System construction. Because of the effect on ground water of the slurry trench barrier and wells, construction dates for these system components are important factors in the interpretation of the ground-water maps and water level profiles. The slurry trench was installed in October-November 1983, and thus the first of the ground-water contour maps to show its effects would be for the 3rd quarter FY 84, Plate 16. Well drilling (and other construction activities) were complete by July 1984. Though some pumping of

the system occurred during the 1st quarter of FY 85, system operation essentially began in January 1985. Thus the ground-water map for the 2nd quarter of FY 85, Plate 18, is the first map to show effects of substantial system pumping.

74. Flow rates and precipitation. System flow rates, since start-up, and precipitation, before and after start-up, were the major influences on ground-water levels in the area of the system. This section summarizes the system flow rates for FY 85 and 86, Figure 33, and precipitation for FY 81-86, Figure 34.

75. Figure 33 is a plot of average system flow rates in gpm for weeks in FY 85 and 86. Flows during initial system testing in the 1st quarter of FY 85 were of low magnitude resulting in a quarterly average flow rate of less than 30 gpm. During the last three quarters of FY 85 a generally increasing flow rate is periodically interrupted by two to three week periods of lower flow rates, e.g., late January 1985, early March 1985, late April 1985 etc. There is a sharp drop in flow at the end of FY 85 but higher flow rates resume within three or four weeks. While 2nd quarter FY 85 average flow is near 500 gpm, average flows for the last two quarters of FY 85 at 800 to 850 gpm are the highest quarterly average flows of the system for FY 85 and 86.

76. During the first three quarters of FY 86 flow varied considerably before the relatively stable flow of the last quarter. Three periods of low flows occur during the first three quarters; late November 1985-early January 1986, March to mid April 1986, and May 1986. Quarterly average flows for FY 86 consistently range from 550 to 600 gpm.

77. Precipitation. Precipitation records for Rocky Mountain Arsenal near the NWBCT System were not available for the period of this study. However, the National Weather Service at Stapleton Airport supplied monthly precipitation amounts for their observation station located just south of the Arsenal, Figure 34. The rainfall records, while not necessarily reflecting local storm events, (the station is approximately 3-5 miles south of the Northwest Boundary System), provide general indications of wet and dry years and seasons. Figure 34 provides monthly amounts and yearly totals of precipitation for the study period.

78. FY 81 and 82 were relatively dry years followed by three relatively wet years, FY 83, 84, and 85, followed by a relatively dry FY 86 (average precipitation for FY 71 through 86 is 15.0 inches/year).

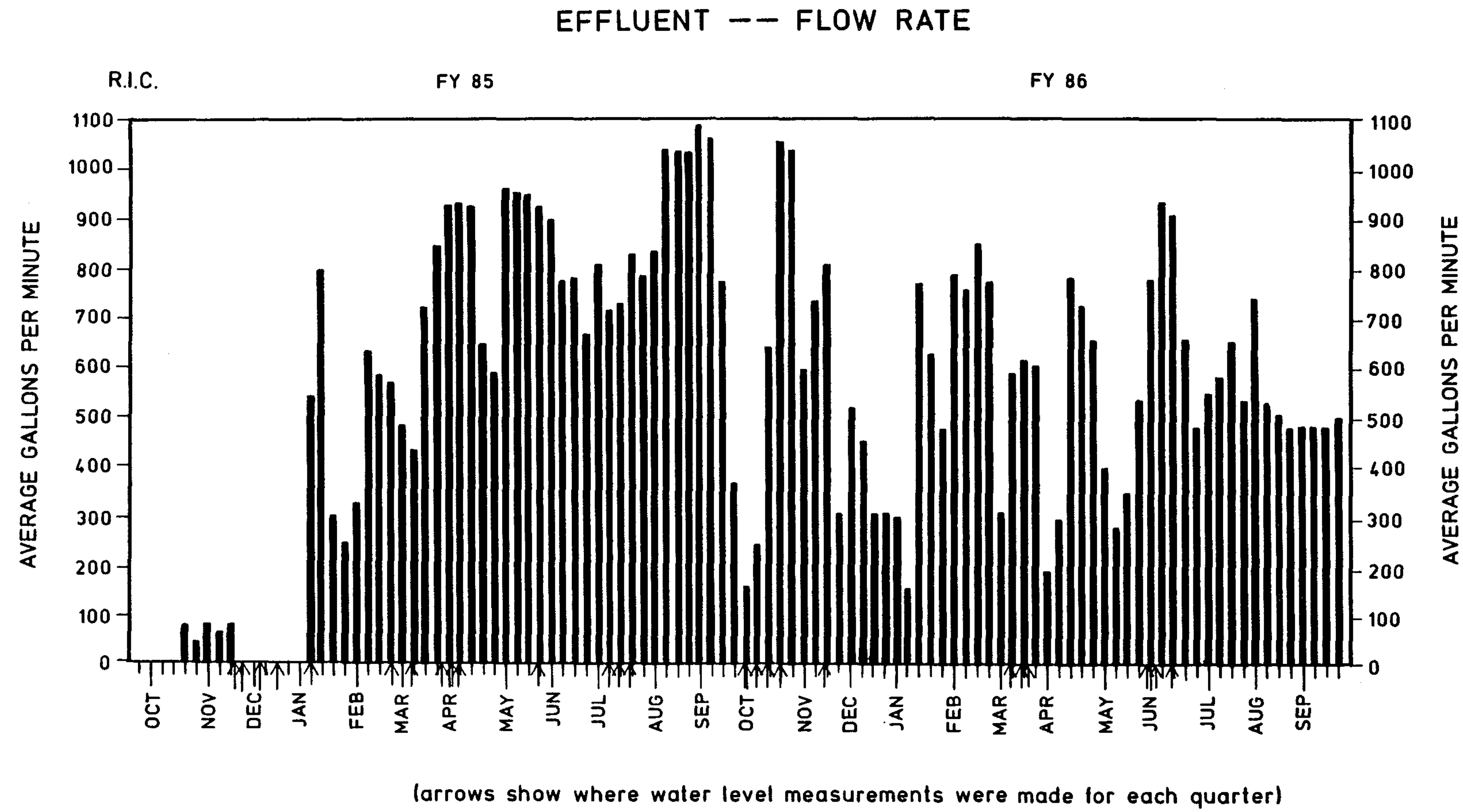



Figure 33. NWBCT System flow rates

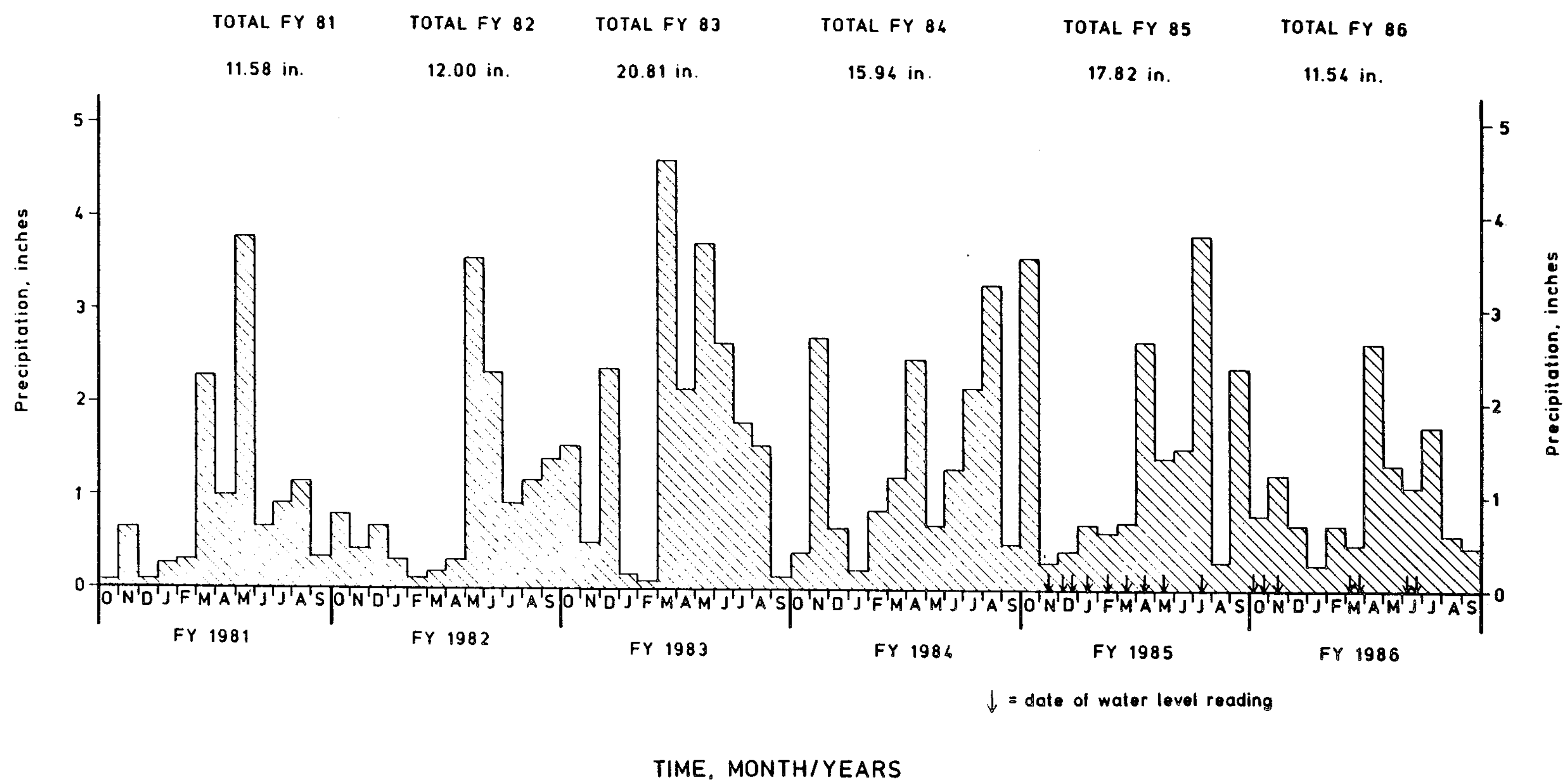



Figure 34. Precipitation as measured by the National Weather Service, Stapleton Airport, Denver, Colorado

79. For the years of system operation, FY 85 and 86, the graph indicates the wet months were April through September or October and the drier months were October or November through March. This is a general trend from FY 81 through 86.

