REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	10/00/79	

4. TITLE AND SUBTITLE
BASIN F TO THE NORTH BOUNDARY AREA, ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO
Vol II

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MS

8. PERFORMING ORGANIZATION REPORT NUMBER
81266R19

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ROCKY MOUNTAIN ARSENAL (CO.)
COMMERCE CITY, CO

DTIC ELECTE JAN 23 1995 S B D

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

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

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

VOL I: THIS STUDY WAS MADE TO PROVIDE A DETAILED DEFINITION OF THE GEOLOGY AND GROUND WATER IN THE ALLUVIUM BETWEEN BASIN F AND THE NORTH BOUNDARY. THE STUDY AREA INCLUDES RMA SECTIONS 23, 24, 19, 26 & 25. THREE SPECIFIC QUESTIONS ARE ADDRESSED IN THIS STUDY: 1. WHAT ARE THE HYDROGEOLOGICAL CHARACTERISTICS OF THE ALLUVIAL AQUIFER FROM BASIN F TO THE NORTH BOUNDARY? 2. WHAT ARE THE LOCATIONS, MOVEMENTS & CONCENTRATIONS OF VARIOUS POLLUTANTS IN THE ALLUVIAL AQUIFER? 3. ARE FIRST CREEK, THE SEWAGE LAGOON, SANITARY SEWER LINE AND DEEP WASTE INJECTION DISPOSAL WELL POLLUTION SOURCES CONCURRENT WITH THIS STUDY, A CONTAMINANT IDENTIFICATION & MIGRATION STUDY WAS PERFORMED. THE RESULTS OF THAT STUDY ARE SUBMITTED SEPARATELY IN "BASIN F TO THE NORTH BOUNDARY, VOL II: GROUNDWATER ANALYSIS II VOL II PRESENTS ANSWERS TO QUESTIONS 2 AND 3 ABOVE. (SEE # 81352M045).

19950118 040

14. SUBJECT TERMS
GROUNDWATER, CHEMICALS, SEWAGE, GEOLOGIC CONDITIONS

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED			

61

81266R19
VOLUME II
1ST COPY

BASIN F TO THE NORTH BOUNDARY AREA
ROCKY MOUNTAIN ARSENAL, DENVER, COLORADO
VOLUME II: GROUNDWATER ANALYSES

DRAFT REPORT

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October 1979

Prepared for

Rocky Mountain Arsenal
Commerce City, CO 80222

WORKING DRAFT

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PART I: INTRODUCTION AND BACKGROUND

Introduction

1. In recent years, environmental controls on waste disposal activities have significantly increased, and pollution resulting from waste disposal activities has come under increasing public scrutiny. Disposal practices that were acceptable at the time of utilization have been found to be inadequate for environmental protection over extended periods of time. This problem has particular significance to military facilities where wastes stemming from manufacture of military materiel have been buried for years. In order to manage and contain pollutants potentially migrating from old or abandoned disposal facilities, the Department of Defense established a program of Installation Restoration under the Department of the Army. This program was designed to survey potential problem sites, quantify the pollution problem at each site, and institute remedial measures as required. The program developed rapidly and is now being directed by the U. S. Army Toxic and Hazardous Materials Agency (USATHAMA) at Aberdeen Proving Ground, Maryland.

2. One of the initial sites identified as having a potentially significant problem was Rocky Mountain Arsenal (RMA) near Denver, Colorado. Preliminary investigation revealed widespread groundwater pollution that could be related to past disposal activities at the arsenal. As intensive pollution containment program was initiated along with further action to define and quantify the sources of pollution. The U. S. Army Engineer Waterways Experiment Station (WES) at Vicksburg, Mississippi, was tasked to conduct a detailed contamination survey and identify the sources of pollution. This work was initiated in the summer of 1978 on the Basin A study area followed by work in the Basin A Neck and Basin F to North Boundary study areas. The results of the work in the Basin A and Basin A Neck study areas have been presented in previous reports.* The results of the work in the Basin F to North

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* "Rocky Mountain Arsenal Basin A Groundwater Quality Analysis" and "Basin A Neck Area, Rocky Mountain Arsenal Contamination Survey."

Boundary study area are presented in this report.

Background

3. RMA occupies 1700 acres in Adams County, Colorado, 10 miles northeast of center-city Denver, and is immediately north of Denver's Stapleton International Airport (Figure 1). The arsenal was established in 1942, and from that time until the present has had missions relating to the manufacture, assembly, and demilitarization of military chemical materiel. Also, starting in 1946, certain portions of the arsenal were leased to private industry for chemical manufacturing. Since 1952 Shell Chemical Company has been the major lessee, engaging in the manufacture of various pesticides at the arsenal. Thus, since its inception, RMA activities have largely been in the areas of military and commercial industrial chemical projects.

4. The wastes from these chemical facilities were disposed on the arsenal. In the early years of arsenal operations, 1942-1956, the wastes were disposed in unlined basins. The primary disposal area was a basin just north of the original plants area, referred to as Basin A. This basin received the majority of industrial wastes discharged from all Government and lessee operations up to 1956. Use of this disposal area was terminated when a new lined disposal area (Basin F) was put into operation in 1956. As a result of complaints of groundwater pollution due to waste disposal at the arsenal, groundwater studies were conducted by a consulting engineering firm, the U. S. Geological Survey, and the University of Colorado, which confirmed some groundwater pollution. Thus, the lined basin was constructed. From 1956 to 1978, this basin was used for all industrial waste disposal. In 1978, Shell Chemical Company terminated use of the basin and the Army has plans to develop a treatment complex for RMA wastes, presently being discharged to the Basin F. Use of the basin should be completely terminated by 1980.

5. Minor waste disposal activities were also pursued at other unlined basins on the arsenal but these activities were minor compared to the use of Basins A and F.

