MBMG 237-B

IMPACTS OF OIL FIELD WASTES ON SOIL AND GROUND WATER IN RICHLAND COUNTY, MONTANA PART II

CONTAMINANT MOVEMENT BELOW OIL FIELD DRILLING MUD DISPOSAL PITS, FAIRVIEW, MONTANA

by

Jon C. Reiten
Hydrogeologist
Montana Bureau of Mines and Geology
Billings, Montana 59101

Final Report for

RIT Grant
RIT-87-8513

1991

IMPACTS OF OIL FIELD WASTES ON SOIL
AND GROUND IN RICHLAND COUNTY, MONTANA
PART II
CONTAMINANT MOVEMENT BELOW OIL FIELD DRILLING MUD DISPOSAL PITS,
FAIRVIEW, MONTANA

Table of Contents

PART II - Figures

PART II - Figures continued

PART II - Tables

Table Page

PART II - Appendices

Appendix

IMPACTS OF OIL FIELD WASTES ON SOIL AND GROUNDWATER

IN RICHLAND, COUNTY, MONTANA

PART II

CONTAMINANT MOVEMENT BELOW OIL FIELD DRILLING MUD DISPOSAL PITS,

FAIRVIEW, MONTANA

INTRODUCTION

Oil field wastes consisting of sludge from reserve pits were disposed of at an unauthorized and unengineered central disposal site near Fairview, Montana periodically from 1980 to 1985. It was reported that up to 270 truck loads (2700 to 4050 cubic yards) of mud were buried in several long narrow pits (Donovan, 1987). The chemistry of the waste material was not assessed prior to disposal. Based on nationwide studies of reserve pit toxicity it is unlikely that the waste muds would be classified as hazardous wastes (EPA, 1987). Although not considered hazardous, the waste materials had a potential for damaging soils and water supplies because of the high concentrations of salts typically found in reserve pits in the Williston Basin.

This research project was designed to determine:

1.) The toxicity and volume of waste muds buried at the disposal site.

2.) The extent and composition of leachate plumes and assess potential damage to water supplies.

3.) The suitability of electromagnetic conductivity survey methods for identifying and assessing contamination from reserve pit wastes.

4.) Methods for reducing impact of wastes on nearby groundwater resources.

The Hunter Disposal Pits are located in the N½SW¼SE¼ of section 33, Township 25 N., Range 59 E (Figure 1). The site is in eastern Richland County 3 miles northwest of Fairview, Montana. The disposal pits are situated on a terrace about 300 feet above the Yellowstone River. The terrace is part of a poorly defined larger terrace surface dissected by small streams and tributary valleys separating the original terrace surface into numerous smaller remnants. The terrace remnant occupied by this site trends northwest-southeast for about 4 miles and ranges from 1/2 to 2-1/2 miles wide. The elevation of the terrace surface is from 2100 feet at the south edge to 2200 feet in the center as well as the north edge of the terrace. The stream valleys of Third Hay Creek and Fourmile Creek mark the west and north terrace boundaries and the breaks of the Yellowstone River valley mark the east and south terrace boundaries.

The texture of the soils on this terrace segment are sandy loam to sandy clay loam developed in fluvial deposits, eolian deposits, and glacial till. Cultivating small grains and grazing livestock are the primary forms of land use. Several sand and gravel pits have been excavated into the fill and several oil wells are sited on the terrace surface.

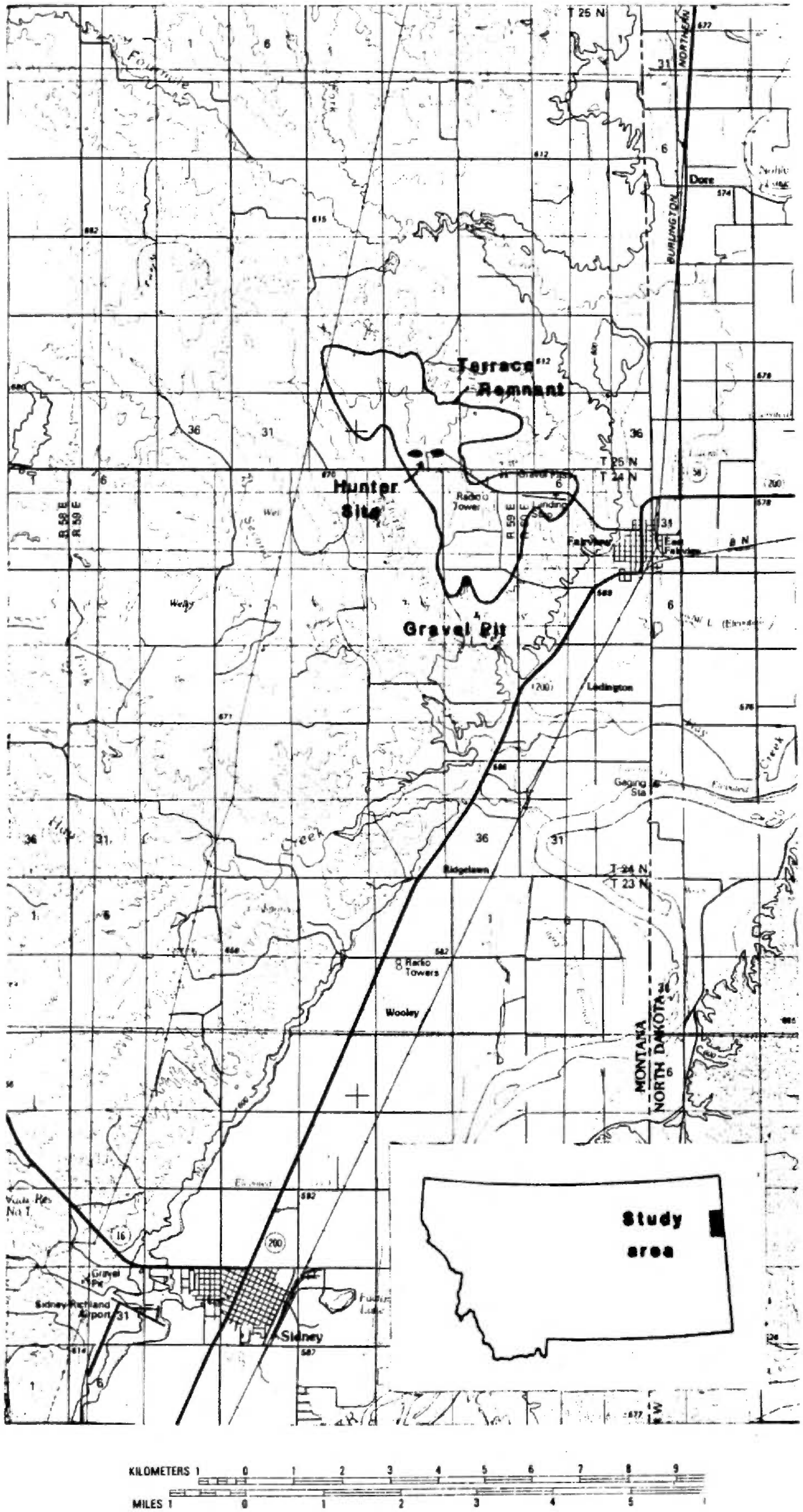


Figure 1. Location of the Hunter Disposal Site, Richland County, Montana

SITE DESCRIPTION AND OPERATION

Surface expression and reported information indicate that disposal trenches were apparently excavated both northwest and northeast of the Hunter farmstead (Figure 2). The surface expression of the pits is marked by vegetation changes with salt resistant weeds (Kochia) replacing native grasses over the pits. The Hunter West Pits on the northwest side accepted wastes from about 1980 to 1982. Based on surface expression, the dimensions of the west pits are about 900 feet long by 50 to 100 feet wide. The Hunter East Pits on the northeast side were operated from 1982-1985. The surface expression of the East pits indicates two trenches; one trench to the north about 800 feet long by 30 feet wide and a shorter one to the south about 250 feet long by 30 feet wide. It was reported that 120 truckloads of waste mud were dumped at the Hunter West Pits and 150 truckloads at the Hunter East Pits at 10 to 15 cubic yards per truckload (Donovan, 1987). The water content of the waste muds was reported to be about 13 percent by volume. The mud was dumped into backhoe excavated disposal cells having dimensions of 10 feet long by 6 feet wide by 23 feet deep. The disposal cells were connected by shallower trenches, 5-10 feet deep. When a disposal cell was completely filled the mud would flow down the trench to the next downgradient cell. The disposal cells were covered with 1 to 5 feet of sandy fill and topped with about 1 foot of grubbed topsoil for final reclamation.

EXPLANATION

□ Oilfield waste disposal pits

■ Farm buildings

═ County road

-2170- Topographic contours (CI=10 ft)

-2105- Water table contours on 11/27/88 (CI=1 ft) dashed where inferred

A-A′ Line of cross-section

● Nested soil water (lysimeters) and ground water (monitor wells) sampling devices

Site Number	Well* or Lysimeter* Number	Depth Sampled (feet)	Site Number	Well or Lysimeter Number	Depth Sampled (feet)
1	L-01	28	2	L-05	25
1	L-02	34	2	L-06	30
1	L-03	45	2	L-07	35
1	H-03	64-74	2	L-08	40
3	L-13	9	2	L-09	50
3	L-14	40	2	L-11	14
3	L-15	36	2	L-12	8
3	L-16	30	2	H-05	66-76
3	L-17	20			
3	H-04	77-87			

*H- designates well L- designates lysimeter

▲ Monitor wells

Site Number	Well Number	Depth Sampled (feet)
4	H-02	57-63
5	H-06	40-50
6	H-07	59-69
6	H-0	69 (estimate) No driller's log available

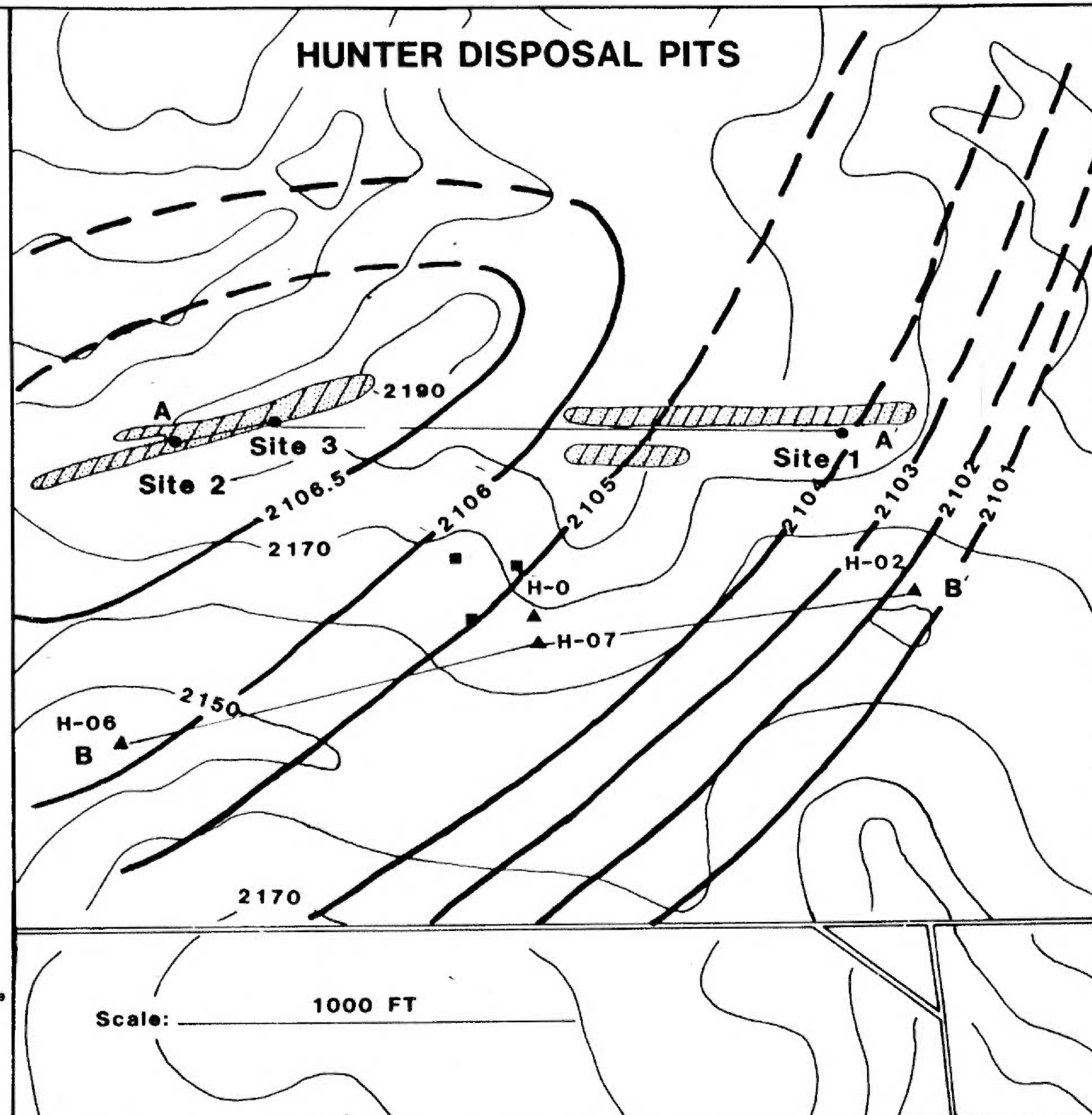


Figure 2. Detailed map of the Hunter Disposal site.

The land surface over the pits is hummocky with circular pits 10 to 15 feet in diameter by 1 to 3 feet deep overlying disposal cells. When the site was visited in February 1987, the hummocky surface, along with weeds from 3 to 5 feet tall immediately above the disposal pits, collected wind-blown snow into massive wind packed and sun crusted drifts.

METHODS

Investigative methods were devised to define the extent of contamination moving from the disposal pits and to determine ways of mitigating the damages. The progression of methods utilized were a preliminary site evaluation, EM-conductivity survey, installation of wells and lysimeters, monitoring water levels in observation wells, and monitoring water quality in both observation wells and lysimeters. The initial study plan was based on the results of the preliminary site evaluation.

PRELIMINARY SITE EVALUATION

The preliminary site evaluation consisted of inspecting the disposal sites, viewing photographs of site operations, and discussing site operations with the landowner, service contractors, and regulators. This preliminary information determined that hydrogeologic conditions at the site were conducive to damaging nearby ground water sources. The waste muds contained high concentrations of sodium chloride and possibly other contaminants. Sediments were coarse grained to depths of at least 35 feet.

Recharge water could potentially pick up highly soluble salts and develop contaminant plumes below the pits. The nearest water supply was a well located only 400 feet southwest of the Hunter East Pits and 600 feet southeast of the Hunter West Pits. This well was reported to be about 75 feet deep with water levels ranging from 65 to 70 feet below land surface. Other water supplies are located 1/2 mile west of the sites but would not likely be impacted by the disposal activities.

ELECTROMAGNETIC CONDUCTIVITY SURVEY

An electromagnetic conductivity survey was conducted over the disposal pits using a Geonics model EM 34-3 conductivity meter. The EM 34-3 consists of a transmitter coil and a receiver coil connected by 10 meter, 20 meter or 40 meter cables. Cable length (intercoil spacing) determines depth of penetration of the induced electromagnetism. The transmitter coil induces an electromagnetic current with its dipole perpendicular to the plane of the coil. When properly aligned the receiver coil measures the magnitude of the current by measuring the magnetic field the currents generate. This is directly proportional to the apparent conductivity of the soil within the zone of influence of the survey. In addition to intercoil spacing, the depth of penetration of the survey can be controlled by the orientation of the transmitting and receiving coils. In the vertical dipole position, (coils laying on ground) soil conductivity is measured to about 1.5 times the intercoil spacing and is relatively insensitive to surface soil conductivity effects (McNeil, 1980). In the horizontal dipole position (coils vertical) soil conductivity is measured to about .75 times the intercoil spacing and is more sensitive to surface soil conductivity effects.

Terrain conductivity is a measurement of the electrical properties of the soil. Specific physical properties combining to influence the terrain conductivity are lithology, porosity, grain size, moisture content, and electrical conductivity of the pore fluids. Apparent conductivity is the field reading taken from the instrument. At low terrain conductivity values the apparent conductivity is linearly proportional to the terrain conductivity. At high terrain conductivity values the apparent conductivity is no longer linearly proportional to the terrain conductivity. In this study the high electrical conductivity of the pore fluids in the waste brine produces this type of nonlinear response, causing the apparent conductivity to fall towards zero and in some cases to fall below zero. A typical survey is conducted by traversing an area and mapping apparent conductivity. Mapping apparent conductivity at the disposal pits was initiated by setting up a reference grid at 50 foot intervals marked by pin flags. Stations where apparent conductivity measurements were collected are shown on the grid maps in Figure 3. Apparent conductivity was measured at each station in both the vertical and horizontal dipole position. Appendix A contain tables of apparent conductivity readings at each station. Apparent conductivity values were contoured, identifying areas of high conductivity. Maps were

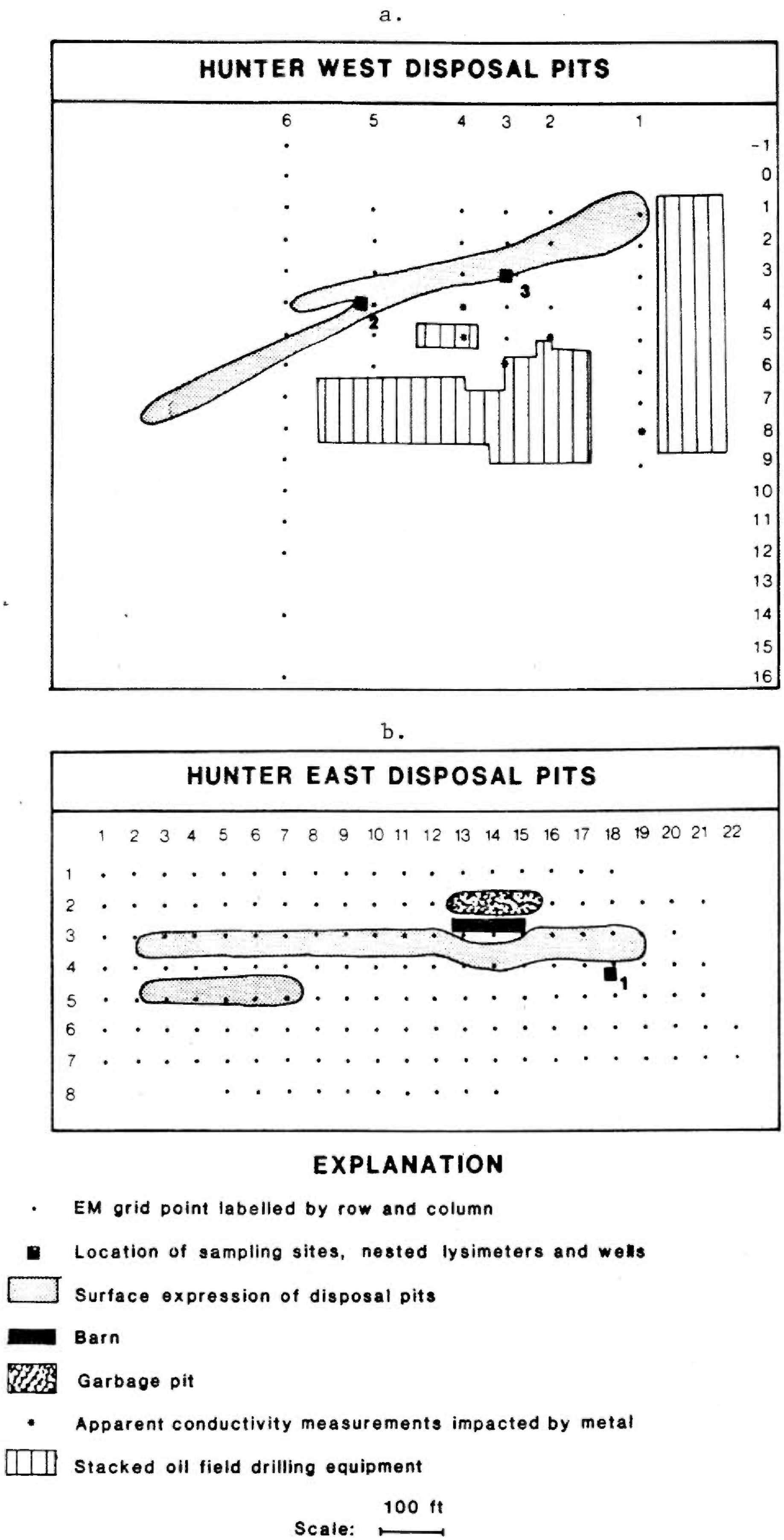


Figure 3. Electromagnetic conductivity grid maps at the Hunter Disposal site, a.) Hunter East Pits, b.) Hunter West Pits.

produced for the 10 meter, 20 meter, and 40 meter intercoil spacing (Figures 4 and 5). Data from these maps were interpreted using standard methods and used to locate optimum sites for test drilling.

MONITOR WELL AND LYSIMETER INSTALLATION

Monitor wells and ceramic cup pressure-vacuum lysimeters were installed using the MBMG Mobile B-50 auger rig. Monitor wells provide access to measure water levels and to sample water chemistry in the saturated zone. Lysimeters provide access to sample water chemistry in the unsaturated zone. Potential locations of stratigraphically nested lysimeter/observation well clusters were determined by siting them near areas mapped as having anomalously high apparent conductivity from the EM 34-3 survey. Holes were drilled using 7.0 inch O.D. and 3.25 inch I.D. hollow stem auger flights. Lithology of the test holes was logged based on sample returns and drill rig response. Types of lysimeter installation methods, and monitor well construction methods are discussed in Appendix B-1. Monitor wells were surveyed by US Soil Conservation Service technicians from Sidney. Logs of monitor wells and lysimeters are listed in Appendix B-2 and results of grain size analyses are listed in Appendix B-3.

WATER LEVEL MEASUREMENTS

Water levels were measured using an electric water level meter, read to the nearest one-hundredth of a foot. Water levels

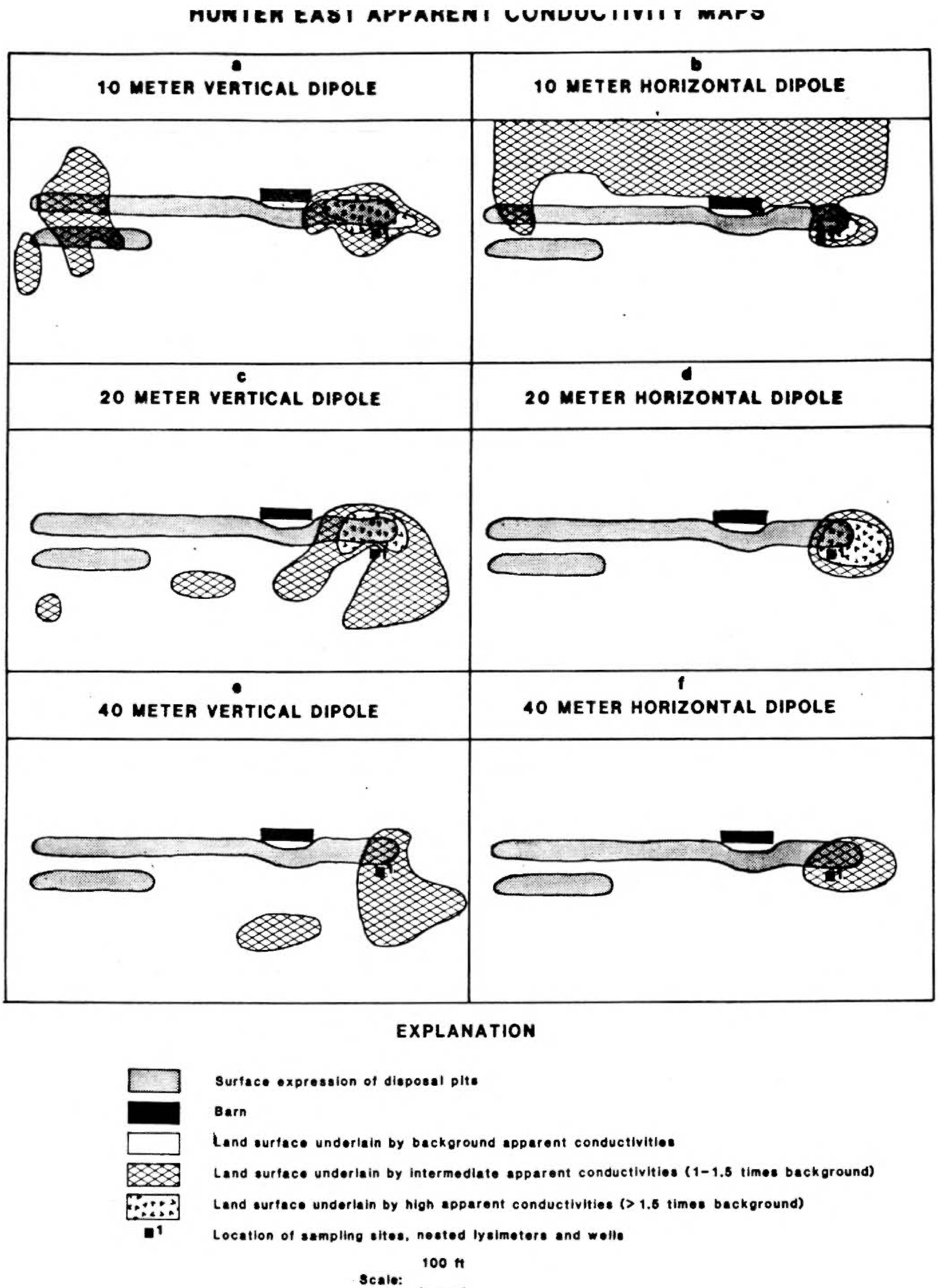


Figure 4. Apparent conductivity maps for the Hunter East Disposal Pits.

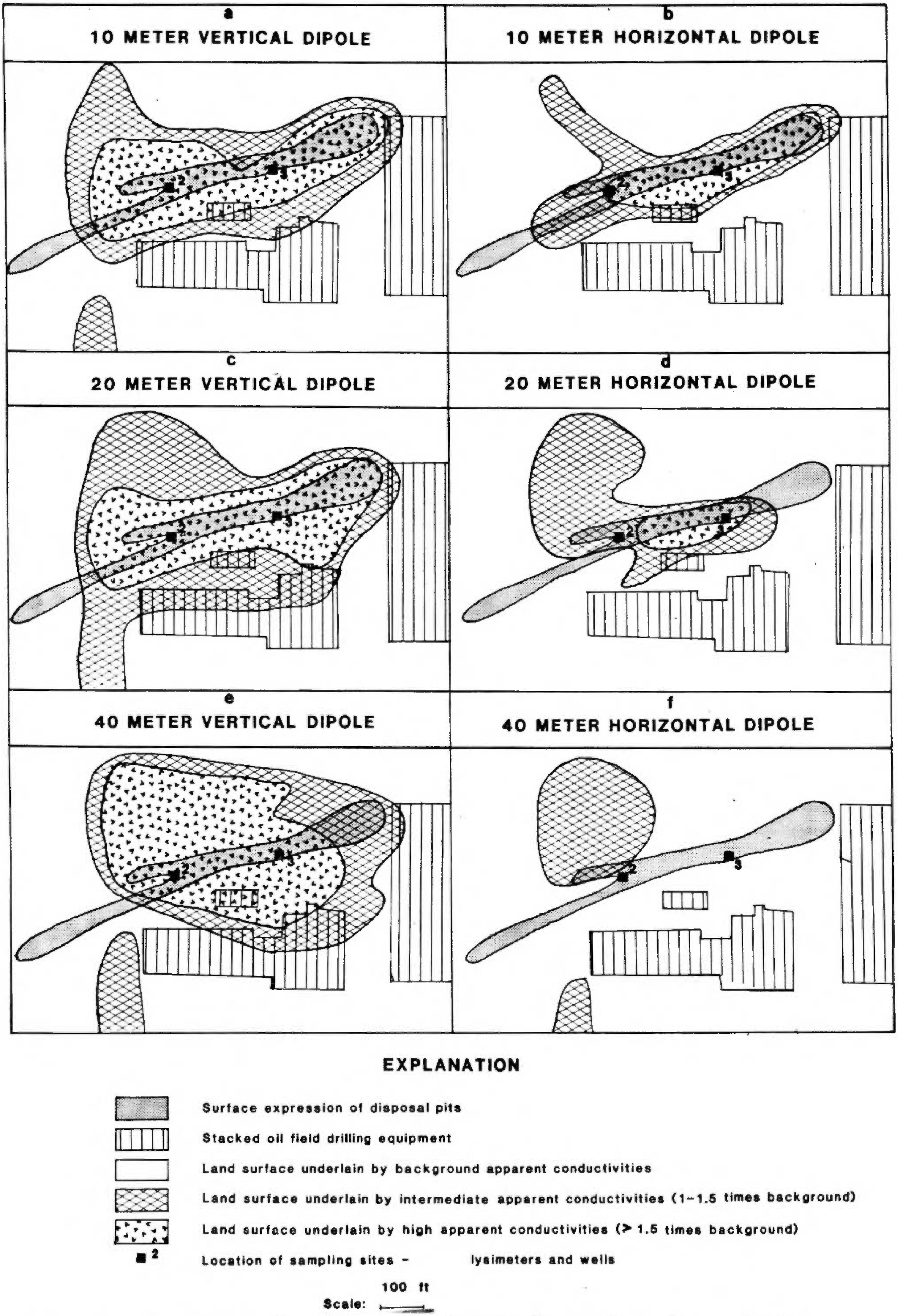


Figure 5. Apparent conductivity maps for the Hunter West Disposal Pits.

were measured on a monthly frequency when possible. A local high school student was hired to collect field measurements from November, 1987 to November, 1988. A Stevens type F water-level recorder was installed on well #H-03 and operated during the summer of 1988. Water level measurements for all monitor wells are listed in Appendix C.