80. Analysis of water level changes from profiles. Figures 35-44 describe ground-water levels along lines of indicator wells labeled Profiles I, II, and III, Plate 1.

81. Profile I. Profile I, Figures 35-37, is a line of wells parallel to and approximately 800 feet southeast of the system. This profile exhibits a relatively gentle, stable gradient between wells 27003 and 22051 which is due to the alignment of this portion of the profile with the eastern edge of the large paleochannel through which ground water flows. This trend is prevalent prior to system operation, Plates 14-17, and after system start up, Plates 18-24.

82. The steeper portion of the profile between wells 22051 and 22049 reflects the steeper slope of the Denver surface and the presence of finer-grained sediments through which the ground water is flowing, Plate 2 and Plates 5 and 6. Again the trend is consistent prior to and during system operations.

83. Comparison of Profile I water levels for FY 81-84, Figure 35, with Profile I water levels for FY 85 and FY 86, Figures 36 and 37, indicate lower water levels in FY 85 and FY 86 for most wells with FY 86 having somewhat lower levels than FY 85. This trend is more pronounced in the part of the Profile I just southeast (upgradient) of the system. The FY 81 profile is lower than other pre-system years due to the below average precipitation for FY 81 and above average precipitation for the other pre-system years. During FY 85 and 86, 1st and 4th quarters tend to have slightly higher water levels than the 2nd and 3rd quarters.

84. Profile II. Profile II, Figures 38-40, is a line of wells between and parallel to the system dewater and recharge alignments, Plate 1. Again as with Profile I, gradients in the southwestern portion of Profile II, wells 27009 to 27010, are relatively stable and gentle. The steeper portion of Profile II, wells 22010 to 22018, is due to the presence of fine-grained soils in this area, Plates 3 and 4 (borings DH 82-5, RW 15 and RW 15A and paragraphs 63 and 64 above).