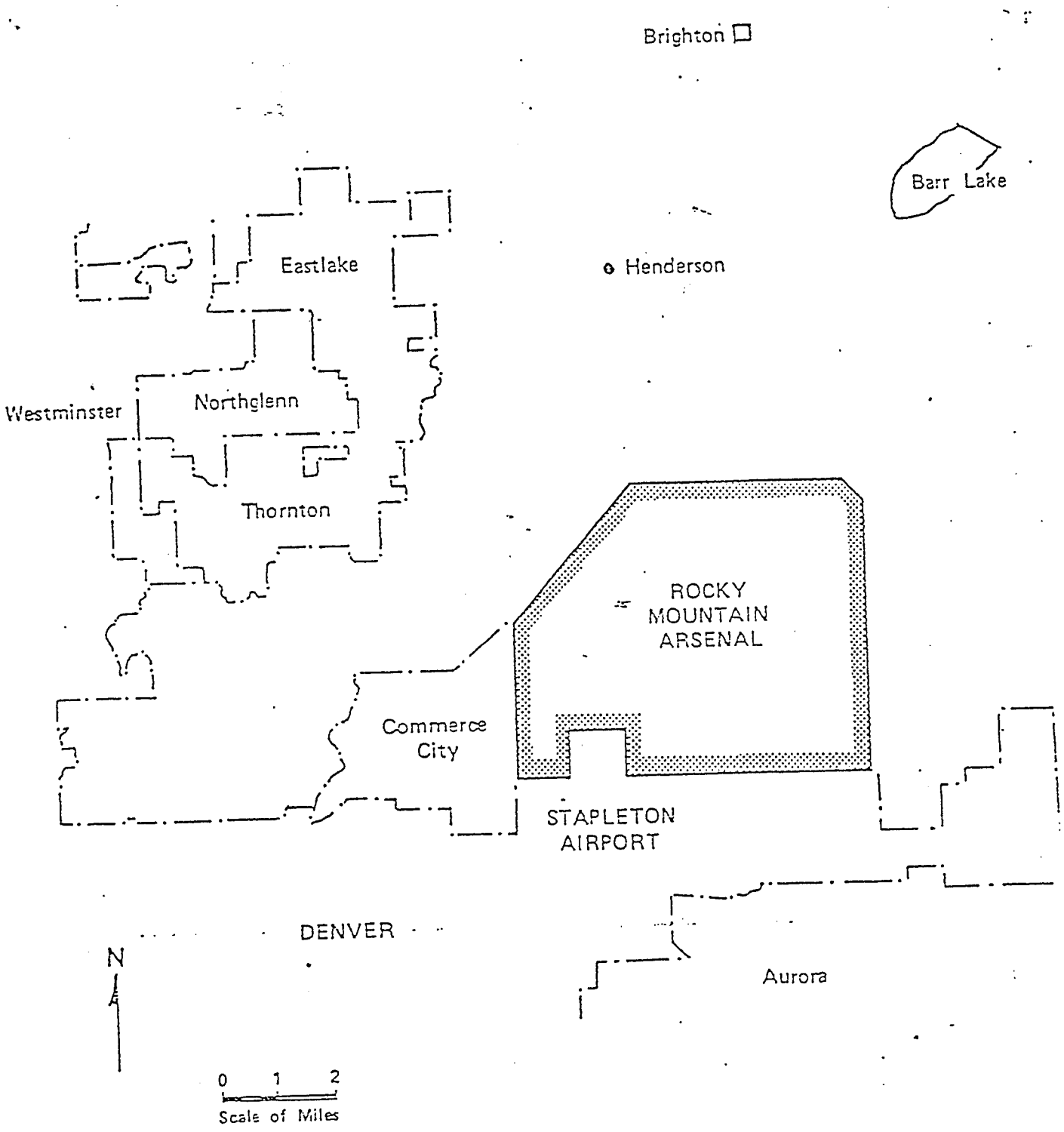

Figure 1. MAP OF RMA – DENVER VICINITY

6. Due to the waste disposal history at RMA and previous survey,* Basin F was identified as one of the potential areas of continuing pollutant discharge to the groundwater systems. The direction, and concentrations of these migrating pollutants in the groundwater was not known. Quantification of these parameters was needed so that the significance of Basin F as an active pollution source could be determined. Also of interest was the distribution of contaminants along the northern boundary of RMA where an interim barrier and treatment system are to be expanded to stop the migration of contaminants off the Arsenal. In order to quantify the unknown conditions, a coordinated geologic, groundwater, and water quality investigation for the Basin F to North Boundary study area was developed and implemented. Existing data were reviewed and additional sampling wells, as required, were installed. The specific objective of this work was to quantify the degree and extent of contaminant migration in the alluvial aquifer from Basin F to the North Boundary of RMA. The results and a discussion of this work are included in this report.

* "Basin F Investigative Studies - Chemical Assessment and Survey and Historical Review."

PART II: DATA COLLECTION AND REDUCTION

7. The work conducted in the Basin F to North Boundary contamination survey was a joint effort between the Geotechnical and the Environmental Laboratories at the WES. The determination and assessment of geologic conditions within the study area as well as the evaluation of groundwater flow conditions was done by the Geotechnical Laboratory. The development of a water quality monitoring program, sampling strategy, and reduction of water quality data, as well as integration of these data with groundwater flow conditions, was the responsibility of the Environmental Laboratory. The geology of the area and the groundwater flow characteristics are discussed in detail in the report: "Geotechnical Definition: Basin F to North Boundary." The data contained in that report are integral to the discussion contained herein and, as required, have been reproduced in this report.

8. Groundwater sample collection for chemical analysis was initiated in the Basin F to North Boundary area in April 1979, and completed in August 1979. The groundwater sampling well locations are shown in Plate 1. The samples were collected in accordance with the sampling plan used in the Basin A and Basin A Neck studies (Appendix A). Once collected, the samples were delivered to the Materials Analysis Laboratory Division (MALD) at RMA for preparation and analysis. All samples were delivered to the MALD the same day they were collected from the field. The analytical procedures used by the MALD for the various contaminants, as well as the quality control program employed by the MALD are not presented in this report but are on record at RMA.

9. The schedule for sample collection and analysis was primarily determined by the capacity of the MALD. Also, during brief periods, sampling was suspended because of weather conditions and to obtain groundwater level measurements throughout the study area. Individual sample results and collection data such as date, well number, screen location, and laboratory identification number have not been reproduced in this report due to the volume of these data. This information is contained in the appropriate files of the data management system for the RMA program.

10. The primary objective of the Basin F to North Boundary contamination survey was to develop a detailed understanding of the groundwater flow and contaminant movement in the upper water-bearing zone, termed the alluvial aquifer. Consistent with this objective, the major emphasis for field sampling and the resulting data density were toward the shallow-water unit. Sampling and analysis of water from deeper units in this area is ongoing and the results of this work will be presented in a later report. The chemical data for all contaminants were plotted on plan maps as well as geologic cross-sectional maps. A minimum of two samples were obtained from each sampling well. Each set of analytical data was compared for consistency prior to final analysis. The compiled data for each contaminant from each sampling well were averaged. These averaged values were plotted on plan maps, and contaminant concentration contour maps (isoconcentration maps) were constructed. The contour lines represent large area extrapolations of the averaged data thus providing general distributions of the contaminants in this area. Not all contaminants listed for analysis in Appendix A were mapped. The contaminants found in sufficient quantities in the study area to warrant evaluation are listed in Table 1. These contaminants were mapped and are discussed in detail in this report.

Table 1

Contaminants Found in the Basin F to North Boundary Study Area

Chloride	Endrin
DBCP	Fluoride
DCPD	O-sulfide
Dieldrin	O-sulfoxide
DIMP	O-sulfone
Dithiane	Oxathiane

11. Groundwater flow data were obtained from the WES Geotechnical Laboratory. The groundwater elevation map, Figure 2, indicates a general groundwater flow in Section 23 from Basin F northeast to the north boundary of RMA. Flow in Section 24 originates in the southeast corner of the section and moves northwest to a point where the elevation lines become parallel with the north boundary. There is indication from these data and other geotechnical data of an old channel running northeast from Section 26 to the north boundary. As will be shown in this report, the channel provides an easy route of migration for contaminants out of the Basin F area. The average groundwater flows for this area are given in Table 2. The groundwater flow and flux diagrams were developed along three separate lines (A-A', B-B', and C-C') as indicated in Plate 1. The flow across each line was further divided into zones which are also shown in Plate 1. Flux diagrams were developed only along the lines where contaminants were found. The flux quantities are given in mass per ft per day. The total flux is given by the area under the line between the wells of interest.

12. The data used in the development of the isoconcentration maps and the contaminant flux diagrams were collected over a short period of time. For this reason, the analytical results for each contaminant were averaged which produces a single picture in time of the general distribution of the various contaminants within the study area. Data collected by RMA during other past and ongoing studies were evaluated with data from this study to determine historical trends concerning the migration of contaminants in the Basin F to North Boundary area. These trends will be discussed later in this report. The data collected in this study provide a baseline that can be used along with historical data and continuous monitoring, to predict and define long-term contaminant migration patterns in this area of RMA.