WATER QUALITY SAMPLING

Wells and lysimeters were routinely sampled for specific conductivity, pH, temperature, and chloride content (Table 1). The concentration of the chloride ion is the best indicator of waste drilling fluid contamination in most Williston Basin oil fields. The chloride ion is a nonreactive conservative tracer; meaning that its concentration will not be reduced along a flow path by adsorption onto clay minerals or other chemical processes. High concentrations of chloride (>100,000 mg/L) are typical in drilling mud with sodium chloride being the major contaminant. The shallow ground water system has low concentrations (< 40 mg/L) of the chloride ion. Interference from other sources of chloride salts is unlikely, since other common chloride sources such as road salt stockpiles and factory discharges are not found in this rural environment. Chlorides in septic tank effluent would be relatively dilute but may cause localized elevated chloride ion concentrations. Improper disposal of produced waters is the only other likely major source of chlorides. Corrosion of pipelines and injection wells are common causes of produced water discharges.

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
H-00	6	2168.23	69.0	09/30/87	679		10.5		<34.0		
	6	2168.23	69.0	04/21/88	782		8.3		<34.0		
	6	2168.23	69.0	04/24/88	742		8.1	6.80	30.0		
	6	2168.23	69.0	05/14/88	776		10.8	7.50	<34.0		
	6	2168.23	69.0	05/22/88	756		11.0		<34.0		
	6	2168.23	69.0	06/05/88	729		12.5	7.80	<50.0		
	6	2168.23	69.0	06/25/88	815		11.5		<50.0		
	6	2168.23	69.0	06/29/88	778	1047	12.5	8.21	<34.0	21.0	
	6	2168.23	69.0	07/17/88	782		12.5		<50.0		
	6	2168.23	69.0	07/27/88	853		8.4	7.58	<34.0		
	6	2168.23	69.0	08/16/88	727		12.6		<30.0		
	6	2168.23	69.0	09/24/88	686		11.9		<30.0		
	6	2168.23	69.0	10/29/88	722		9.9		<30.0		
	6	2168.23	69.0	11/10/88	834		10.2		<30.0		
	6	2168.23	69.0	11/22/88	706		9.2		<50.0		
	6	2168.23	69.0	04/22/89	858		9.6		<44.0		
	6	2168.23	69.0	06/06/89	830		11.9		<44.0		
	6	2168.23	69.0	07/13/89	836		10.0	7.40	<50.0		
	6	2168.23	69.0	08/31/89	840		10.8	7.19	<50.0		
	6	2168.23	69.0	10/11/89	835		11.3	7.64	<44.0		
H-02	4	2149.79	60.0	07/22/87	658		11.2	6.80			
	4	2149.79	60.0	10/24/87	704	761	7.5	7.90	<34.0	21.4	
	4	2149.79	60.0	04/21/88	513		9.2		<34.0		
	4	2149.79	60.0	04/24/88	580		8.0	7.10	<36.0		
	4	2149.79	60.0	05/14/88	559		7.9	7.60	<34.0		
	4	2149.79	60.0	05/22/88	552		10.9		<50.0		
	4	2149.79	60.0	06/05/88	551		12.9	7.70	<50.0		
	4	2149.79	60.0	06/25/88	489		13.9		<34.0		
	4	2149.79	60.0	06/29/88	680		8.8		<34.0		
	4	2149.79	60.0	07/17/88	647		10.1		<50.0		
	4	2149.79	60.0	08/16/88	453		11.9		<30.0		
	4	2149.79	60.0	09/24/88	474		9.9				
	4	2149.79	60.0	10/29/88	566		8.9		<30.0		
	4	2149.79	60.0	11/10/88	575		8.6		<30.0		
	4	2149.79	60.0	11/27/88	426		9.8		<30.0		
	4	2149.79	60.0	04/22/89	585		8.9		<44.0		
	4	2149.79	60.0	06/06/89	570		8.8		65.0		
	4	2149.79	60.0	07/13/89	650		8.6	6.90	<50.0		
	4	2149.79	60.0	08/31/89	600		8.7	6.86	<44.0		
	4	2149.79	60.0	10/10/89	836		8.7	7.75	<44.0		
H-03	1	2149.79	60.0	10/24/87	892	982	19.0	7.51	41.0	40.4	
	1	2168.85	69.0	03/27/88	853		8.4	7.58	38.0		
	1	2168.85	69.0	04/21/88	840		9.0		41.0		
	1	2168.85	69.0	04/24/88	866		8.5	6.70	54.0		
	1	2168.85	69.0	05/14/88	910		7.9	7.70	35.0		
	1	2168.85	69.0	05/22/88	872		12.0		41.0		
	1	2168.85	69.0	06/25/88	903		13.0		40.0		
	1	2168.85	69.0	06/29/88	985	1066	8.8		41.0	40.2	
	1	2168.85	69.0	07/17/88	917		10.0		40.0		
	1	2168.85	69.0	08/16/88	718		13.1		30.0		
	1	2168.85	69.0	09/24/88	801		11.5		71.0		
	1	2168.85	69.0	10/29/88	852		9.1		36.0		
	1	2168.85	69.0	11/10/88	958		8.6		50.0		
	1	2168.85	69.0	11/27/88	740		8.2				

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
H-03	1	2168.85	69.0	04/22/89	943		8.9		50.0		
	1	2168.85	69.0	06/06/89	920		8.9		102.0		
	1	2168.85	69.0	07/13/89	936		9.0	6.72	60.0		
	1	2168.85	69.0	08/31/89	950		8.9	7.11	<44.0		
	1	2168.85	69.0	10/10/89	940		9.1	7.35	44.0		
H-04	3	2180.68	82.0	10/23/87	661	687	7.6	7.70	58.0	62.3	
	3	2180.68	82.0	03/27/88	492		7.9	8.05	34.0		
	3	2180.68	82.0	04/21/88	426		9.0		<34.0		
	3	2180.68	82.0	04/24/88	440		8.5	7.20	30.0		
	3	2180.68	82.0	05/14/88	440		11.0	7.70	34.0		
	3	2180.68	82.0	05/22/88	522		7.9		<34.0		
	3	2180.68	82.0	06/05/88	874		11.9	7.50	<50.0		
	3	2180.68	82.0	06/25/88	542		12.1		<50.0		
	3	2180.68	82.0	06/29/88	445	447	9.1		<34.0	10.8	
	3	2180.68	82.0	07/17/88	439		10.2		<50.0		
	3	2180.68	82.0	08/16/88	399		11.1		<30.0		
	3	2180.68	82.0	09/24/88	420		10.3		<30.0		
	3	2180.68	82.0	10/29/88	417		9.1		<30.0		
	3	2180.68	82.0	11/10/88	450		8.9		<30.0		
	3	2180.68	82.0	11/27/88	301		6.2		<30.0		
	3	2180.68	82.0	04/22/89	479		9.2		<50.0		
	3	2180.68	82.0	06/06/89	455		9.3		59.0		
	3	2180.68	82.0	07/13/89	435		8.9		<50.0		
	3	2180.68	82.0	08/31/89	528		9.0	7.16	<50.0		
	3	2180.68	82.0	10/11/89	440		9.1	7.94	<44.0		
H-05	2	2172.60	72.0	10/23/87	595	671	8.0	7.80	54.0	64.8	
	2	2172.60	72.0	03/27/88	385		7.4	7.26	<34.0		
	2	2172.60	72.0	04/21/88	395		8.3		<34.0		
	2	2172.60	72.0	04/24/88	387		8.0	7.30	<36.0		
	2	2172.60	72.0	05/14/88	549		10.1	7.60	61.0		
	2	2172.60	72.0	05/22/88	422		13.9	7.90	<34.0		
	2	2172.60	72.0	06/05/88	808		12.5	7.50	<50.0		
	2	2172.60	72.0	06/25/88	498		12.9		<50.0		
	2	2172.60	72.0	06/29/88	413	413	9.1		<34.0	3.1	
	2	2172.60	72.0	07/17/88	408		10.8		<50.0		
	2	2172.60	72.0	08/16/88	770		13.1		<30.0		
	2	2172.60	72.0	09/24/88	344		11.1		<30.0		
	2	2172.60	72.0	10/29/88	793		11.9		75.0		
	2	2172.60	72.0	11/10/88	425		8.8		<50.0		
	2	2172.60	72.0	11/27/88	1491		7.9				
	2	2174.10	72.0	04/22/89	433		9.6		<50.0		
	2	2174.10	72.0	06/06/89	432		9.5		65.0		
	2	2174.10	72.0	07/13/89	800		9.5	7.12	<50.0		
	2	2174.10	72.0	08/31/89	458		8.9	7.40	<50.0		
	2	2174.10	72.0	10/11/89	425		9.0	7.94	<44.0		
H-06	5	2142.83	45.0	10/24/87	463	503	9.0		<34.0	5.4	
	5	2142.83	45.0	04/21/88	484		8.5		<34.0		
	5	2142.83	45.0	04/24/88	475		8.1	7.40	<36.0		
	5	2142.83	45.0	05/14/88	466		10.0	7.80	<34.0		
	5	2142.83	45.0	05/22/88	477		11.9	7.10	<34.0		
	5	2142.83	45.0	06/05/88	820		11.9	7.20	<50.0		
	5	2142.83	45.0	06/25/88	481		9.9		<50.0		
	5	2142.83	45.0	06/29/88	500		9.4		<34.0		
	5	2142.83	45.0	07/17/88	677		13.2		<50.0		

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
H-06	5	2142.83	45.0	08/16/88	471		15.1		<30.0		
	5	2142.83	45.0	09/24/88	437		9.9		<30.0		
	5	2142.83	45.0	10/29/88	480		10.0		<30.0		
	5	2142.83	45.0	11/10/88	520		8.8		<50.0		
	5	2142.83	45.0	11/27/88	430		10.0				
	5	2142.83	45.0	04/22/89	515		9.3		<50.0		
	5	2142.83	45.0	06/06/89	515		9.2		<44.0		
	5	2142.83	45.0	07/13/89	530		8.9	7.72	<50.0		
	5	2142.83	45.0	08/31/89	515		8.8	6.92	<44.0		
	5	2142.83	45.0	10/11/89	515		8.7		<44.0		
H-07	6	2164.10	64.0	10/24/87	820	854	7.9	7.50	30.0	26.6	
	6	2164.10	64.0	04/21/88	739		9.0		<34.0		
	6	2164.10	64.0	04/24/88	707		9.9	6.90	30.0		
	6	2164.10	64.0	05/14/88	701		11.0	7.60	<34.0		
	6	2164.10	64.0	05/22/88	713		11.1		<34.0		
	6	2164.10	64.0	06/05/88	736		12.1	7.70	<50.0		
	6	2164.10	64.0	06/25/88	774		12.9		<50.0		
	6	2164.10	64.0	06/29/88	806		12.5		<34.0		
	6	2164.10	64.0	07/17/88	774		12.2		<50.0		
	6	2164.10	64.0	08/16/88	699		11.9		<30.0		
	6	2164.10	64.0	09/24/88	677		10.8		30.0		
	6	2164.10	64.0	10/29/88	722		9.1		<30.0		
	6	2164.10	64.0	11/10/88	818		9.3		30.0		
	6	2164.10	64.0	11/27/88	697		10.4				
	6	2164.10	64.0	04/22/89	795		9.5		<50.0		
	6	2164.10	64.0	06/06/89	815		10.4		168.0		
	6	2164.10	64.0	07/13/89	800		9.5	7.12	<50.0		
	6	2164.10	64.0	08/31/89	795		9.4	6.83	<50.0		
	6	2164.10	64.0	10/10/89	836		9.5	7.65	44.0		
L-01	1	2169.00	28.0	07/23/87	924		12.5		130.0		650
	1	2169.00	28.0	08/19/87	1159		12.8	7.10	130.0		650
	1	2169.00	28.0	10/19/87	1234	1532	8.0	7.60	184.0	202.0	600
	1	2169.00	28.0	03/27/88	1776		8.5	7.57	456.0		400
	1	2169.00	28.0	05/14/88	2248		12.8	7.30	>586.0		600
	1	2169.00	28.0	05/22/88	2617		13.0		861.0		200
	1	2169.00	28.0	06/25/88					1087.0		10
	1	2169.00	28.0	06/30/88	3746	3430	14.8	7.52	1183.0	966.0	400
	1	2169.00	28.0	08/16/88	3427		14.1		1503.0		100
	1	2169.00	28.0	09/26/88	2262		14.9		1312.0		100
	1	2169.00	28.0	10/29/88					569.0		5
	1	2169.00	28.0	05/30/89	3790		22.5		1270.0		600
	1	2169.00	28.0	06/06/89	5200		22.0		1455.0		300
	1	2169.00	28.0	07/13/89	5600		23.0		1287.0		20
	1	2169.00	28.0	08/31/89	7000		11.0	7.08	2712.0		500
	1	2169.00	28.0	10/10/89							0
L-02	1	2169.00	34.0	07/23/87	1978		13.0	6.80	456.0		600
	1	2169.00	34.0	08/19/87	1758		13.5	7.60	430.0		600
	1	2169.00	34.0	10/20/87	1680	1813	7.0	7.71	425.0	335.0	600
	1	2169.00	34.0	03/27/88	2246		8.0	7.57	703.0		400
	1	2169.00	34.0	05/14/88	4034		11.9	7.30	1468.0		400
	1	2169.00	34.0	05/22/88	4993		13.9		1965.0		100
	1	2169.00	34.0	06/25/88	4987		14.9		2109.0		100
	1	2169.00	34.0	06/30/88	5600				2532.0	2080.0	20
	1	2169.00	34.0	08/16/88							0

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
L-02	1	2169.00	34.0	09/26/88							0
	1	2169.00	34.0	10/29/88							0
	1	2169.00	34.0	05/30/89	10510		22.5		6416.0		500
	1	2169.00	34.0	06/06/89	11500		23.0		5946.0		400
	1	2169.00	34.0	07/13/89	14900		9.5	6.05	4874.0		100
	1	2169.00	34.0	08/31/89	14040		11.6	7.02	5934.0		500
	1	2169.00	34.0	10/10/89	16000		15.0	7.45	5934.0		50
L-03	1	2169.00	45.0	07/27/87	3098		13.9		1039.0		125
	1	2169.00	45.0	08/19/87	2991		21.0	7.80	1039.0		125
	1	2169.00	45.0	10/19/87		2859	8.0	7.64	991.0	789.0	100
	1	2169.00	45.0	03/27/88	2069		8.5	7.75	578.0		150
	1	2169.00	45.0	05/14/88							0
	1	2169.00	45.0	05/22/88							0
	1	2169.00	45.0	06/25/88	2083		16.0		608.0		100
	1	2169.00	45.0	06/30/88	1941	2125	14.0		547.0	437.0	100
	1	2169.00	45.0	08/16/88					505.0		20
	1	2169.00	45.0	09/26/88							0
	1	2169.00	45.0	10/29/88							0
	1	2169.00	45.0	05/30/89							0
	1	2169.00	45.0	06/06/89	1700				401.0		100
	1	2169.00	45.0	07/13/89							1
	1	2169.00	45.0	08/31/89	1450		12.3	7.19	215.0		500
	1	2169.00	45.0	10/10/89	1420		12.5	7.84	205.0		300
L-05	2	2174.50	25.0	07/22/87	1408		13.8		232.0		600
	2	2174.50	25.0	08/19/87	36859		14.2	6.80	>5885.0		600
	2	2174.50	25.0	10/23/87	39300	46290	10.0	7.10	>5771.0	20200.0	500
	2	2174.50	25.0	03/27/88	31148		7.0	7.00	>5825.0		400
	2	2174.50	25.0	05/14/88				7.30			20
	2	2174.50	25.0	05/22/88	25502		15.1	7.30	>5771.0		100
	2	2174.50	25.0	06/25/88					>5771.0		20
	2	2174.50	25.0	06/30/88	32729		16.2	7.10	20250.0	13600.0	75
	2	2174.50	25.0	08/16/88							0
	2	2174.50	25.0	09/26/88							0
	2	2174.50	25.0	10/29/88							0
	2	2174.50	25.0	05/30/89	20404		23.0		14645.0		450
	2	2174.50	25.0	06/06/89							0
	2	2174.50	25.0	07/13/89	24800		16.6	7.06	12500.0		250
	2	2174.50	25.0	08/31/89	38000		12.0	6.87	19416.0		400
	2	2174.50	25.0	10/11/89	46000		13.0	6.95	24270.0		50
L-06	2	2174.00	30.0	07/22/87					93.0		10
	2	2174.00	30.0	07/29/87	765		24.0		88.0		50
	2	2174.00	30.0	08/19/87							0
	2	2174.00	30.0	10/23/87	1260	1476	9.0	8.20	241.0	295.0	100
	2	2174.00	30.0	03/27/88					365.0		5
	2	2174.00	30.0	05/14/88							0
	2	2174.00	30.0	05/22/88							0
	2	2174.00	30.0	06/25/88					3949.0		10
	2	2174.00	30.0	06/30/88	9961		14.0	7.45	4936.0	3990.0	50
	2	2174.00	30.0	08/16/88					5946.0		20
	2	2174.00	30.0	09/26/88					7500.0		10
	2	2174.00	30.0	10/29/88					6400.0		10
	2	2174.00	30.0	05/30/89	17840		22.5		13209.0		500
	2	2174.00	30.0	06/06/89	26000		22.0		7900.0		3
	2	2174.00	30.0	07/13/89	32500		23.0		12185.0		3

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
L-06	2	2174.00	30.0	08/31/89	27000		12.0	7.00	10238.0		20
	2	2174.00	30.0	10/11/89	28200		16.0	7.55	11160.0		10
L-07	2	2174.00	35.0	07/22/87	694		16.0		79.0		50
	2	2174.00	35.0	08/19/87				8.20	88.0		10
	2	2174.00	35.0	10/23/87							0
	2	2174.00	35.0	03/27/88	2298		6.9	7.88	660.0		250
	2	2174.00	35.0	05/14/88							0
	2	2174.00	35.0	05/22/88							0
	2	2174.00	35.0	06/25/88	4010		16.1		912.0		50
	2	2174.00	35.0	06/30/88	2831		17.0	7.71	895.0	751.0	75
	2	2174.00	35.0	08/16/88							0
	2	2174.00	35.0	09/26/88							0
	2	2174.00	35.0	10/29/88							0
	2	2174.00	35.0	05/30/89	3520		22.5		1027.0		260
	2	2174.00	35.0	06/06/89					1217.0		1
	2	2174.00	35.0	07/13/89							0
	2	2174.00	35.0	08/31/89	3900		12.0	7.90	1124.0		15
	2	2174.00	35.0	10/11/89					2464.0		1
L-08	2	2173.50	40.0	07/22/87	1156		17.5		168.0		400
	2	2173.50	40.0	08/19/87	2391		14.4	7.40	296.0		375
	2	2173.50	40.0	10/23/87					365.0		10
	2	2173.50	40.0	03/27/88							0
	2	2173.50	40.0	05/14/88							0
	2	2173.50	40.0	05/22/88							0
	2	2173.50	40.0	06/25/88							0
	2	2173.50	40.0	06/30/88	3760		13.8	7.70	1231.0	1034.0	75
	2	2173.50	40.0	08/16/88	3493		20.1		1312.0		50
	2	2173.50	40.0	09/26/88					1121.0		10
	2	2173.50	40.0	10/29/88							0
	2	2173.50	40.0	05/30/89	4180		22.5		1416.0		300
	2	2173.50	40.0	06/06/89							0
	2	2173.50	40.0	07/13/89							1
	2	2173.50	40.0	08/31/89							0
	2	2173.50	40.0	10/11/89							0
L-09	2	2173.00	50.0	07/22/87	632		16.0		55.0		100
	2	2173.00	50.0	08/19/87			15.5	7.30	70.0		20
	2	2173.00	50.0	10/23/87					<304.0	116.0	20
	2	2173.00	50.0	03/27/88			4.0		304.0		20
	2	2173.00	50.0	05/14/88				7.60	>586.0		20
	2	2173.00	50.0	05/22/88							0
	2	2173.00	50.0	06/25/88	2382		15.0		577.0		100
	2	2173.00	50.0	06/30/88	2806		15.0	7.70	943.0	759.0	100
	2	2173.00	50.0	08/16/88					1121.0		10
	2	2173.00	50.0	09/26/88							10
	2	2173.00	50.0	10/29/88							0
	2	2173.00	50.0	05/30/89	4190		23.5		1890.0		30
	2	2173.00	50.0	06/06/89	5100		22.0		1360.0		30
	2	2173.00	50.0	07/13/89							1
	2	2173.00	50.0	08/31/89							0
	2	2173.00	50.0	10/11/89							0
L-11	2	2172.00	14.0	07/22/87	56288		15.1		>5900.0		500
	2	2172.00	14.0	07/27/87	116200		21.2		39870.0		1000
	2	2172.00	14.0	08/19/87							0
	2	2172.00	14.0	10/19/87	100000	110000	12.0	6.27	>30000.0	78000.0	500

Table 1. HUNTER SITE FIELD WATER QUALITY

MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
L-11	2	2172.00	14.0	03/27/88							0
	2	2172.00	14.0	05/14/88	148500		12.1	6.30	>17313.0		1000
	2	2172.00	14.0	05/22/88							0
	2	2172.00	14.0	06/25/88	87243				>11542.0		1000
	2	2172.00	14.0	06/30/88	230000	96546	24.0	6.52	>58850.0	92200.0	500
	2	2172.00	14.0	08/16/88	259000		19.0		132900.0		1000
	2	2172.00	14.0	09/26/88	324300		18.0		121700.0		500
	2	2172.00	14.0	10/29/88					150300.0		10
	2	2172.00	14.0	08/31/89							0
L-12	2	2172.00	8.5	07/22/87	180000		25.2		>17655.0		500
	2	2172.00	8.5	08/19/87							0
	2	2172.00	8.5	10/19/87	150000	110000	8.0	7.98	>30000.0	68500.0	500
	2	2172.00	8.5	03/27/88							0
	2	2172.00	8.5	05/14/88							0
	2	2172.00	8.5	05/22/88							0
	2	2172.00	8.5	06/25/88							0
	2	2172.00	8.5	06/30/88	215000	81494	22.0	7.02	>58850.0	64100.0	500
	2	2172.00	8.5	08/16/88	309000		19.0		121700.0		1000
	2	2172.00	8.5	09/26/88	291100		18.1		121700.0		1000
	2	2172.00	8.5	10/29/88	360000		11.1		102600.0		1000
	2	2172.00	8.5	05/30/89	91300		22.3		118680.0		500
	2	2172.00	8.5	06/06/89	150000		23.0		77000.0		1000
	2	2172.00	8.5	07/13/89	150000		15.0	6.55	78700.0		700
	2	2172.00	8.5	08/31/89	150000	240000	15.5	6.57	80910.0		1000
	2	2172.00	8.5	10/11/89	120000		14.0	6.59	80910.0		4500
L-13	3	2180.00	9.0	07/22/87	9968		19.9	6.60	3227.0		100
	3	2180.00	9.0	07/23/87	10001		11.2		3417.0		100
	3	2180.00	9.0	08/19/87							0
	3	2180.00	9.0	10/23/87					4366.0		10
	3	2180.00	9.0	03/27/88							0
	3	2180.00	9.0	05/14/88							0
	3	2180.00	9.0	05/22/88							0
	3	2180.00	9.0	06/25/88							0
	3	2180.00	9.0	06/30/88					>5885.0	20200.0	50
	3	2180.00	9.0	08/16/88	341000		19.1		24630.0		50
	3	2180.00	9.0	09/26/88							0
	3	2180.00	9.0	10/29/88							0
	3	2180.00	9.0	05/30/89							0
	3	2180.00	9.0	06/06/89							0
	3	2180.00	9.0	07/13/89							0
	3	2180.00	9.0	08/31/89							0
	3	2180.00	9.0	10/11/89							0
L-14	3	2181.00	40.0	07/22/87	702		16.2		75.0		400
	3	2181.00	40.0	08/19/87				7.70	70.0		10
	3	2181.00	40.0	10/23/87		3008	8.0	7.59	161.0	192.0	500
	3	2181.00	40.0	03/27/88							0
	3	2181.00	40.0	05/14/88				7.70	586.0		20
	3	2181.00	40.0	05/22/88	2727		16.2		456.0		100
	3	2181.00	40.0	06/25/88							0
	3	2181.00	40.0	06/30/88					486.0	426.0	50
	3	2181.00	40.0	08/16/88							0
	3	2181.00	40.0	09/26/88							0
	3	2181.00	40.0	10/29/88							0
	3	2181.00	40.0	05/30/89							0

Table 1. HUNTER SITE FIELD WATER QUALITY

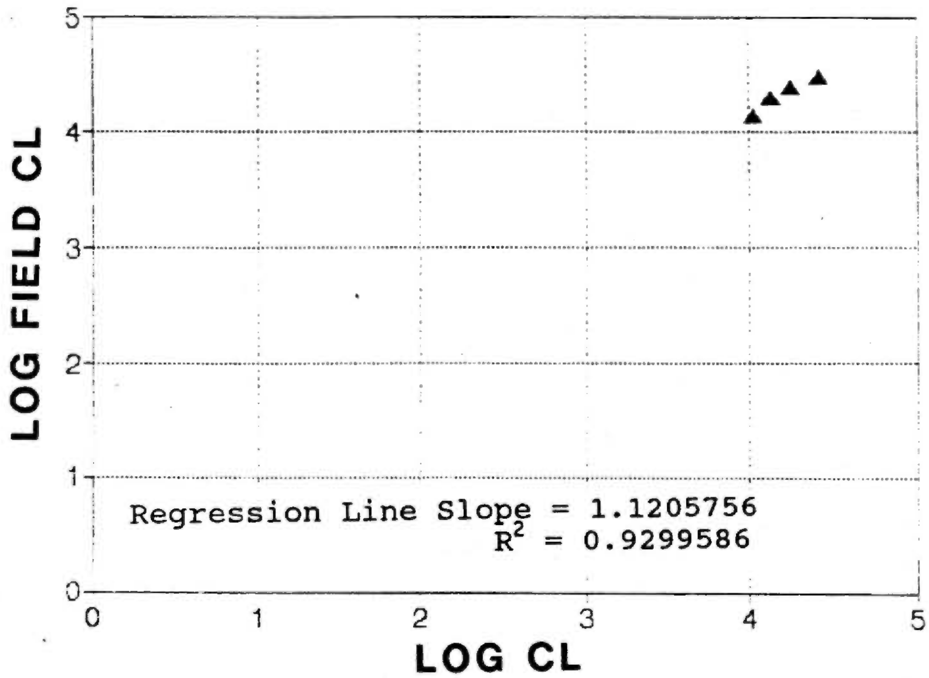
MBMG SITE	SITE NO	ELEVATION (FT)	DEPTH SAMPLED	DATE SAMPLED	FIELD SC (us/cm)	LAB SC (us/cm)	TEMPERATURE (C)	pH (units)	FIELD CHLORIDE (mg/L)	LAB CHLORIDE (mg/L)	SAMPLE VOLUME ml
L-14	3	2181.00	40.0	06/06/89							0
	3	2181.00	40.0	07/13/89							1
	3	2181.00	40.0	08/31/89	3400		14.5	7.30	686.0		40
	3	2180.00	40.0	10/11/89	3500				735.0		15
L-15	3	2181.00	36.0	07/22/87	2130		16.9		505.0		300
	3	2181.00	36.0	08/19/87	3864		16.5	7.10	1085.0		375
	3	2181.00	36.0	10/23/87					1603.0	1370.0	20
	3	2181.00	36.0	03/27/88					1603.0		5
	3	2181.00	36.0	05/14/88				6.70	>5771.0		20
	3	2181.00	36.0	05/22/88	39744		18.9		>5771.0		200
	3	2181.00	36.0	06/25/88							0
	3	2181.00	36.0	06/30/88	53588		16.0	6.60	30090.0	26200.0	150
	3	2181.00	36.0	08/16/88							0
	3	2181.00	36.0	09/26/88					26580.0		5
	3	2181.00	36.0	10/29/88					18770.0		1
	3	2181.00	36.0	05/30/89	39600		23.0		40610.0		10
	3	2181.00	36.0	06/06/89	40000				24630.0		30
	3	2181.00	36.0	07/13/89			23.0		20000.0		1
	3	2181.00	36.0	08/31/89	58000		15.0	7.18	26970.0		40
	3	2181.00	36.0	10/11/89	55000		14.0	7.35	23653.0		15
L-16	3	2181.00	30.0	07/22/87	1095		16.8		208.0		500
	3	2181.00	30.0	08/19/87	5355		16.8	7.20	1680.0		500
	3	2181.00	30.0	10/23/87					3417.0		10
	3	2181.00	30.0	03/27/88					3227.0		5
	3	2181.00	30.0	05/14/88				7.00	>5771.0		20
	3	2181.00	30.0	05/22/88	20807		18.0	6.60	>5771.0		200
	3	2181.00	30.0	06/25/88							0
	3	2181.00	30.0	06/30/88	25364	24784	14.5	6.93	13750.0	10600.0	350
	3	2181.00	30.0	08/16/88					>5946.0		5
	3	2181.00	30.0	09/16/88					>5946.0		5
	3	2181.00	30.0	10/29/88							0
	3	2181.00	30.0	05/30/89							0
	3	2181.00	30.0	06/06/89							0
	3	2181.00	30.0	07/13/89							0
	3	2181.00	30.0	08/31/89	30000		13.0	7.08	14208.0		400
	3	2181.00	30.0	10/11/89	31000		11.0	7.14	13520.0		300
L-17	3	2181.00	20.0	07/23/87	21255		20.9		8442.0		30
	3	2181.00	20.0	08/19/87					>5885.0		5
	3	2181.00	20.0	10/23/87			14.0	6.70	>5885.0	8940.0	30
	3	2181.00	20.0	03/27/88	17032		6.5	7.40	5885.0		20
	3	2181.00	20.0	05/14/88			6.7		>5771.0		10
	3	2181.00	20.0	05/22/88			6.5		>5771.0		10
	3	2181.00	20.0	06/25/88					>5885.0		10
	3	2181.00	20.0	06/30/88	37126		13.9	7.53	24470.0	17700.0	200
	3	2181.00	20.0	08/16/88	32703		19.5		>5946.0		50
	3	2181.00	20.0	09/26/88					20720.0		10
	3	2181.00	20.0	10/29/88					22670.0		10
	3	2181.00	20.0	05/30/89	41050		23.5		33800.0		300
	3	2181.00	20.0	06/06/89	62000		23.0		25600.0		50
	3	2181.00	20.0	07/13/89	94000		23.0		36380.0		20
	3	2181.00	20.0	08/31/89					24640.0		1
	3	2181.00	20.0	10/11/89							0
L-18	7	2175.00	18.0	07/23/87	514		16.1	6.80	<34.0		50

All pipelines and oil wells are downgradient and over 1 mile from this site. Therefore, elevated chloride concentration from produced water discharges appears unlikely.