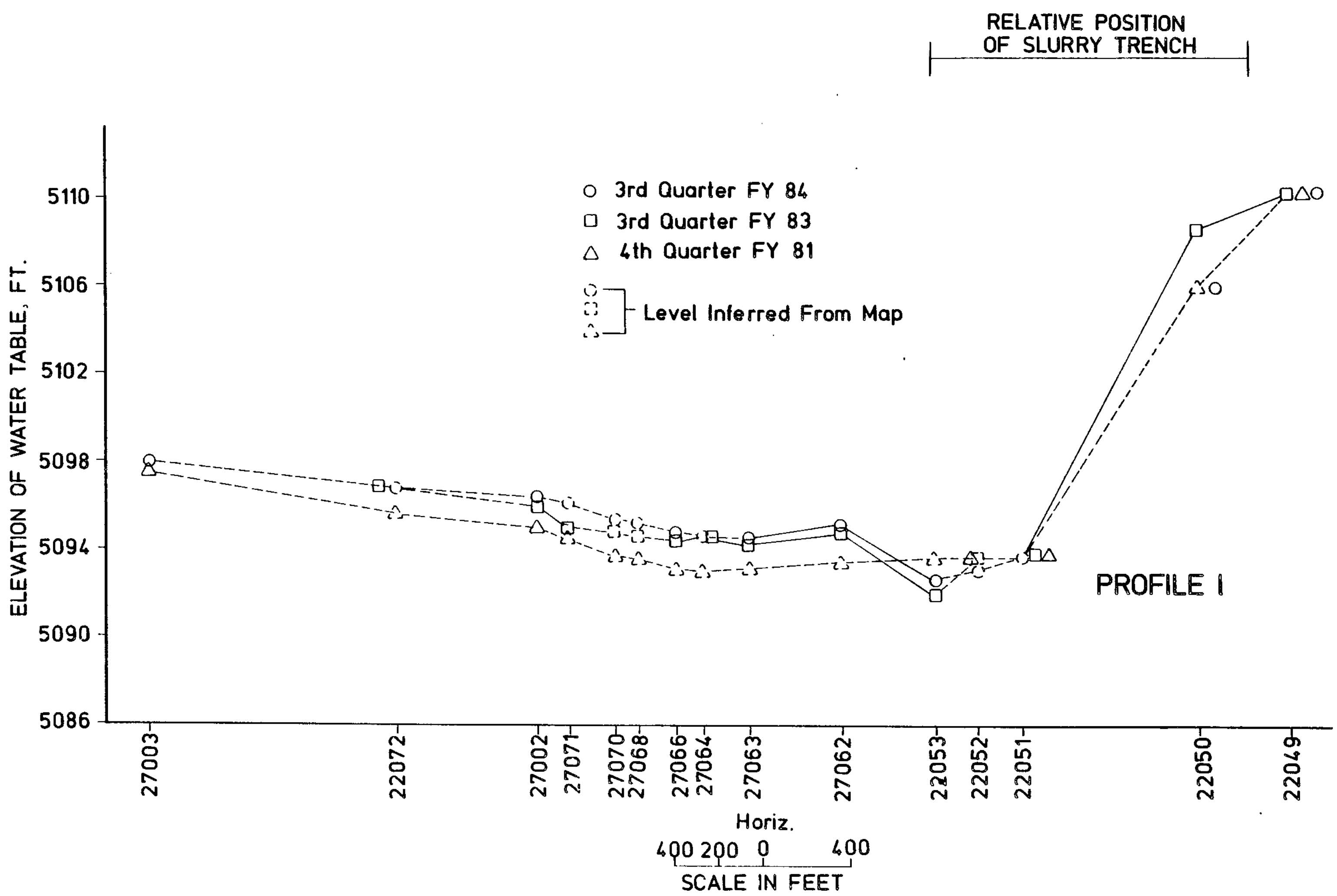



Figure 35. Profile I. FY81, 83, 84

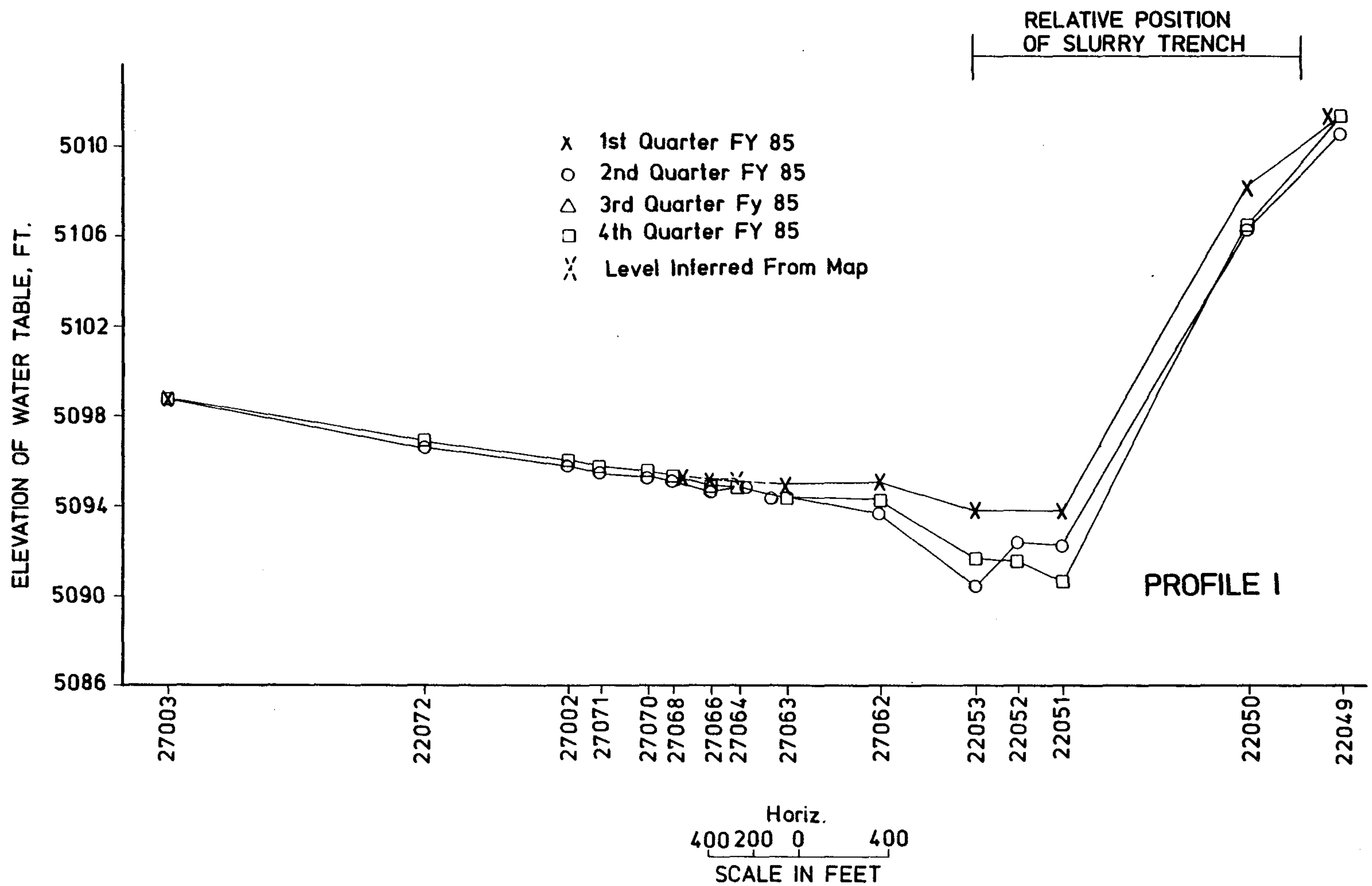



Figure 36. Profile I, FY85

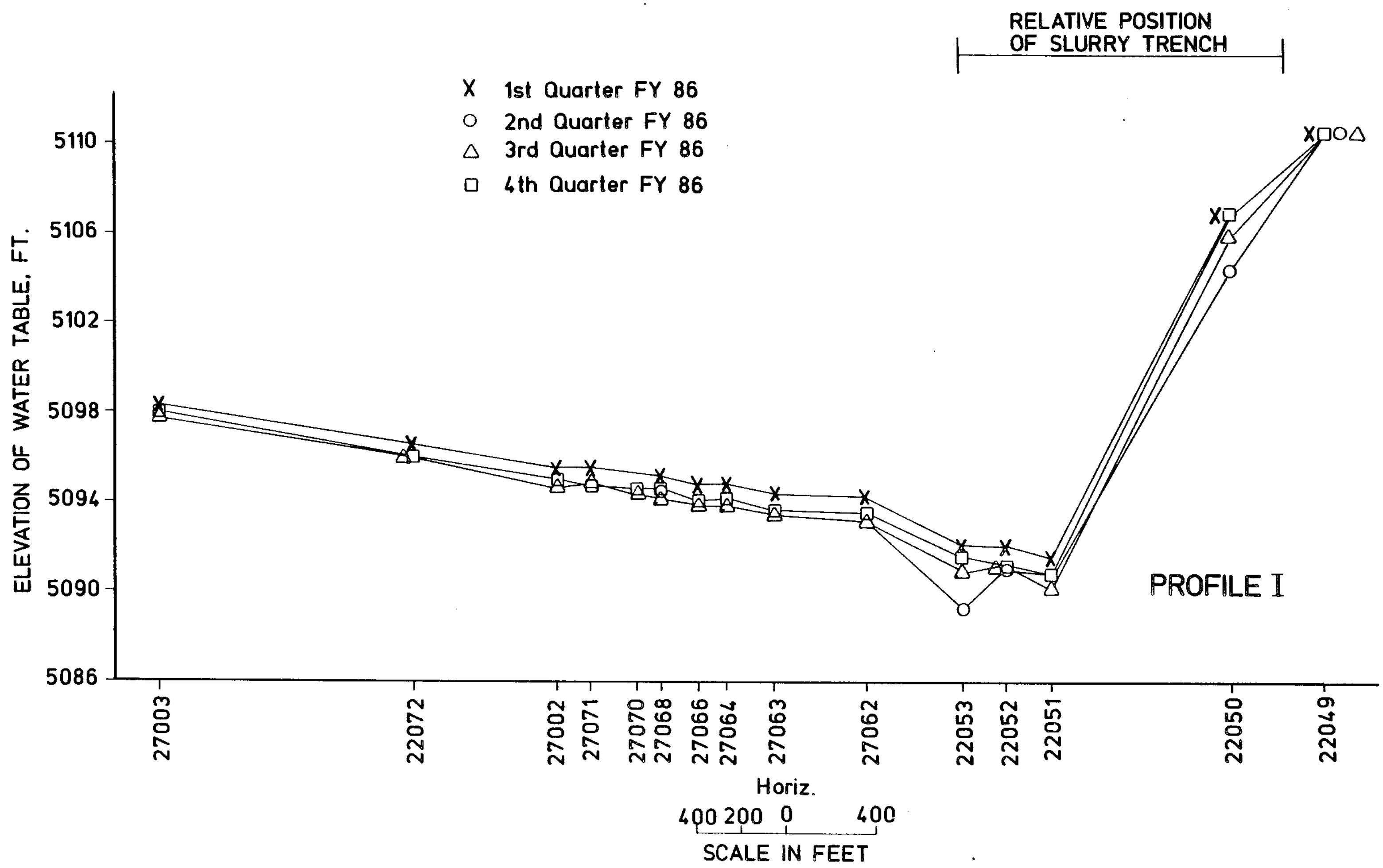



Figure 37. Profile I, FY86

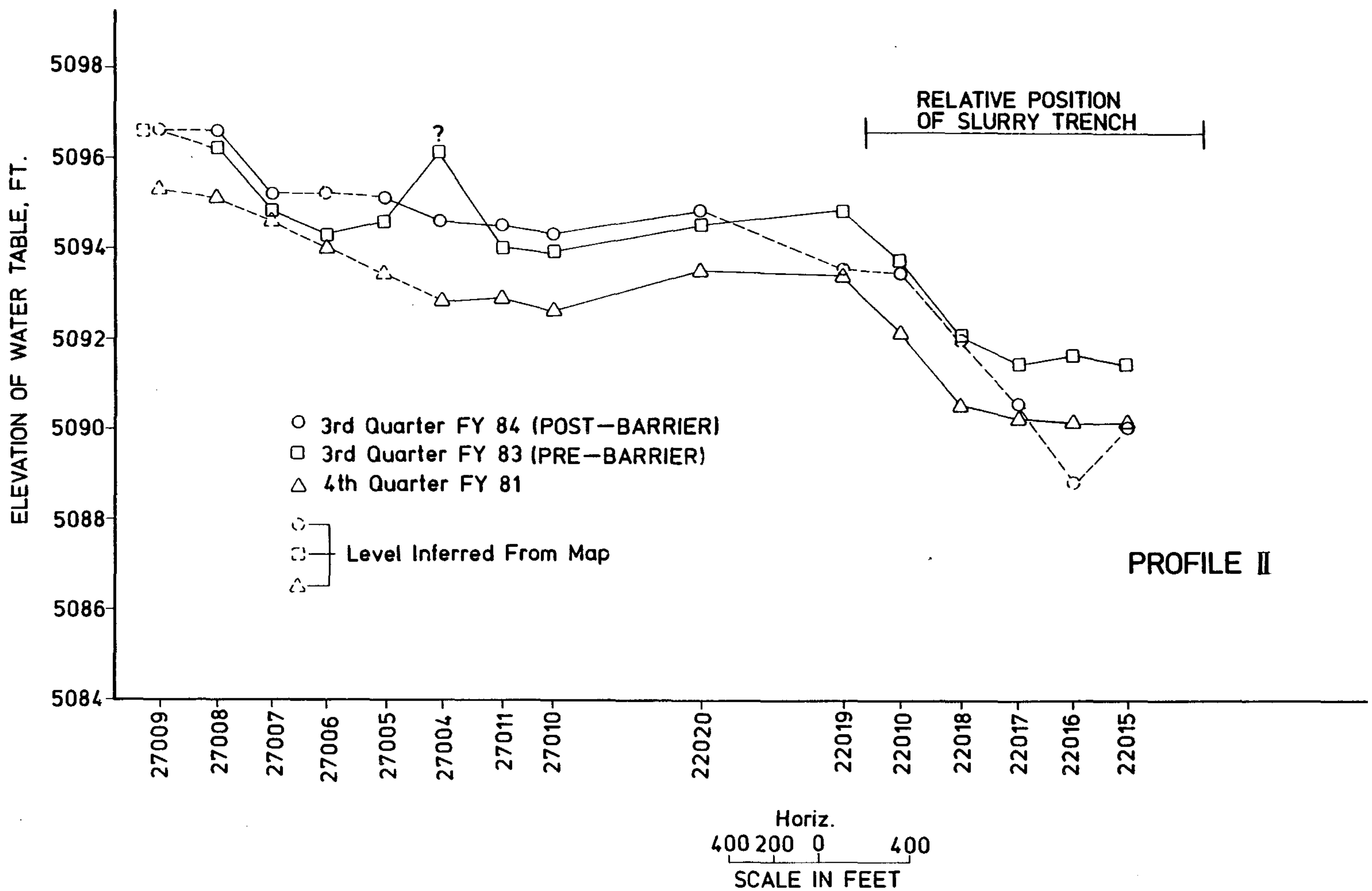



Figure 38. Profile II, FY81, 83, 84

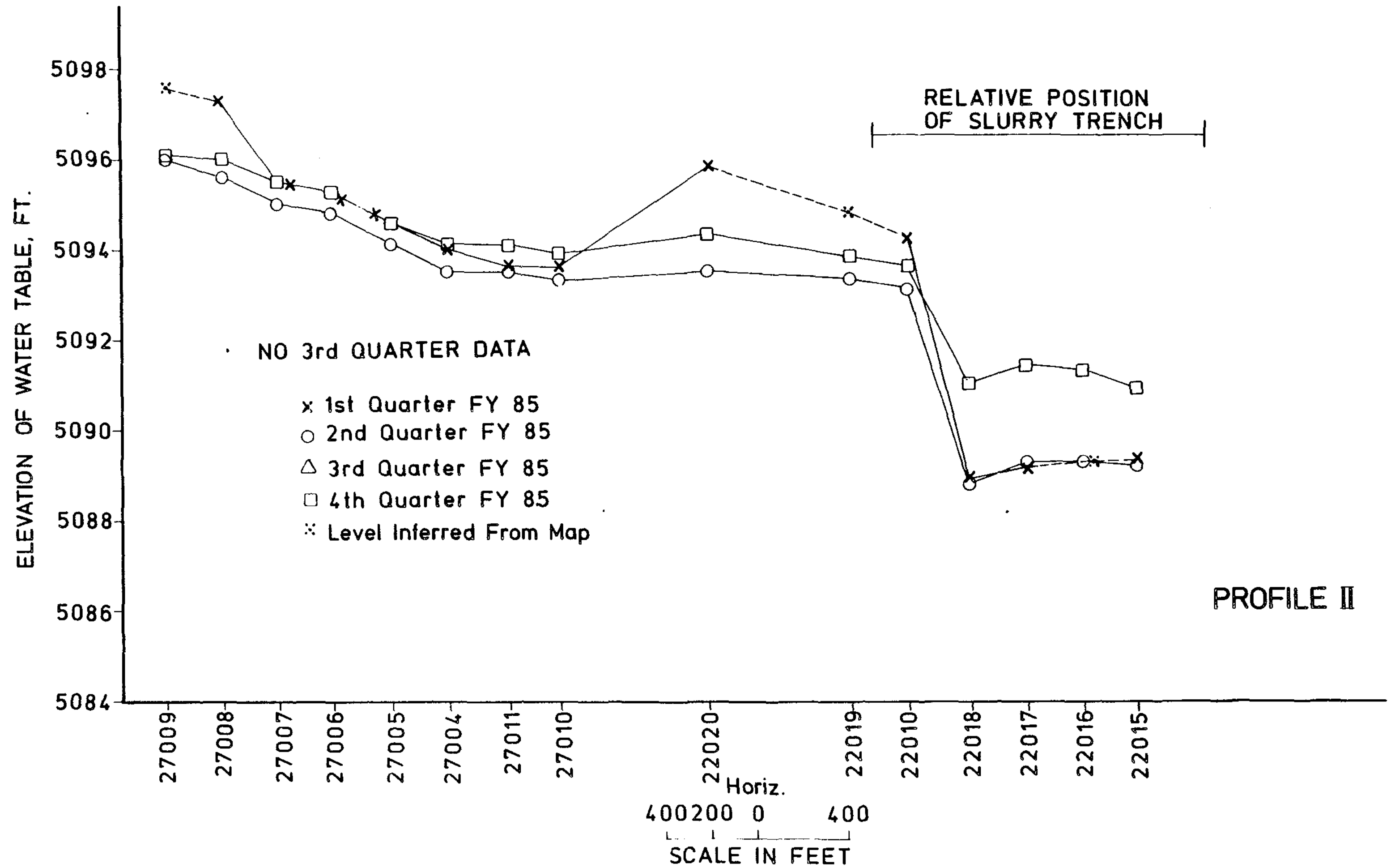



Figure 39. Profile II, FY85

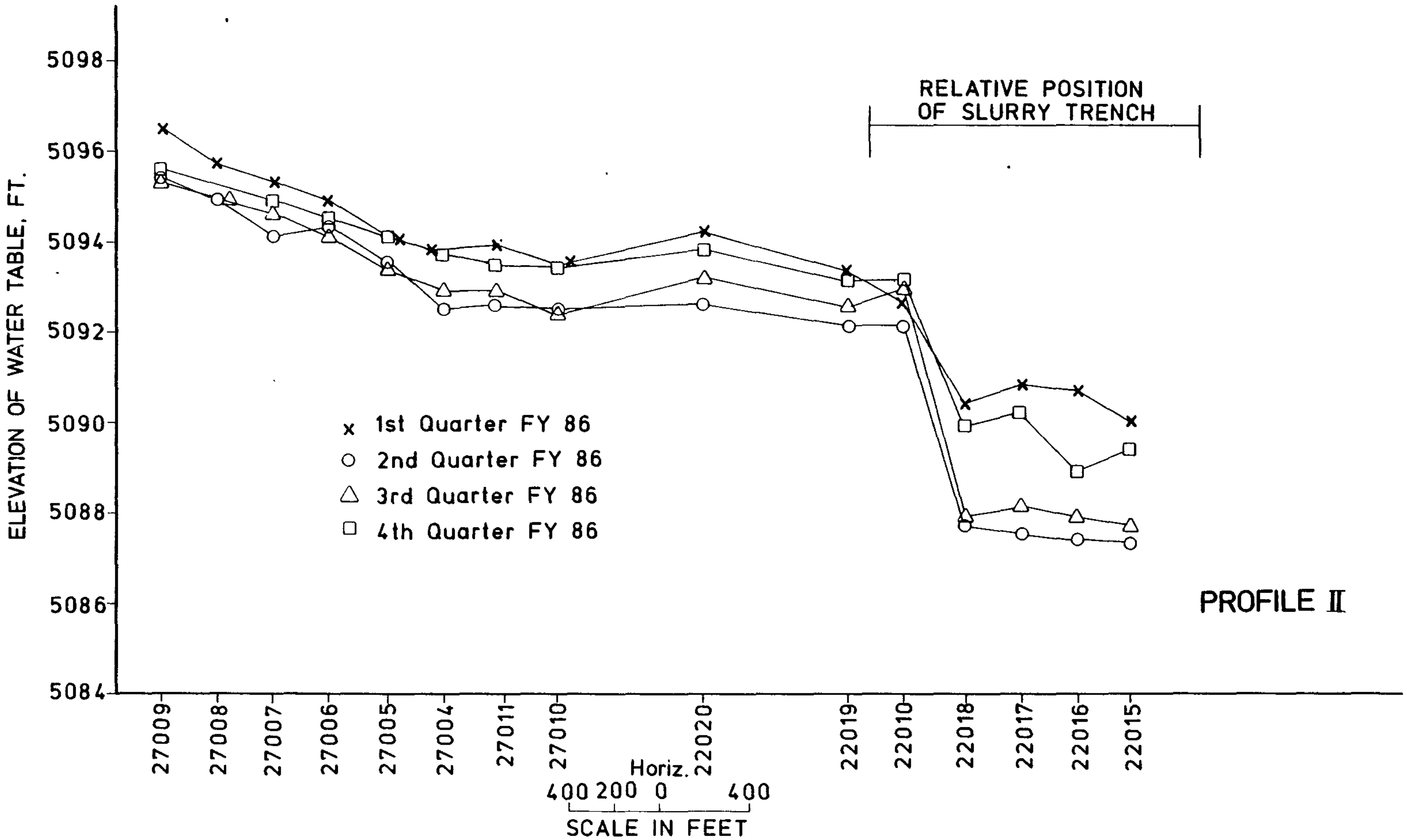



Figure 40. Profile II, FY86

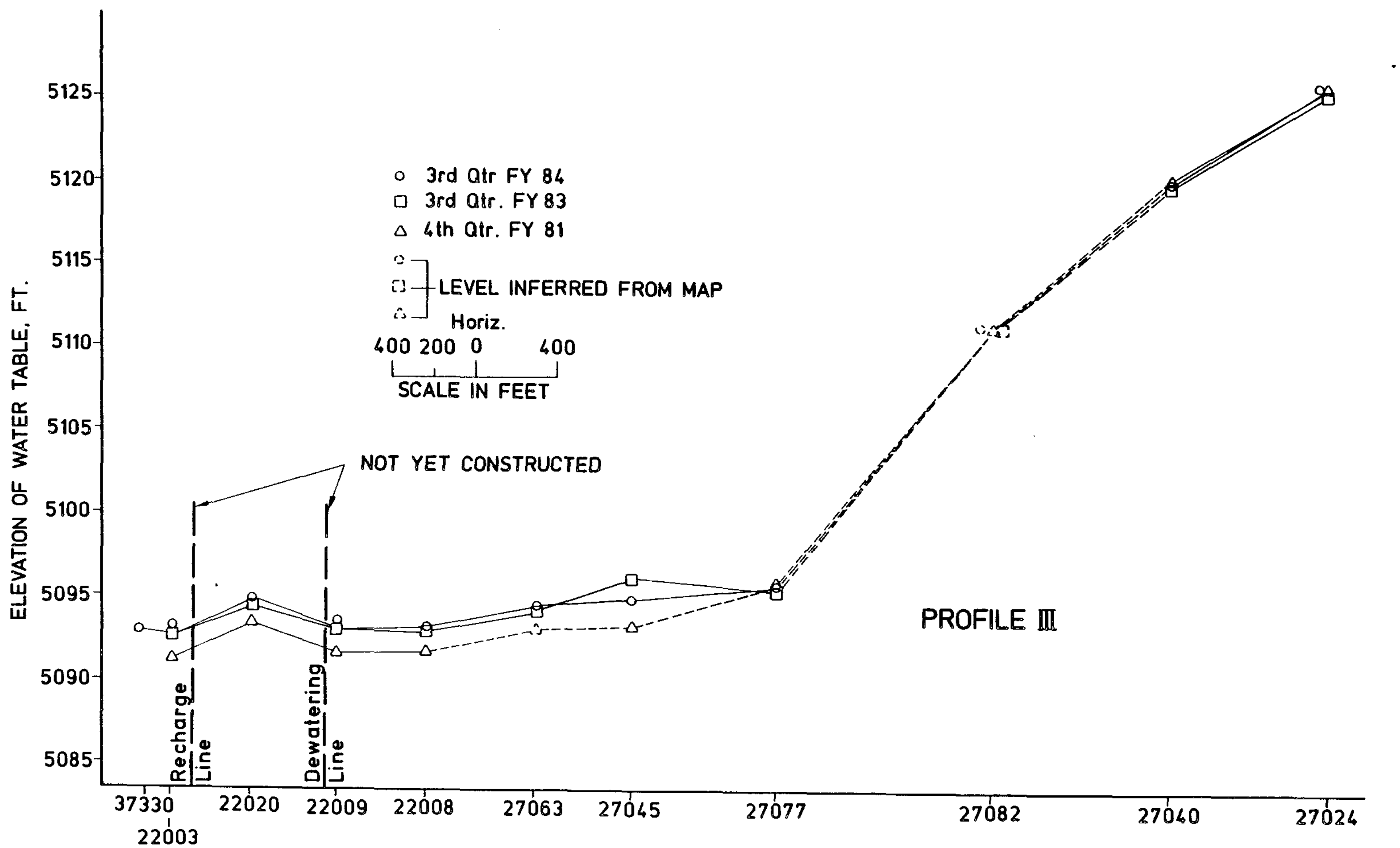



Figure 41. Profile III FY 81, 83, 84

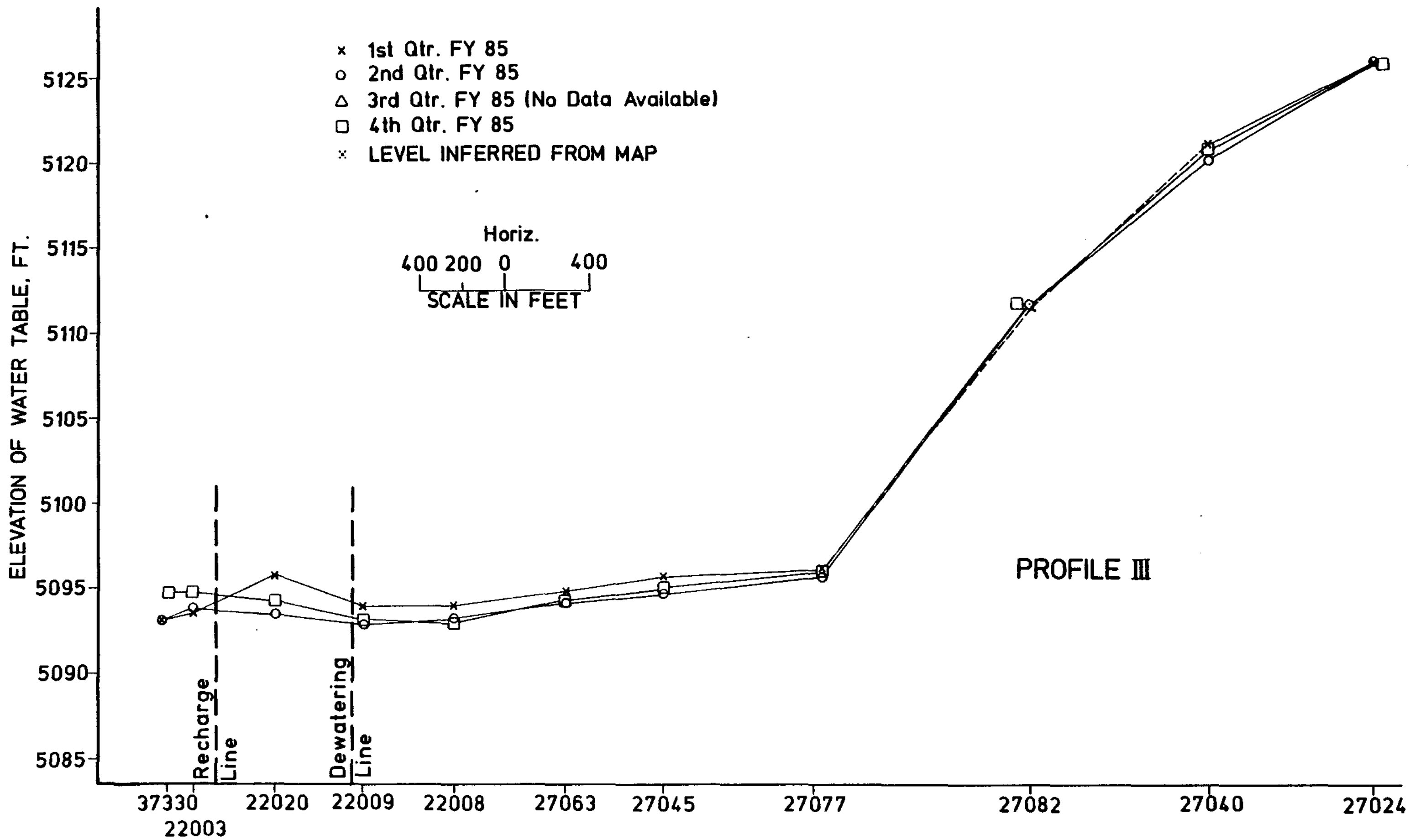



Figure 42. Profile III, FY85

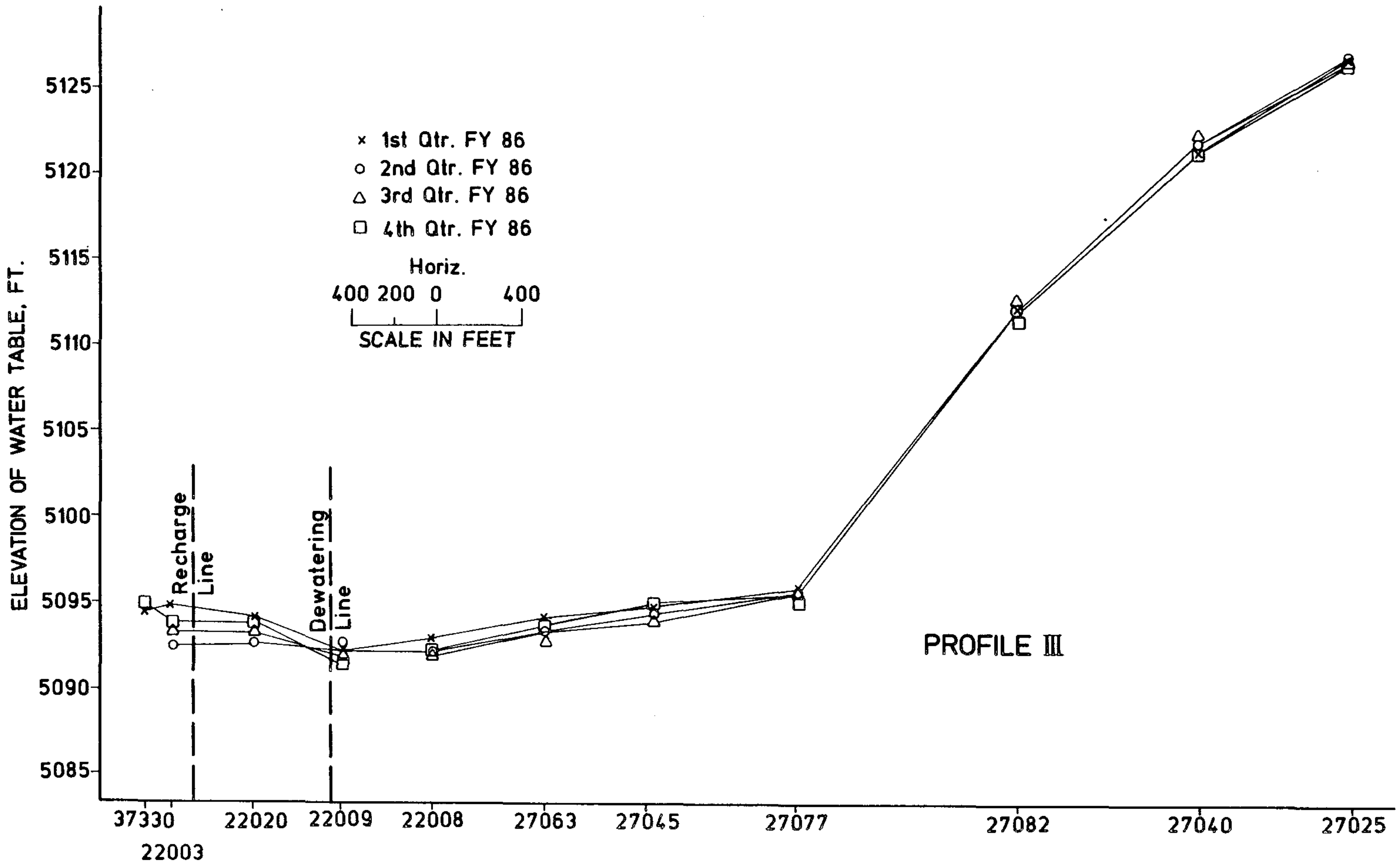



Figure 43. Profile III, FY86

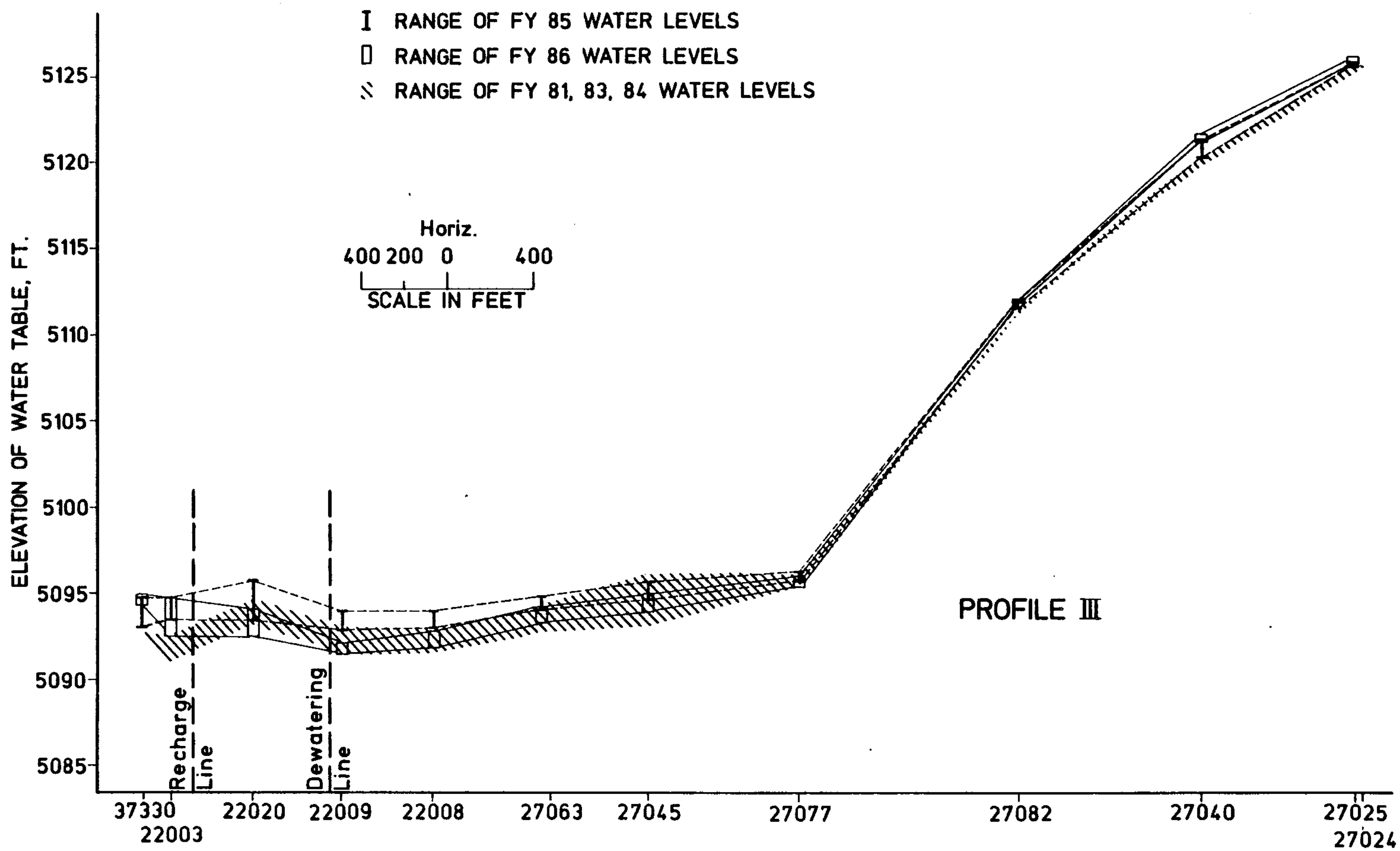



Figure 44. Profile III composite FY81-86

85. Profile II also repeats the trend of lower ground-water levels for FY 86 relative to FY 85. Additionally, for both years the first and fourth quarters generally have higher water levels than the second and third quarters (the third quarter is not plotted for FY 85). The lower water levels directly northwest of the slurry trench show the barrier's blockage of ground-water flow northwestward and the lower flow rates of the recharge wells in this portion of the recharge alignment.

86. Profile III. Profile III, Figures 41-44, approximates the alignment of the higher concentrations of contaminants angling northwestward across Section 27 to well 27077 turning north across 9th Avenue toward the southwestern end of the system and then crossing the system. The profile, starting at well 27024 (or 27025 for FY 86) follows a smaller valley in the Denver surface intercepting the larger filled paleochannel valley near well 27077 then skirting the eastern edge of this valley to well 22008 then crossing the southwestern portion of the system to well 37330.

87. Profile III has a consistent, steep gradient between wells 27024 (or 27025 for FY 86) and 27077 prior to and during system operations. The steep gradient reflects the Denver surface, Plate 11, and the finer-grained alluvium in this area. The next portion of the profile from well 27077 to 22009 has a much flatter gradient reflecting the lower gradients of the large filled paleochannel valley. The remainder of the profile, which crosses the southwestern portion of the system, wells 22009 to 37330, displays, prior to system operation (FY81-84 and 1st Qtr FY85), a peak at well 22020. During system operation (2nd Qtr FY85 and later), the profile gradient in this portion slopes from the recharge alignment to the dewater alignment indicating establishment of a continuous reverse gradient from recharge to dewater alignments.