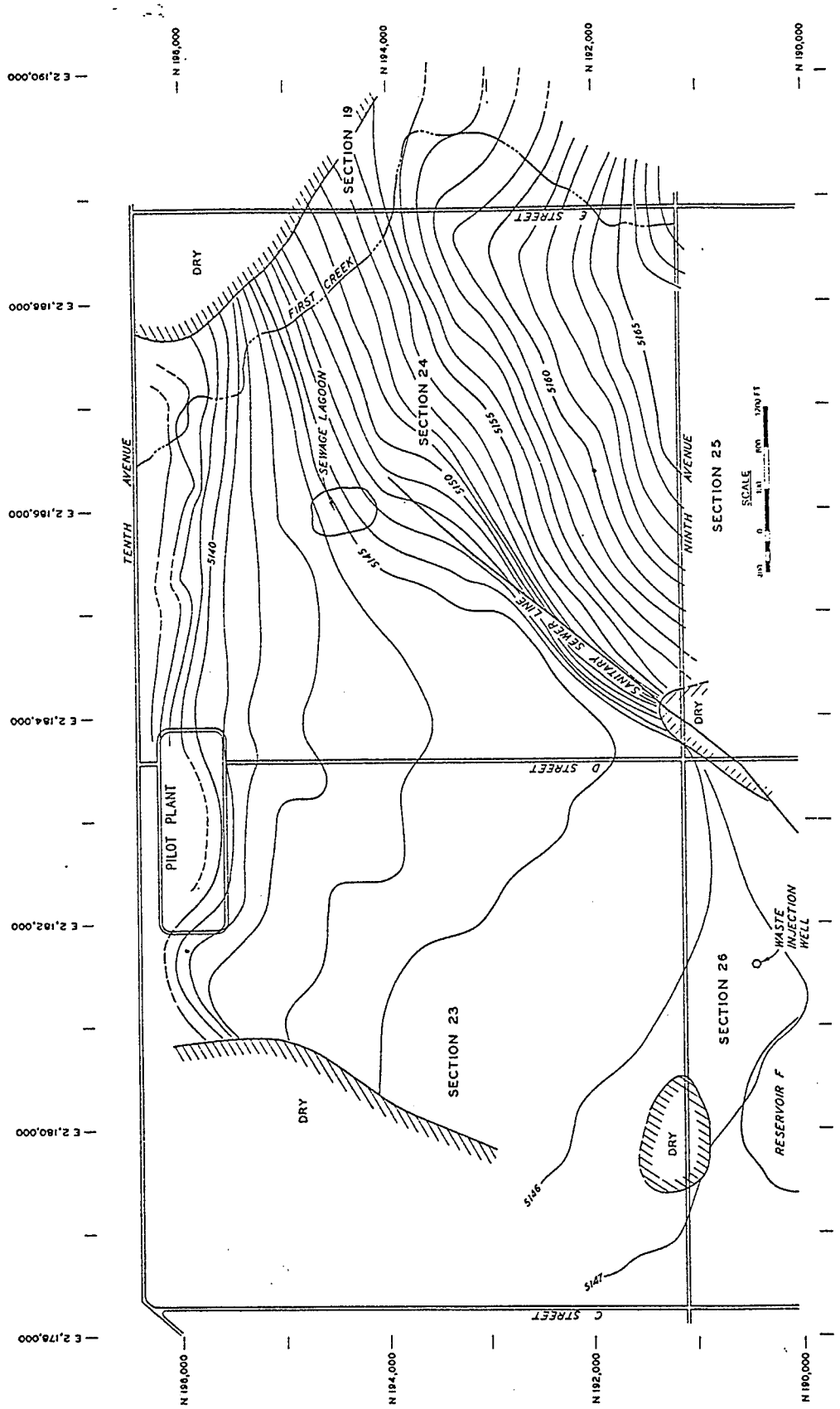

Figure 2. Groundwater Elevation Contour Map: Basin F - North Boundary Study Area

Table 2

Summary of Flow Rates, Areas, and Velocities - Basin F to North Boundary

Section	Zone	Flow litre/d × 10^3	Area m^2	Velocity cm/d
A-A'	1	354.31	1839.4	19.2
	2	1.33	455.2	0.3
	3	18.17	873.3	2.1
	4	314.19	5462.5	5.8
	5	13.44	1811.6	0.6
B-B'	1	64.73	1690.8	4.0
	2	108.07	2081.0	5.2
	3	287.69	2238.9	12.8
	4	48.07	1170.5	7.0
	5	753.11	3604.5	21.0
	6	105.99	994.0	10.7
C-C'	1	5.68	483.1	1.2
	2	335.01	826.8	40.5
	3	729.07	1217.0	60.1
	4	2276.93	2173.9	104.9

PART III: CONTAMINANT DISTRIBUTIONS

13. As detailed in the previous discussion, the contaminants listed in Table 1 were mapped and flux diagrams were constructed where applicable. Aldrin and Isodrin concentrations in the study area were found to be below detectable levels and therefore no discussion of their distribution was included in this report. The discussion of the remaining contaminants includes historical disposal information and contaminant distribution and migration patterns. The rates of movement of each of the contaminants will be addressed in Part IV of this report.

Chloride

14. Chloride waste in the form of sodium chloride was disposed of in Basin F since construction of the basin in 1956. This waste was generated by both the Army and Shell Chemical Company over a period of years. High concentrations of chloride were found migrating out of the Basin A area in previous studies. Groundwater in Sections 23 and 26 in the Basin F to North Boundary study area was found to contain high concentrations of chloride as indicated on the isoconcentration map presented as Plate 2. A large plume is evident exiting the northeast corner of Basin F. Chloride concentrations in excess of 4000 mg/ℓ were found in several wells in this area. It appears that the leading edge of the plume is at the B-B' well line. High chloride concentrations were found in many of the wells surrounding Basin F. These concentrations are probably the result of direct chloride migration from Basin F and additional migration from the other basins south of Basin F. It should be noted that wells west of Basin F were found to contain chloride concentrations of 1000 mg/ℓ which may indicate some migration in that direction.

15. A secondary plume or high was found in the north central part of Section 23. This area is west of the existing interim pilot system in an area where very little alluvial groundwater was found. The soil permeabilities in this area are low compared to other areas

farther east. For these reasons, it appears that the chloride found in this area is a residual from historical migration at a time when groundwater elevations were higher along the C-C' line. Probably at that time, contaminated groundwater slowly migrated into this low permeability area. This water was left in the area after the groundwater level fell.

16. Chloride concentrations found over most of Section 24 appear to be essentially background concentrations. The plume originating from Basin F is apparent only on the west edge of Section 24.

17. Chloride flux diagrams were constructed for all three lines and are presented as Plates 14, 15, and 16. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. As indicated in Table 2, the groundwater flow increases substantially from line A-A' to B-B' to C-C'. This results from an inflow of relatively clean water to the east side of the study area. This inflow prevented the development of a mass balance for the contaminants, particularly in the case of chloride where a background concentration exists. However, the total chloride flux decreases between lines A-A' and B-B' illustrating that the chloride plume is crossing line A-A' and moving toward line B-B'. The total flux across line C-C' is approximately equal to the flux across line A-A' as a result of background concentrations of chloride in the water flowing into the area from the east. The significance of this flux can be seen in the flux diagrams by noting the relative areas of flux east of Well 378 on line A-A', east of Well 122 on line B-B', and east of Well 196 on line C-C'. These contributions to the total flux are all due to background concentrations.

18. The chloride flux across the A-A' line north of Basin F can be expected to increase somewhat as the plume continues to move northward. The actual chloride concentration in the groundwater may vary as the amount of infiltration or leakage from Basin F varies and as the groundwater flow under Basin F varies. The chloride flux will eventually cross line B-B' and migrate north with the groundwater flow. The concentrations observed will probably decrease due to dilution by the additional groundwater flow moving northwest from Section 24.