Chloride concentrations were measured using Quantab chloride titrators (Appendix D) and the results are listed in Table 1. Field chloride concentrations measured using Quantab chloride titrators compared closely to laboratory determined chloride concentrations. Plots of field chloride values, against lab chloride values showed a nearly 1:1 relationship over a wide range of concentrations. Samples with chloride concentrations above the range of the Quantab titrators required dilution and are plotted on Figure 6a. Samples with chloride concentrations falling within the range of the Quantab titrators are plotted on Figure 6b. The Quantab titrators proved to be a quick and reliable method for measuring chloride concentrations.

Two sets of water samples were analyzed for standard and trace constituents by the MBMG analytical lab in Butte. Samples were filtered through 0.45 micron filters in the field and acidified in the lab. Small sample volumes precluded filtering of 3 samples -- L-03 sampled on 10/17/87, L-09 sampled on 10/23/87, and L-15 sampled on 10/23/87. Trace constituent concentrations for these 3 samples are reported as biologically available rather than dissolved. Seventeen water samples were collected from October 19 to October 24, 1987 and nineteen water samples were collected from June 29 to June 30, 1988. The results of these water analyses are listed in Table 2 and discussed in the following section.

a.



b.

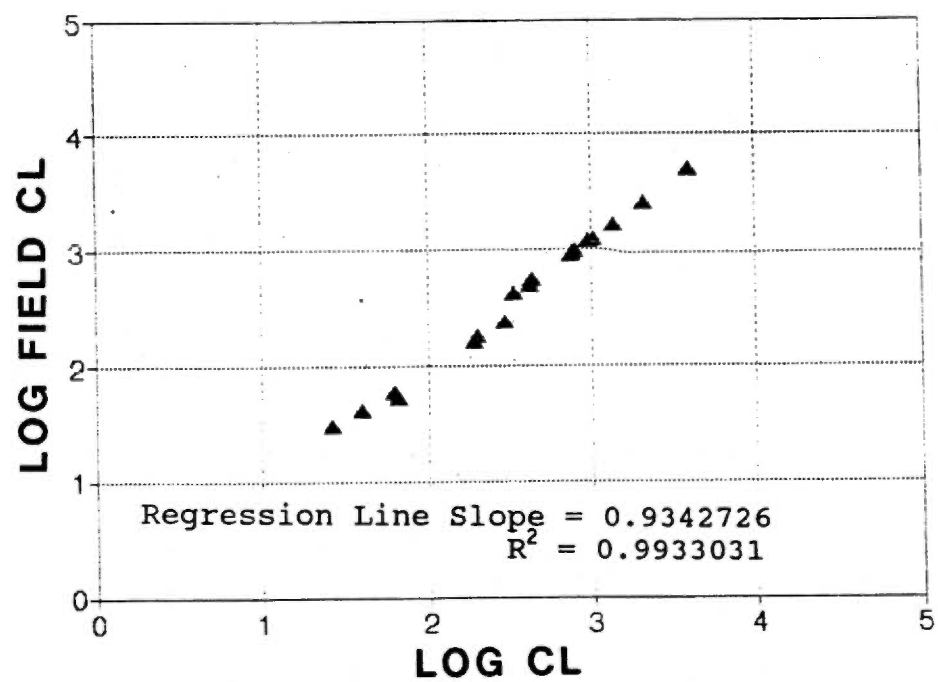


Figure 6. Comparison of field chloride concentrations with laboratory chloride concentrations, a.) water samples with chloride concentrations above the range of the Quantab titrators requiring dilution, b.) water samples with concentrations within the range of Quantab titrators.

Table 2. HUNTER SITE WATER QUALITY ANALYSES
(units are milligrams/litre except where indicated)
(negative values are below detection limits)

SITE ID	DATE SAMPLED	LAB NUMBER	CALCIUM	MAGNESIUM	SODIUM	POTASSIUM	IRON	MANGANESE	SILICA SIO2	BICARBONATE	CHLORIDE	SULFATE	NITRATE as N	FLUORIDE	TOTAL PHOSPHATE as P
H-00	06/29/88	88Q0741	97.90	35.00	33.6	5.7	0.002	-0.001	27.60	373.0	21.0	57.8	18.50	0.1	-0.100
H-02	10/24/87	87Q0915	88.90	39.80	16.1	8.3	-0.002	0.068	20.40	344.0	21.4	20.4	25.60	0.2	-0.100
H-03	10/24/87	87Q0916	117.00	45.90	22.2	6.2	0.004	0.067	24.50	319.0	40.4	43.1	37.80	0.1	-0.100
H-03	06/29/88	88Q0742	112.00	44.40	23.1	6.3	0.003	0.031	28.40	343.0	40.2	47.6	39.10	0.2	-0.100
H-04	10/23/87	87Q0917	72.20	26.60	32.4	5.5	-0.002	0.240	17.50	255.7	62.3	21.4	6.27	0.1	-0.100
H-04	06/29/88	88Q0743	51.80	19.30	10.6	3.0	0.019	0.065	18.40	242.5	10.8	12.1	3.42	0.1	-0.100
H-05	10/23/87	87Q0918	80.50	28.90	17.8	4.9	-0.002	0.140	16.80	275.2	64.8	14.2	2.74	0.2	-0.100
H-05	06/29/88	88Q0744	49.60	17.70	8.6	2.9	0.032	0.240	16.10	251.8	3.1	8.2	0.72	0.1	0.100
H-06	10/24/87	87Q0919	59.40	31.40	10.2	4.5	0.023	0.069	20.00	289.9	5.4	20.2	6.44	0.2	-0.100
H-07	10/24/87	87Q0920	89.20	43.00	28.0	7.6	-0.002	0.004	24.70	373.0	26.6	37.1	19.20	0.1	-0.100
L-01	10/19/87	87Q0921	135.00	80.60	58.7	11.9	-0.002	0.007	72.20	331.0	202.0	63.1	27.10	0.3	0.100
L-01	06/30/88	88Q0726	280.00	206.00	55.5	15.3	0.004	0.004	79.40	216.2	966.0	46.7	33.30	0.3	0.100
L-02	10/20/87	87Q0922	144.00	114.00	71.2	11.5	-0.002	0.140	45.80	306.0	335.0	44.3	45.00	0.2	-0.100
L-02	06/30/88	88Q0727	530.00	388.00	168.0	17.7	0.006	0.001	45.00	201.1	2080.0	36.6	45.50	0.5	-0.100
L-03	10/19/87	87Q0923	151.00	92.40	302.0	14.2	-0.002	0.180	37.60	252.8	789.0	108.0	8.69	0.4	0.100
L-03	06/30/88	88Q0728	143.00	77.70	154.0	10.9	-0.002	0.001	49.40	246.9	437.0	73.9	37.60	0.3	-0.100
L-05	10/23/87	87Q0924	3340.00	2360.00	4620.0	152.0	-0.002	3.750	45.30	233.3	20200.0	92.0	1.65	0.3	-0.100
L-05	06/30/88	88Q0729	2180.00	1640.00	3230.0	117.0	-0.002	0.920	56.30	164.5	13600.0	123.7	9.52	3.0	-0.100
L-06	10/23/87	87Q0925	105.00	63.30	96.7	13.2	-0.002	0.036	63.90	292.8	295.0	79.6	1.61	0.3	-0.100
L-06	06/30/88	88Q0730	669.00	657.00	793.0	45.4	0.004	0.006	75.10	180.6	3990.0	254.0	6.10	0.1	-0.100
L-07	06/30/88	88Q0731	145.00	170.00	194.0	21.0	0.002	0.001	71.60	313.0	751.0	175.0	9.65	0.4	0.100
L-08	06/30/88	88Q0732	178.00	243.00	187.0	20.4	0.002	-0.001	65.80	290.8	1034.0	174.0	6.42	0.5	-0.100
L-09	10/23/87	87Q0926	58.50	47.40	69.7	7.2	0.150	0.045	59.90	329.0	116.0	89.0	0.28	0.3	-0.100
L-09	06/30/88	88Q0733	142.00	167.00	198.0	17.6	-0.002	0.001	76.70	260.1	759.0	205.0	5.17	0.3	0.200
L-11	10/19/87	87Q0927	13000.00	864.00	32000.0	2040.0	-0.002	26.700	20.80	208.2	78000.0	147.0	2.00	1.5	-0.100
L-11	06/30/88	88Q0734	15400.00	1190.00	37500.0	2280.0	-0.002	32.700	14.70	138.1	92200.0	126.0	2.00	0.7	-0.100
L-12	10/19/87	87Q0928	12100.00	591.00	28700.0	1720.0	0.055	0.210	-0.10	1080.0	68500.0	218.0	1.00	5.0	-0.100
L-12	06/30/88	88Q0735	8580.00	2370.00	26100.0	1600.0	8.120	1.640	12.30	1383.0	64100.0	236.0	2.00	0.3	-0.100
L-13	06/30/88	88Q0736	2910.00	2100.00	5660.0	150.0	-0.002	0.260	58.90	346.0	20200.0	1430.0	-0.10	-1.0	-0.100
L-14	10/23/87	87Q0929	97.30	70.00	124.0	13.6	-0.002	0.028	63.10	415.0	192.0	177.0	4.01	0.3	-0.100
L-14	06/30/88	88Q0737	148.00	131.00	228.0	19.8	0.005	0.004	73.70	483.0	426.0	382.0	11.00	0.3	-0.100
L-15	10/23/87	87Q0930	221.00	149.00	584.0	36.4	0.044	0.220	63.10	433.0	1370.0	198.0	0.71	0.5	-0.100
L-15	06/30/88	88Q0738	4100.00	3540.00	5790.0	133.0	-0.002	4.240	49.10	240.1	26200.0	528.0	2.40	3.0	-0.100
L-16	06/30/88	88Q0739	1880.00	1820.00	1600.0	66.1	-0.002	0.900	48.70	303.0	10600.0	415.0	2.97	-2.0	-0.100
L-17	10/23/87	87Q0931	1150.00	345.00	4210.0	96.6	0.098	7.300	38.50	394.0	8940.0	623.0	0.04	0.3	-0.100
L-17	06/30/88	88Q0740	2770.00	1360.00	6010.0	140.0	-0.002	21.100	46.00	253.8	17700.0	245.0	9.50	-5.0	-0.100

Table 2. (cont.) HUNTER SITE WATER QUALITY ANALYSES
(units are milligrams/litre except where indicated)
(negative values are below detection limits)
* DIS=dissolved BIO=biologically available

LAB NUMBER	TRACE METALS TYPE*	ALUMINUM	SILVER	BORON	CADMIUM	CHROMIUM	COPPER	LITHIUM	MOLYBDENUM	BARIUM	BROMIDE	NICKEL	STRONTIUM	TITANIUM	VANADIUM
88Q0741	DIS	-0.03	-0.002	0.07	-0.002	-0.002	0.130	0.011	-0.02	0.46	-0.10	-0.01	0.68	0.005	-0.001
87Q0915	DIS	-0.03	-0.002	0.05	-0.002	-0.002	0.004	0.021	-0.02		-0.10	-0.01	0.61	-0.001	-0.001
87Q0916	DIS	-0.03	-0.002	0.05	-0.002	-0.002	-0.002	0.015	-0.02	0.26	-0.10	-0.01	0.79	-0.001	-0.001
88Q0742	DIS	-0.03	-0.002	0.06	-0.002	-0.002	-0.002	0.012	-0.02	0.51	-0.10	-0.01	0.80	0.006	-0.001
87Q0917	DIS	-0.03	-0.002	0.05	-0.002	-0.002	-0.002	0.009	-0.02		-0.10	-0.01	0.40	-0.001	-0.001
88Q0743	DIS	-0.03	-0.002	-0.02	-0.002	-0.002	-0.002	0.004	-0.02	0.35	-0.10	-0.01	0.27	0.003	-0.001
87Q0918	DIS	-0.03	-0.002	0.04	-0.002	-0.002	-0.002	0.007	-0.02		0.20	-0.01	0.47	-0.001	-0.001
88Q0744	DIS	-0.03	-0.002	-0.02	-0.002	-0.002	-0.002	0.003	-0.02	0.33	-0.10	-0.01	0.28	0.003	-0.001
87Q0919	DIS	-0.03	-0.002	0.05	-0.002	-0.002	-0.002	0.010	-0.02		-0.10	-0.01	0.41	0.001	-0.001
87Q0920	DIS	-0.03	-0.002	0.10	-0.002	-0.002	-0.002	0.011	-0.02		-0.10	-0.01	0.54	-0.001	-0.001
87Q0921	DIS	-0.03	-0.002	0.03	-0.002	-0.002	0.004	0.046	-0.02	0.36	0.20	-0.01	1.18	-0.001	0.038
88Q0726	DIS	-0.03	-0.002	0.05	-0.002	0.007	0.018	0.044	-0.02	1.00	-0.10	-0.01	2.73	0.014	0.014
87Q0922	DIS	-0.03	-0.002	0.05	-0.002	-0.002	0.003	0.047	-0.02	0.34	-0.10	0.01	1.48	0.004	0.044
88Q0727	DIS	-0.03	0.002	0.03	0.002	0.007	0.028	0.047	-0.02	2.14	-0.10	0.01	5.33	0.021	0.023
87Q0923	BIO	-0.03	-0.002	0.11	-0.002	-0.002	0.008	0.072	-0.02	0.40	0.20	-0.01	1.30	0.002	0.072
88Q0728	DIS	-0.03	-0.002	0.09	-0.002	0.003	0.005	0.043	-0.02	0.34	-0.10	-0.01	1.16	0.013	0.015
87Q0924	DIS	-0.03	-0.002	0.77	0.023	-0.002	0.083	3.890	0.04	6.84	20.00	0.08	60.30	-0.001	0.015
88Q0729	DIS	-0.03	0.007	0.67	0.017	-0.002	0.170	2.370	-0.02	2.96	-0.10	0.04	38.20	-0.001	0.032
87Q0925	DIS	-0.03	-0.002	0.16	0.003	-0.002	0.008	0.068	-0.02	0.26	0.30	-0.01	1.00	-0.001	0.049
88Q0730	DIS	-0.03	0.002	0.21	0.003	0.005	0.030	0.360	-0.02	0.87	-0.10	-0.01	9.02	0.015	0.026
88Q0731	DIS	-0.03	-0.002	0.30	-0.002	0.002	0.008	0.081	-0.02	0.26	-0.10	-0.01	2.13	0.009	0.029
88Q0732	DIS	-0.03	-0.002	0.27	-0.002	-0.002	0.011	0.070	-0.02	0.30	-0.10	-0.01	2.61	0.013	0.021
87Q0926	BIO	-0.03	-0.002	0.20	-0.002	-0.002	0.380	0.029	-0.02	0.22	0.30	-0.01	0.64	-0.001	0.012
88Q0733	DIS	-0.03	-0.002	0.29	-0.002	-0.002	0.014	0.061	-0.02	0.18	-0.10	-0.01	1.85	0.012	0.009
87Q0927	DIS	0.27	0.084	59.80	0.037	0.015	0.230	39.100	0.04	1.05	60.00	0.14	388.00	-0.001	-0.001
88Q0734	DIS	0.43	0.079	56.30	0.051	0.052	-0.002	45.100	-0.02	0.76	-0.10	0.15	495.00	-0.001	0.041
87Q0928	DIS	0.21	0.027	45.30	0.022	0.018	0.370	35.000	0.18	0.52	80.00	0.06	319.00	-0.001	-0.001
88Q0735	DIS	0.04	0.034	97.40	0.038	-0.002	0.830	32.200	0.07	0.22	-0.10	0.02	267.00	-0.001	-0.001
88Q0736	DIS	-0.03	0.009	5.00	0.021	0.015	0.160	2.140	-0.02	0.31	-0.10	0.04	51.80	-0.001	0.030
87Q0929	DIS	-0.03	-0.002	0.51	-0.002	-0.002	0.004	0.068	-0.02		-0.10	-0.01	0.87	-0.001	0.019
88Q0737	DIS	0.03	-0.002	0.25	-0.002	-0.002	0.016	0.077	0.02	0.91	-0.10	-0.01	1.47	0.002	0.013
87Q0930	BIO	-0.03	-0.002	0.56	-0.002	-0.002	0.690	0.210	-0.02		-0.10	0.02	2.61	-0.001	0.020
88Q0738	DIS	-0.03	0.007	0.53	0.044	-0.002	0.370	0.960	-0.02	0.91	-0.10	0.06	51.20	-0.001	-0.001
88Q0739	DIS	-0.03	-0.002	0.48	0.009	-0.001	0.082	0.300	-0.02	0.42	-0.10	0.02	19.80	-0.001	-0.001
87Q0931	DIS	-0.03	-0.002	3.18	0.009	0.051	0.800	1.660	0.07		-0.10	0.10	21.80	-0.001	0.120
88Q0740	DIS	-0.03	0.006	3.58	0.021	0.010	0.150	2.190	0.02	0.21	-0.10	0.12	44.50	-0.001	-0.001

Table 2 (cont.) HUNTER SITE WATER QUALITY ANALYSES
(units are milligrams/litre except where indicated)
(negative values are below detection limits)

LAB NUMBER	ZINC	ZIRCONIUM	ORTHO-PHOSPHATE	SELENIUM	ARSENIC	LEAD	CALCULATED DISSOLVED SOLIDS	SUM OF DISSOLVED CONSTITUENTS	LAB SPECIFIC CONDUCTIVITY (microsiemens/cm) (at 25 degrees C)	LAB pH (units)	SODIUM ADSORPTION RATIO	FIELD SPECIFIC CONDUCTIVITY (microsiemens/cm) (at 25 degrees C)	FIELD pH (units)	FIELD TEMPERATURE (degrees C)	FIELD CHLORIDE
88Q0741	0.018	-0.004	-0.1			-0.040	481.0	670.0	1047.0	8.21	0.74	778.0		12.5	<34.0
87Q0915	-0.003	-0.004	-0.1				411.0	585.0	761.0	7.63	0.35	704.0	7.50	7.9	<34.0
87Q0916	-0.003	-0.004	-0.1	0.004	0.001	-0.040	494.0	656.0	982.0	7.52	0.44	892.0	7.51	8.0	41.0
88Q0742	0.004	-0.004	-0.1			-0.040	510.0	684.0	1066.0	7.72	0.46	985.0		8.8	41.0
87Q0917	-0.003	-0.004	-0.1				371.0	500.0	687.0	7.47	0.82	661.0	7.77	7.6	58.0
88Q0743	-0.003	-0.004	-0.1			-0.040	249.0	372.0	447.0	7.83	0.31	445.0		9.0	<34.0
87Q0918	-0.003	-0.004	0.2				367.0	506.0	671.0	7.50	0.43	595.0	7.80	8.0	54.0
88Q0744	-0.003	-0.004	0.2			-0.040	231.0	359.0	413.0	7.88	0.26	413.0		9.1	<34.0
87Q0919	-0.003	-0.004	-0.1				301.0	448.0	503.0	7.83	0.26	463.0		9.0	<34.0
87Q0920	-0.003	-0.004	-0.1				459.0	649.0	854.0	7.87	0.60	820.0	7.50	7.9	30.0
87Q0921	0.008	-0.004	0.2				814.0	982.0	1532.0	8.11	0.98	1234.0	7.60	8.0	184.0
88Q0726	0.014	-0.004	-0.1			-0.040	1789.0	1899.0	3430.0	7.62	0.61	3746.0	7.52	14.8	1183.0
87Q0922	0.004	-0.004	-0.1				962.0	1117.0	1813.0	8.05	1.07	1680.0	7.71	7.0	425.0
88Q0727	0.007	-0.004	-0.1			0.040	3410.0	3512.0		8.00	1.35	5600.0			2532.0
87Q0923	0.003	-0.004	0.1				1628.0	1756.0	2859.0	6.97	4.77		7.64	8.0	991.0
88Q0728	0.004	-0.004	-0.1			-0.040	1105.0	1231.0	2125.0	7.89	2.57	1941.0		14.0	547.0
87Q0924	0.015	-0.004	-1.0				30930.0	31048.0	46290.0	6.07	14.96	39300.0	7.10	10.0	>5771.0
88Q0729	0.026	0.012	-0.1			-0.040	21042.0	21125.0		7.45	12.72	32729.0	7.10	16.2	20250.0
87Q0925	0.004	-0.004	-0.1				863.0	1011.0	1476.0	8.25	1.84	1260.0	8.20	9.0	241.0
88Q0730	0.039	-0.004	-0.1			-0.040	6579.0	6670.0		8.00	5.21	9961.0	7.45	14.0	4936.0
88Q0731	-0.003	-0.004	0.1			-0.040	1692.0	1851.0		7.80	2.59	2831.0	7.71	17.0	895.0
88Q0732	0.005	-0.004	-0.1			-0.040	2052.0	2200.0		8.05	2.14	3760.0	7.70	13.8	1231.0
87Q0926	11.800	-0.004	0.2				611.0	778.0		8.14	1.64				<304.0
88Q0733	0.034	-0.004	0.2			-0.040	1699.0	1831.0		8.04	2.66	2806.0	7.70	15.0	943.0
87Q0927	0.120	0.080	-1.0	0.006	0.002	0.420	126205.0	126310.0	110000.0	7.12	73.38	100000.0		12.0	>30000.0
88Q0734	0.270	0.110	-0.1	0.006	0.002	0.480	148814.0	148884.0	96546.0	6.65	78.38	230000.0	6.52	15.0	>58850.0
87Q0928	0.056	0.062	-1.0	0.003	0.002	0.380	112367.0	112915.0	110000.0	7.85	69.12	150000.0	7.98	8.0	>30000.0
88Q0735	0.020	0.043	-0.1	0.002	0.002	0.050	103748.0	104450.0	81494.0	7.24	64.32	215000.0	7.02	15.0	>58850.0
88Q0736	0.260	0.020	-0.1			0.050	32680.0	32855.0		7.79	19.52				>5885.0
87Q0929	-0.003	-0.004	0.2				946.0	1156.0	3008.0	7.82	2.34		7.59	8.0	161.0
88Q0737	0.043	-0.004	-0.1			-0.040	1658.0	1903.0		8.28	3.29				486.0
87Q0930	4.070	-0.004	-0.1				2836.0	3056.0		8.05	7.44				1603.0
88Q0738	0.460	0.020	-0.1			0.040	40468.0	40590.0		7.20	15.99	53588.0	6.60	16.0	30090.0
88Q0739	0.029	-0.004	-0.1			-0.040	16583.0	16737.0	24784.0	7.49	6.30	25364.0	6.93	14.5	13750.0
87Q0931	1.140		-0.1				15605.0	15805.0		7.82	27.96				>5885.0
88Q0740	0.200	0.007	-0.1			-0.040	28427.0	28555.0		7.50	23.37	37126.0	7.53	13.9	24470.0

RESULTS

ELECTROMAGNETIC CONDUCTIVITY SURVEY

The EM 34-3 surveys at the Hunter disposal sites identified areas with higher than background apparent conductivities at both the Hunter East Pits and the Hunter West Pits. The apparent conductivity maps (Figures 4 and 5) indicate changes in conductivity resulting from both the disposed salt saturated mud and background conductivity variations.

High conductivity materials were identified only under a small area near the east edge of the Hunter East Pits (Figure 4). Apparently, much less waste reserve pit material was buried than the 150 truck loads previously reported. Subsequent reports and shallow test drilling confirmed this interpretation. Intermediate apparent conductivities mapped north of this disposal pit using the 10 meter horizontal dipole configuration are probably the result of increased background conductivities. The field on the north edge of the EM 34-3 grid was in summer fallow, while the remaining area was in pasture. Higher soil moisture content in the summer fallow than in the pasture probably caused the higher apparent conductivities in that area.

Conductivity maps around the known source of high conductivity muds at both the 20 meter vertical dipole configuration and 40 meter vertical dipole configuration tend to indicate high conductivity materials moving downward and radially away from the source.

High apparent conductivity materials were identified under most of the Hunter West Pits (Figure 5). Photographs of site operations confirmed that most of these pits were completely filled with waste mud. The resultant maps are biased because surface access was restricted by cropland on the west boundary of the grid and surface access was restricted by stacked oil rigs on the south and east boundary of the grid (Figure 3). Consequently, the mapped boundary of intermediate conductivity on the west and south sides of the west disposal pits are an artifact of the grid design and do not necessarily represent a contact between intermediate and background conductivities.

As at the east site, both the 20 meter vertical dipole map and the 40 meter vertical dipole map indicate high conductivity materials moving downward and radially away from the disposal pits.

The EM 34-3 survey proved to be a valuable tool to identify areas contaminated by the salt saturated muds. The information helped determine best possible locations for monitoring the contaminant movement in the subsurface. Without the survey it is doubtful that a monitoring site near the Hunter East Pits would have been located close enough to the source to document contaminant movement. The EM 34-3 survey was relatively quick, both sites were completed in two days. The survey was relatively insensitive to surface metallic debris, only a few errant readings were attributed to the stacked drill rigs at the Hunter West Site. Although not attempted, the results of the survey could probably be used to assess stratigraphic variability of apparent conductivity, indicating depth of contamination.

HYDROGEOLOGY

On the basis of test drilling, outcrop investigations and topography, the Hunter disposal pits are situated on top of a terrace underlain by up to 90 feet of sand and gravel. The relatively flat underlying bedrock surface ranges in elevation from 2070 feet at the south edge of the terrace in T. 24 N., R. 59 E., Sec. 13AAA to 2095 feet at the study site. Several springs crop out on the east and south edges of this terrace between elevations of 2050 to 2100 feet. These are contact springs developed at the intersection of the bedrock surface and the valley wall. The greatest impact of leachate migration will develop in saturated zones within this terrace. Consequently, the areal extent, stratigraphy, hydraulic properties and direction of ground-water flow within this terrace are of primary importance to this investigation.

Stratigraphy

The stratigraphic relationships of sediments within 90 feet of the land surface underlying the study area is shown in Figure 7. The orientation of the cross-sections are located on Figure 2. Cross-section A-A' cuts through the disposal pits and cross-section B-B' cuts through undisturbed sediments south of the disposal pits. Fine-grained clayey bedrock of the Tongue River Member of the Fort Union Formation forms the base of the terrace sand and gravel deposits underlying the Hunter Disposal pits.

EXPLANATION FOR FIGURE 7

Dark-brown sandy loam and clay loam; topsoil

Light-brown sand; fill material

Dark-grayish-brown brine saturated, oily, sandy silty clay; waste drilling mud

Brownish-gray sandy, pebbly clay loam; glacial till

Yellowish brown to reddish-brown fine- to medium-grained sand with thin clay layers in upper part, coarsens with depth, a few thin gravel layers; stream deposits

Reddish-brown fine- to coarse-sand interbedded with layers of fine- to coarse-gravel, coarsens with depth; stream deposits

Gray silty fine sand; glacial lake and/or stream deposits

Light-olive-green, yellowish-green and light-bluish-gray silt and silty pebbly clay; glacial lake deposits, (till?)

Yellowish-brown to bluish-gray slightly silty clay; bedrock, Fort Union Formation, overbank deposits

Stratigraphic contact, dashed where inferred.