88. As with Profiles I and II, Profile III exhibits, during FY 81, lower ground-water levels likely due to low precipitation; lower water levels in FY 86 than in FY 85 for the portion from well 27077 north; and, during FY 85 and FY 86, a slight tendency for 1st and 4th quarter ground-water levels to be higher than 2nd and 3rd quarter levels.

89. Analysis of water level changes from ground-water level contour maps. The ground-water level maps, Plates 14-24, illustrate general ground-water elevations and flow trends for years prior to system operation (FY 81,83,84)

and during system operation in FY 85 and FY 86. Three contours; 5100 foot, 5094 foot, 5090 foot; were chosen to illustrate general ground-water trends.

90. A review of the maps indicates generally stable ground-water levels for ground water at elevations higher than the 5100 foot contour. The 5100 foot contour extends from near well 22004, its northernmost point in the study area, southerly through Section 22 crossing 9th Avenue east of well 27062. It continues south to the central portion of Section 27 where it rather abruptly turns westward and crosses the western section line of Section 27 near well 27044. Ground-water levels in the study area east and south of this contour are stable for the study period.

91. System dewatering operations markedly influence the 5094 contour. Relative to the pre-operation contour maps there is a slight upgradient (southeastern) displacement of contour 5094 over the period of system operations in FY 85 and FY 86 near wells 22051, 22052, 22053, and 22062. The east-west trending portion of the 5094 contour in Section 27 moves south (upgradient) after system operations start (FY 85 and FY 86) except for the fourth quarter of FY 85 when it approaches the northern section line of Section 27 during high system flow rates.

92. High system flow rates and associated high recharge rates, Figure 33, would tend to increase recirculation between the recharge and dewatering wells in the southwestern portion of the system (where the majority of dewatering and recharge is occurring). High recirculation within this part of the system could reduce the capacity of the dewater wells to remove ground water upgradient of the system thus allowing the 5094 foot contour to move north toward the system (i.e. causing the water table to rise). This possibility cannot be evaluated with current data, but might be characterized by modeling. Additionally, the 3rd quarter and the first part of the 4th quarter of FY 85 were periods of considerable precipitation, Figure 34. The 5094 foot contour gradually retreats south and appears to stabilize over the last three quarters of FY 86.