DBCP

19. DBCP (Nemagon), a soil fumigant used for nematode control, was produced by Shell Chemical from 1955 through 1975. Traces of this pesticide from tank washout were disposed of in Basin F. Nemagon has also been found in the sanitary sewer system at RMA. A concentration distribution map, Plate 3, was prepared for Nemagon. No isoconcentration lines were constructed due to the scattered nature of the data. Average concentrations above the detection limit are noted for each well. The highest concentrations of Nemagon were found in wells in the northwest corner of Section 24. Several wells in this area were found to contain concentrations of Nemagon in excess of 30 µg/ℓ. As indicated in the map, lower concentrations of Nemagon were found in a string of wells south through Section 23 towards Basin F. Concentrations of Nemagon in perimeter wells on the northeast corner of Basin F were found to be close to the detection limit. This indicates that Basin F is not currently a source of Nemagon contamination in this area. Also, analysis of Basin F liquid has shown the current concentration of Nemagon to be less than 20 µg/ℓ. This differs from the conditions found associated with chloride, DIMP, and several other contaminants. Concentrations of Nemagon above the detection limit were found in several perimeter wells on the east side of Basin F.*

20. No contaminant flux diagrams were developed for Nemagon due to the very limited distribution found for the contaminant. Flux quantities were calculated and are presented in Tables 3, 4, and 5. Since the highest concentrations of Nemagon found are north of the B-B' line, Nemagon concentrations in wells along the C-C' line just east of the existing interim system can be expected to remain in the same concentration range until such time as the main slug of this contaminant migrates north past the C-C' line. Nemagon concentrations

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* It should be noted that the sediment in Basin F near the chemical sewer discharge (southeast corner) contains a high concentration of Nemagon.

Table 3

Summary of Contaminant Flux: Line A-A'

Zone	Cl Kg/d	Sulfone g/d	Sulfoxide g/d	DBCP g/d	DCPD g/d	DIMP g/d	Dith g/d	Dldrn g/d	Endrn g/d	F g/d	Oxat g/d	Sulfide g/d
1	435.1	32.19	--	1.17	13.83	256.55	7.28	0.72	0.64	915.5	1.44	23.4
2	--	--	--	--	--	--	--	--	--	2.2	--	--
3	0.3	--	--	--	--	3.67	--	--	--	29.0	--	--
4	30.3	1.36	--	--	--	2.56	--	--	--	442.9	--	--
5	1.5	--	--	--	--	--	--	--	--	15.4	--	--
Total flux	467.2	33.55	-0-	1.17	13.83	262.78	7.28	0.72	0.64	1405.0	1.44	23.4

Table 4

Summary of Contaminant Flux: Line B-B'

Zone	Cl Kg/d	Sulfone g/d	Sulfoxide g/d	DBCP g/d	DCPD g/d	DIMP g/d	Dith g/d	Dldrn g/d	Endrn g/d	F g/d	Oxat g/d	Sulfide g/d
1	24.8	0.24	--	--	0.12	97.66	0.77	0.02	0.05	220.1	--	--
2	31.7	3.85	1.42	0.11	38.88	56.85	1.85	0.36	0.46	453.5	--	2.0
3	42.7	9.17	9.37	0.73	60.10	50.42	1.27	0.54	0.43	797.0	--	7.6
4	4.2	--	--	--	--	1.47	--	--	--	71.9	--	--
5	79.6	--	--	--	--	10.31	--	--	--	1024.0	--	--
6	12.0	--	--	--	--	0.54	--	--	--	167.8	--	--
Total flux	195.1	13.26	10.79	0.84	99.10	217.25	3.89	0.92	0.95	2734.3	-0-	9.6

Table 5

Summary of Contaminant Flux: Line C-C'

Zone	Cl Kg/d	Sulfone g/d	Sulfoxide g/d	DBCP g/d	DCPD g/d	DIMP g/d	Dith g/d	Dldrn g/d	Endrn g/d	F g/d	Oxat g/d	Sulfide g/d
1	1.7	--	--	--	--	9.12	0.04	--	--	23.7	0.01	--
2	17.9	6.69	8.27	0.25	18.77	821.10	6.37	--	0.25	1322.4	0.02	5.7
3	150.8	7.11	66.31	3.11	106.06	265.70	1.19	1.24	1.23	2307.0	1.68	61.2
4	263.2	5.23	--	--	--	107.88	--	--	--	3856.0	--	--
Total flux	433.6	19.03	74.58	3.36	124.83	1194.80	7.60	1.24	1.48	7509.1	1.71	66.9

should then decrease since only lower concentrations were found in wells south of the B-B' line. The data indicate that Basin F is no longer a source of input of high concentrations of Nemagon to the groundwater systems.

DCPD

21. DCPD (Dicyclopentadiene), a process intermediate in the production of Aldrin, Dieldrin, and Endrin, was disposed of at RMA by Shell Chemical Company from 1952 to 1974. After the construction of Basin F, this waste was continuously disposed of there. DCPD is a difficult compound to sample reliably and consistently since it volatilizes and oxidizes when in contact with the atmosphere. In the sampling procedure used in this study, some DCPD may have been lost between sample collection and analysis. A concentration distribution map, Plate 4, was prepared for DCPD. No isoconcentration lines were constructed due to the scattered and inconsistent nature of the data. Average concentrations above the detection limit are noted for each well. Significant concentrations of DCPD were found in wells scattered along a line running northeast from Basin F to just east of the dividing line between Sections 23 and 24, and then turning north to the C-C' line. Concentrations of DCPD above 1000 µg/ℓ were found in certain wells all along this line. The varying distribution found for DCPD contamination could be due to the problems associated with sampling and analysis of the contaminant, although concentrations found in replicate samples were for the most part consistent.

22. DCPD flux diagrams were constructed for all three lines and are presented as Plates 17, 18, and 19. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. As indicated, the total flux for each line increases from line A-A' to line C-C'. This trend is misleading since the wells containing the highest concentrations of DCPD are not located on these lines. The flux across line C-C' can be expected to increase as the DCPD found in high concentrations south of line C-C' continues to migrate north, although

the actual concentrations may decrease due to the inflow of clean water through Section 24. The flux across line B-B' will probably remain somewhat constant for some time as DCPD migration appears to be continuing northeast from Basin F.

23. It appears evident from the data collected in this study that Basin F is the source of DCPD contamination in the alluvial aquifer in this area of RMA and that DCPD is migrating northeast from the basin. There are certain inconsistencies associated with this scenario. First, no significant concentrations of DCPD were found in Basin F perimeter wells except in those located at the northeast corner of the basin. Next, previous analyses of the Basin F liquid have indicated DCPD concentrations of less than 10 µg/ℓ, much lower than those found in the groundwater analyses. Therefore, it can be theorized that the DCPD must be being leached into the groundwater from sediment or soils in Basin F that contain high concentrations of DCPD. This cannot be verified from the existing data.

Dieldrin

24. Dieldrin, a chlorinated hydrocarbon insecticide, was produced by Shell Chemical Company from 1952 to 1973. Wastes from the production process were disposed of in Basin F after its construction. An isoconcentration map of the distribution of Dieldrin in the study area was developed and is presented in Plate 5. As indicated, the area of highest concentration of Dieldrin north of Basin F was found in a series of wells on a line between B-B' and C-C'. This appears to be the trailing edge of a plume crossing the C-C' line stretching back to Basin F. Lower concentrations of Dieldrin were found in wells southwest of line B-B' toward Basin F. The overall area of contamination has a "dogleg" shape as found with most of the contaminant distributions. The concentrations of Dieldrin found in perimeter wells along the northeast corner of Basin F indicate that the basin is still providing a source of Dieldrin contamination to the alluvial groundwater system.