L*01 — Pressure-vacuum lysimeter, indicating sampling point

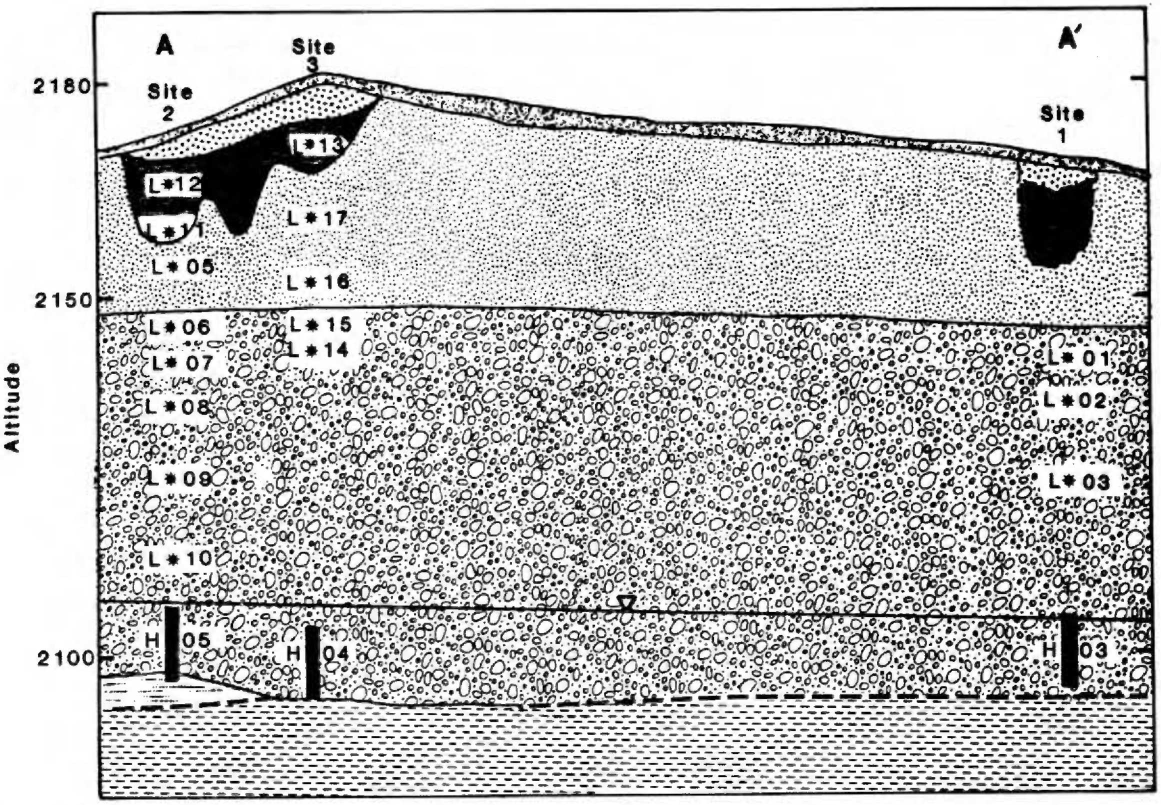
H 02 — Monitor well, indicating screened interval

∇ — Water table altitude (11/27/88)

A-A — Line of cross-section from Figure 2

Site 5 — Location of test drilling site

a.



b.

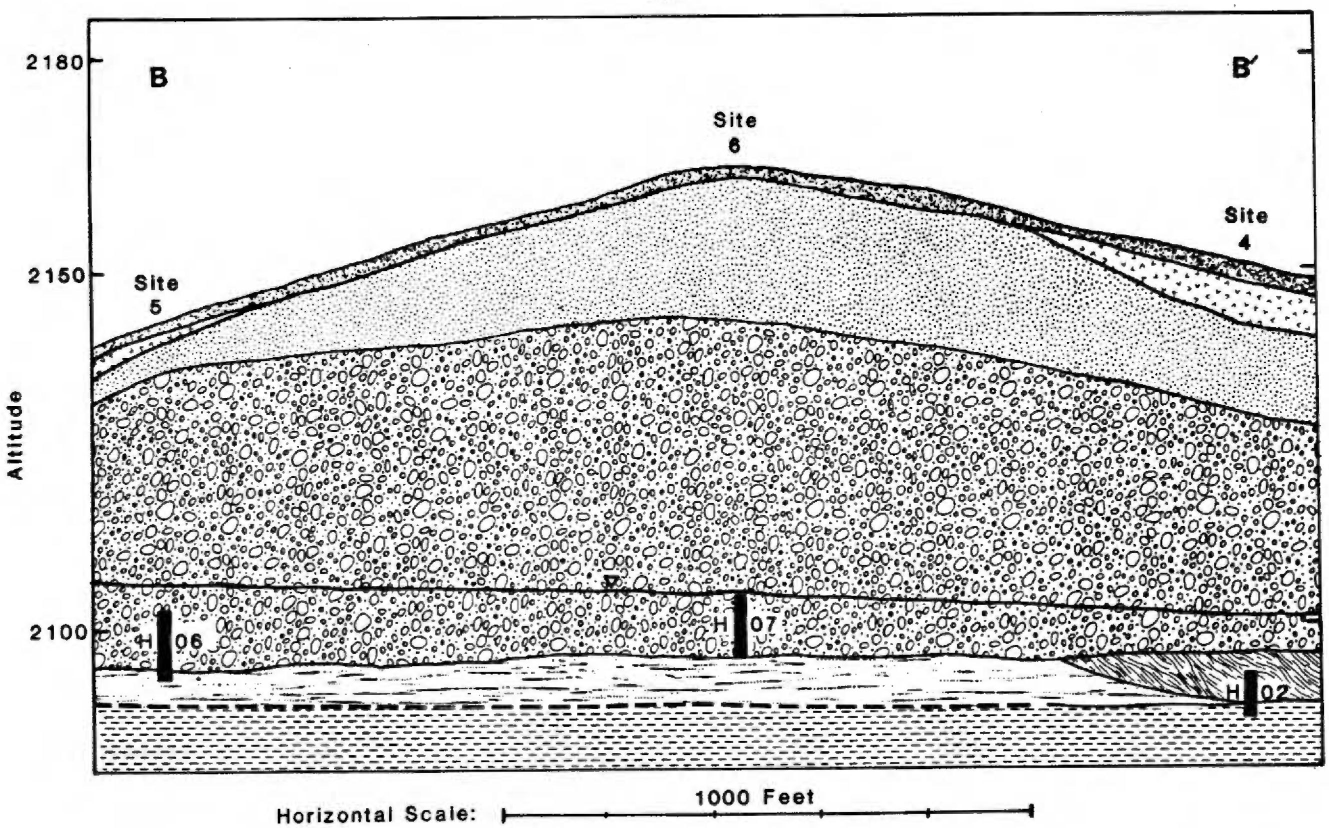


Figure 7. Cross-sections at the Hunter site showing stratigraphic relationships and sampling intervals of monitor wells and lysimeters, a.) cross-section A-A', b.) cross-section B-B'.

A thin discontinuous layer of pebbly clay of undetermined origin was encountered overlying the bedrock during well drilling at H-05, H-06 and H-07. Silty fine sand directly overlies the bedrock at H-02 but was not identified in any other test holes. This unit may be a lateral coarser grained equivalent of the pebbly clay unit or a finer grained facies of the overlying sand and gravel deposit. Interbedded terrace sand and gravel up to 90 feet thick underlies the study area. About 1-1/2 miles south of the disposal pits, a gravel pit in Township 24 N., Range 59 E., Sec. 13 BAB exposes up to 60 feet of the terrace fill (Figure 1). Complex stratigraphic relationships are exposed in the walls of the gravel pit indicating several cut and fill channels as well as interlayered horizontal beds of sand and gravel. The terrace fill stratigraphy displayed at the outcrop, with both coarse gravel filled channels and fine sand filled channels, is much more complex than the stratigraphy interpreted from test drilling at the disposal pits. Consequently, the following description of stratigraphic relationships within the terrace fill at the Hunter site probably indicates a more simplified setting than what actually exists.

A stratigraphic break based on grain size separates the terrace fill into a lower gravelly deposit and an upper sandy deposit. The lower unit consists of interbedded sand and gravel with the gravel beds increasing in thickness with depth. A few thin clay beds are located below the contact of the lower and upper units. The upper sandy unit consists largely of sand interbedded with a few thin layers of clay and gravel. Thin deposits (2-5 feet thick) of glacial till overlie the sandy unit. Where the till has been removed by erosion, glacial erratics scattered on the land surface are commonly the only remnants of the last glaciation. Thin irregular deposits (less than 5 feet thick) of eolian sand and silt cover much of the study site. Soils range from a sandy loam to a silty clay loam. The waste muds are very dark gray clayey sandy silt, with a strong diesel odor. The muds appear uniform within the disposal cells. The sandy fill on top of the waste mud consists of massive fine to medium sand and is covered by reclaimed topsoil.

Hydrologic Characteristics of the Unsaturated Zone

The unsaturated zone is developed largely in the interbedded sand and gravel deposits underlying the study site. Water moves through unsaturated materials generally in a more complicated manner than through saturated materials. Water movement through the unsaturated zone is, by definition, through interconnected pore spaces that are only partially filled with water (Freeze and Cherry, 1978). The percent of the pore spaces filled with water is referred to as the volumetric moisture content. Pressure heads in the unsaturated zone are negative due to surface tension effects holding water in the pores. The hydraulic conductivity of unsaturated materials is not a constant as in similar saturated materials. Both hydraulic conductivity and pressure head depend on the volumetric moisture content. Although not measured, qualitative estimates of moisture content during test drilling were observed to increase with depth. Precipitation and snow melt readily infiltrate through the sandy soils. Infiltration rates were not measured but will undoubtedly vary depending on the antecedent volumetric moisture content in the unsaturated zone. Recharge water from precipitation moves vertically towards the water table. Thin clay layers found in the coarse grained materials have the potential for retarding, ponding and diverting the percolating recharge water.

Hydrologic Characteristics of the Basal Terrace Aquifer

The sand and gravel beds are saturated at depths of 55 to 65 feet below the disposal pits. The aquifer extends downward from the water table for about 10 to 15 feet where the basal clayey layer retards downward flow. Water in the aquifer is under unconfined conditions. Contours of water level elevations indicate a gradient to the southeast under most of the site (Figure 2). Ground water probably also flows to the north and west under part of the Hunter West Pits. The dashed contour lines on Figure 2 are water level elevations estimated on the basis of surface topography.

Based on grain size analysis (Appendix B-3), the average hydraulic conductivity of the sand and gravel deposit was calculated to be between 1 X 10^{-2} cm/sec and 3 X 10^{-3} cm/sec using the Hazen Method (Freeze and Cherry, 1978).

Precipitation and snowmelt readily infiltrate through the sandy soil and vadose zone to recharge the aquifer. Several recharge events are easily identified by studying water level hydrographs. Plots of water levels in wells below the disposal pits (H-03, H-04, and H-05) are displayed in Figure 8. Plots of water levels in wells located away from the disposal pits (H-02, H-06, and H-07) are displayed in Figure 9. Static water levels declined an average of .5 ft during the monitoring period. The decline rate decreased in response to minor recharge events during the winter of 1988 and again in the fall of 1988. In 1989, spring rains reversed the declining trend and water levels rose rapidly from April to late May. Following the spring reversal, water levels dropped for the remainder of the monitoring period.

Water levels in well H-02 were more sensitive to recharge events than in the other wells. This effect is shown best on Figure 9, where, during the spring of 1989, water levels rose both sooner and more than in other wells. Well H-02 is located near the edge of a shallow depression that occasionally ponds water during the spring. Depression focused recharge probably accounts for the faster and greater response to recharge events in this well than in the other wells.

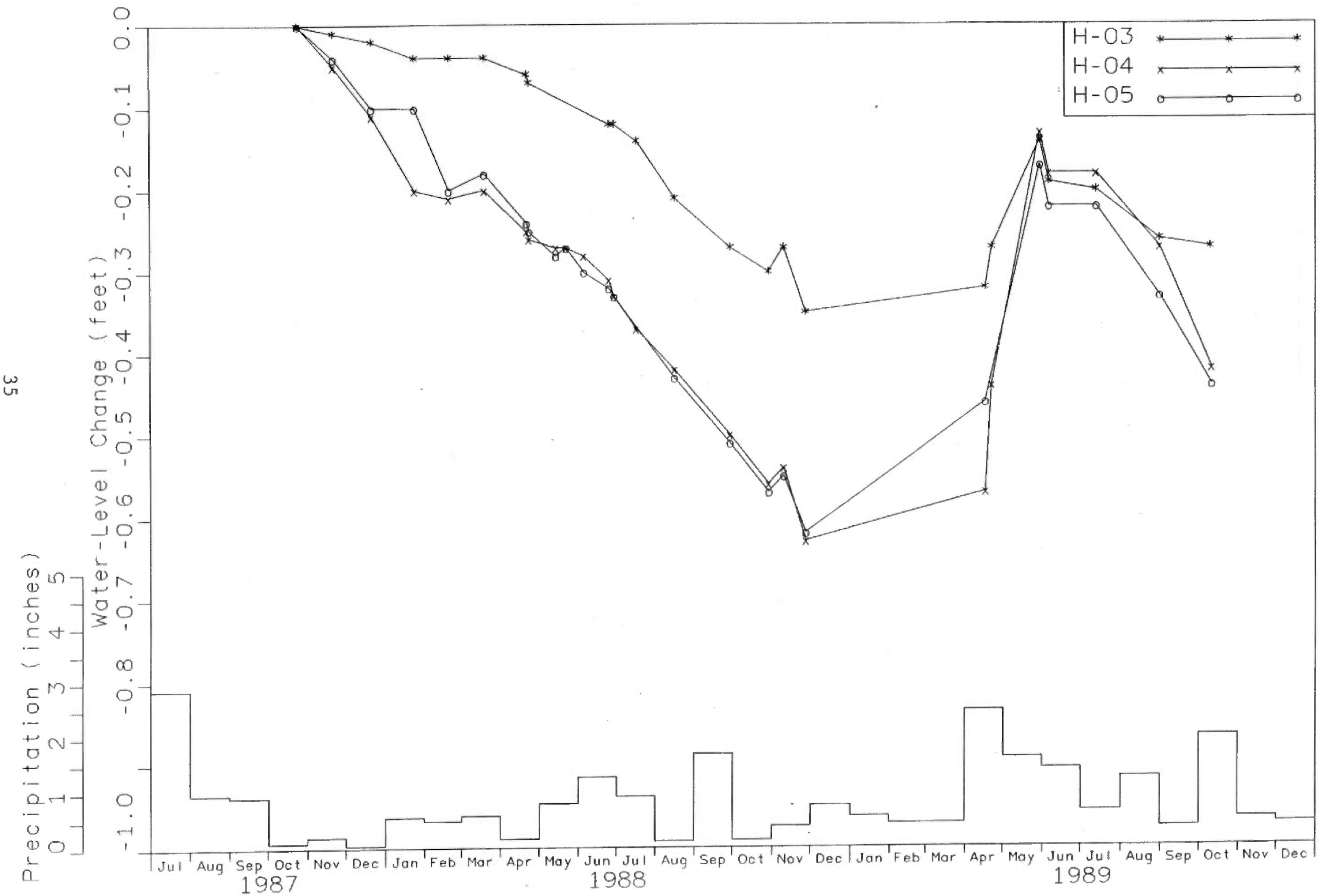


Figure 8. Hydrographs of monitor wells H-03, H-04, and H-05.

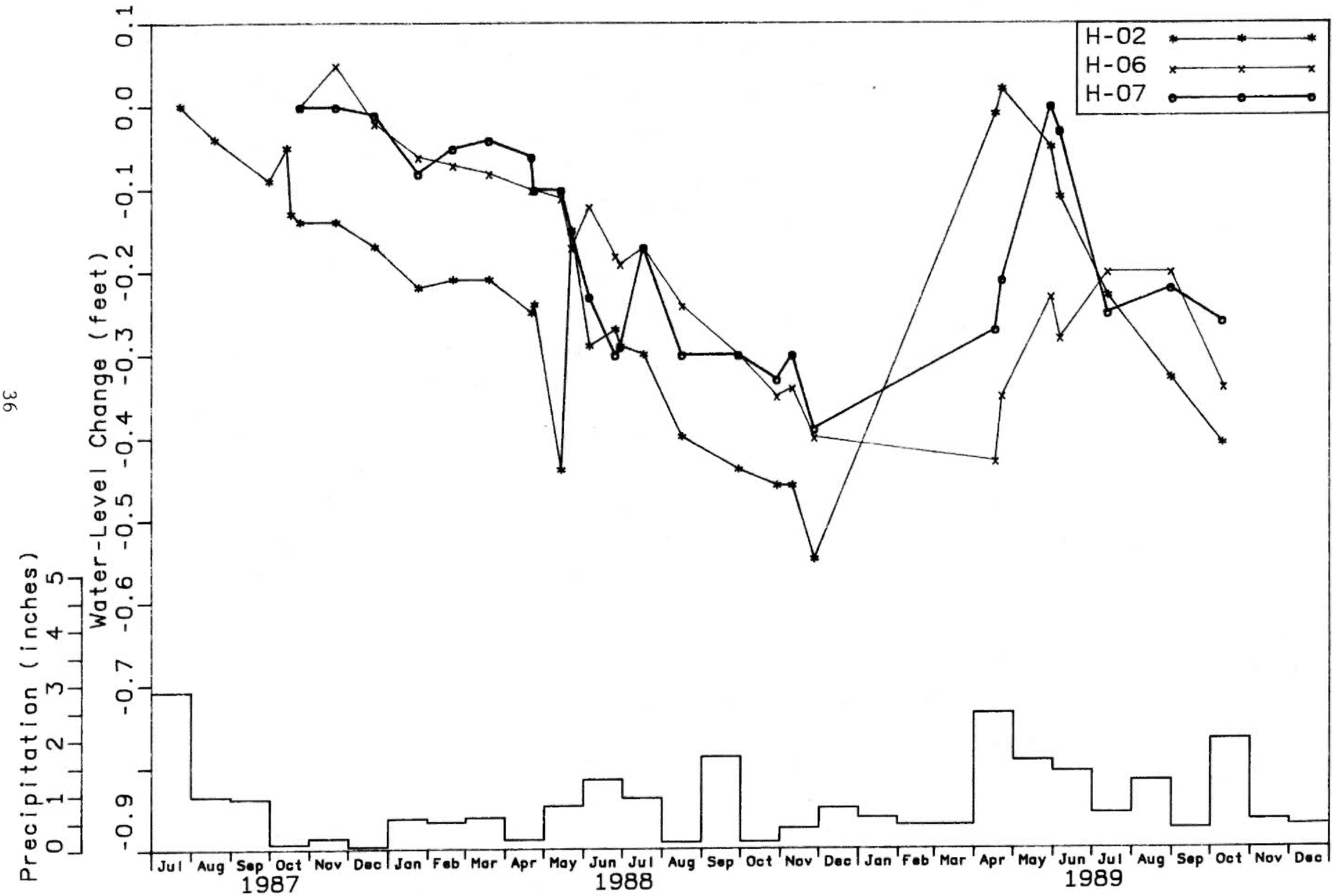


Figure 9. Hydrographs of monitor wells H-02, H-06, and H-07.

WATER QUALITY

Background Water Quality

Water quality in the basal terrace/outwash aquifer is fresher than most eastern Montana aquifers. Calculated total dissolved solids (CDS) in the observation wells located away from the disposal pits based on 4 laboratory analyses ranges from 300 mg/L to 480 mg/L and average 410 mg/L. A more typical CDS average for eastern Montana aquifers ranges between 1000 mg/L to 2000 mg/L. The terrace aquifer water is hard with calcium, magnesium, and bicarbonate ions dominating the chemical makeup (Table 3). The ranges of percent reacting values for cations from background aquifer samples are: calcium -- 47%-52%, magnesium -- 31%-42%, sodium plus potassium -- 9%-17%. The ranges of percent reacting values for anions from background aquifer samples are: Chloride -- 5%-14%, bicarbonate -- 74%-88%, sulfate -- 6%-15%. Concentrations of trace constituents were generally below detection limits. Both the low CDS and the dominant chemical makeup of the water indicates the study area is in the recharge area of this aquifer. Most of the naturally available salts have been flushed out of both the unsaturated zone and the saturated zone.

Nitrate concentrations are high, particularly under the east half of the study area. The standard health limits for nitrates (10 mg/L as N) are exceeded in 5 out of 10 water samples from the saturated zone. Highest nitrate concentrations in the saturated

Table 3. Percent Reacting Values

Sample	Date	Lab Number	%Ca	%Mg	%(Na+K)	%Cl	%SO4	%HCO3	TDS (mg/L)	TDS (meq/L)	%error
H-00	06/29/88	88Q0741	52.13	30.72	17.15	10.85	14.66	74.48	481	14.47	6.62
H-02	10/24/87	87Q0915	51.45	37.97	10.58	14.36	6.00	79.64	411	12.84	9.83
H-03	10/24/87	87Q0916	54.37	35.16	10.47	22.21	11.39	66.39	494	15.96	15.38
H-03	06/29/88	88Q0742	53.70	35.09	11.20	21.06	11.83	67.11	510	15.93	10.80
H-04	10/23/87	87Q0917	49.08	29.81	21.11	28.62	6.86	64.42	371	11.71	6.11
H-04	06/29/88	88Q0743	54.88	33.71	11.42	7.85	5.49	86.66	249	7.28	1.33
H-05	10/23/87	87Q0918	55.07	32.59	12.33	28.03	4.43	67.54	367	11.68	4.41
H-05	06/29/88	88Q0744	56.52	33.25	10.24	2.25	3.88	93.87	231	6.68	0.24
H-06	10/24/87	87Q0919	48.55	42.30	9.15	4.72	7.75	87.53	301	9.12	5.87
H-07	10/24/87	87Q0920	47.35	37.63	15.02	13.34	9.72	76.94	459	14.24	8.39
L-01	10/19/87	87Q0921	41.52	40.87	17.61	47.65	10.20	42.15	814	26.34	11.50
L-01	06/29/88	88Q0726	41.43	50.25	8.32	86.01	3.01	10.98	1,790	64.23	2.14
L-02	10/20/87	87Q0922	36.01	47.00	16.99	63.15	5.72	31.12	962	33.52	10.65
L-02	06/29/88	88Q0727	40.00	48.27	11.74	93.61	1.20	5.19	3,410	127.92	2.05
L-03	10/19/87	87Q0923	26.31	26.54	47.14	77.79	7.81	14.40	1,630	55.32	0.27
L-03	06/29/88	88Q0728	34.80	31.17	34.03	69.84	8.31	21.85	1,100	36.97	5.09
L-05	10/23/87	87Q0924	29.46	34.32	36.22	99.00	0.33	0.66	30,900	1,139.32	0.87
L-05	06/29/88	88Q0729	28.10	34.84	37.06	98.65	0.66	0.69	21,000	774.90	0.24
L-06	10/23/87	87Q0925	34.95	34.74	30.31	56.39	11.19	32.42	863	27.36	0.63
L-06	06/29/88	88Q0730	27.12	43.91	28.97	93.18	4.37	2.45	6,580	242.48	0.89
L-07	06/29/88	88Q0731	23.96	46.31	29.73	70.86	12.10	17.04	1,690	57.71	0.13
L-08	06/29/88	88Q0732	23.67	53.27	23.07	77.73	9.62	12.66	2,050	72.77	0.18
L-09	10/23/87	87Q0926	29.09	38.86	32.05	31.14	17.61	51.25	611	17.82	2.37
L-09	06/29/88	88Q0733	23.71	45.97	30.33	71.57	14.21	14.22	1,700	57.75	0.24
L-11	10/19/87	87Q0927	29.98	3.28	66.74	99.71	0.14	0.15	126,000	4,369.09	0.98
L-11	06/29/88	88Q0734	30.07	3.83	66.10	99.81	0.10	0.09	149,000	5,160.63	0.97
L-12	10/19/87	87Q0928	31.05	2.50	66.45	98.86	0.23	0.91	112,000	3,890.48	0.25
L-12	06/29/88	88Q0735	23.79	10.83	65.37	98.50	0.27	1.23	104,000	3,623.71	1.00
L-13	06/29/88	88Q0736	25.56	30.41	44.02	94.14	4.92	0.94	33,000	1,170.40	3.18
L-14	10/23/87	87Q0929	29.69	35.21	35.11	34.32	23.08	42.60	946	28.87	1.20
L-14	06/29/88	88Q0737	25.84	37.70	36.47	43.45	28.34	28.21	1,660	52.63	0.92
L-15	10/23/87	87Q0930	22.22	24.70	53.07	77.51	8.26	14.23	2,840	95.89	0.26
L-15	06/29/88	88Q0738	27.24	38.77	33.99	98.02	1.46	0.52	40,500	1,503.12	0.20
L-16	06/29/88	88Q0739	29.80	47.56	22.65	95.65	2.76	1.59	16,600	624.97	0.34
L-17	10/23/87	87Q0931	21.15	10.46	68.40	92.85	4.78	2.38	15,600	539.71	0.05
L-17	06/29/88	88Q0740	26.83	21.72	51.45	98.18	1.00	0.82	28,400	1,021.73	0.62

zone were detected in water from well H-03 (Site #1). Nitrate levels in this well were measured at 37.80 mg/L on 10/24/87 and at 39.10 mg/L on 6/29/88. Water samples from the unsaturated zone below site #1 also had high to very high nitrate concentrations. Nitrate levels in the 3 lysimeters at this site ranged from 8.70 mg/L at L-03 sampled on 10/19/87 to 45.50 mg/L at L-02 sampled on 6/29/88. With the exception of a sample from L-14 collected on 6/29/88, water from all wells and lysimeters below site #2 and site #3 contained low to moderate nitrate concentrations.

Past agricultural practices appear to have concentrated the nitrates in the ground water to very high levels. A former pig barn is within 200 feet of the well and lysimeter cluster at site #1. It was also reported that a livestock feedlot had once been operated on the east side of the farmstead.

Sodium chloride in the drilling mud is both the major contaminant and the major tracer for identifying movement of the contaminant plume. Therefore, determining the level of chloride in the unaffected aquifer system is critical for documenting the extent of contamination.

Background chloride concentrations averaged 15 mg/L in the saturated zone based on laboratory analyses of water samples not impacted by salt contamination. Similar chloride concentrations probably are also found in the unsaturated zone. Unfortunately, the lysimeter installed to measure background conditions (L-18) failed to produce water early in the study. Consequently, only one field measurement was collected and the background water quality in the unsaturated zone was not confirmed by a laboratory analysis.

Disposal Site Water Quality

Water samples were evaluated both temporally and stratigraphically. Samples were collected from the drilling mud, the unsaturated zone below the drilling mud, and the saturated zone at the base of the terrace deposit. Chloride concentrations are plotted against time in Figure 10 (site #1), Figure 11 (site #2) and Figure 12 (site #3). Both field chloride values and laboratory chloride values are plotted on these figures to provide a more complete, and continuous, graph. Field chloride concentrations that exceeded the limits of the Quantab titrators after dilution were not plotted. Field chloride concentrations less than the detection limits were plotted at the detection limit. Trend lines were plotted showing changes in chloride concentration with time for each well and lysimeter. The trend lines emphasized laboratory derived values when both field and laboratory values were measured. Field values showed a slight tendency to overestimate the laboratory concentrations, although this tendency is not statistically significant as shown in Figure 6.

Chloride concentrations in all the lysimeters except L-03 increased from late July 1987 to late June 1988. Chloride measurements during this time period appear to reflect dilution by distilled water from the slurry used during lysimeter installation.

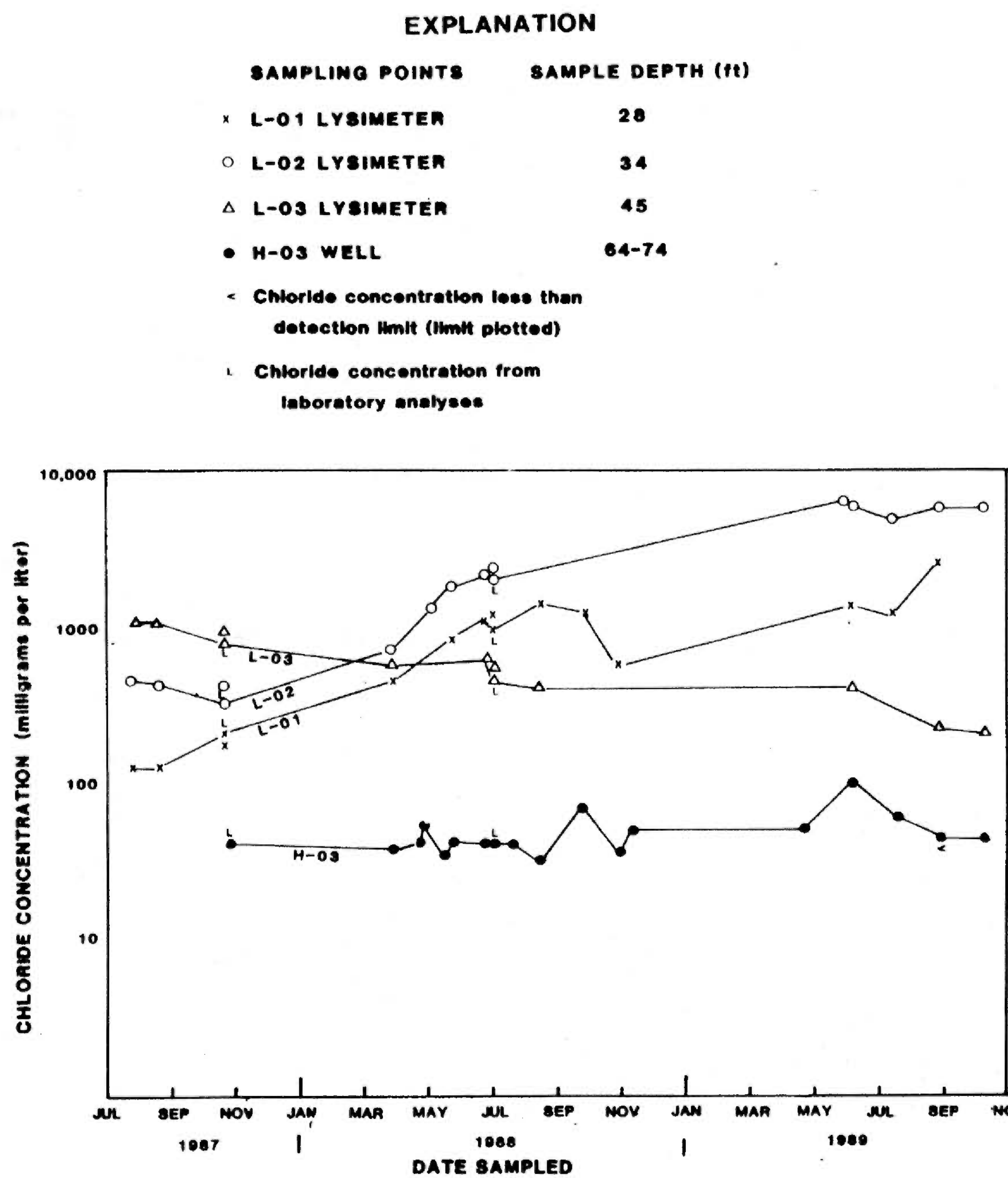


Figure 10. Fluctuations of chloride concentrations at monitoring site #1.