93. The 5094 foot contour is also evident in the area of the southwestern recharge wells, particularly in the 1st and 4th quarters of FY 85 and 86 during and following the wetter portions of the year. This condition is also present, to a lesser extent, in the 2nd quarter of FY 85 and in the FY 83 and 84 maps, Plates 18, 15, and 16.

94. Surface drainage appears to enhance the cyclicly higher ground-water levels in the southern portion of the system. The system boundary road, RMA perimeter road, and 9th Avenue restrict flow of surface water from several acres of section 22 into a low area in the southwest portion of the system. The Facilities Engineer of RMA indicated this is normally an annual occurrence during the spring and early summer months and is verified by periodic aerial photographs of RMA. Effects of recharge from the ponding apparently contribute to the higher ground-water levels in the 4th (summer) and 1st (fall) quarters following the ponding.

95. The western extremity of contour 5094 moves between wells 27004 and 27006 during FY 85 and FY 86 again with the exception of the fourth quarter of FY 85. On the FY 81 map, Plate 14, the east-west portion of this contour is nearer its position during system operation than for the other two pre-operation maps. As noted in the discussion of ground-water profiles, precipitation for FY 81 was below average and well below that for FY 83 and 84, Figure 34.

96. Contour 5090 has historically been located along the RMA boundary near the position of the slurry trench, Plates 14 and 15. This trend continues through installation and operation of the system. As seen in subsequent Plates covering FY 85 and FY 86 the 5090 contour intersects the slurry trench and with continued dewatering moves to the upgradient side of the slurry trench after the second quarter of FY 85.

## Distribution of Contaminants

### Background

97. Ground-water contamination at the northwest boundary of RMA is a result of the historical disposal of wastes from various activities conducted on RMA. Although the contaminants found at the boundary cannot be traced back to a particular source, they are known to be associated with the operation of the disposal basins, chemical plants, and the waste handling systems. Historical data on the contaminants are discussed in Thompson et al. (1985).