25. High concentrations of Dieldrin were found in perimeter wells along the southeast corner of Basin F. Historical data have indicated that significant quantities of pesticides were dumped in the southeast corner of Basin F through the years. The basin sediments in this area are probably providing a high concentration source of Dieldrin which is being leached into the groundwater.

26. Flux diagrams for Dieldrin were developed for all three lines and are presented as Plates 20, 21, and 22. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The total flux values across lines A-A' and B-B' are comparable. The total flux across line C-C' is somewhat higher indicating the movement of the mass of the plume across this line. The flux across line C-C' can be expected to remain fairly constant until such time as the mass of the Dieldrin contamination has migrated north from the B-B' line and crosses the C-C' line. The flux across the B-B' line will probably decrease slightly with time as will the flux across the A-A' line. This is as a result of the slow decrease in the amount of Dieldrin being released to the alluvial groundwater system by Basin F.

DIMP

27. DIMP (diisopropylmethylphosphonate) contamination at RMA is reportedly due to the disposal of wastes from chemical warfare agent manufacturing. Wastes from this process were originally disposed of in Basin A and later transferred to Basin F after its construction. DIMP contamination has been found in groundwater samples taken in many areas of RMA. An isoconcentration map of DIMP distribution in the study area is presented in Plate 6. A plume is evident exiting the northeast corner of Basin F similar to the chloride plume. Concentrations of DIMP in excess of 3000 µg/ℓ were found in this area. Another area of high DIMP concentration was found in the northeast corner of Section 23 near the existing interim treatment system. This area appears to contain the trailing edge of a plume migrating to the north across C-C'. DIMP concentrations in excess of 1000 µg/ℓ were found in

wells extending from Basin F to the C-C' line located in Section 23.

28. Low concentrations of DIMP, generally less than 50 µg/ℓ were found in a number of wells in Section 24. The source of this contamination is not apparent from the existing data. Concentrations of DIMP in excess of 1000 µg/ℓ were found in several perimeter wells around Basin F indicating a potential migration of DIMP in several directions away from the basin.

29. Contaminant flux diagrams for DIMP were prepared for all three lines and are presented in Plates 23, 24, and 25. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The flux calculated for the interim standard of 500 µg/ℓ is also indicated on the flux diagrams. The total DIMP fluxes across lines A-A' and B-B' are comparable. The total flux across line C-C' is significantly higher due to the plume presently crossing the line. It should be noted from the flux diagrams that the total allowable flux is higher than the existing flux. The significance of this situation will be discussed later in this report. The flux values across line A-A' and B-B' can be expected to increase in the future as the plume exiting Basin F continues to migrate northeast. The flux across line C-C' can be expected to decrease in the near future with the passage of the trailing edge of the plume associated with that area. The flux will then increase again as the plume now exiting Basin F approaches the C-C' line.

30. The data collected in this study indicate that Basin F is continuing to provide a source of DIMP contamination to the alluvial groundwater in the Basin F to North Boundary area. Recent analysis of Basin F liquid have indicated a sufficient concentration of DIMP in the liquid to provide for continuing contamination through leakage to the groundwater.

Dithiane

31. Dithiane is a decomposition product associated with wastes from the manufacture of mustard agent. Wastes from the manufacture of

this agent at RMA were originally disposed of in Basin A. These wastes were later transferred to Basin F after its construction. An isoconcentration map of dithiane distribution in the study area was developed and is presented in Plate 7. A dithiane plume similar to those found for chloride and DIMP is evident exiting the northeast corner of Basin F. Dithiane concentrations in excess of 100 µg/ℓ were found in wells along a line running northeast from Basin F to a point just north of the B-B' line, then turning somewhat northwest crossing the C-C' line just west of the existing interim treatment system.

32. Dithiane concentrations in excess of 25 µg/ℓ were found in perimeter wells on the north, west, and south sides of Basin F, indicating probable migration. No other significant concentrations of dithiane were found in the study area.

33. Contaminant flux diagrams for dithiane were developed for all three lines and are presented in Plates 26, 27, and 28. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The total dithiane flux across line A-A' is higher than that across line B-B' indicating the migration of the plume across the A-A' line. The quantity of total flux across line B-B' is somewhat misleading as there are a number of wells north of the line with dithiane concentrations higher than in the wells on the line. This is reflected in the quantity of flux across the C-C' line which is approximately equal to that across the A-A' line. This again indicates a possible old plume crossing C-C' and a relatively new plume exiting the northeast corner of Basin F. If such a historical dithiane plume does exist, it is not as well defined as are plumes for some of the other contaminants.

34. The dithiane flux across line A-A' can be expected to increase slightly as the plume exiting the Basin F area continues to move northeast. The flux across line B-B' can be expected to increase significantly as the dithiane plume approaches. The dithiane flux across line C-C' will probably remain relatively constant as the diathine contamination evident just north of the B-B line continues to move north.

35. It appears from the data collected in this study that Basin F is a source of dithiane contamination in the alluvial groundwater in the study area. As discussed previously, dithiane concentrations in excess of 100 µg/ℓ were found in perimeter wells on the northeast corner of Basin F. However, recent analyses of Basin F liquid have shown an average dithiane concentration of only 50 µg/ℓ, much less than what would be required to produce the concentrations found in the perimeter wells. Therefore, the contaminant is probably leaching from sediments or soils in or underlying Basin F that contain high concentrations of dithiane, although this cannot be verified from existing data.

Endrin

36. Endrin, a chlorinated hydrocarbon insecticide, was produced by Shell Chemical Company from 1952 to 1965. Wastes from the production process were disposed of in Basin A and in Basin F after its construction. A concentration distribution map, Plate 8, was prepared for Endrin. No isoconcentration lines were constructed due to the scattered nature of the data. Average concentrations above the detection limit are noted for each well. Concentrations of Endrin, all less than 10 µg/ℓ, were found in wells located along a line running northeast from Basin F, crossing the dividing line between Sections 23 and 24, and then turning north to the C-C' line. Again, this is the "dogleg" distribution found for many of the contaminants. Endrin was found in perimeter wells on the northeast corner of Basin F indicating probable continuing migration from the basin. There appears to be a break in the Endrin distribution just south of the B-B' well line indicating that the Endrin contamination exiting Basin F is possibly a relatively new plume although the concentrations found provide no distinguishable pattern.

37. Several wells on the northwest end of the B-B' line were found to contain Endrin. This is in an area where groundwater was found to be in a "stagnant" or slow flow condition. The Endrin was probably

introduced into this area at a time when the groundwater elevation was higher. Several perimeter wells on the southeast corner of Basin F were found to contain Endrin. As mentioned previously, significant amounts of pesticides were dumped in this area of Basin F in the past.

38. Endrin contaminant flux diagrams were developed for all three well lines and are presented in Plates 29, 30, and 31. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The total flux across the well lines increases from south to north with the flux across line C-C' twice the flux across line A-A'. This indicates that the amount of Endrin migrating towards the north boundary of RMA is slowly decreasing. For this reason, the flux across all three well lines can be expected to decrease slowly until such time as the Endrin migration from Basin F stabilizes or becomes negligible.

39. Basin F has the potential to continue providing a source of Endrin contamination to the alluvial groundwater system. The liquid in Basin F has been found to contain Endrin in concentrations of up to 30 µg/ℓ with even higher concentrations found in the sediments.