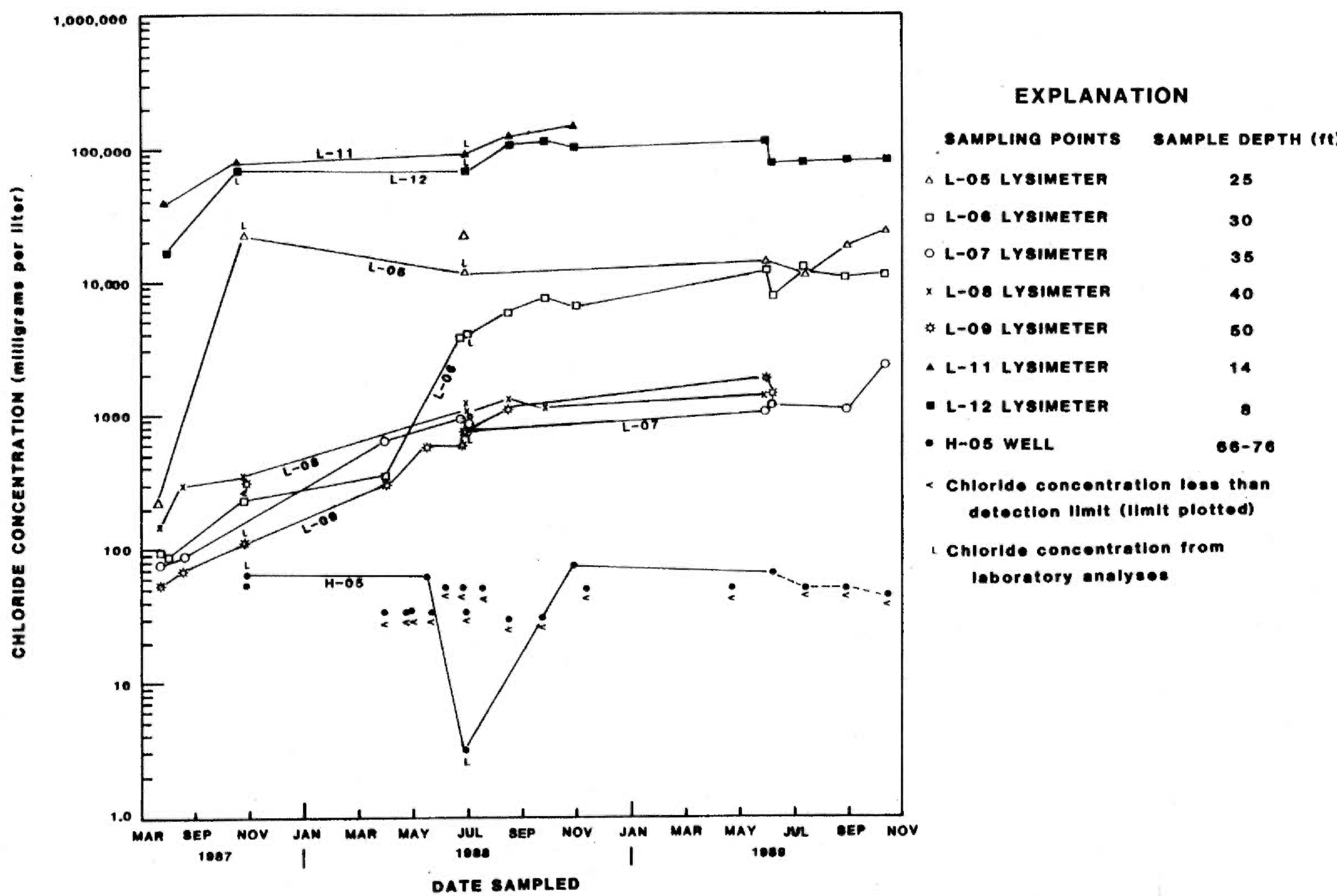


Figure 11. Fluctuations of chloride concentrations at monitoring site #2.

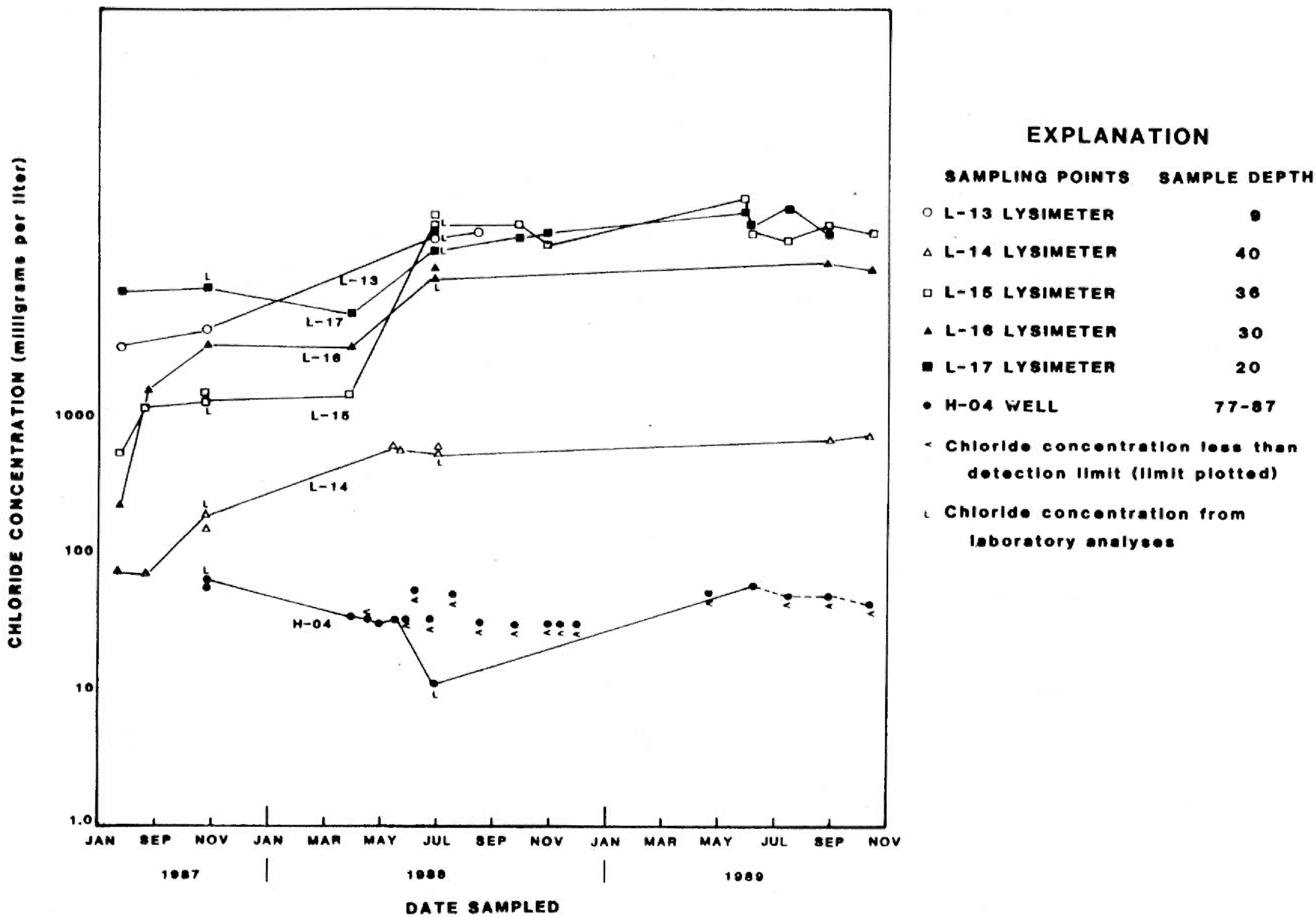


Figure 12. Fluctuations of chloride concentrations at monitoring site #3.

After late June 1988, the rate of increasing chloride concentration declined, probably due to a combination of purging the diluted water while sampling, and mixing of the slurry water with the contaminated recharge water. Consequently, most of the lysimeter water samples collected prior to late June 1988 probably do not represent the true chemistry of soil water. But, lysimeter water samples after late June 1988 appear to be representative of field conditions.

The declining trend of chloride concentrations in L-03 is not well understood (Figure 10). The early chloride measurements appear anomalously high when compared to chloride measurements in L-01 and L-02 which are closer to the contaminant source. A possible explanation is that chloride contaminated cuttings were accidently placed near the ceramic cup when L-03 was installed. This could cause high initial chloride concentrations that decreased to more representative concentrations with time.

Several of the lysimeters intermittently failed to produce water during the period of sampling (Table 1). Mechanical problems may have caused air leaks in some of the lysimeters. But, most of the lysimeters did produce water at a later date indicating other possible reasons for the lack of sample water. Undoubtedly, the shortage of precipitation impacted the moisture content in the unsaturated zone. Grain size differences between sampling zones of the lysimeters could result in different moisture retention capacities. Consequently, moisture would drain out of coarser grained zones faster than fine grained zones. This would require fortuitous timing between movement of wetting front past the lysimeter cup and application of suction to the lysimeter to collect a water sample.

Waste Drilling-Mud Pore Water

Waste drilling-mud pore water has similar water quality now as when the muds were buried. CDS in samples from L-11 and L-12, based on 4 laboratory analyses, ranges from 104,000 mg/L to 149,000 mg/L and averages 123,000 mg/L. Although the water is diluted from the original concentration (CDS=200,000-300,000 mg/L), it is still classified as a brine. Sodium, calcium, and chloride are the major constituents combining to cause the high CDS (Table 3). Average percent reacting values for brine cations are calcium -- 29%, magnesium -- 5%, and sodium plus potassium -- 66%. Average percent reacting values for brine anions are chloride -- 99%, bicarbonate less than 1%, and sulfate -- less than 1%.

Several of the trace constituents are concentrated at high levels in the waste mud. Concentrations of boron, lithium, bromide, and strontium are at levels ranging from tens to hundreds of mg/L. High levels of these elements probably are the result of the chemistry of oil field brines used to make up the drilling mud. Concentrations of silver, cadmium, and lead in the mud pore water are greater than drinking water standards. Concentrations of chromium and barium exceeded drinking water standards in one sample and are moderately high in the other three samples (Table 4). Concentrations of aluminum, nickel, and zinc are elevated above

Table 4. Recommended limits and maximum levels of constituents in drinking water, stock water and irrigation water

Parameter	Drinking Water: *Maximum Contaminant Levels (Mg/L)	Drinking Water: ** USPHS Recommended Limits (Mg/L)	***Stock Water Limits (Mg/L)	***Irrigation Water Limits, Water Used Continuously On All Soils (Mg/L)
Aluminum			5	5
Arsenic	.05	.01	.2	.1
Beryllium				.1
Barium	1.0			
Boron			5	1.0
Bromide				
Cadmium	.01		.05	.01
Chloride		250		
Chromium	.05		1.0	.1
Cobalt			1.0	.05
Copper		1.0	.5	.2
Cyanide		.2		
Fluoride	2.4	.8-1.7	2.0	1.0
Iron		.3		5.0
Lead	.05		.1	5.0
Lithium				2.5
Manganese		.05		.2
Mercury	.002		.01	
Molybdenum				.01
Nickel				.2
Nitrate				
(No_3 as N)	10	10	100	
(as No_3)	44			
Selenium	.01		.05	.02
Silver	.05			
Strontium				
Sulfate		250		
Tin				
Titanium				
Total dissolved solids		500	10,000	
Vanadium			.1	.1
Zinc		5	24	2
Zirconium				

* National Primary Drinking Water Regulations from Safe Drinking Water Act (Public Law 93-523)

** U.S. Public Health Service (1962)

*** Environmental Studies Board: Nat. Acad. of Sci., Nat. Acad. of Eng. Water Quality Criteria background values but none of these have primary drinking water standards set. High levels of most of these constituents are probably the result of drilling additives used in the mud.

Unsaturated Zone Pore Water

Unsaturated zone pore water below the disposal pits has a diverse water chemistry. In general, the unsaturated zone water quality covers a wide spectrum limited at the fresh end by the background water chemistry in the aquifer and limited at the briny end by the water chemistry in the waste-mud pore water. Sample water was initially diluted by water in the slurry used to install the lysimeters. The initial dilution effects decreased with time as indicated by increases in CDS, increases in chloride percent, decreases in bicarbonate percent, and slight decreases in sodium plus potassium percent between the first and second samples (Table 3). CDS values range from 610 mg/L to 40,000 mg/L in the unsaturated zone. The ranges of percent reacting values for unsaturated zone cations are: calcium -- 21%-42%, magnesium -- 3%-53%, and sodium -- 8% - 68%. The ranges of percent reacting values for unsaturated zone anions are: chloride -- 34%-99%, bicarbonate -- 0.5%-51%, and sulfate -- 0.1%-28%.

Trace constituent concentrations are much lower in the unsaturated zone than in the overlying waste mud. Brine related trace constituents (boron, lithium, bromide and strontium) in the unsaturated zone are 1 to 3 orders of magnitude lower than in the waste materials. Cadmium concentrations are above drinking water standards in four samples from the unsaturated zone. Concentrations of other trace constituents range from below detection limits to an order of magnitude below drinking water standards.

Basal Terrace/Outwash Aquifer Water Quality

The basal terrace/outwash aquifer below the disposal pits has similar water quality as the background water quality in the portion of the aquifer located away from the pits. CDS in wells below the disposal pits based on 6 laboratory analyses ranges from 230 mg/L to 510 mg/L. Calcium, magnesium, and bicarbonate are the dominant ions (Table 3). The ranges of percent reacting values for the terrace aquifer cations are: calcium -- 49%-57%, magnesium -- 29%-35% and sodium plus potassium 10%-21%. The ranges of percent reacting values for the terrace aquifer cations are: chloride -- 2%-29%, bicarbonate -- 64%-94%, and sulfate -- 4%-12%. As in water from background locations, concentrations of trace constituents were generally below detection limits.

Both the lowest CDS and the highest CDS measured were from samples of wells underlying the disposal pits. It appears that true background concentrations are a function of sample timing in addition to proximity of the sample to the contamination source. Differences in chloride concentrations between the October 1987 and June 1988 samples from wells H-04 and H-05 best display the importance of sample timing (Figures 11 and 12). Salt concentrations in October, 1987 samples from wells H-04 and H-05 were relatively high. Chloride concentrations were measured at 62.3 mg/L (28.6% reacting value of cations) and 64.8 mg/L (28.0% reacting value of cations) respectively. In contrast, salt concentrations in June, 1988 samples from wells H-04 and H-05 were very low. Chloride concentrations were measured at 10.8 mg/L (7.8% reacting value of cations) and 3.1 mg/L (2.2% reacting value of cations) respectively. The 8 to 20 fold drop in chloride concentration corresponded to a 60-70% decline in CDS. Collection of the October, 1987 sample coincided with a time of recharge when salts were moving into the aquifer. While the June, 1988 sample coincided with a time of no recharge; salts were not moving into the aquifer but had been flushed from this part of the aquifer system. Fluctuations of chloride concentrations were also detected from periodic field measurements. Water samples from all monitor wells except H-06 indicated detectable chloride concentrations. Samples collected on June 6, 1989 showed the most widespread impact of chloride contamination. Detectable chloride levels were measured on this date in wells H-02 (65 mg/L), H-03 (102, mg/L), H-04 (59 mg/L), H-05 (65 mg/L), and H-07 (168 mg/L). Increases in chloride concentrations on this date correspond with rising water levels in the aquifer that were caused by the 1989 spring recharge event.

CONTAMINANT MOVEMENT BELOW THE DISPOSAL PITS

MOBILIZATION OF THE CONTAMINANT SOURCE

Recharge is the method the contaminant plume is mobilized in the disposal pits. Once a wetting front develops the salts and other soluble contaminants are dissolved and carried with the recharge water. The salt concentrations and trace constituents are very high within the pits. Several constituents are concentrated at levels well above drinking water standards. Immediately below the waste muds, most of the heavy metals concentrations are greatly reduced.

High concentrations of heavy metals in the waste muds and low concentrations of heavy metals below the waste muds are probably the result of chemical reactions occurring in and below the disposal pits muds including formation of complex ions and adsorption. High concentrations of the chloride ion aid in mobilizing ions such as cadmium, lead, and silver by forming complexes with these ions (Krauskopf, 1967). Adsorption reduces the concentration of these ions by reactions with clay minerals. Formation of chloride complexes may account for elevated concentrations of dissolved trace metals (specifically silver, cadmium, and lead) in the waste drilling mud. While adsorption reactions with clays in the muds and the unsaturated zone probably account for the removal of these ions from the contaminant plume.

The mass of contaminants available to leach out of the disposal pits is not clearly defined. The best estimates of the mass can be determined by calculating the mass based on the reported volume of wastes hauled to the site. The service company reported the volume of mud hauled to the site was between 3700 to 4050 cubic yards. The mud was reported to contain 13 percent water by volume. The haulage records indicate much more mud was buried at the Hunter East pits than was verified by the apparent conductivity survey. A probable assumption is that most of this mud was actually buried at the Hunter West site. Based on the conductivity survey, about 10% of the total wastes were buried at the Hunter East pits and 90% of the total wastes were buried at the Hunter West pits. The average chloride content measured in the waste-mud pore water was 123,000 mg/L. It is also assumed that all the chloride ions are combined with sodium ions as NaCl. Using these assumptions the mass of sodium chloride available to be mobilized at each site can be calculated by the following equation:

Equation 1:

$$\text{Kg NaCl} = \text{volume of water in the muds (L)} * 1.6485 \times 10^{-6} \frac{\text{Kg Nacl}}{\text{Mg Cl}} * \text{Cl concentration mg/L}$$

The results of applying this equation to the two disposal sites are shown below:

HUNTER EAST DISPOSAL PITS

Low estimate = 3700 cubic yards * .10 * 764.6 liters/cubic yard * .13 * $1.6485 \times 10^{-6} \frac{\text{Kg NaCl}}{\text{Mg Cl}}$ * 123,000 mg/L Cl = 7500 kg NaCl

High estimate = 4050 cubic yards * .10 * 764.6 liters/cubic yard * .13 * 1.6485×10^{-6} * $\frac{\text{Kg NaCl}}{\text{Mg Cl}}$ 123,000 mg/L Cl = 8100 kg NaCl

HUNTER WEST DISPOSAL PITS

Low estimate = 3700 cubic yards * .90 * 764.6 liters/cubic yards * .13 * 1.6485 X^{-6} * 123,000 mg/L Cl = 67,000 kg NaCl

High estimate = 4050 cubic yards * .90 * 764.6 liters/cubic yards * .13 * 1.6485 X^{-6} * 123,000 mg/L Cl = 73,000 kg NaCl

The worst case total mass of sodium chloride is the sum of the high estimates for both the Hunter East and Hunter West pits which equals 81,100 kg. The largest source of error in these calculations are the reported volume of mud buried at the disposal pits and the original estimates of water content.

Equation 1 can be rearranged to estimate the volume of water required to dilute the calculated mass of NaCl to the recommended drinking water standards for Cl (250 mg/L).

Equation 2:

$$\text{Volume of water required for dilution (L)} = \frac{\text{Total Mass kg NaCl}}{250 \text{ mg/L Cl} * 1.6485 \text{ X } 10^{-6} \text{ kg NaCl/Mg Cl}}$$

Solving Equation 2 for the worst case results in 2.0 X 10^7 liters (16 acre feet) of water required to dilute the mass of salt at the Hunter East pits to 250 mg/L and in 1.8 X 10^8 liters (146 acre feet) of water required to dilute the mass of salt at the Hunter West pits to 250 mg/L. Therefore, the total available mass of salt could be dissolved in 162 acre feet of water and be at the secondary drinking water standard for chloride.

The total volume of water in the aquifer underlying the Hunter farmstead can be determined by Equation 3. A possible worst case example can be demonstrated by assuming the mass of salt is instantaneously dumped into the aquifer under the Hunter farmstead.

Equation 3:

$$\text{Aquifer volume} = \text{Area} * \text{Aquifer thickness} * \text{Porosity}$$

The Hunter farmstead covers about 40 acres and is underlain by an aquifer that is about 10 feet thick having a porosity of about 0.25. Based on these values there is about 100 acre feet of water underlying the farmstead at any moment in time. Mixing all the salt buried at both sites instantaneously into the volume of aquifer water under the farmstead would result in a chloride concentration of 400 mg/L.

DILUTION OF THE CONTAMINANT PLUME

Dilution of the brines with relatively pure recharge water appears to be causing the ionic concentrations observed below the disposal pits. Figures 10, 11, and 12 depict a general decrease of chloride concentrations with depth of the sample. Perusal of the chemical data indicate concentrations of other ions also decrease with depth. To test this hypothesis, the Hunter site data was applied to a dilution model.

A brine study in Missouri used a dilution model to determine that saline waters displaying a wide range of salinity were of ancient origin. The basic premise of the model is: "If a salt solution containing several different ions is diluted with pure water, the ratios of various ions with respect to each other will remain constant (except in the case of pH sensitive ions), even though the salinity may be changed drasticallly" (Carpenter and Miller, 1969). The relationship between ions can be demonstrated by constructing scatter plots comparing the log concentrations of pairs of ions. The slope of the regression line of the scatterplots will approach and ideal slope of 1 if the relationship is consistent with the dilution model. To test if the observed regression line slope meets the model constraints, a 95% confidence interval is calculated for the regression line (Steel and Torrie, 1960) . If the ideal slope is within this interval the dilution model is valid. Deviations from the ideal slope indicate chemical processes other than dilution affecting one or both of the ions.

The dilution model was tested using water quality data from the Hunter site. Chloride is used as the independent variable and plotted on the x-axis because it is least likely to be affected by chemical reactions other than dilution. The selected ion being compared to chloride is plotted as the dependent variable on the y-axis. Scatter plots shown in Figures 13, 14, 15, and 16 indicate relationships between each selected ion and chloride concentrations. The model statistics are summarized in Table 5. Two sets of data were used in the dilution model analysis: 1) chemical data from samples in the unsaturated zone, 2) chemical data from samples in both the unsaturated zone and the saturated zone.

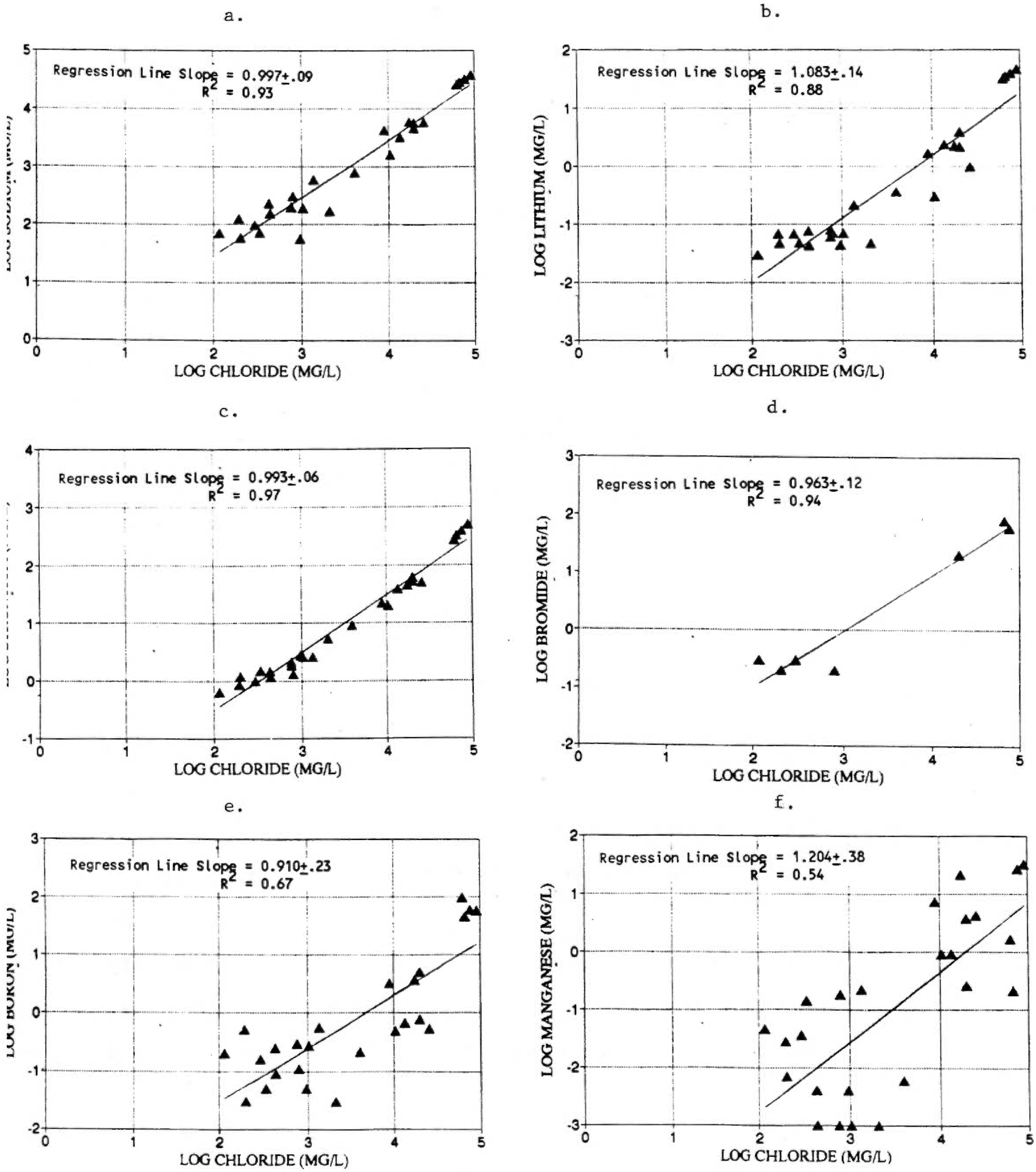


Figure 13. Relationships between chloride concentrations and selected ion concentrations, a.) sodium, b.) lithium, c.) strontium, d.) bromide, e.) boron, f.) manganese, based on water quality data from the unsaturated zone.

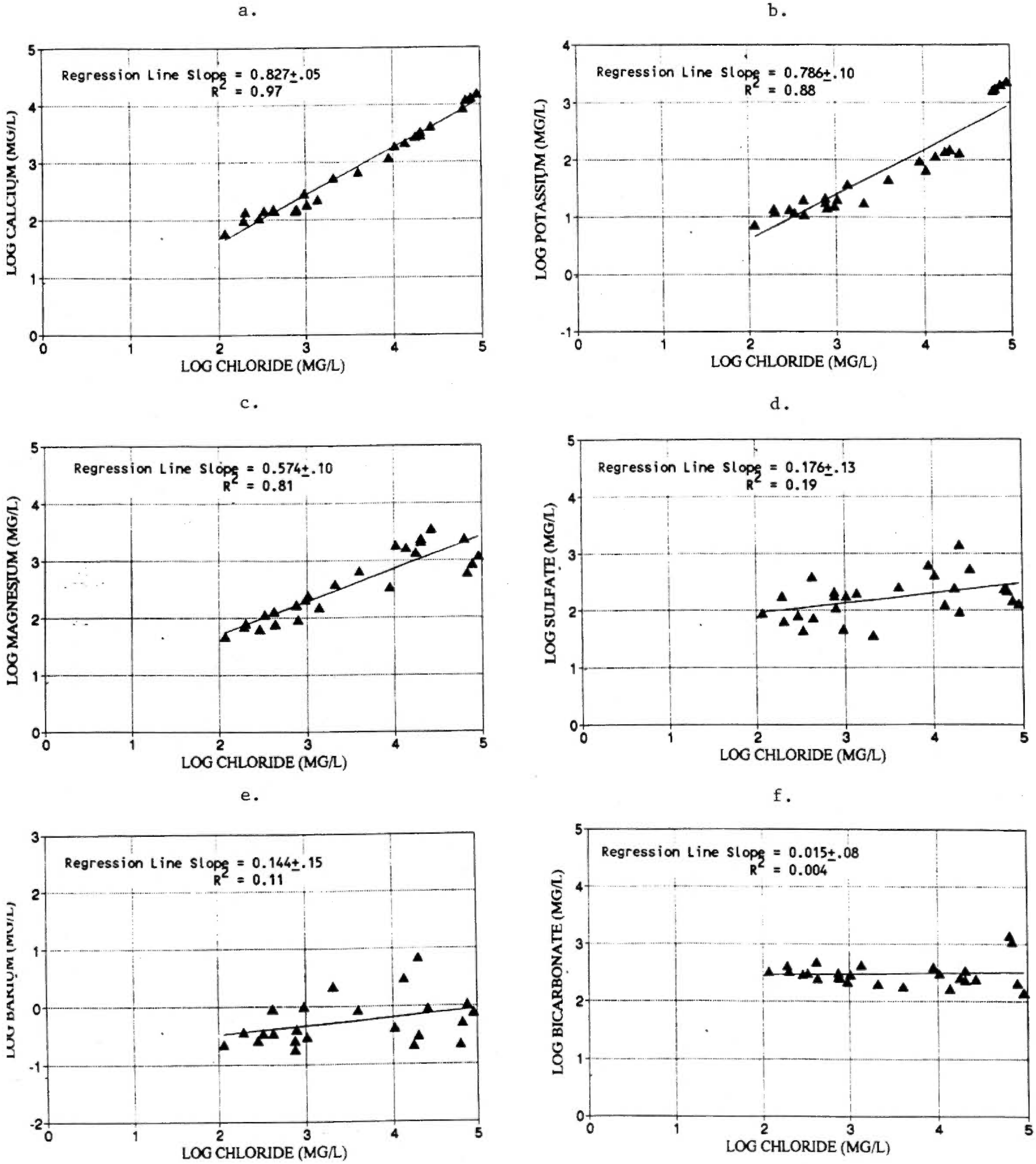


Figure 14. Relationships between chloride concentrations and selected ion concentrations, a.) calcium, b.) potassium, c.) magnesium, d.) sulfate, e.) barium, f.) bicarbonate, based on water quality data from the unsaturated zone.