98. In order to illustrate the changes in the distribution of the contaminants along the northwest boundary prior to and after construction of the system, a series of isoconcentration maps have been developed for those major contaminants for which sufficient data exists (Volume II, Plates 25 thru 76).

The contaminants plotted include DBCP, DIMP, dieldrin, chloride, and fluoride. Isoconcentration maps were not developed for aldrin, endrin, or isodrin because very few concentrations above the detectable level were found for these contaminants. The analytical data from which the isoconcentration maps were developed are presented in Volume III of this report. Sufficient data were available to develop isoconcentration maps for the 4th quarter of FY81, 3rd quarter of FY83 and FY84, and all four quarters of FY85 and FY86. Dieldrin was mapped only for the four quarters of FY85 and FY86 because earlier data were not available.

99. The data collection period associated with each individual isoconcentration map is identified on the respective plate. Only limited data for DBCP and DIMP were available for the 4th quarter of FY81 which did not provide sufficient information to draw isoconcentration lines. As a result, the isoconcentration maps for this period were constructed using isoconcentration maps for the later years as a guide for contouring. The contour lines thus generated are depicted as dashed lines. In general, on all the isoconcentration maps, dashed lines indicate a lack of sufficient data to allow the drawing of an isoconcentration line using the standard rules of line construction.

100. As previously mentioned, the concentrations of the contaminants in the dewatering wells (and the corresponding influent to the treatment plant) are significantly lower than those concentrations upgradient of the dewatering wells. This is attributed to dilution resulting from the recycling of water along the dewatering wells and from the quantity of relatively clean water intercepted by the dewatering wells. As a result, the isoconcentration lines often change abruptly as they approach the dewatering system since the concentrations of contaminants in the dewatering well are much lower than those found in the next wells upgradient of the system. In order to alleviate the problems caused in trying to fit the isoconcentration lines around these low values, the lines were constructed to and stopped at the dewatering system for those quarters during which the system was in operation. On these isocentration maps, the actual concentrations of the contaminants found in the dewatering wells are noted adjacent to the well location.