Fluoride

40. Fluoride contamination at RMA has been linked to the manufacture and destruction of the agent GB. The waste from these processes was disposed of in Basin F. No fluoride contamination has been found in the Basin A area. An isoconcentration map for fluoride was developed from data collected in this study and is presented in Plate 9. Two areas containing fluoride concentrations in excess of 5 mg/ℓ were found. One area is located in the northeast corner of Section 23. These two areas were probably connected at some time in the past and have been separated by groundwater movement. The concentration found in the center of Section 23 is in an area of slow flow and the contaminants have remained somewhat stationary. The fluoride probably migrated into this area when groundwater elevations were higher.

41. There is a general distribution of fluoride above 2 mg/ℓ in wells located along the northern perimeter of Basin F, through most of

Section 23 and the western part of Section 24, to the northern boundary. The highest concentrations of fluoride appear to be crossing the C-C' line to the west of the existing interim treatment system. No well-defined plume was found exiting the northeast corner of Basin F which is surprising since Basin F liquid contains fluoride in concentrations in excess of 100 mg/ℓ. Several wells in Section 24 east of the main area of contaminant distribution were found to contain fluoride concentrations above background levels. Several perimeter wells on the southwest corner of Basin F were found to contain fluoride in excess of 4 mg/ℓ indicating possible migration in that direction.

42. Contaminant flux diagrams for fluoride were developed for all three well lines and are presented in Plates 32, 33, and 34. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The total flux across each well line increases significantly from A-A' to C-C'. As indicated in the flux diagrams, some of this increase is due to inflow of groundwater with background fluoride concentrations from Section 24. The rest is an indication of a reduction in fluoride migration from south to north. The flux across line C-C' will probably increase slightly as the center of mass of the contamination passes and then will start to decrease slowly. Well lines A-A' and B-B' will experience the same slow decrease in flux due to the lack of a significant plume exiting Basin F.

43. Although Basin F still appears to be the source of fluoride contamination in study area, the amount of fluoride leaching to the groundwater appears to be decreasing. The allowable flux as indicated on the Flux diagrams is very close to the actual flux.

O-sulfide

44. O-sulfide (p-chlorophenylmethylsulfide) is a process intermediate from the production of Planavin, a herbicide which was manufactured by Shell Chemical Company from 1966 to 1975. The wastes from the process were disposed of in Basin F. A contaminant distribution map

for o-sulfide was developed and is presented in Plate 10. No isoconcentration lines were constructed due to the scattered and limited nature of the data. Concentrations of o-sulfide in a range from 20 to 100 µg/ℓ were found in wells northeast of Basin F. The perimeter wells on the northeast corner of Basin F did not contain significant concentrations of o-sulfide indicating a break in the migration of the contaminant from Basin F. Numerous wells located in an area between lines B-B' and C-C' and just east of the boundary between Sections 23 and 24 were found to contain o-sulfide in concentrations up to 200 µg/ℓ. There is a break in the contaminant distribution south of the B-B' line. Such a distribution may have resulted from historical contaminant migration followed by a newer release of contaminants from Basin F. Other possible explanations for this distribution will be discussed later in this report along with contaminant migration rates.

45. No o-sulfide flux diagrams were constructed for the study area due to the limited number of wells on the well lines found to contain o-sulfide. Flux calculations were made and are presented in Tables 3, 4, and 5. The o-sulfide flux across line C-C' is significantly higher than that across lines A-A' and B-B' as a result of more numerous wells being found to contain the contaminant in the area of the north boundary. The flux across line A-A' can be expected to decrease as the mass of contaminant in that area continues to migrate north. The flux across line B-B' should soon decrease until such time as the contaminant mass approaches from the south. The o-sulfide flux across the C-C' line can be expected to remain somewhat constant as the contaminant found south of that line continues to migrate north.

46. The potential of Basin F to provide a future source of o-sulfide contamination to the alluvial groundwater is difficult to evaluate. Only one perimeter well around Basin F was found to contain o-sulfide and it is located south of the general area found to be the exist point of many of the other contaminants. The o-sulfide concentration in the Basin F liquid was found to be very low. Based on this information, Basin F does not appear to be contributing high concentrations of o-sulfide contamination to the groundwater at present. It should be noted however,

that the particular form of the organo-sulfur compound found in a certain area can depend on the oxidation/reduction potential of the surrounding environment in that area. This means that theoritically, the o-sulfide form of the organo-sulfur compound of interest could be produced by the reduction of another form of the compound having a higher oxidation state. Conversely, the o-sulfide form could be oxidized to the o-sulfoxide or even the o-sulfone form. Although information on the rates of these reactions in the environment is limited, this may significantly influence the contaminant distributions found for each of the organo-sulfur compounds.

O-sulfoxide

47. O-sulfoxide (p-chlorophenylmethylsulfoxide) contamination at RMA is reportedly a result of the oxidation of the o-sulfide compound produced during Planavin manufacture as discussed above. Only a few wells in the study area were found to contain significant concentrations of o-sulfoxide. All of the wells except for one are located on the west side of Section 24 between well lines B-B' and C-C' as shown in Plate 11. One perimeter well on the southeast corner of Basin F was found to contain o-sulfoxide. No isoconcentration lines were constructed due to the limited distribution of the contaminant. The o-sulfoxide distribution is very similar to the o-sulfide distribution along the north boundary as discussed previously. The data from this study indicate that Basin F is not currently providing a source of o-sulfoxide contamination to the alluvial groundwater in the study area. This is surprising since o-sulfoxide concentrations in the Basin F liquid currently exceed 5 mg/ℓ. One possible explanation is that the o-sulfoxide has been either oxidized to o-sulfone or reduced to o-sulfide. Both of these compounds have been found in wells northeast of Basin F.

48. No contaminant flux diagrams were constructed for o-sulfoxide due to the very limited distribution of the contaminant. Flux values were calculated for lines B-B' and C-C' and are presented in Tables 4 and 5. The data indicate that the o-sulfoxide flux across line C-C' will remain fairly constant until such time as the contaminant mass

located south of that line migrates north across the line.

O-sulfone

49. O-sulfone (p-chlorophenylmethylsulfone) is a process intermediate from the production of Planavin as discussed previously. An isoconcentration map was developed based on the information obtained in this study and is presented in Plate 12. A plume containing concentrations of o-sulfone in excess of 500 µg/ℓ is evident existing from the north and northeast sides of Basin F. Concentrations of o-sulfone in excess of 25 µg/ℓ were found in wells on the west side of Section 24 between lines B-B' and C-C' which along with the plume form a "dogleg" distribution from Basin F to the C-C' line.

50. One isolated well on the east end of the A-A' line was found to contain o-sulfone. Several perimeter wells on the southwest corner of Basin F were found to contain concentrations of o-sulfone in excess of 25 µg/ℓ indicating probable migration in that direction. Lesser concentrations of o-sulfone were found in wells in the northeast corner of Section 23.

51. Contaminant flux diagrams for o-sulfone were developed for all three well lines and are presented in Plates 35, 36, and 37. The flux for each zone and the total flux for each line are given in Tables 3, 4, and 5. The o-sulfone flux across the A-A' line is significantly higher than for the other two lines indicating the migration of the plume across the A-A' line. The flux values across lines B-B' and C-C' are similar. The total flux across line A-A' can be expected to remain constant as the o-sulfone plume from Basin F continues to move northeast. The flux across line B-B' will increase as the plume approaches from the A-A' line and turns north. The flux across the C-C' line will increase initially as the contaminant mass located southwest of the existing interim treatment system moves north, and later as the plume now crossing A-A' approaches after crossing the B-B' line. Concentrations of o-sulfone associated with the plume will probably decrease as the plume moves north due to the inflow of clean water from Section 24.