Table 5. Statistical summary of brine dilution model

Constituent	Unsaturated Zone Data			Aquifer plus Unsaturated Zone Data		
	Regression Line[a] Slope	Dilution Model[b] Fit	R^{2c}	Regression Line[a] Slope	Dilution Model[b] Fit	R^{2c}
LI	1.083±.14	Yes	0.88	0.843±.11	No	0.88
NA	0.997±.09	Yes	0.93	0.845±.08	No	0.94
SR	0.993±.06	Yes	0.97	0.730±.09	No	0.90
BR	0.963±.12	Yes	0.94	N/A	--	--
B	0.910±.23	Yes	0.67	0.668±.15	No	0.70
CA	0.827±.05	No	0.97	0.573±.08	No	0.87
MG	0.574±.10	No	0.81	0.511±.07	No	0.88
K	0.786±.10	No	0.88	0.589±.08	No	0.86
MN	1.204±.38	Yes	0.54	0.553±.31	No	0.27
BA	0.144±.15	No	0.11	N/A	--	--
HCO_3	0.015±.08	No	0.004	0.004±.05	No	0.001
SO_4	0.176±.13	No	0.19	0.305±.09	No	0.57

[a] Observed slope (b)±95% confidence limits

[b] Observed data fits dilution model if the ideal slope (B) is within the 95% confidence limits of the observed slope (b)

[c] Coefficient of determination

The unsaturated zone data (Figures 13 and 14) indicates a good positive relationship between chloride (Cl) and lithium (Li), sodium (Na), strontium (Sr), bromide (Br), boron (B), calcium (Ca), magnesium (Mg), and potassium (K) based on the coefficient of determination. A moderately good positive relationship is indicated between chloride and manganese (Mn). Little or no positive relationship is indicated between chloride and barium (Ba), bicarbonate (HCO_3), or sulfate (SO_4). The constraints of the dilution model were met by six of the nine constituents (Li, Na, Sr, Br, B, Mn) showing a good or moderately good correlation with chloride. This implies that dilution of the brine in the waste drilling mud by pure water can account for most of the ion concentrations measured in the unsaturated zone.

Other chemical processes apparently affect the concentrations of Ca, Mg, and K. Since the regression line slopes of all three of these ions is less than the ideal slope (1:1), their concentration is being enriched with respect to chloride. The source of additional Ca, Mg, and K cannot be ascertained simply by examining the scatterplots. But, other possible sources of these elements can be demonstrated. Additional Ca and Mg could be derived from dissolution of calcite or dolomite in the unsaturated zone. A possible source of K is from dissolution of K-feldspar in the unsaturated zone. Unfortunately, the mineralogic composition of the unsaturated zone sediments was not determined. Therefore, dissolution of these minerals cannot be confirmed as the added source of Ca, Mg, and K at the expense of Na. Clay was observed both as part of the drilling mud mixture and as thin layers in the unsaturated zones. Cation exchange reactions in these clay minerals could release additional Ca, Mg, and K to the water infiltrating through the unsaturated zone. Such exchange processes are the likely source of the added Ca, Mg, and K.

Little or no positive relationships were indicated between chloride and HCO_3, Ba, and SO_4. Bicarbonate concentrations are relatively uniform throughout the range of chloride concentrations. There is a tendency for greater variability in bicarbonate at higher chloride concentrations. Barium and sulfate concentrations fluctuated in a similar fashion throughout the range of chloride concentrations. Both showing greater variability over the entire range of chloride concentrations when compared to fluctuations between bicarbonate and chloride.

The second data set (unsaturated zone plus saturated zone chemical data) (Figures 15 and 16) indicates a good positive relationship between chloride and Li, Na, Sr, B, Ca, Mg, and K, based on the coefficient of determination. A moderately good positive relationship is indicated between chloride and SO_4. Little or no positive relationships were indicated between chloride and Mn or HCO_3. All of the constituents in the second data set failed to meet the constraints of the dilution model. The dilution model failed because once the contaminant plume intersects the aquifer background water quality of the aquifer water controls the chemical relationships and little or no trace of the contaminant plume exists.

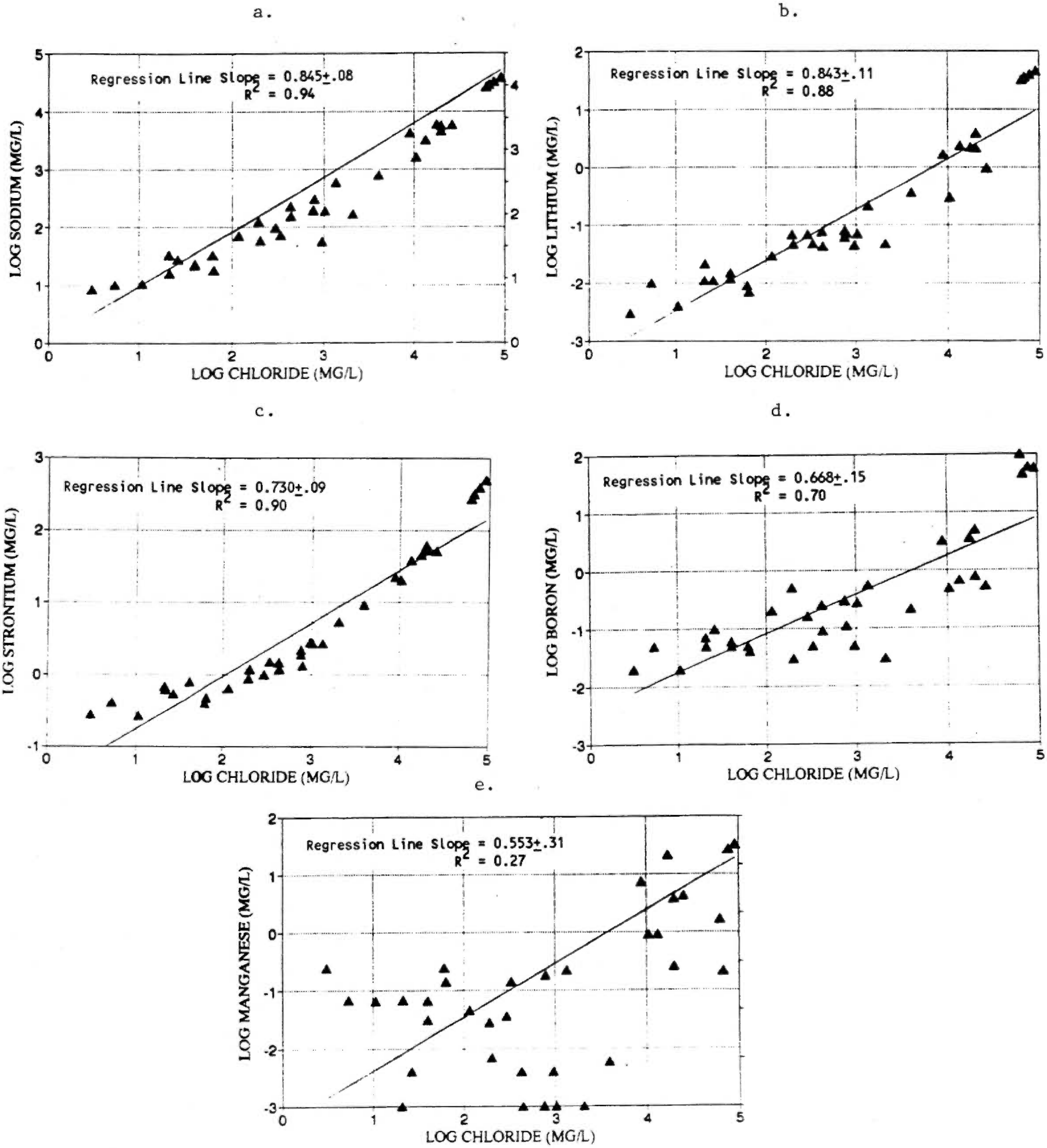


Figure 15. Relationships between chloride concentrations and selected ion concentrations, a.) sodium, b.) lithium, c.) strontium, d.) boron, e.) manganese, based on water quality from both the unsaturated zone and saturated zone.

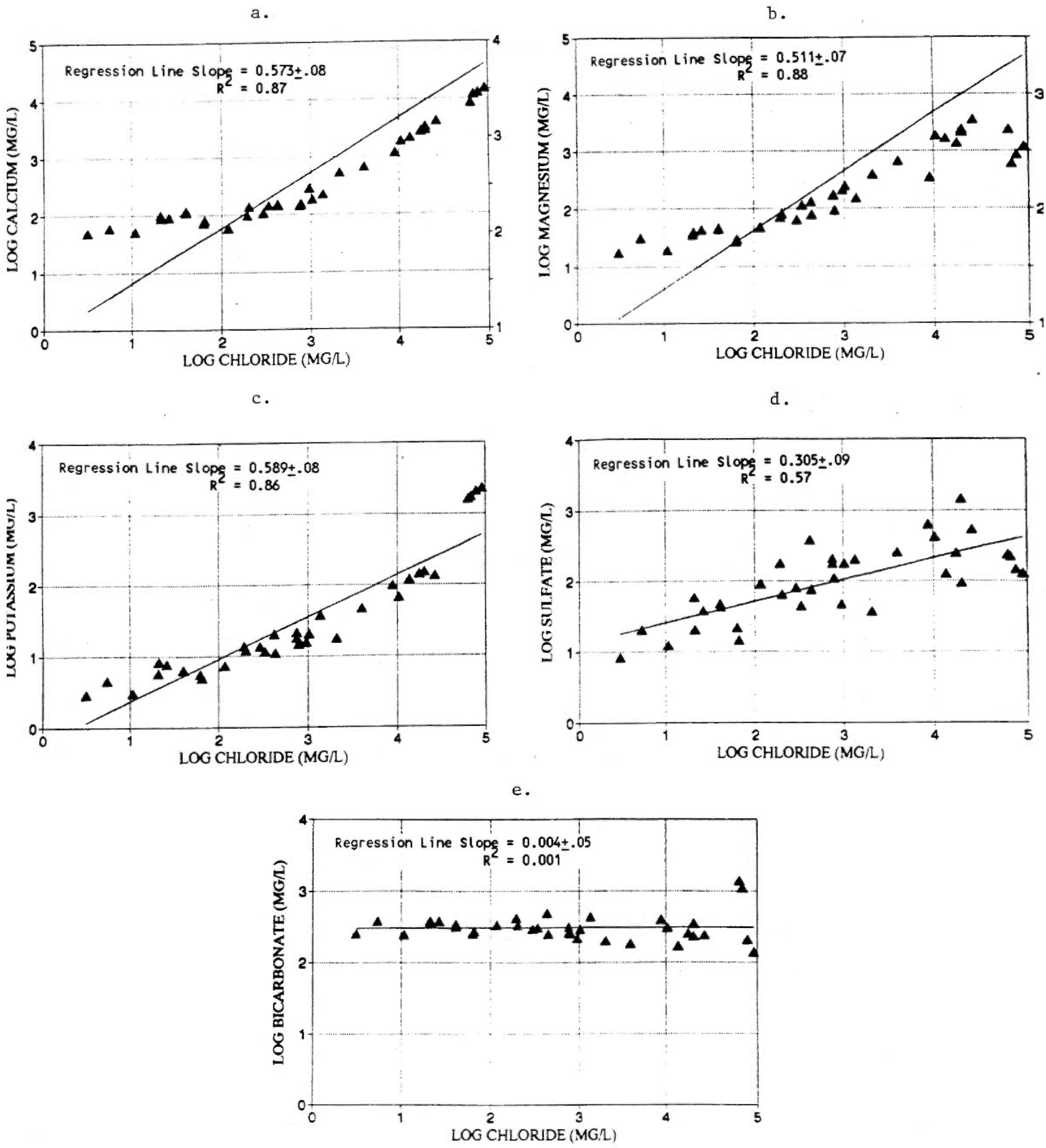


Figure 16. Relationships between chloride concentrations and selected ion concentrations, a.) calcium, b.) magnesium, c.) potassium, d.) sulfate, e.) bicarbonate, based on water quality data from both the unsaturated zone and the saturated zone.

METHOD OF DILUTION

The decrease in chloride concentrations with depth demonstrates the dilution effects at each of the test sites. Mechanical dispersion is a likely process for the observed dilution (Freeze and Cherry, 1978). In isotropic and homogeneous sediments, a good negative relationship between the distance away from a contaminant source and the log of the contaminant concentration would indicate mechanical dispersion as the cause of the dilution (Appendix E). Mechanical dispersion in the unsaturated zone would develop a zone of mixing between salt laden recharge water that moves through the waste muds and fresh recharge water that moves through the adjacent unsaturated zone. Dispersion can be divided into two components, longitudinal dispersion in the primary direction of flow and transverse dispersion which is perpendicular to the primary direction of flow. Longitudinal dispersion results in dilution of the contaminant in the direction of flow and transverse dispersion results in lateral spreading of the contaminant plume. The dilution effects are shown in scatterplots comparing the logarithm of the average chloride concentration at each sampling device with sample depth (Figure 17). The average chloride concentrations were limited to field measurements after June 28, 1988 after the influence of sample dilution by slurry water was over.

The first plot (Figure 17a) is a composite of data from all three test sites. A good negative relationship between sample depth and chloride concentration is shown on this plot. Similar

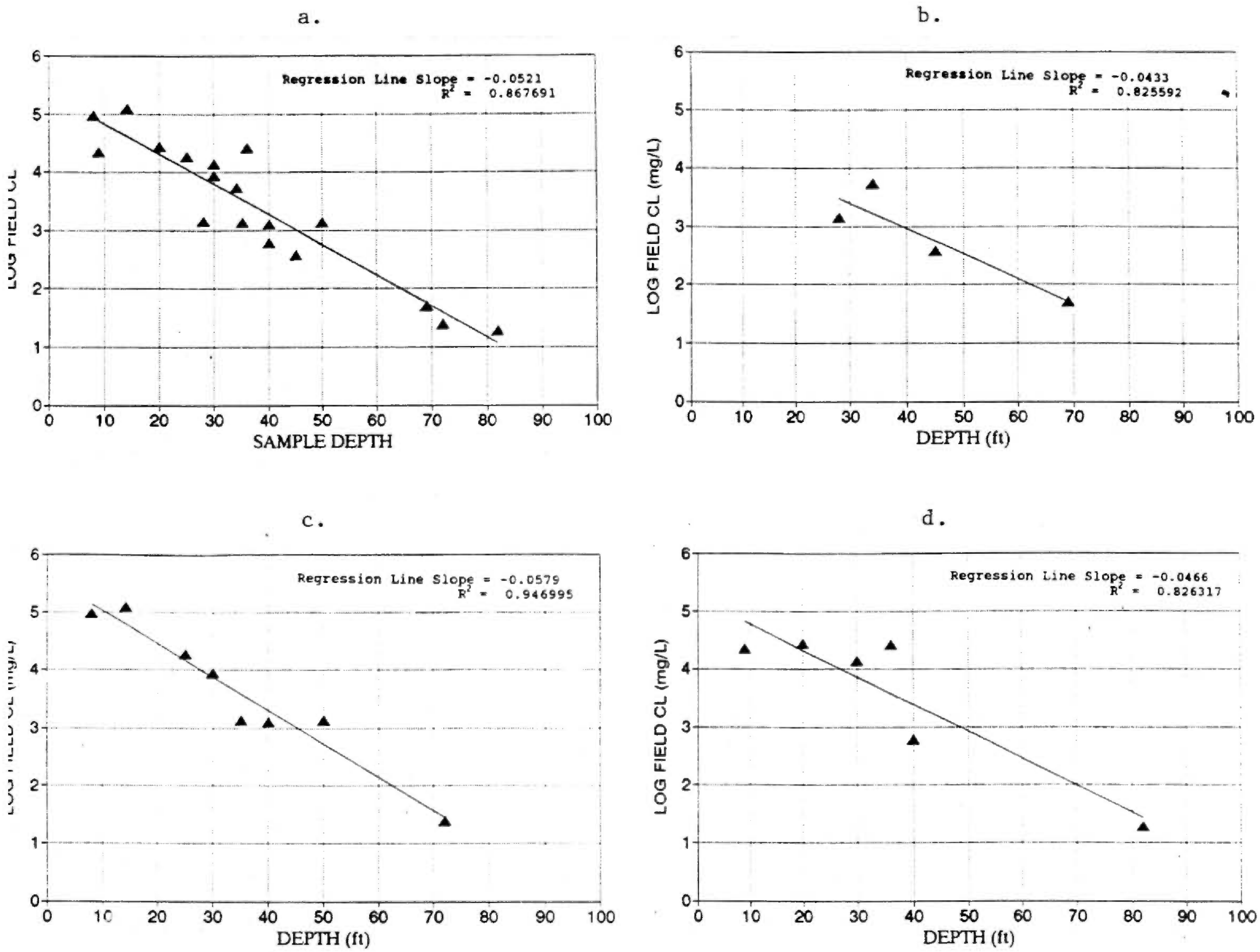


Figure 17. Relationships between depth and average field chloride concentration since 6/28/88 based on data from; a.) all three sampling sites, b.) site #1, c.) site #2, d.) site #3.

relationships are shown in plots from site #1 (Fig. 17b), site #2 (Fig. 17c), and site #3 (Fig. 17d). Subdividing the data by individual site also shows a good relationship between sample depth and chloride concentration.

The use of log values tends to subdue some of the important spatial relationships in the comparison of depth to chloride concentrations observed in the unsaturated zone (Fig. 18). Anomalous relationships between lysimeter depth and chloride concentration are apparent at all three test sites. A dilution factor of 14:1 is indicated at site #1 between L-02 and L-03, a vertical distance of 11 feet. A dilution factor of 100:1 is indicated at site #2 between L-11 and L-07, a vertical distance of about 30 feet. A dilution factor of 40:1 is indicated at site #3 between L-15 and L-14, a vertical distance of 4 feet. In addition, reversed concentration gradients were observed at Site #1 where L-02 is further from the source but had higher chloride concentrations than L-01 and at Site #3 where similar concentration gradient reversals were observed between L-16 and L-15.

These relationships indicate a large degree of heteregeneity in the subsurface. Thin beds of clay observed during drilling could cause percolating water to be ponded and diverted laterally. The lateral offset between lysimeters required for installation may cause samples to be derived from greater or less concentrated parts of the plume. Poorly seated bentonite seals in the boreholes could form conduits allowing accelerated migration of the brines.

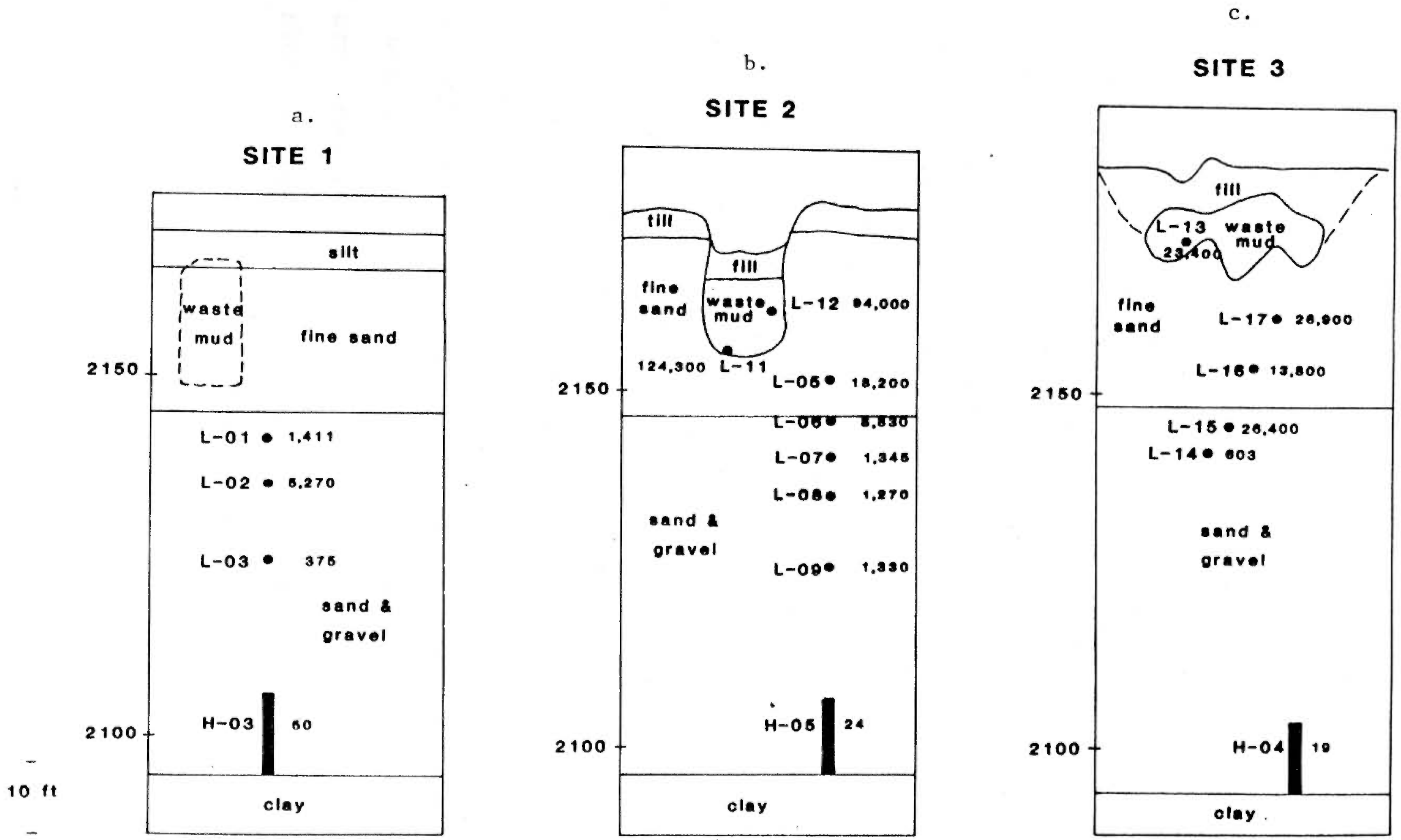


Figure 18. Cross-sections of the three test sites, a.) site #1, b.) site #2, c.) site #3, showing the average field chloride concentrations in mg/L of measurements after 6/28/88 for each sampling device.

Instantaneous dilution of the entire mass of salt in the disposal pits has not occurred now nor is it likely to occur in the future. The dilution process is closely related to recharge rates. In addition, physical properties of the unsaturated zone including hydraulic conductivity, hydraulic gradient, moisture content, average linear velocity, longitudinal dispersion, transverse dispersion, and inhomogeneity in the sediments affect the dilution process. These physical properties are often considered as constants in the saturated zone but are not constant in the unsaturated zone. The result is sporadic movement of contaminants carried through the unsaturated zone by recharge water causing intermittent chlorinity increases in the underlying aquifer. Following recharge events the salts are flushed to downgradient parts of the aquifer until background conditions are approached near the site. The process will then repeat itself during the next recharge event.

The previously mentioned calculation of the total mass of salt can be used to estimate the amount of time required for the salt to be leached out of the pits. The surface area of the disposal pits cover about 1 acre. For the purpose of evaluating duration of salts in the pits a recharge rate of 3 inches per year was used. Assuming 3 inches of recharge per year, it will take over 600 years for 160 acre feet of water to move through the pits diluting the salt concentration to 250 mg/L. Since recharge events are sporadic in this region, significant degradation of the aquifer is unlikely.

Short term degradation of water quality in the Hunter domestic well is a possibility. The greatest potential for degradation of this nearby water supply is from high infiltration rates caused by allowing snow and ice to accumulate over the disposal pits. This situation would concentrate recharge through the disposal pits possibly elevating chloride concentrations in the aquifer above the secondary health limit for short periods of time.

Preventing excessive recharge through the pits is probably the best method for mitigating short term aquifer degradation. This can be accomplished by establishing a natural grass cover above the disposal pits.

The soil reclamation part of this project smoothed the land surface over the pits and seeded the cover with natural grasses. Weed control and fall cutting will prevent snow drifts from accumulating over the pits preventing excessive recharge through the pits.

SUMMARY

Specific objectives determined by the Hunter site study are:

1.) Waste drilling muds at the Hunter site contain high concentrations of sodium chloride salts. Calculated dissolved solids of these brines range from 100,000 mg/L to over 300,000 mg/L. Average percent reacting values for brine cations are: calcium -- 29%, magnesium -- 5%, and sodium plus potassium -- 66%. Average percent reacting values for brine anions are: chloride -- 99%, bicarbonate -- less than 1%, and sulfate -- less than 1%.

Trace constituents are also present at high concentrations in the brines. High concentrations of boron, lithium, bromide, and strontium are the result of geochemistry of brines associated with oil producing zones. High concentrations of silver, cadmium, lead, chromium, barium, aluminum, nickel, and zinc are probably the result of drilling additives. Several of these constituents are found at levels exceeding drinking water standards in waste drilling mud.

2.) Leachate plumes migrate vertically through the unsaturated zone and develop when recharge water infiltrates through the waste mud mobilizing the available salt. Chloride concentrations decrease with distance from the source. Trace constituents that were at high concentrations in the mud pore water are reduced by adsorption and dilution. Mechanical dispersion in the unsaturated zone causes mixing between uncontaminated recharge water and recharge water contaminated by the salts. The dilution process is complicated by clay layers that pond and divert the recharge water. Dispersion and dilution effects are accelerated when the plume reaches the water table. During this study the contaminant plume was diluted enough for stock or domestic use by the time it reached the water table.

3. Electromagnetic conductivity surveys proved to be fast effective methods to identify areas of brine contamination. The surveys were especially valuable in this study for identifying the small amount of muds buried at the Hunter East pits. Without the survey it is unlikely that lysimeters and wells at this site would have been placed near the source of contamination.
4. Significant degradation of nearby aquifers is unlikely due to salt leaching out of the pits because of dilution.

   Limiting recharge through the pits will slow the leaching process and allow more fresh water dilution in both the unsaturated zone and saturated zone.

   Periodic monitoring of chloride concentrations in the Hunter domestic well following snow melt or other recharge events would be a good method for identifying aquifer degradation. If chloride concentrations reached undesirable levels alternative supplies could be used until the salts were flushed out of the system.

Other observations and recommendations include:

1. One of the main goals of this study was to identify the potential damaging impacts of oil field wastes to ground water resources. Although the drilling wastes were buried at a site vulnerable to aquifer degradation the most significant contamination of the water supply at this site is nitrates. Nitrate concentrations well above

the drinking water standard were detected in wells underlying the east half of the Hunter farmstead. The high nitrate levels are not related to oil field wastes but are the result of past agricultural practices. Nitrate concentration should be periodically measured and the water should not be consumed by infants, pregnant women, or nursing mothers if nitrate concentrations are greater than 10 mg/L (NO_3).

2. Potential impacts to water resources and soils should be addressed prior to the centralized disposal of oil field wastes. The site assessment should include test drilling and water sampling to collect background hydrogeological information. Toxicity of the waste materials should be identified prior to disposal. A design plan should be implemented including the projected maximum capacity of the facility and the projected methods of facility operations. A monitoring network of wells and or lysimeters should be established and periodic water samples should be collected.
3. Future research topics concerning oil field waste contamination include the impact of waste hydrocarbons and other organic compounds (on water supplies), the effect of heterogeneity in sediments on dilution and dispersion of contaminant plumes, and the development of a method to rate sites for contamination potential.

REFERENCES - PART II

Carpenter, Alden B. and Miller, John C., 1969. Geochemistry of saline subsurface water, Saline County, Missouri, Chemical Geology, Vol.4, No. 1, Elsevier Publishing Company, pp 135-167.

Donovan, J.J., 1987. MBMG file data.

Folk, R.L., 1974. Petrology of sedimentary rocks; Hemphill Publishing Co., Austin, Texas, 182 p.

Freeze, Allan R. and Cherry, John A., 1978. Groundwater, Prentice Hall, Inc.

Krauskopf, Konrad B., 1967. Introduction to geochemistry, McGraw-Hill, 721 p.

McNeil, J.D., 1980, Electrical conductivity of soils and rock. Technical note TN-5, Geonics Limited, Ontario, Canada, 22 p.

Steel, Robert, G.D., and Torrie, James H., 1960. Principles and procedures of statistics with special reference to the biological sciences: McGraw Hill Book Company, Inc., New York, 481 p.

U.S. Environmental Protection Agency, 1987. Technical report -- exploration, development, and production of crude oil and natural gas -- field sampling and analytical results: EPA 530-SW-87-005, Office of Solid Waste and Emergency Response, Washington, D.C.