101. It should be noted that contaminant concentration data were not available for the same wells during each quarter because of changes in the sampling program over the study period. The resulting deletion or addition of

data at a certain well on the map can result in changes in the position of a particular isoconcentration line between monitoring periods. Although an attempt has been made to smooth the lines and make them comparable to the other maps in the series, changes in the positions of isoconcentration lines over time may occur which do not necessarily represent contaminant plume movement. Therefore, each isoconcentration map should be viewed as a snapshot in time of the general distribution of a contaminant for that monitoring period and not necessarily as an absolute indicator of contaminant migration.

102. In reviewing the isoconcentration maps, it becomes evident that the contaminant distributions tend to follow a general pattern. The overall pattern is that of a "dogleg" entering the study area near the southeast corner of Section 27, continuing northwest towards the center of the section, and then turning north and continuing towards the Arsenal boundary. This distribution is consistent with the ground-water flow paths in this area as previously discussed. A more detailed discussion of the distribution of each contaminant over time follows.

DBCP

103. The DBCP isoconcentration maps are presented as Plates 25 through 35. Concentrations of DBCP in the study area range from below detectable level to over 2 ppb. Concentration contours of 0.2, 0.5, 1, and 2 ppb are shown on each isoconcentration map as needed. In the study area, the DBCP distribution exhibits the "dogleg" shape previously noted, entering the area near the southeast corner of Section 27, continuing northwest, and then turning north near the center of the section.

104. During the 4th quarter of FY81, the limited available data indicate DBCP above the detection level found in ground water in the southeast corner of Section 27 and in wells 22005 and 22008. Additional data collected during the 3rd quarter of FY83 show the DBCP distribution continuing into the area of the system with the center of the distribution located just south of the slurry wall alignment. The highest concentration of DBCP, in excess of 2 ppb, was found in the sample taken from well 22018, northwest of the slurry wall alignment.

105. By the 3rd quarter of FY84, the "knee" of the "dogleg" distribution pattern had moved slightly southward. The concentrations of DBCP west of the slurry wall alignment had decreased to less than 0.5 ppb.

106. The DBCP distribution during the 1st quarter of FY85 was very similar to that found during the 3rd quarter of FY84. There were no significant changes in DBCP concentrations associated with the various wells. During the 2nd quarter of FY85, the DBCP concentrations found in the distribution pattern in the northern half of Section 27 increased to between 0.5 and 1 ppb. By the 3rd quarter of FY85, the concentrations associated with these wells had decreased to below 0.5 ppb. Concentrations along the distribution pattern in the southeastern corner of Section 27 increased slightly. The DBCP distribution during the 4th quarter of FY85 was very similar to that found during the previous quarter with the exception that a concentration of 0.5 ppb was found associated with well 27011 adjacent to the treatment building. No concentrations of DBCP have been found associated with this well before or since this sampling period suggesting that the data point may be anomalous.

107. During the 1st quarter of FY86, concentrations of DBCP in samples from wells in the northern part of Section 27 and all of Section 22 fell to below the detectable level. No data were available for the system dewatering wells during this period. Concentrations in the distribution in the southeastern corner of Section 27 were found right at the detection level. During the 2nd quarter of FY86, concentrations of DBCP slightly above the detection level were found in two of the dewatering wells and in well 27062. Concentrations in wells near the center of Section 27 were below the detection level. A concentration of 0.24 ppb was found associated with well 37-332 north of the recharge well alignment. The DBCP distribution during the 3rd quarter of FY86 was very similar to that found for the previous quarter, however, no data were available for the wells located near the center of Section 27. The concentration in well 37-332 decreased to below 0.2 ppb. By the 4th quarter of FY86, a continuous distribution of DBCP was again visible, although the concentrations found were all at or below 0.4 ppb.

108. Comparing the DBCP distribution plots over time indicates that the shape and size of the area of distribution has changed little. The concentrations found have decreased over time with the most significant reduction occurring in the area between the dewatering and recharge wells, since the 3rd quarter of FY83. The distribution appears to intercept the system farther north along the slurry wall alignment, but this may be in part an artifact of the dilution occurring along the hydraulic portion of the barrier as previously discussed.

DIMP

109. The DIMP isoconcentration maps are presented as Plates 36 through 46. Concentrations of DIMP in the study area range from below the detectable level (10 ppb) to over 400 ppb. Concentration contours of 10, 25, 50, and 100 ppb are shown on each isoconcentration map as needed. The DIMP distribution exhibits the characteristic "dogleg" shape in the study area. DIMP was also found north and due east of the system at wells 22007 and 22001, respectively, and near the east side of Section 27 associated with well 27016. Since these wells were not sampled during each monitoring period, it is difficult to evaluate the DIMP distribution in these areas.

110. During the 4th quarter of FY81, the available data indicate DIMP is above the detection level in the southeast corner of Section 27 and is associated with wells 22008, 22001, and 22003 in Section 22. Additional data collected during the 3rd quarter of FY83 indicate that the distribution continues north towards the system. DIMP concentrations were found north and east of the system as previously noted. The distribution of DIMP in these two areas is difficult to describe due to the high variability in the hydrologic conditions and the resulting limited availability of data.

111. During the 3rd quarter of FY84, increased DIMP concentrations were found associated with well 37-332, north of the system along the arsenal boundary. The distribution in Section 27 did not change appreciably. During the 1st quarter of FY85, increased DIMP concentrations were found north and east of the system and near the center of Section 27. The distributions and concentrations found during the 2nd quarter of FY85 were very similar to the 1st quarter.

112. By the 3rd quarter of FY85, the DIMP concentration associated with well 37-332 had decreased, probably due to the recharge of clean water over a period of several months. A DIMP concentration in excess of 450 ppb was found associated with well 27016 on the eastern edge of Section 27. This concentration is suspect since no DIMP above the detection level was found in the quarters immediately prior to and after this sampling period. The DIMP distribution and concentrations found during the 4th quarter of FY85 were very similar to the 3rd quarter.

113. During the 1st quarter of FY86, the DIMP concentration associated with well 37-332 continued to decrease. The distribution south and east of the system was similar to the previous quarter. During the 2nd quarter of

FY86, DIMP concentrations north of the barrier decreased to below the detection level. Concentrations increased slightly in the southeast corner and central part of Section 27 along the distribution. The distributions found in the 3rd and 4th quarters of FY86 were very similar to that found in the 2nd quarter. In general, DIMP concentrations appeared to decrease slightly over the last half of FY86.

114. Comparing the DIMP distribution plots over time indicates that the shape and size of the area of distribution south of the system has changed little. Concentrations of DIMP north of the slurry wall alignment have decreased to below detectable levels.

Dieldrin

115. The dieldrin isoconcentration maps are presented as Plates 47 through 54. Concentrations of dieldrin in the study area range from below the detectable level (0.2 ppb) to approximately 2 ppb. Concentration contours of 0.2, 1, and 2 ppb are shown on each map as needed. The dieldrin distribution exhibits the characteristic "dogleg" shape in the study area. Dieldrin was also found north and west of the system and near the east side of Section 27 associated with well 27016.

116. The earliest dieldrin data available, covering the 1st quarter of FY85, indicate dieldrin was distributed from near the center of Section 27 north to the system. Concentrations over the detectable level were also found in wells 37-330 and 37-332 along the Arsenal boundary, and in well 27016. Dieldrin concentrations in the southeast corner of Section 27 were below detectable levels. The highest concentrations, 2 ppb, were found during the 2nd quarter of FY85 and were associated with the dewatering wells immediately southwest of the slurry wall. Concentrations north of the slurry wall increased slightly during the 2nd quarter of FY85. Concentrations in the southeast corner of Section 27 were above detectable levels.

117. During the 3rd quarter of FY85, dieldrin concentrations in the dewatering wells decreased somewhat. The distribution remained similar to the previous quarter. During the 4th quarter of FY85, the dieldrin concentrations in the dewatering wells associated with hydraulic portion of the dewatering system had generally decreased to below the detectable level probably due to the dilution effect previously discussed. The distribution of dieldrin in Section 27 was similar to that found during the 3rd quarter. A dieldrin

concentration of 0.3 ppb was found in well 27011 adjacent to the treatment building.

118. During the 1st quarter of FY86, dieldrin concentrations north of the slurry wall increased as did those in the northern half of Section 27 along the distribution area. No data were available for the dewatering wells during this period. The dewatering well data available for the 2nd quarter of FY86 indicate very little change from the concentrations found in the 4th quarter of FY85. No data were available for the wells located between the lines of dewatering and recharge wells, and, thus, it is not possible to assess changes in dieldrin concentrations in this area. A concentration of 0.6 ppb was found in well 27016 during the 2nd quarter of FY86.

119. During the 3rd quarter of FY86, the concentration of dieldrin in the dewatering wells associated with the hydraulic dewatering system increased. Very little data were available in Section 27 for this quarter, and, thus any changes in distribution could not be assessed. By the 4th quarter of FY86, the concentrations in the dewatering wells associated with the hydraulic barrier had again decreased. Available data in the area between the lines of dewatering and recharge wells indicate that the dieldrin concentration had decreased by this time period.

120. Comparing the dieldrin distribution plots over time indicates that the shape and size of the area of distribution in Section 27 has changed little. The dieldrin concentrations north of the slurry wall have decreased and are approaching the detectable level. Concentrations of dieldrin in the dewatering wells associated with the hydraulic barrier generally decreased to below detectable levels by the end of FY86.