52. It is evident from the data that Basin F is continuing to provide a source of o-sulfone contamination to the groundwater system in the study area. Some of this o-sulfone contamination may be resulting from the oxidation of o-sulfoxide as it migrates from the basin although Basin F liquid has been found to contain o-sulfone concentrations in excess of 50 mg/ℓ. Therefore, it cannot be verified from existing data that this oxidation reaction is responsible for the distribution of the organo-sulfur compounds found in the study area.

Oxathiane

53. Oxathiane is a decomposition product associated with wastes from the manufacture of mustard agent. Wastes from the manufacture of this agent at RMA were originally disposed of in Basin A. These wastes were later transferred to Basin F after its construction. A concentration distribution map, Plate 13, was prepared for oxathiane. No isoconcentration lines were constructed due to the limited contaminant distribution found. Average concentrations above the detection limit are noted for each well. Concentrations of oxathiane in a range from 10 to 30 µg/ℓ were found in perimeter wells and wells just northeast of Basin F. This appears to be a plume although the distribution is somewhat scattered. Several wells southwest of Basin F were also found to contain oxathiane. This distribution probably resulted from contaminant migration from both Basin F and the other basins south of Basin F. Oxathiane was also found in several isolated wells in the northeast corner of Section 23. Dithiane (a related compound) contamination was also found in this area.

54. No flux diagrams were developed for oxathiane due to the limited number of wells on the well lines found to contain the contaminant. Flux values were calculated for lines A-A' and C-C' and are presented in Tables 3 and 5. The values for these two lines are similar. The oxathiane flux across the A-A' line will probably remain fairly constant as the contaminant migrates northeast from Basin F. The flux across line B-B' can be expected to remain negligible and the flux across line C-C' will probably decrease to a similar level due to dilution of the low

concentrations of oxathiane, as it moves north, by the inflow of uncontaminated water from Section 24.

55. The data collected during the study indicate that the oxathiane contamination is migrating from the Basin F area. The source of this contamination inside the basin must be the sediment since the Basin F liquid was found to contain no oxathiane.

PART IV: FACTORS AFFECTING CONTAMINANT MIGRATION AND DISTRIBUTION

56. The groundwater flow in the Basin F to North Boundary study area is predominantly from south to north. The groundwater elevation map, Figure 2, provides a more precise definition of this flow. This map indicates that the groundwater tends to flow to the northeast from Section 26 through Section 23 until it approaches the north boundary of RMA. The groundwater elevation lines in Section 24 indicate that the flow in this area moves to the northwest to a point where the elevation lines straighten and become parallel to the north boundary. In this area the groundwater flows north. Although the groundwater in the study area is continuous and is hydraulically a single body of water, a clearer picture of contaminant migration and distribution can be presented by considering two separate bodies of water flowing through the study area and converging at the north boundary. One of these groundwater bodies moves under Basin F northeast to the boundary. Contaminants leached from the basins move with this body of water as it moves north. The other body of water is relatively free of contaminants and has a larger volume than does the contaminated flow. The average quantities of flow are given in Table 2 along with the groundwater velocities.

57. The current groundwater levels in the study area force the contaminants to follow an old channel that moves northeast out of the Basin F area. As the contaminants migrate along the channel to a point just east of the line between Sections 23 and 24 (where the groundwater elevation lines straighten), they are pushed to the north by the inflow of uncontaminated water from the southeast. This results in their crossing the C-C' well line at or just east of the existing interim treatment systems. This inflow of uncontaminated water can also result in a reduction in the concentration of the contaminants due to dilution.

58. The scenario just discussed applies to the present groundwater elevation situation. Higher groundwater elevations north of Basin F

have been documented in historical data. These higher groundwater elevations would have resulted in a paralleling of the elevation lines further south. Therefore, the groundwater moving out of the Basin F area would have tended to flow in a more northerly direction than is currently the case. The contaminants, moving with the groundwater would also have migrated in a more northerly direction. Evidence of such a migration has been found in the case of chloride, DIMP, and several other contaminants. Concentrations of these contaminants were found in wells to the west and southwest of the interim treatment system.

59. The groundwater velocity in the study area significantly affects the contaminant distribution since the contaminants move with respect to the groundwater flow. Flow velocities calculated at the well lines (Table 2) range from 0.3 cm/day in Zone 2 on line A-A' to 100 cm/day in Zone 4 on line C-C'. The flow velocity in Zone 1 on line A-A', where most of the contaminants exiting Basin F cross the line, is approximately 12 cm/day. Using this velocity and chloride as an example, the time required for the chloride plume exiting Basin F to reach its current position between well lines A-A' and B-B' would have been 14 years. This time frame seems appropriate if we consider the idea that the Basin F liner probably remained intact for some time after its construction. Therefore, the contaminant plumes evident exiting the northeast corner of Basin F are probably the result of leakage which started 8 to 10 years after the basin was constructed. If the contaminants continue to migrate as indicated, the existing plumes from Basin F should reach the north boundary in 15 to 20 years taking into consideration the higher flow velocities at the north boundary.

60. Even though this scenario seems logical, it does not explain the presence of contaminants near the north boundary of RMA such as the organo-sulfur compounds or Nemagon that were disposed of only in Basin F. There are a number of possible explanations for this contaminant distribution, none of which can be verified from existing data. One important point to note is that the flow velocity increases in the direction of the north boundary. Also, a historically steeper groundwater level gradient would have resulted in higher flow velocities. An increase in flow velocity shortens the time frame associated with

contaminant migration. The first possible explanation centers around Basins C, D, and E located south of Basin F. These unlined basins were used to hold overflow from Basin A. Also, the contents of Basin F were at one time pumped into Basin C while repair work was being done on the Basin F liner. Contaminants in these basins could have immediately started leaching to the groundwater and migrating north due to an absence of any liner. The flow velocities would have to have been higher than they currently are for this contamination to reach the north boundary in the 22 years since Basin F was constructed. It should be noted that the sediments in this basin are still a potential source of contamination to the groundwater sytem.

61. The existence of additional contamination sources could also explain the contaminant distribution along the north boundary. There are four well documented candidate sources in the study area. They are the deep well in Section 26 used to dispose of Basin F liquid, the sanitary sewer line, the sewage treatment plant, and First Creek. No evidence was found in this study to indicate that any of these facilities are currently acting as sources of contamination to the groundwater system although they may have in the past. The sanitary sewer and the sewage treatment plant are currently being upgraded so as to limit their potential as future contaminant sources.

62. The last possible explanation is less well defined. It involves historical evidence that contaminated water was applied to or distributed over various areas in Section 23. The details concerning these activities are not well documented and therefore this explanation cannot be given more credence than the others. Although it cannot be proven from existing data that any of the possible explanatory scenarios occurred, the three most suspect are migration from Basins C, D, and E; migration from the sanitary sewer; and application of contaminated waters to various areas in Section 23. In any case, the important point is that the contamination distributions found in the study area have resulted from a historical migration overlain by a fairly recent contaminant migration from Basin F. Additional documentation on this recent increase in contaminant migration from Basin F can be found in historical data collected for the RMA 360 Monitoring Program (Appendix B).