APPENDIX A-1

Electromagnetic Conductivity Survey
Hunter East Apparent Conductivity Values (mmho/meter)

Station Number	Coil Spacing 10 meter V[a]	H[b]	20 meter V	H	40 meter V	H
1.2	6.5	8.6				
1.3	7.2	12.0				
1.4	8.2	12.2				
1.5	5.7	12.0				
1.6	5.8	15.0				
1.7	7.7	15.5				
1.8	3.8	16.5				
1.9	7.1	17.0				
1.10	5.0	16.0				
1.11	6.2	13.5				
1.12	7.3	13.0				
1.13	6.0	15.0				
1.14	6.9	16.3				
1.15	6.9	16.8				
1.16	6.5	16.2				
1.17	7.6	15.5				
1.18	5.7	14.0				
1.19	6.7	13.5				
1.20	6.3	13.0				
2.2	5.4	7.6	8.5	8.1	15.5	9.0
2.3	7.8	12.5	11.0	10.0	12.0	10.0
2.4	3.0	13.8	5.2	11.0	14.0	11.0
2.5	10.2	8.2	10.0	9.5	14.0	10.0
2.6	7.3	7.2	11.5	8.5	17.0	11.0
2.7	8.0	7.4	10.0	9.0	18.0	12.0
2.8	8.1	9.8	10.5	9.0	18.0	11.0
2.9	7.5	10.0	9.5	8.4	17.0	13.0
2.10	6.2	12.8	10.0	8.3	10.0	12.0
2.11	5.5	14.2	11.5	10.0	19.0	11.0
2.12	4.1	8.6	12.0	18.0	13.0	
2.13	6.6	13.5	8.2	11.0	17.0	13.0
2.14	4.8	14.3	7.6	11.0	16.0	12.0
2.15	7.8	13.0	8.8	11.0	15.0	12.0
2.16	8.0	12.5	10.5	10.0	16.0	11.0
2.17	6.4	12.5	11.0	8.9	17.0	10.5
2.18	8.7	10.5	10.0	9.5	17.5	12.0
2.19	5.7	11.0	10.0	9.2	18.0	11.5
2.20	6.2	10.5	9.1	8.9	19.0	12.0
3.2	4.8	6.7				
3.3	10.5	3.2				
3.4	3.4	3.6				
3.5	10.0	7.6				
3.6	7.4	7.0				
3.7	5.8	6.6				
3.8	6.4	5.4				
3.9	6.4	4.7				
3.10	6.0	5.3				
3.11	6.3	5.6				
3.12	5.1	5.6				
3.13	6.5	6.4				
3.14	6.6	9.4				
3.15	13.7	11.0				
3.16	18.2	9.1				
3.17	20.0	9.2				
3.18	15.8	12.8				
3.19	11.0	7.1				
3.20	5.9	9.3				
4.2	8.0	8.8	9.2	9.2	16.5	9.0
4.3	9.0	7.8	11.0	7.5	16.0	9.0

Station Number	Coil Spacing 10 meter V	H	20 meter V	H	40 meter V	H
4.4	11.5	11.0	11.5	10.0	16.0	11.0
4.5	13.5	8.4	13.0	8.7	15.5	9.0
4.6	7.2	7.6	10.0	7.5	18.0	11.0
4.7	7.0	6.8	11.5	7.8	19.5	10.0
4.8	6.7	6.5	11.0	6.6	19.5	10.0
4.9	5.4	6.5	9.2	7.2	17.5	10.0
4.10	6.7	6.1	11.0	7.3	18.5	10.0
4.11	7.3	6.6	10.5	7.3	19.5	10.0
4.12	6.7	6.6	8.3	7.1	17.5	10.5
4.13	5.4	7.0	10.5	7.4	17.0	11.0
4.14	7.1	6.9	8.4	6.7	16.5	12.0
4.15	9.2	7.2	11.0	7.0	16.5	11.0
4.16	8.1	6.3	13.5	7.0	17.5	10.0
4.17	18.5	8.3	24.0	11.5	16.0	17.0
4.18	11.5	3.5	9.1	19.0	9.0	22.0
4.19	-11.0	7.4	-7.0	42.0	5.0	21.0
4.20	-1.1	13.5	3.7	19.5	15.5	21.0
4.21	8.2	8.1	11.0	8.3	18.0	17.0
5.2	3.2	4.2				
5.3	7.8	6.1				
5.4	10.0	6.0				
5.5	5.3	9.0				
5.6	3.8	9.1				
5.7	6.8	6.0				
5.8	7.4	5.3				
5.9	5.8	6.7				
5.10	6.0	5.8				
5.11	5.3	6.2				
5.12	6.3	5.8				
5.13	6.3	5.7				
5.14	6.3	5.8				
5.15	6.6	6.6				
5.16	7.5	6.1				
5.17	8.6	7.3				
5.18	8.6	6.1				
5.19	7.0	6.0				
5.20	6.3	5.7				
5.21	5.7	7.0				
6.2	2.6	7.0	7.2	5.1	15.0	8.2
6.3	5.7	7.1	9.3	7.4	14.0	10.0
6.4	1.9	9.0	9.5	7.6	16.0	9.2
6.5	8.1	6.6	5.8	6.8	16.5	9.4
6.6	6.2	6.5	8.0	6.3	17.0	11.0
6.7	7.3	6.5	8.6	7.0	17.5	10.0
6.8	5.6	7.2	8.1	6.9	15.5	11.0
6.9	5.6	6.4	12.0	7.3	15.0	15.0
6.10	-.85	8.2	14.0	7.7	17.0	11.0
6.11	6.3	5.9	-2.4	13.0	17.5	11.0
6.12	6.2	5.7	11.0	7.4	18.0	12.0
6.13	5.9	6.3	9.4	7.2	19.0	12.0
6.14	6.3	5.9	12.0	6.9	18.0	11.5
6.15	6.1	5.7	12.0	6.9	19.0	11.5
6.16	6.9	9.7	9.9	6.8	18.0	11.5
6.17	7.3	6.0	9.6	7.0	19.0	12.0
6.18	6.4	5.8	13.0	7.2	22.0	11.5
6.19	6.6	5.3	13.0	7.2	19.0	12.0
6.20	5.8	5.5	12.0	7.1	21.5	12.0
6.21	5.7	3.2	12.0	6.8	19.0	12.0
6.22	6.9	6.0	11.0	6.4	20.0	12.0

APPENDIX A-1 (continued)

Electromagnetic Conductivity Survey
Hunter East Apparent Conductivity Values (mmho/meter) (Continued)

Station Number	Coil Spacing 10 meter V[a]	H[b]	20 meter V	H	40 meter V	H	Station Number	Coil Spacing 10 meter V	H	20 meter V	H	40 meter V	H
7.2	-.53	5.6					7.17	5.4	5.6	12.0	6.4	19.0	13.0
7.3	7.6	6.1	13.0	6.8			7.18	6.7	5.7	12.5	7.3	20.0	13.0
7.4	6.4	4.9	9.5	5.6	17.0	9.0	7.19	6.6	6.0	12.5	7.7	21.0	11.5
7.5	6.2	5.6	9.3	5.5	16.0	9.0	7.20	7.2	5.6	13.0	8.0	20.0	12.5
7.6	2.8	5.3	7.4	5.8	16.0	10.0	7.21	5.0	3.6			18.5	13.0
7.7	6.6	5.6	9.7	6.4	15.5	10.0	7.22	7.6	6.7				
7.8	5.6	6.3	7.2	6.5	17.0	11.0	8.6	4.6	5.2				
7.9	6.6	5.8	9.5	6.8	17.5	11.5	8.7	5.7	5.4				
7.10	7.2	6.0	9.8	7.3	18.0	13.0	8.8	5.1	5.3				
7.11	5.7	6.2	9.8	7.3	19.0	12.0	8.9	7.0	5.3				
7.12	6.7	5.8	11.0	7.7	19.5	12.0	8.10	7.2	5.6				
7.13	6.6	5.8	8.6	7.2	19.5	12.0	8.11	5.0	6.6				
7.14	6.8	5.8	11.0	7.2	20.0	12.0	8.12	8.0	5.8				
7.15	7.1	5.9	11.5	7.3	20.5	12.5	8.13	5.8	5.9				
7.16	6.7	5.7	10.5	7.5	18.5	13.0	8.14	7.0	6.1				

APPENDIX A-2

Electromagnetic Conductivity Survey
Hunter West Apparent Conductivity Values (mmho/meter)

Station Number	Coil Spacing 10 meter V[a]	H[b]	20 meter V	H	40 meter V	H
1.1	-12.0	22.0	6.4	6.9		
1.2	15.0	10.0	-0.8	6.6	10.5	8.2
1.3	8.4	6.8	12.5	7.7	19.5	7.5
1.4	7.5	6.8	11.0	7.2	17.5	10.5
1.5	7.3	6.8	9.5	7.7	19.5	8.5
1.6	7.0	6.1	10.0	8.2	17.5	10.5
1.7	7.4	6.7	9.0	8.2	17.5	10.5
1.8	4.5	8.6	10.5	7.2	*26.0	13.0
1.9	6.4	6.3				
2.0			9.8	6.2		
2.1	13.5	7.1	21.0	7.4		
2.2	-86.0	26.0	-27.0	8.2		
2.3	-35.0	42.0	-24.0	10.5		
2.4	12.0	8.4	19.0	9.2		
2.5	*11.0	4.8	*21.0	-5.5		
3.0			9.2	6.4	21.5	11.0
3.1	6.5	5.5	11.0	6.4	16.0	11.0
3.2	9.6	11.0	-9.5	8.5	-2.2	9.0
3.3	-42.0	68.0	-37.0	14.0	5.2	7.8
3.4	-1.2	22.5	-23.5	10.5	-5.2	8.8
3.5	8.5	5.9	15.0	6.7	30.5	11.0
3.6	*8.6	4.4	*26.0	-0.7	*33.0	-1.0
4.0			9.6	7.8		
4.1	7.2	6.3	12.0	7.8		
4.2	10.5	5.4	21.5	7.8		
4.3	8.4	40.0	-42.0	13.5		
4.4	-54.0	25.0	-32.0	-9.8		
4.5	19.5	-2.0	23.0	7.4		
5.0			13.0	9.8		
5.1	7.5	6.3	13.5	8.9		
5.2	-3.6	4.2	8.2	7.5		
5.3	14.5	11.0	22.0	10.5		
5.4	-22.5	29.5	-23.5	10.5		
5.5	2.0	12.0	-3.8	7.0		
5.6	9.6	7.0	18.0	9.2		
-6.1	13.0	10.5	17.0	13.5	25.0	21.0
6.0	12.0	9.0	18.0	13.0	24.0	19.0
6.1	9.6	8.6	18.5	11.5	27.5	18.0
6.2	-4.1	6.1	6.3	8.9	20.0	15.5
6.3	20.0	7.0	32.0	9.0	5.0	13.0
6.4	19.5	7.6	25.0	8.6	49.0	14.0
6.5	26.5	11.0	5.5	8.5	15.0	11.0
6.6	-3.6	11.5	-1.0	7.2	12.5	10.5
6.7	8.5	7.6	16.0	7.8	23.0	11.0
6.8	7.4	5.8	13.0	7.1	23.5	11.5
6.9	8.1	5.8	12.0	7.0	23.0	12.0
6.10	9.8	6.7	13.0	7.4	23.0	12.0
6.11	9.6	6.4	14.0	7.7		
6.12			16.0	8.6	24.5	14.0
6.13			14.5	9.8		
6.14			12.0	11.5	19.5	15.0
6.15			14.5	11.5		
6.16			18.5	11.0	25.5	17.0
6.17			19.0	11.0		
6.18			19.0	11.5	32.0	18.0
6.19			20.0	11.0		
6.20			19.5	11.5	29.0	16.5
6.21			18.5	11.0		
6.22			20.0	10.5	31.0	16.0
6.23			19.0	10.0		
6.24					38.0	12.0

[a] vertical dipole position

[b] horizontal dipole position

* reading influenced by metal at surface

APPENDIX B-1

Lysimeter Description, Installation and Monitor Well Construction

LYSIMETER DESCRIPTION:

Soil Moisture, Inc. Models #1900, 1920, 1940 pressure-vacuum ceramic cup soil water samplers were installed. These lysimeters consist of a porous ceramic cup sealed to a sample chamber. Model #1900 lysimeters are composed of only a ceramic cup and must be assembled by sealing 1-1/4 inch PVC to the porous cup, inserting one polyethylene tube into the cup and one tube below top of PVC. The tubes are pushed through a rubber stopper that seals the top of the casing. Model #1920 lysimeters are composed of a porous cup attached to a 2 foot length of 19" PVC sealed at the top. Polyethylene tubes are again inserted into the top of the lysimeter one into the cup and one below the top of the lysimeter one into the cup and one below the top of the sample chamber. Model #1940 are similar to the Model #1920 lysimeters with the exception of more elaborate seals, check valve on tubing between sample chamber and water line tubing, and access tube fittings on top of the lysimeter. Three methods of lysimeter installation are summaries below.

TEMPORARY CASING METHOD:

1. Test vacuum and rinse lysimeters with deionized water.
2. Connect polyethylene tubes to access parts of pre-constructed pressure-vacuum ceramic cup lysimeters (Soil Moisture, Inc. Model #1920 or #1940).

3. Drill hole, using 7 inch O.D. 3-1/2 inch I.D. hollow stem auger with aluminum center plug, to just below depth desired for lysimeter placement.
4. Complete log of lithology and drilling conditions.
5. Lift auger string and drop weight to pop out center plug.
6. Set 2-inch temporary casing to sample depth.
7. Mix slurry of deionized water and silica flour and pour slurry down temporary casing.
8. Drop lysimeter into slurry.
9. Pull out temporary casing and auger flights allowing hole walls to cave in if waste mud was penetrated.
10. Set bentonite seal below mud while pulling out casing and auger flights.
11. Set surface bentonite seal.
12. Install larger diameter protective casing at surface.

PERMANENT CASING METHOD:

1. Same as temporary method.
2. Same as temporary method.
3. Same as temporary method.
4. Same as temporary method.
5. Same as temporary method.
6. Set 2-inch permanent casing to desired sample depth.
7. Mix slurry of deionized water and silica flour; pour slurry down casing.
8. Drop lysimeter into slurry just below bottom of casing.

9. Pull out auger flights allowing hole to collapse around casing.
10. If waste mud was penetrated bentonite seals below waste mud while pulling out auger flights.
11. Set surface bentonite seal.
12. Install larger diameter protective casing at surface.

SHALLOW METHOD

1. Test vacuum and rinse lysimeters with deionized water.
2. Drill hole, using 5 inch O.D. solid stem auger or 3-inch tube.
3. Complete log of lithology and drilling conditions.
4. Mix slurry of deionized water and silica flour; pour slurry into hole.
5. Drop lysimeter into slurry.
6. Backfill with cuttings.
7. Set surface bentonite seal
8. Install larger diameter protective casing at surface.

MONITOR WELL CONSTRUCTION:

1. Drill hole, using 7-inch O.D. 3-1/2 I.D. hollow stem auger to base of sand and gravel if possible.
2. Complete log of lithology and drilling conditions.
3. Lift auger string and drop weight to pop out center plug.
4. Set 2" screen and casing to desired depth through hollow stem auger.
5. Pull out auger flights allowing hole to collapse around screen and casing.

6. If waste mud was penetrated bentonite seal below waste mud while pulling out auger flights.
7. Set surface bentonite seal.
8. Develop well by bailing and backwashing with formation water.

APPENDIX B-2

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAA01 Hole name or Number L-01

Hole location: South edge of Hunter East disposal pits (site #1); between EM grid points 4.18 and 5.18.

Recorded by: JR Date hole Started: 07/14/87 Date hole Completed: 07/14/87 Driller: F. Schmidt Drilling Company MBMG auger

Total Lys. depth (ft) 28 Well diameter: 7" Casing diameter(s) and length (s): 2" PVC to 27 ft Surface Elevation: 2169

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1920 Lysimeter

Interval-perforated or screened: 27.8-28.0 Model #1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: yes Were material samples taken?: yes Was a water sample taken?: yes

Remarks: Drilled on edge of pit in area of EM conductivity high. Installed Lysimeter to 20 feet; used permanent casing method. Set bentonite seals from 18 to 23 feet and at the surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt, dark-brown, very fine, sandy. (topsoil)
1	5	Silt, pale-brown, very fine, sandy. (eolian)
5	24	Very fine to medium sand, yellowish-brown, slightly silty with a vew thin (<2") clay layers; sand becomes less silty with depth, a few clay balls with cuttings; sand is moderately well sorted, moderately well rounded, largely fine-grained quartz fragments. (stream deposits)
24	31	Fine sand, reddish-brown, with intermittent coarse gravel layers. (stream deposits)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAA02 Hole name or Number L-02

Hole location: Hunter East disposal pits (site #1); L-02 is 3 ft north of L-01.

Recorded by: JR Date hole Started: 07/14/87 Date hole Completed: 07/14/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 34 Well diameter: 7" Casing diameter(s) and length (s): 34 ft of 2" PVC Surface Elevation: 2169

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1920 Lysimeter

Interval-perforated or screened: 33.8-34 ft model #1920 pressure vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: : Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed lysimeter using temporary casing method. Set bentonite seals from 15-20 feet and at the surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt, dark-brown, very fine sandy (topsoil).
1	4	Silt, pale-brown, very fine sandy (eolian)
4	18	Very fine to medium sand, yellowish-brown, moderately well sorted, moderatily well rounded; largely fine sand; a few reddish-brown colored layers; a few thin clay layers; coarsens downward. (stream deposits)
18	24	Fine to coarse sand, yellowish-brown, moderately well sorted, moderately well rounded; largely fine to medium grained quartz sand. (stream deposits)
24	38	Fine to coarse sand, yellowish-brown, moderately well sorted, moderately well rounded; largely fine to medium grained quartz sand. (stream deposits)
24	38	Fine to coarse sand, reddish-brown, interbedded with thin layers of coarse gravel. (stream deposits)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAA03 Hole name or Number L-03

Hole location: Hunter East disposal pits (site #1); 6 feet east and 3 feet north of L-01.

Recorded by: JR Date hole Started: 07/14/87 Date hole Completed: 07/14/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 45 Well diameter: 7" Casing diameter(s) and length (s): 45 ft of 2" PVC Surface Elevation: 2169

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 44.8-45.0 Model #1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed lysimeter to 45 feet, used temporary casing method. Set first bentonite seal between 20-25 feet; backfilled with cuttings and set surface bentonite seal.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt, dark-brown. (topsoil)
1	4	Silt, pale-brown, sandy. (eolian)
4	18	Fine to medium sand, yellowish-brown, with few clay layers. (see L-02 log)(stream deposits)
18	25	Fine to coarse sand, yellowish brown. (see L-02 log)(stream deposits)
25	38	Fine to coarse sand, reddish brown, with thin layers of gravel (see L-02 log)(stream deposits)
38	46	Sand and gravel, reddish brown, similar to above interval but gravel layers are thicker and more numerous. Hard drilling. (Stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 24 N R. 59 E Sec. 33 Tract: DCAA04 Hole name or Number L-04

Hole location: Hunter East Disposal site; 16 feet east and 3 feet north of L-01 -- closer to pit --

Recorded by: JR Date hole Started: 07/14/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 56 Well diameter: 7" Casing diameter(s) and length (s): 56' of 2" PVC Surface Elevation: 2169

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 54.8-55 - Abandoned and removed lysimeter

Does lysimeter hold vacuum?: No Were material samples taken?: Yes Was a water sample taken?: No

Remarks: Installed lysimeter (permanent casing method) to 55 feet, lost 40 feet of auger in hole, made fishing tool but it broke first time out. Removed lysimeter, abandoned site and moved to Hunter west pit.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt, dark-brown, clayey. (topsoil)
1	3	Fine sand, yellowish-brown, silty. (eolian)
3	18	Very fine to medium sand, yellowish-brown, with thin clay layers (see L-02 log). (stream deposits)
18	39	Fine to coarse sand, yellowish-brown, (see L-02 log) color changes to reddish-brown with depth. (stream deposits)
39	45	Sand and gravel, reddish-brown, gravel layer at 41 feet. (stream deposits)
45	56	Medium to coarse sand, reddish brown, interbedded with layers of coarse gravel, gravel layers increase in thickness and number with depth. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAB01 Hole name or Number L-05

Hole location: Hunter west pits (site #2); near EM location 5.4 near edge of disposal pits.

Recorded by: JR Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 25 Well diameter: 7" Casing diameter(s) and length (s): 25 ft of 2" PVC Surface Elevation: 2177

Type of casing(s): None Weight or gage of casing: ___ Method-perforated or screened: 2" #1920 Lysimeter

Interval-perforated or screened: 24.8-25 Model #1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed lysimeter to 25 feet, used temporary casing method. Set bentonite seals from 15 to 20 feet and at the surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Clay loam, grayish-brown, silty, pebbly (till?).
4	6	Very fine sand, yellowish-brown, silty, with layers of clay, a lot of clay balls in cuttings. (stream deposits)
6	9	Very fine to fine sand, grayish-brown, with a few thin clay layers. (stream deposits)
9	13	Fine to medium sand, pale-yellowish-brown, moderately well sorted, moderately well rounded, with a few thin clay layers. (stream deposits)
13	14	Gravel, coarse (stream deposits)
14	27	Fine to coarse sand, light reddish-brown, moderately well sorted, moderately well rounded with a few thin gravel layers. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAB02 Hole name or Number L-06

Hole location: Hunter west pits (site #2); near EM location 5.4, 3 ft west of L-05.

Recorded by: JR Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 30 Well diameter: 7" Casing diameter(s) and length (s): 30 feet of 2" PVC Surface Elevation: 2176

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 29.8-30 Model 1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 31 feet. Used temporary casing method. Set bentonite seals from 15 to 20 feet and at the surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, silty (topsoil).
1	4	Clay loam, grayish- brown, silty, pebbly (till?)
4	6	Very fine sand, yellowish-brown, silty, with layers of clay. (stream deposits)
6	8	Very fine to fine sand, grayish-brown, with a few thin clay layers. (stream deposits)
8	15	Fine to medium sand, pale-yellowish-brown, moderately well sorted, moderately well rounded -- no clay -- (stream deposits)
15	31	Fine to coarse sand, light reddish-brown, largely medium but less well sorted and well rounded than above interval -- few thin gravel layers. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAB03 Hole name or Number L-07

Hole location: Hunter west pits (site #2); near EM location 5.4, 6 feet west of L-05.

Recorded by: JR Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 35 Well diameter: 7" Casing diameter(s) and length (s): 35 feet of 2" PVC Surface Elevation: 2176

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 34.8-35.0 feet Model #1920 pressure vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 36 ft; used temporary casing method; set bentonite seals at surface and from 15 to 20 feet.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, silty (topsoil).
1	4	Clay loam, grayish-brown, silty, pebbly (till?)
4	6	Very fine sand, yellowish-brown, silty, with layers of clay. (stream deposits)
6	8	Very fine to fine sand, grayish-brown, with a few thin clay layers. (stream deposits)
8	15	Fine to medium sand, pale-yellowish-brown, moderately well sorted, moderately well rounded -- no clay --
15	30	Fine to coarse sand, light-reddish-brown, largely medium but less well sorted and well rounded than above interval -- few thin gravel layers. (stream deposits)
30	36	Fine to coarse sand, light-reddish-brown, with a few layers of dark reddish brown fine to coarse sand; gravel layers are thicker and more numerous than in the 15-30 interval. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CAAB04 Hole name or Number L-08

Hole location: Hunter west pits (site #2); near EM location 5.4, 9 feet west of L-05.

Recorded by: JR Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 40 Well diameter: 7" Casing diameter(s) and length (s): 40 feet of 2" PVC Surface Elevation: 2175

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 39.8-40 ft Model #1920 pressure vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 41 feet; used temporary casing method; set bentonite seals at surface and at about 20 feet.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, silty (topsoil).
1	4	Clay loam, grayish-brown, silty, pebbly (till?)
4	6	Very fine sand, yellowish-brown, silty, with layers of clay. (stream deposits)
6	8	Very fine to fine sand, grayish-brown, with a few thin clay layers. (stream deposits)
8	15	Fine to medium sand, pale-yellowish-brown, moderately well sorted, moderately well rounded -- no clay -- (stream deposits)
15	30	Fine to coarse sand, light-reddish-brown, largely medium but less well sorted and well rounded than above interval -- few thin gravel layers. (stream deposits)
30	41	Fine to coarse sand, light-reddish-brown, with layers of dark-reddish-brown fine to coarse sand; several layers of coarse gravel. (stream deposits)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 24 N R. 59 E Sec. 33 Tract: CDAB05 Hole name or Number L-09

Hole location: Hunter west pits (site #2); near EM location 5.4, 12 feet west of L-05.

Recorded by: JR Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 50 Well diameter: 7" Casing diameter(s) and length (s): 52 feet of 2" PVC Surface Elevation: 2175

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1940 lysimeter

Interval-perforated or screened: 49.8-50 ft Model #1940 high pressure vacuum ceramic cup

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 51 feet, used permanent casing method. Set bentonite seals at surface and from 15 to 20 feet.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, silty (topsoil).
1	4	Clay loam, grayish-brown, silty, pebbly (till?)
4	6	Very fine sand, yellowish-brown, silty, with layers of clay. (stream deposits)
6	8	Very fine to fine sand, grayish-brown, with a few thin clay layers. (stream deposits)
8	15	Fine to medium sand, pale-yellowish-brown, moderately well sorted, moderately well rounded -- no clay -- (stream deposits)
15	30	Fine to coarse sand, light-reddish-brown, largely medium but less well sorted and well rounded than above interval -- few thin gravel layers. (stream deposits)
30	45	Fine to coarse sand, light-reddish-brown, with layers of dark-reddish-brown fine to coarse sand; several layers of coarse gravel. (stream deposits)
45	50	Fine to coarse sand, reddish-brown, with layers of coarse gravel, gravel is nearly 50% of interval. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland   Location: T. 24 E R. 59 E Sec. 33 Tract: CDAB06   Hole name or Number: L-10

Hole location: Hunter west pits (site #2); near EM location 5.4, 15 feet west of L-05.

Recorded by: JR   Date hole Started: 07/17/87 Date hole Completed: 07/17/87 Driller: F. Schmidt   Drilling Company: MBMG auger

Total well depth (ft): 60   Well diameter: 7"   Casing diameter(s) and length (s): 60 feet of 2" PVC   Surface Elevation: 2173

Type of casing(s): PVC   Weight or gage of casing: 160 psi   Method-perforated or screened: 2" #1940 lysimeter

Interval-perforated or screened: 59.8-60 feet; Model 1940 high pressure vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: No Were material samples taken?: Yes Was a water sample taken?: No

Remarks: Drilled hole to 61 feet; used temporary casing method; set bentonite seals from 15 to 20 feet and at the land surface. Lysimeter would not hold vacuum, hoses separated?

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	48	See logs for L-06 and L-08.
48	53	Gravel; sandy coarsens from fine to medium gravel at top of interval to cobbles near base-- hard drilling. (stream deposits)
53	61	Fine to coarse sand, reddish-brown, easier drilling than above interval.

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAB07 Hole name or Number L-11

Hole location: Hunter west pits (site #2); near EM location 5.4; in pit depression northeast of L-05.

Recorded by: JR Date hole Started: 07/18/87 Date hole Completed: 07/18/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 14 Well diameter: 3" Casing diameter(s) and length (s): 14' of 1-1/4" PVC Surface Elevation: 2170

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1900 lysimeter

Interval-perforated or screened: 13.8-14.0 feet Model 1900 lysimeter glued to PVC pipe

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Used shallow lysimeter installation mehtod, installed lysimeter to 14 feet, backfilled with cuttings, sealed top with bentonite.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Fine to medium sand, yellowish-brown. (fill).
4	14	Silt, dark-bluish-gray, sandy, clayey, soft, soupy, very moist, diesel smell -- pit material sampled at 4-6, 10-12, 13-14 (brine saturated drilling mud).
14	15	Fine to medium sand, yellowish-brown, base of pit. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 24 N R. 59 E Sec. 33 Tract: CDAB08 Hole name or Number L-12

Hole location: Hunter west pits (site #2); near EM location 5.4; in pit depression, 2 feet west of L-11.

Recorded by: JR Date hole Started: 07/18/87 Date hole Completed: 07/18/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 8.5 Well diameter: 3" Casing diameter(s) and length (s): 8.5' of 1-1/4" PVC Surface Elevation: 2170

Type of casing(s): Plastic Weight or gage of casing: Method-perforated or screened:

Interval-perforated or screened: 8.3-8.5 ft Model 1900 lysimeter glued to PVC pipe

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Used shallow lysimeter installation method. Installed lysimeter to 8.5 feet, backfilled with cuttings, sealed top with bentonite

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Fine to medium sand, yellowish-brown, silty. (fill)
4	85	Silt, dark-bluish-gray, sandy, clayey, soft, soupy, diesel smell, pit material (brine saturated drilling mud).

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA01 Hole name or Number L-13

Hole location: Hunter west disposal pits (site #3); near EM location 3.3; drilled in pit depression.

Recorded by: JR Date hole Started: 07/18/87 Date hole Completed: 07/18/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 9 Well diameter: 5" Casing diameter(s) and length (s): 11' of 1-1/4" PVC Surface Elevation: 2180

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1900 lysimeter

Interval-perforated or screened: 8.8-9.0 Model 1900 pressure-vacuum ceramic cup lysimeter glued to PVC pipe

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: No

Remarks: Used shallow lysimeter installation method, installed lysimeter to 9.0 feet, backfilled with cuttings, sealed surface with bentonite.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Fine to medium sand, yellowish-brown, fine to medium. (fill)
4	10	Sand, bluish-gray, clayey, silty, oily, diesel smell. (brine saturated drilling mud)
10	12	Fine to medium sand, yellowish-brown. (stream deposits)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA02 Hole name or Number L-14

Hole location: Hunter west disposal site; 6 feet east of L-13; drilled on edge of pit depression.