Chloride

121. The chloride isoconcentration maps are presented as Plates 55 through 65. Concentrations of chloride in the study area range from less than 100 ppm to approximately 4000 ppm. Concentration contours of 250, 500, 1000, 2000, and 3000 ppm are shown on each isoconcentration map as needed. The chloride distribution exhibits the characteristic "dogleg" shape in the study area stretching from the southeast corner of Section 27 northwestward to the center of the Section and then north to the Arsenal boundary. Elevated concentrations of chloride (above 100-150 ppm background levels) were also found north and east of the slurry wall alignment. The distribution of the chloride in

these two areas is difficult to evaluate due to high variability of the hydrology and the resulting lack of available data.

122. Available data from the 4th quarter of FY81 indicates elevated chloride concentrations in the southeast corner of Section 27, along the boundary at well 22005, and east of the system area at well 22001. Additional data available during the 3rd quarter of FY83 provide a better definition of the distribution. Concentrations ranging from 500 to 1000 ppm were found in the northern half of Section 27 stretching north across the system area to the boundary. A chloride concentration of 2000 ppm was found associated with well 22001 while a concentration of 800 ppm was found associated with well 27016. During the 3rd quarter of FY84, the concentrations in the southeast corner of Section 27 and the southwest end of the system area increased. Chloride concentrations associated with wells 22001 and 27016 decreased.

123. The chloride distributions during the 1st and 2nd quarters of FY85 were very similar to that found during the 3rd quarter of FY84. The concentration found associated with well 22001 increased through both quarters. During the 2nd quarter, the chloride concentrations associated with the dewatering wells along the hydraulic dewatering system decreased slightly probably as a result of the dilution caused by system operation. The concentrations in these dewatering wells continued to decrease during the 3rd quarter of FY85. In addition, concentrations associated with the wells along the boundary (i.e. well 37-332) decreased during the 3rd quarter as recharged water from the system began to affect a dilution of the chloride in the area. A chloride concentration approaching 4000 ppm was reported for a sample from well 27016 during the 3rd quarter. This concentration was much higher than those found before and after this sampling period. The distribution and chloride concentrations found during the 4th quarter of FY85 were very similar to the 3rd quarter.

124. The limited data available in the 1st quarter of FY86 indicated a distribution very similar to that found in the previous two quarters. Chloride concentrations north of the slurry wall continued to decrease. During the 2nd quarter of FY86, chloride concentrations in the center of Section 27 associated with the distribution increased to approximately 1000 ppm. The limited data available for the 3rd and 4th quarters of FY86 indicate a distribution very similar to the 1st and 2nd quarters.

125. Comparing the chloride distribution plots over time indicates that the shape and size of the area of distribution south of the system has changed little. The chloride concentrations north and west of the slurry wall alignment have decreased significantly over the study period.

Fluoride

126. The fluoride isoconcentration maps are presented as Plates 66 through 76. Concentrations of fluoride in the study area range from less than 1 to 11 ppm. Concentration contours beginning with 1 ppm in 1 ppm increments are shown on each isoconcentration map as needed. The fluoride distribution does not exhibit the strict "dogleg" shape in the study area as do the other contaminants. The highest concentrations of fluoride are generally found north of the NWBCT system area along the boundary and associated with well 27016. Background concentrations in the range of 1 ppm can be expected on the Arsenal.

127. The limited data available for the 4th quarter of FY81 indicate the highest fluoride concentration associated with well 22004 at the boundary. Concentrations in Section 27 were all at or below 2.5 ppm. During the 3rd quarter of FY83, fluoride concentrations at the north end of the system were in the 4 to 5 ppm range and 2 to 3 ppm range on the south end of the system. A fluoride concentration in excess of 6 ppm was found associated with well 27016. The distribution found in the 3rd quarter of FY84 was very similar to that found in FY83. A sample collected from well 22051 was found to have a concentration of 5 ppm.

128. The fluoride distribution found during the 1st and 2nd quarters of FY85 were very similar to that found in the 3rd quarter of FY84. By the 3rd quarter of FY85, the concentration north of the system had increased to 7 ppm. The other concentrations found were similar to the previous quarter. By the 4th quarter of FY85, the fluoride concentration north of the system had decreased to approximately 3 ppm. A concentration of 11 ppm was found associated with well 27016.

129. The limited data available for the 1st quarter of FY86 indicated very little change from the previous quarter. The same was true for the 2nd quarter of FY86 except that fluoride concentrations in the dewatering wells upgradient of the slurry wall increased somewhat from the last quarter of FY85. During the 3rd quarter of FY86, the fluoride concentrations north of the system and those associated with the dewatering wells generally decreased.

Concentrations north of the system continued to decrease during the 4th quarter of FY86. The dewatering wells associated with the northeast end of the hydraulic dewatering system were found to have increased fluoride concentrations during this period. Concentrations associated with wells in Section 27 stayed fairly constant.

130. Comparing the fluoride distribution plots over time indicates that the fluoride concentrations in Section 27 have remained fairly constant through time. The areas north and west of the slurry wall alignment that originally had fluoride concentrations in the 5 to 7 ppm range were found to have concentrations of approximately half that amount at the end of the study period. This probably resulted from the recharge of the treatment plant effluent containing lower fluoride concentrations due to dilution in the treatment system.

## PART V: CONCLUSIONS AND COMMENTS

### Geology and Hydrogeology

131. Conclusions about geology, ground water, and system operations effects on ground water are given below:

a. Ground-water contours indicate that, at current operating rates (FY 86), the NWBCT System is effectively intercepting ground-water flow moving toward the system in the alluvium. By the end of FY86, ground-water contours and profiles indicate that ground-water levels have stabilized and a consistent and effective reverse gradient has been established along the hydrological control portion of the system.

b. Primary ground-water flow and contaminant transport in the Northwest Boundary study area are in the alluvial sand and gravel aquifer overlying the Denver formation. The aquifer is from 5 to 20 feet thick in the study area. Transmissivities in the aquifer range from 33,000 gpd/sq ft to 405,000 gpd/sq ft. Primary ground-water flow directions are west, northwest, and north.

c. Ground-water flow is influenced by the shape of the buried rock (Denver formation) surface. The potentiometric lines roughly parallel the rock surface contour lines. Greatest saturated thicknesses of the alluvial aquifer occur in the paleochannel cut in the Denver Formation surface. A primary contaminant pathway is coincident with two intersecting alluvium-filled paleochannels in the Denver surface.

d. Three distinct levels of the alluvial sand and gravel aquifer units occur in the study area. The "lower sand" lies between elevation 5066 feet and 5107 feet, the "middle sand" between 5104 feet and 5136 feet, and the "upper sand" above 5140 feet. Greatest saturated thicknesses occur in the lower sand. The three sand sub-units are interpreted to be depositional terraces deposited during succeeding cycles of erosion and deposition by ancient streams. The sub-units are probably discontinous down-slope and continuous along the trend of the rock-cut terraces.

e. The large Denver valley in the western part of Section 27 is the major route of ground-water flow toward the system.

f. Beyond 1500 feet upgradient from the system, ground-water levels have remained stable during the period of this study (FY 81-86). Seasonal precipitation fluctuations have small effects on the ground-water levels for FY 85 and 86. Because of the small magnitude of the seasonal changes, they do not appear to appreciably affect the system operation at flow rates occurring during the study period.

g. There is an apparent area of lower transmissivity across the system recharge line between recharge wells 412 and 417. The higher gradients along the recharge line in this area and the geologic section, Plate 4, support this interpretation. The pre-system contour maps, Plates 14, 15, and 16 show a similar trend though of less magnitude.

## Water Quality and Treatment System

Conclusions about the ground-water quality and performance of the treatment system are as follows:

a. The NWBCT System is effectively reducing the off-post migration of contaminated ground water in the alluvial aquifer. Historical data indicate a downward trend in contaminant concentrations downgradient of the system over the period of operation of the system.

b. The available data indicate that the control system is intercepting all of the contaminants in the alluvial aquifer migrating toward the system.

c. The treatment system is effectively removing organic contaminants (DBCP, DIMP, DCPD, aldrin, endrin, dieldrin and isodrin) from the influent to the system. The water being recharged contains no levels of the referenced organic contaminants above detectable levels. Inorganic contaminants such as chloride and fluoride are not removed by the treatment system.

d. The concentrations of contaminants in the dewatering wells (and in the corresponding influent to the treatment plant) are significantly lower than what was predicted based on historical ground-water investigations. This is attributed to dilution resulting from the recycling of water along the hydraulic dewatering system and from the quantity of relatively clean water intercepted by the system adjacent to the slurry wall.

e. The alterations and repairs conducted during FY85 and FY86 resulted in a marked improvement in the operational reliability of the NWBCT System.

*f.* Review of the data bases for the NWBCT operational assessment has indicated a lack of sufficient ground-water definition and control to properly define both the geohydrology and ground-water quality upgradient and immediately north of the system. Monitoring of existing wells and installation of new monitoring wells are needed for comprehensive assessment of the operational effectiveness of the NWBCT system.

## COMMENTS

This evaluation indicates the need to improve the ground-water monitoring upgradient and north of the NWBCT system. Additionally, the Program Manager for RMA Contamination Cleanup as part of Tasks 25 and 44 has identified areas in the vicinity of the system that require additional monitoring and ground-water well installation or replacement. In response to these findings, the PM, RMA has initiated work as part of the monitoring programs at RMA. The following specific tasks are in progress.

1. Task 25 has conducted ground-water monitoring of the alluvial and Denver aquifers for the NW boundary system through December 1987.

2. The installation of new or replacement monitoring wells in the NW boundary area is being conducted as part of the composite well program for Tasks 25 and 44. The installation of monitoring wells is based on the technical program requirements of all ground-water monitoring tasks. New monitoring wells are incorporated into the monitoring program as they become available.

3. The Comprehensive Monitoring Program (CMP) will conduct all ground-water monitoring in support of the NW Boundary System starting in 1988. Installation of additional monitoring wells as required for detailed assessment of the system is part of this program.

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