PART V. POTENTIAL EFFECTS OF THE INTERIM TREATMENT SYSTEM EXPANSION

63. The existing interim treatment system or pilot plant consists of a 1500-ft bentonite barrier to stop the alluvial groundwater flow, a series of pump and recharge wells, and an activated carbon treatment system for the removal of organic contaminants. An expansion of this system has been proposed which would include lengthening the barrier to stop all flow of alluvial groundwater off the north boundary of RMA in this area.* The proposed barrier would extend from near Well 263 on the west to near Well 351 on the east. The number of pump and recharge wells would be increased and the carbon adsorption system would be expanded to handle the estimated 600 gpm of flow across the barrier.

64. The current treatment system has proven successful in removing the organic contaminants found in the groundwater. The new system should also be successful in removing the contaminants investigated to date. The proposed expanded barrier will intercept all alluvial groundwater found in this study to contain contaminants. This should eliminate the problem of contaminant migration off the north boundary of RMA.

65. The data collected in this study can provide an estimate of the overall contamination characteristics of the water to be treated. An estimate of the length of time required to operate the system can also be made. The most important factor in determining the chemical nature of the resulting water to be treated concerns the relative quantities of contaminated and uncontaminated water that will be combined by the system. The highest contaminant concentrations and the lowest volume of water are both found in the area at the west end of the proposed barrier. As one moves east along the proposed barrier, the quantity of flow increases while the contaminant concentrations decrease. The mixing of this water in the proposed system will result in a

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* It should be noted that historical data from the RMA Nemagon Monitoring Program has indicated Nemagon contamination in the groundwater near First Creek.

significant dilution effect. As indicated in the flux diagrams for DIMP and fluoride, the allowable flux based on imposed standards is approximately the same or higher than the flux currently crossing the C-C' line. The dilution effect on the other contaminants will also be this significant. In effect, the overall dilution of the contaminants in the system may be sufficient to reduce the contaminant concentrations to levels near or below the imposed standards.

66. The data collected in this study indicate that Basin F is currently a source of contamination to the groundwater system. Basins C, D, and E are also continuing potential sources of contamination. These conditions cannot be expected to change until some action is taken to eliminate these sources. Using the flow velocities calculated from data obtained in this study, the contaminant migration to the north boundary from these sources can be expected to continue for at least 35 to 40 years after the elimination of the sources. The dispersion and dilution of the contaminants after removal of the sources may result in some decrease in the required operating life for the treatment system.

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

67. Significant concentrations of the contaminants listed in Table 1 were found in the Basin F to North Boundary study area. The distribution of these contaminants is a result of a historical migration from undefined sources followed by a more recent migration from Basin F. The main area of distribution was found to cover the eastern half of Section 23, the western quarter of Section 24, and most all of Section 26 covered in the study. The plumes exiting Basin F tend to migrate to the northeast following an old channel to a point just east of the existing interim treatment system.

68. The main source of current contamination to the area is Basin F. The most suspect historical sources are: (a) Basins C, D, and E, (b) the sanitary sewer line, and (c) application of contaminated waters to various areas in Section 23. Contaminant migration rates based on groundwater flow velocities in the area range from 0.3 cm/day to 100 cm/day with the higher velocities being found at the north boundary. The migration rate of the contaminants in the plumes exiting Basin F were found to be approximately 12 cm/day. Based on this flow rate, the plumes now evident northeast of Basin F originated from Basin F approximately 14 years ago. These plumes should reach the north boundary in 15 to 20 years.

69. The proposed expanded treatment system should be successful in eliminating the migration of contaminants across the north boundary of RMA. The large inflow of relatively uncontaminated groundwater through Section 24 will have a significant effect on the contaminant concentrations in the water to be treated by the activated carbon adsorption system. The data indicate that contaminant concentrations will be reduced by dilution to levels at or below standards. It should be noted, however, that there are currently imposed standards only for Nemagon, DCPD, DIMP, and fluoride. The proposed treatment system

can be expected to have a required operating life of 35 to 40 years after the elimination of the contaminant sources unless some action is taken to reduce the contaminant concentrations in the area of the existing plumes.

Recommendations

70. Basins C, D, and E are potential sources of contaminant migrations to the north boundary of RMA. It is recommended that additional work be conducted in this area south and west of Basin F to further define contaminant distribution and movement in this area. This work should also include an evaluation of the effect of a Basin F containment system on the migration of contaminants from these other basins.

71. Work should be initiated as soon as possible on a plan for eliminating the basins as sources of contamination to the ground-water system. The development of this plan will probably require some additional data collection in the Basin C, D, and E areas to define the extent of contamination in the sediments associated with and soils underlying these basins.

72. An evaluation should be made of the cost effectiveness of alternatives such as control structures or dewatering wells for reducing contaminant concentrations in the area of the plumes exiting Basin F. Such a system could significantly reduce the required operating life of the northern boundary treatment system.

APPENDIX A: SAMPLING PROGRAM FOR BASIN F TO NORTH BOUNDARY AREA

PROCEDURES TO BE EMPLOYED TO COMPLETE DEVELOPMENT AND PERFORM SAMPLING

DEVELOPMENT PROCEDURES

1. Measure the depth to the top of water.
2. Measure the depth to the bottom of the well casing.
3. Subtract depth to top of water from depth to bottom of casing (total depth of cased hole) to determine the height of standing water in the well column.
4. For every foot of standing water:
   a. Remove 3 gal of water if the well is pumped, or
   b. Remove 6 bailer volumes (5 ft bailer) if the well is bailed.
5. If well goes dry before pumping or bailing is completed, allow the well to recover and again empty the well.
6. After these development procedures are complete, the well should stabilize for two weeks prior to sampling for chemical analysis.

NOTE: The bailer or pump should be flushed with clean water between wells to prevent cross contamination.

SAMPLING PROCEDURES

1. Measure depth to top of water -- record for future use in development of ground-water contour map.
2. Measure depth to the bottom of the well casing.
3. Subtract depth to top of water from depth to bottom of casing (total depth of cased hole) to determine the height of standing water in the well column.
4. For every foot of standing water:
   a. Remove 1.5 gal of water if well is pumped, or
   b. Remove 3 bailer volumes (5 ft bailer) if well is bailed.
5. If well goes dry before pumping or bailing is complete, allow the well to recover and again empty the well.
6. Immediately recover a sample for chemical analysis after pumping or bailing is complete (Step No. 3). In the case where a well is pumped or bailed dry, recover a ground-water sample as soon as possible while the well is recovering the second time.

7. Notes:

   a. The piezometers should not be sampled until at least two weeks has elapsed since well development.

   b. The sampling bailer or pump should be flushed with clean water between sampling sites to prevent cross contamination.

   c. All sampling sites must be sampled at least twice. The minimum time between sampling should be 30 days and the maximum time 60 days.

   d. If well does not recover at least 50% within 24 hours after being pumped (bailed) dry, it should be noted as a dry hole. The percent recovery (and time) should be recorded as input for the development of geohydrologic definition.

   e. All samples for chemical analyses are to be recovered in glass jars. A piece of aluminum foil should be placed over the top of the jar prior to securing the jar lid. (This foil protects the sample from any plastic on the inside of the cap.) The sample should be placed in a box immediately after recovery (prevent exposure to sunlight), and delivered to the laboratory as soon as possible.

Table A1

Chemical Analyses Performed on Each Sample

Aldrin
Chloride
DBCP (Dibromochloropropane)
DCPD (Dicyclopentadiene)
Dieldrin
DIMP (Diisopropylmethylphosphonate)
Dithiane
Endrin
Fluoride
Isodrin
O-sulfide (p-chlorophenylmethylsulfide)
O-sulfoxide (p-chlorophenylmethylsulfoxide)
O-sulfone (p-chlorophenylmethylsulfone)
Oxathiane

APPENDIX B: DATA FROM THE RMA 360 MONITORING PROGRAM

(To be furnished)