Recorded by: JR Date hole Started: 07/18/87 Date hole Completed: 07/18/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 40 Well diameter: 7" Casing diameter(s) and length (s): 42 feet of 2" PVC Surface Elevation: 2183

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1920 lysimeter

Interval-perforated or screened: 39.8-40.0 feet Model #1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed lysimeter to 40 feet; used temporary casing method; set bentonite seals at 23-25 ft, 8-11 feet, and surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown. (topsoil)
1	3	Clay loam, grayish-brown, pebbly, silty. (fill)
3	8	Fine to medium sand, yellowish-brown, moderately well rounded, moderately well sorted. (stream deposit)
8	11	Silt, dark-blue-gray, sandy, clayey, diesel smell. (brine saturated drilling mud)
11	25	Fine to medium sand, yellowish-brown. (stream deposit)
25	41	Fine to medium sand, reddish-brown, with several thin layers of gravel, mostly in 35-40 interval. (stream deposit)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA03 Hole name or Number L-15

Hole location: Hunter west disposal pits (site #3); near EM site 3.3, 3 feet south of L-14. No pit depression at surface.

Recorded by: JR Date hole Started: 07/18/87 Date hole Completed: 07/18/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 36 Well diameter: 7" Casing diameter(s) and length (s): 36 feet of 2" PVC Surface Elevation: 2182

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1940 lysimeter

Interval-perforated or screened: · 35.8-36.0 feet Model #1940 high-pressure vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 36 feet, used permanent casing method set bentonite seals from 16'-18', 23'-26' and at surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	5	Fine to medium sand, yellowish-brown, silty, a few pebbles. (fill)
5	16	Silt, dark-bluish-gray, sandy, clayey, moist, smells like diesel or other petroleum product. (brine saturated drilling mud)
16	24	Fine to medium sand, yellowish-brown to pale brown. (stream deposits)
24	37	Fine to coarse sand, reddish-brown. (stream deposits)

APPENDIX B-2 (continued)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA04 Hole name or Number L-16

Hole location: Hunter west disposal pits (site #3); near EM site 3.3, 3 feet south of L-15, no pit depression at surface.

Recorded by: JR Date hole Started: 07/19/87 Date hole Completed: 07/19/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 30 Well diameter: 7" Casing diameter(s) and length (s): 32 feet of 2" PVC Surface Elevation: 2182

Type of casing(s): None Weight or gage of casing: Method-perforated or screened: 2" #1940 lysimeter

Interval-perforated or screened: 29.8-30.0 feet, Model #1920 pressure-vacuum ceramic cup lysimeter

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 31 feet, used temporary casing method; set bentonite seals at 14'-16' 22'-25' and at the surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Fine to medium sand, yellowish-brown. (fill)
4	14	Silt, dark-bluish-gray, sandy, clayey, moist, smells like diesel. (brine saturated drilling mud)
14	31	Fine to medium sand, yellowish-brown, changes to dark-reddish-brown, fine to coarse sand at 25 ft. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA03 Hole name or Number L-17

Hole location: Hunter west disposal pits (site #3); near EM site 3.3, 3 feet south of L-16, no pit depression at surface.

Recorded by: JR Date hole Started: 07/19/87 Date hole Completed: 07/19/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 20 Well diameter: 7" Casing diameter(s) and length (s): 21 feet of 2" PVC Surface Elevation: 2181

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1940 lysimeter

Interval-perforated or screened: 19.8-20 feet; Model #1940 ceramic cup lysimeter high

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Drilled hole to 21 feet, used permanent casing method, set bentonite seals from 11'-14' and at surface.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	4	Sandy, yellowish, silty (fill).
4	11	Silt; bluish-gray, sandy, clayey. (brine saturated drilling mud)
11	21	Fine to medium sand, yellowish-brown. (stream deposits)

LYSIMETER LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA03 Hole name or Number L-18

Hole location: Hunter east disposal pits; near EM site 4.11; drilled in or near trench that was not filled with mud.

Recorded by: JR Date hole Started: 07/19/87 Date hole Completed: 07/19/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 18 Well diameter: 5" Casing diameter(s) and length (s): 20' of 1-1/4" PVC Surface Elevation: 2175

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 2" #1900 lysimeter

Interval-perforated or screened: 16.8-17.0 feet Model #1900 pressure-vacuum ceramic cup lysimeter (background lysimeter, no buried mud)

Does lysimeter hold vacuum?: Yes Were material samples taken?: Yes Was a water sample taken?: No

Remarks: Used shallow lysimeter installation method, installed lysimeter to 17 ft, backfilled with cuttings, sealed surface with bentonite. Lysimeter would not hold vacuum after first field sample was collected.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	8	Fine to medium sand, yellowish-brown, moderately well sorted, moderately well rounded. (fill)
8	13	Fine to medium sand, yellowish-brown, with thin layers of silt and clay. (stream deposits)
13	18	Fine to medium sand, yellowish-brown, with layers of reddish brown fine to medium sand. (stream deposits)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAB01 Hole name or Number H-01

Hole location: Hunter east disposal pits; drilled between EM sites 6.11 and 7.11.

Recorded by: JR Date hole Started: 07/11/87 Date hole Completed: 07/13/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 55 Well diameter: 7" Casing diameter(s) and length (s): Not cased

Type of casing(s): None Weight or gage of casing: Method-perforated or screened:

Interval-perforated or screened: No well installed

Has well been test pumped?: No Were material samples taken?: No Was a water sample taken?: No

Remarks: Drilled between EM locations 6.11 and 7.11.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt; dark-grayish-brown. (topsoil)
1	4	Silt, grayish-brown, slightly sandy. (eolian deposits)
4	5	Silt; very light-brownish-gray, sandy. (eolian deposits)
5	25	Very fine to fine sand, light-brownish-yellow, well sorted -- coarsens with depth to fine to medium. 80% quartz - well rounded grains, 10% shale, less well rounded, 10% other - carbonates, a few pebbles, moisture content increases with depth. (stream deposits)
25	26	Silt, light-whitish-gray, thin, gray, sandy, harder drilling layer at 25',a few chunks of gravel. (stream deposits)
26	34	Medium sand, yellowish-brown, well sorted. (stream deposits)
34	48	Medium sand and gravel, probably interbedded layers of sand (as above) and fine to very coarse gravel, gravel is moderately well rounded to well rounded agates, volcanics, siltstone, and shale. (stream deposits)
48	55	Rig broke down at 55' -- (drive gears broken) won't turn to the right, did not install well, coarse gravel -- pre- glacial? well rounded, etc. (stream deposits)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAD Hole name or Number H-02

Hole location: 1/4 mile east of Milo Hunters house; north side of ephemeral pond (site #4).

Recorded by: JR Date hole Started: 07/19/87 Date hole Completed: 07/19/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 63 Well diameter: 7" Casing diameter(s) and length (s): 58.5' of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 Method-perforated or screened: 6' of 2" #30 slot PVC screen

Interval-perforated or screened: 57-63; #30 slot screen (FT Union Bedrock clay at 61') Surface Elevation 2149.79.

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 64.5 feet of casing and screen with plastic cap on bottom, 1-1/2 ft out of ground. Set bentonite seal at surface. Developed well by bailing and backwashing.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	2	Silt, grayish-brown, sandy. (eolian)
2	4	Clay loam, dark-gray, silty, hard drilling. (till or colluvium).
4	7	Clay loam, light-olive-gray, silty, few pebbles. (till or colluvium)
7	8	Rocks -- "hard drilling".
8	17	Very fine to coarse sand, yellowish-brown, moderately well sorted, moderately well rounded, largely fine to medium sand; sampled 15-20 ft. (stream deposits)
17	21	Fine to coarse sand, dark-reddish-brown, moderately well sorted, moderately well rounded, largely medium sand. (stream deposits)
21	30	Fine to coarse sand (as above), dark-reddish brown, with coarse gravel layers every few feet; percent gravel increases with depth; gravels consist of moderately well rounded rocks of western origin including igneous rocks, chert, agates, etc. Possibly Flaxville equivalent or re-worked Flaxville equivalent gravels. (stream deposits)
30	35	Coarse gravel, moderately well rounded-- see above description. (stream deposits)
35	39	Fine to coarse sand, dark-reddish-brown, (as in 17-21). (stream deposits)
39	54	Sand and gravel, largely coarse gravel, hard drilling, a lot of rocks falling in, not as hard drilling from 49 to 61 probably sand or water table. (stream deposits)
54	61	Fine sand, silty gray, with a few coarse gravel layers. (glacial lake and/or stream deposits)
61	64	Clay, light-bluish-gray, silty, thin bedded; Ft Union Formation (bedrock).

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCAA05 Hole name or Number H-03

Hole location: South edge of Hunter east disposal pits (site #1); between EM points 4.18 and 5.18.

Recorded by: JR Date hole Started: 10/14/87 Date hole Completed: Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 74 Well diameter: 7" Casing diameter(s) and length (s): 66' of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 10' of 2" #20 slot PVC screen

Interval-perforated or screened: 64-74 Surface Elevation 2168.85

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 76 feet of casing and screen with plastic cap on bottom, 2 feet out of ground. Set bentonite seal at surface. Developed well by bailing and backwashing. Bottom 3 feet of well sanded in.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Silt, dark-brown, very fine. (topsoil)
1	9	Very fine to medium sand, yellowish-brown, with a few thin clay layers. (stream deposits)
9	15	Very fine to medium sand, light-yellowish-brown. (stream deposits)
15	24	Very fine to coarse sand, dark-yellowish-brown. (stream deposits)
24	45	Fine to coarse sand, dark-reddish-brown, a few thin gravel layers. (stream deposits)
45	60	Fine to coarse sand, dark-reddish-brown, interbedded with layers of coarse gravel. (stream deposits)
60	68	Sand and gravel, drilled smooth well, no returns. (stream deposits)
68	74	Coarse gravel, harder drilling, no returns. (stream deposits)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAA06 Hole name or Number H-04

Hole location: Hunter west disposal pits (site #3); near EM location 3.3.

Recorded by: JR Date hole Started: 10/15/87 Date hole Completed: 10/17/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 87 Well diameter: 7" Casing diameter(s) and length (s): 80' of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 10' of 2" #20 slot PVC screen

Interval-perforated or screened: 77-87 feet Surface Elevation 2180.68

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 90' of casing and screen with plastic cap on bottom, cut off 1 ft, 2 ft out of ground. Set bentonite seals at 15-18 feet and at the surface. Developed well by bailing and backwashing. Bailed 20 times WL dropped 0.2'

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, sandy, silty.
1	6	Sand, yellowish-brown, silty, fine to medium, a few pebbles. (till)
6	13	Silt, dark-bluish-gray, clayey, sandy, moist, petroleum smell. (waste drilling mud).
13	25	Fine to medium sand, yellowish-brown. (stream deposits)
25	36	Fine to medium sand, reddish-brown. (stream deposits)
36	68	Fine to medium sand, as above interbedded with coarse gravel and rocks -- gravel layers 36- 40 numerous others (by drill chatter) 45-48, 51-52, 57-58, 62-63, (easier drilling at 60 feet, possibly water table). (stream deposits)
68	87	Sand and coarse gravel -- gravel layers are thicker (2-3 feet) and more numerous. (stream deposits)
87	89	Clay, light-bluish-gray, silty, sticky,, cohesive, stiff, hard slow drilling. (bedrock)

APPENDIX B-2 (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDAB09 Hole name or Number H-05

Hole location: Hunter west disposal pits (site #2) near EM location 5.4.

Recorded by: JR Date hole Started: 10/15/87 Date hole Completed: 10/15/87 Driller: F. Schmidt Drilling Company MBMG

Total well depth (ft) 79 Well diameter: 7" Casing diameter(s) and length (s): 68 ft of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 10'of 2" #20 slot screen

Interval-perforated or screened: 66-76 feet Surface Elevation 2172.60

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 80 ft of casing and screen with plastic cap on bottom, cut off 2.6 ft, 1.4 ft out of ground. Set bentonite seals at 20-25 feet and at the surface Developed well by bailing and backwashing.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, grayish-brown, silty. (topsoil).
1	4	Silt, pale-brown, slightly sandy. (eolian deposits)
4	15	Very fine to medium sand, yellowish-brown, moderately well-sorted, moderately well rounded, a few thin clay layers. (stream deposits).
15	25	Fine to coarse sand, light-reddish-brown, moderately well sorted, moderately well rounded, largely medium sand. (stream deposits)
25	76	Fine to coarse sand, reddish-brown, interbedded with thin layers of gravel, based on bit chatter gravel layers located at depths of 25-26, 31-33, 36-37, 44-46, 50-51, 58-60, 65-66, 68-69; color change to alternating grayish-brown and yellowish-brown from 43-48; easier drilling at 62 feet possibly water table. (stream deposits)
76	79	Clay, light-bluish-gray, silty, sticky, cohesive, with a few pebbles. (till? lake sediments? Fort Union?)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: CDCA01 Hole name or Number H-06

Hole location: In low spot 1/4 mile west of M. Hunters house in bottom of swale next to fence (site #5).

Recorded by: JR Date hole Started: 10/16/87 Date hole Completed: 10/16/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 50 Well diameter: 7" Casing diameter(s) and length (s): 42 ft of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 10' of 2" #20 slot PVC screen

Interval-perforated or screened: 40-50 Surface Elevation 2142.83

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 52 ft casing and screen with plastic cap on bottom, 2 ft out of ground. Set surface bentonite seal. Developed well by bailing and backwashing.

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, dark-grayish-brown, silty, pebbly. (topsoil)
1	3	Loam, pale-brown, pebbly, silty. (till? colluvium?)
3	6	Fine to coarse sand, yellowish-brown, moderately well sorted, moderately well rounded. (stream deposits)
6	15	Medium sand to coarse gravel, grayish-brown, poorly sorted poorly rounded; more of a mixture of sand and gravel than interlayered. (stream deposits)
15	48	Medium sand to coarse gravel, dark-yellowish-brown, interbedded with pebbles also mixed in the sand. (stream deposits)
48	50	Clay, light-bluish-gray with few pebbles, hard drilling (lake deposits? or till?).

APPENDIX B-2 (continued)

WELL LOG
MONTANA BUREAU OF MINES AND GEOLOGY
GROUND WATER DIVISION

County: Richland Location: T. 25 N R. 59 E Sec. 33 Tract: DCBD02 Hole name or Number H-07

Hole location: Fifty feet south of Hunter domestic well (site #6).

Recorded by: JR Date hole Started: 10/16/87 Date hole Completed: 10/16/87 Driller: F. Schmidt Drilling Company MBMG auger

Total well depth (ft) 69 Well diameter: 7" Casing diameter(s) and length (s): 62 ft of 2" PVC

Type of casing(s): PVC Weight or gage of casing: 160 psi Method-perforated or screened: 10' of 2" #20 slot PVC screen

Interval-perforated or screened: 59-69 2" 20 slot Surface Elevation 2164.13

Has well been test pumped?: No Were material samples taken?: Yes Was a water sample taken?: Yes

Remarks: Installed well through hollow stem auger using 62 ft of 2" casing and 10 ft of 2" slot screen with plastic cap on bottom. Set surface bentonite seal. Developed well by bailing and backwashing

DRILLING LOG
Geological, drilling, and water conditions; remarks and sampling

From	To	
0	1	Loam, dark-brown, sandy. (soil)
1	17	Very fine to medium sand, yellowish-brown, with clay. (stream deposits)
17	19	Fine to coarse sand, very dark-reddish-black, and possibly a soil horizon? (stream deposits)
19	21	Fine to coarse sand, dark-reddish-brown. (stream deposits)
21	68	Sand, as above, mixed with and interbedded with fine to coarse gravel, more gravel in last 10 feet. (stream deposits)
68	69	Silt and silty clay, light-olive-green, yellowish-green, and light-bluish-gray, pebbly. (lake deposits? till).

APPENDIX B-3

Summary of grain size analysis and derived estimations of hydraulic conductivity

Test Hole	Sample Depth Feet	* d_{50}	** d_{90}	*** $_I$	K (Hazen)	K(Masch and Denny)
L-01	27-28	.33	.14	1.10	2×10^{-2}	1.2×10^{-2}
L-02	30-35	.38	.16	1	2.6×10^{-2}	1.5×10^{-2}
L-04	15-18	.31	.16	.71	2.6×10^{-2}	1.7×10^{-2}
L-04	40-45	.44	.21	1.51	4.4×10^{-2}	8.3×10^{-3}
L-05	30	.38	.16	1.97	2.6×10^{-2}	4×10^{-3}
L-08	30-34	.41	.185	1.75	3.4×10^{-2}	6.3×10^{-3}
L-08	35-40	.44	.185	2.26	3.4×10^{-2}	3.3×10^{-3}
L-09	45-50	.38	.17	2.15	2.9×10^{-2}	3.3×10^{-3}
L-10	53-60	.35	.17	1.52	2.9×10^{-2}	8×10^{-3}
L-14	35-40	.30	.14	1.75	2×10^{-2}	9×10^{-3}
L-15	30-35	.23	.105	1	1.1×10^{-2}	8.3×10^{-3}
H-02	15-20	.38	.17	1.15	2.9×10^{-2}	1.2×10^{-2}
			Average K		2.7×10^{-2}	8.9×10^{-3}

* d_{50} Median grain size

** d_{90} 90% of the sample is coarser grained than this

*** $_I$ Inclusive graphic standard deviation, a measure of sorting (Folk, 1974)

APPENDIX C-1

OBSERVATION WELL RECORD

WELL NUMBER: H-0
LOCATION: 47°52'11"N 104°06'16"W 25N59E33DCBD01
LAND SURFACE ALTITUDE: 2168.23 feet above sea level
MEASURING POINT: 1.77 feet above land surface
WELL DEPTH: 75 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
08/19/87	66.27	0	06/25/88	66.60	-.33
09/30/87	66.37	-.10	06/29/88	66.61	-.34
10/16/87	66.32	-.05	07/17/88	66.44	-.17
10/24/87	66.32	-.05	08/16/88	66.73	-.46
11/21/87	66.28	-.01	09/29/88	66.58	-.31
12/21/87	66.30	-.03	10/29/88	66.59	-.32
01/24/88	66.49	-.22	11/10/88	66.55	-.28
02/22/88	66.30	-.03	11/27/88	66.99	-.72
03/19/88	66.75	-.48	04/17/89	66.77	-.50
04/21/88	66.39	-.12	05/30/89	66.95	-.68
04/23/88	66.54	-.12	06/06/89	66.34	-.07
05/14/88	66.67	-.40	07/13/89	66.58	-.31
05/22/88	66.42	-.15	08/31/89	66.51	-.24
06/05/88	66.56	-.29	10/11/89	66.57	-.30

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-02
LOCATION: 47°52'09"N 104°06'03"W 25N59E33DCAD
LAND SURFACE ALTITUDE: 2149.79 feet above sea level
MEASURING POINT: 1.62 feet above land surface
WELL DEPTH: 63 feet
AQUIFER: OUTWASH\TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
07/23/87	49.05	0	06/25/88	49.32	-.27
08/19/87	49.09	-.04	06/29/88	49.34	-.29
09/30/87	49.14	-.09	07/17/88	49.35	-.30
10/14/87	49.10	-.05	08/16/88	49.45	-.40
10/17/87	49.18	-.13	09/29/88	49.49	-.45
10/24/87	49.19	-.14	10/29/88	49.51	-.46
11/21/87	49.19	-.14	11/10/88	49.51	-.46
12/21/87	49.22	-.17	11/27/88	49.60	-.55
01/24/88	49.27	-.22	04/17/89	49.06	-.01
02/20/88	49.26	-.21	04/22/89	49.03	.02
03/19/88	49.26	-.21	05/30/89	49.10	-.05
04/21/88	49.30	-.25	06/06/89	49.16	-.11
04/23/88	49.29	-.24	07/13/89	49.28	-.23
05/14/88	49.49	-.44	08/31/89	49.38	-.33
05/22/88	49.20	-.15	10/10/89	49.46	-.41
06/05/88	49.34	-.29			

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-03
LOCATION: 47°52'16"N 104°06'05"W 25N59E33DCAA05
LAND SURFACE ALTITUDE: 2168.85 feet above sea level
MEASURING POINT: 1.32 feet above land surface
WELL DEPTH: 74 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
10/24/87	65.75	0	08/16/88	65.96	-.21
11/21/87	65.76	-.01	09/29/88	66.02	-.27
12/21/87	65.77	-.02	10/29/88	66.05	-.30
01/24/88	65.79	-.04	11/10/88	66.02	-.27
02/20/88	65.79	-.04	11/27/88	66.10	-.35
03/19/88	65.79	-.04	04/17/89	66.07	-.32
04/21/88	65.81	-.06	04/22/89	66.02	-.27
04/23/88	65.82	-.07	05/30/89	65.89	-.14
05/14/88	65.82	-.07	06/06/89	65.94	-.19
05/22/88	65.82	-.07	07/13/89	65.95	-.20
06/25/88	65.87	-.12	08/31/89	66.01	-.26
06/29/88	65.87	-.12	10/10/89	66.02	-.27
07/17/88	65.89	-.14			

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-04
LOCATION: 47°52'15"N 104°06'26"W 25N59E33CDAA06
LAND SURFACE ALTITUDE: 2180.68 feet above sea level
MEASURING POINT: 1.93 feet above land surface
WELL DEPTH: 87 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
10/24/87	75.23	0	07/17/88	75.60	-.37
11/21/87	75.28	-.05	08/16/88	75.65	-.42
12/21/87	75.34	-.11	09/29/88	75.73	-.50
01/24/88	75.43	-.20	10/29/88	75.79	-.56
02/20/88	75.44	-.21	11/10/88	75.77	-.54
03/19/88	75.43	-.20	11/27/88	75.86	-.63
04/21/88	75.48	-.25	04/17/89	75.80	-.57
04/23/88	75.49	-.26	04/22/89	75.67	-.44
05/14/88	75.50	-.27	05/30/89	75.36	-.13
05/22/88	75.50	-.27	06/06/89	75.41	-.18
06/05/88	75.51	-.28	07/13/89	75.41	-.18
06/25/88	75.54	-.31	08/31/89	75.50	-.27
06/29/88	75.56	-.33	10/11/89	75.65	-.42

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-05
LOCATION: 47°52'16"N 104°06'30"W 25N59E33CDAB09
LAND SURFACE ALTITUDE: 2172.60 feet above sea level
MEASURING POINT: 1.5 feet above land surface
WELL DEPTH: 76 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
10/24/87	66.62	0	07/17/88	66.95	-.33
11/21/87	66.66	-.04	08/16/88	67.05	-.43
12/21/87	66.72	-.10	09/29/88	67.13	-.51
01/24/88	66.72	-.10	10/29/88	67.19	-.57
02/20/88	66.82	-.20	11/10/88	67.17	-.55
03/19/88	66.80	-.18	11/27/88	67.24	-.62
04/21/88	66.86	-.24	04/17/88	67.22	-.60
04/23/88	66.87	-.25	04/22/89	67.08	-.46
05/14/88	66.90	-.28	05/30/89	66.79	-.17
05/22/88	66.89	-.27	06/06/89	66.84	-.22
06/05/88	66.92	-.30	07/13/89	66.84	-.22
06/25/88	66.94	-.32	08/31/89	66.95	-.33
06/29/88	66.94	-.32	10/11/89	67.06	-.44

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-06
LOCATION: 47°52'09"N 104°52'09"N 25N59E33CDAC01
LAND SURFACE ALTITUDE: 2142.83 feet above sea level
MEASURING POINT: 1.41 feet above land surface
WELL DEPTH: 50.0 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
10/24/87	37.72	0	07/17/88	37.89	-.17
11/21/87	37.67	.05	08/16/88	37.96	-.24
12/21/87	37.74	-.02	09/29/88	38.02	-.30
01/24/88	37.78	-.06	10/29/88	38.07	-.35
02/20/88	37.79	-.07	11/10/88	38.06	-.34
03/19/88	37.80	-.08	11/27/88	38.12	-.40
04/21/88	37.82	-.10	04/17/89	38.15	-.43
04/23/88	37.82	-.10	04/22/89	38.07	-.35
05/14/88	37.83	-.11	05/30/89	37.95	-.23
05/22/88	37.89	-.17	06/06/89	38.00	-.28
06/05/88	37.84	-.12	07/13/89	37.92	-.20
06/25/88	37.90	-.18	08/31/89	37.92	-.20
06/29/88	37.91	-.19	10/11/89	38.06	-.34

APPENDIX C-1 (continued)

OBSERVATION WELL RECORD

WELL NUMBER: H-07
LOCATION: 47°52'11"N 104°06'16"W 25N59E33DCBD02
LAND SURFACE ALTITUDE: 2164.13 feet above sea level
MEASURING POINT: 2.83 feet above land surface
WELL DEPTH: 69 feet
AQUIFER: OUTWASH/TERRACE GRAVEL

DATE	DEPTH TO WATER (feet below MP)	VARIATION (feet)	Date	DEPTH TO WATER (feet below MP)	VARIATION (feet)
10/24/87	61.81	0	07/17/88	61.98	-.17
11/21/87	61.81	0	08/16/88	62.11	-.30
12/21/87	61.82	-.01	09/29/88	62.11	-.30
01/24/88	61.89	-.08	10/29/88	62.14	-.33
02/20/88	61.86	-.05	11/10/88	62.11	-.30
03/19/88	61.85	-.04	11/27/88	62.20	-.39
04/21/88	61.87	-.06	04/17/89	62.08	-.27
04/23/88	61.91	-.10	04/22/89	62.02	-.21
05/14/88	61.91	-.10	05/30/89	61.81	0
05/22/88	61.96	-.15	06/06/89	61.84	-.03
06/05/88	62.04	-.23	07/13/89	62.06	-.25
06/25/88	62.11	-.30	08/31/89	62.03	.22
06/29/88	62.10	-.29	10/10/89	62.07	-.26

QUANTAB CHLORIDE TITRATORS

Quantab chloride titrators are measuring devices for chloride in aqueous solutions. General and technical information are summarized in the following section.

QUANTAB® CHLORIDE TITRATORS

INFORMATION SUMMARY

GENERAL

INTRODUCTION: QUANTAB Chloride Titrators are convenient measuring devices for salt (chloride) in aqueous solutions or dilute aqueous extractions of solids. QUANTAB Titrators are self-acting and provide objective results which are easy to read and interpret.

PRODUCT IDENTIFICATION	APPROXIMATE TITRATION RANGE
QUANTAB Chloride Titrator No. 1175	.01% to 0.08% NaCl 60 to 480 ppm. Cl^-
QUANTAB Chloride Titrator No. 1176	.05% to 0.8% $NaCl^-$ 300 to 4,900 ppm. Cl^- (With dilution/extraction procedure up to 8.0% Cl or 49,000 ppm. Cl^-

PREPARATION OF TEST SOLUTIONS

Good results with QUANTAB Chloride Titrators may be achieved by following these instructions carefully.

For Aqueous Samples

Measure directly by using the appropriate QUANTAB Chloride Titrator and carefully following the section headed "DIRECTIONS." Aqueous samples containing more salt than the QUANTAB upper limit can be measured with QUANTAB Chloride Titrators by diluting the sample to be tested before performing the measurement. To obtain the correct value of salt content before dilution, multiply the result on QUANTAB calibration table by the dilution factor.

For Solid or Semi-Solid Samples, Use Dilution/Extraction Procedure Below

1. Mix or grind a representative portion of solid or semi-solid product, thus dividing the product into small particles to insure extraction of salt.
2. Weigh 10 grams of finely-divided product and place in a suitable container.
3. Add 90 ml. boiling water. Stir mixture vigorously for 30 seconds, then wait one minute and stir another 30 seconds to obtain a good extraction of salt from the sample. (Dilution factor is 10 in this example.)
4. Fold filter paper circle in half twice; open into cone-shaped cup and place cup into extraction solution to collect a few drops of filtrate solution inside cup before performing test.

DIRECTIONS

1. Place *lower* end of QUANTAB in the solution to be tested. (Immersion of entire QUANTAB will pre-trigger completion signal.)
2. Allow test solution to saturate column. This is accomplished two minutes after the yellow test completion signal across the top of the column begins to turn dark blue.
3. Results may be read up to 5 minutes after signal color change occurs.

INTERPRETATION OF DATA

1. Record QUANTAB reading to the nearest one-half division on the numbered scale at the tip of the white color change.
2. Convert QUANTAB reading to percent salt or ppm. chloride (mg. chloride per liter) using the calibration table.
3. If sample has been diluted, multiply result on calibration table by dilution factor to obtain salt content of sample.
4. Strip excess fluid out open end to make test result permanent.

TECHNICAL

CHEMISTRY: QUANTAB Chloride Titrators consist of a thin, chemically inert plastic strip. Laminated within the strip is a column impregnated with silver dichromate. When QUANTAB is placed in aqueous solutions, fluid will rise in the column by capillary action. The reaction of silver dichromate with chloride (salt) produces a white color change in the capillary column. When the capillary column is completely saturated, a moisture-sensitive signal across the top of the column turns dark blue.

The length of the white color change in the *capillary* column is proportional to chloride concentration.

SPECIFICITY: Bromides, Iodides, Sulfates, strong acids and strong bases can react with QUANTAB Chloride Titrators, however, they are not present in most samples to be tested in sufficient amounts to affect test results. Nitrite and nitrate have no effect on the test.

Chloride concentrations between about 40 mg/L to about 500 mg/L can be measured using low range 1175 titrators. Chloride concentrations between about 400 mg/L and 5000 mg/L can be measured using high range 1176 titrators. Chloride concentrations were measured up to 150,000 mg/L by diluting the original solution using high range titrators.

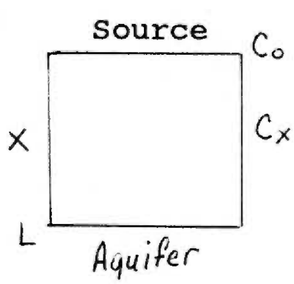
APPENDIX E.

The advection-dispersion equation is typically used to describe bulk movement of non-reactive dissolved constituents in homogeneous saturated materials. The simplest form of this equation is a one-dimensional steady-state solution with a constant linear velocity and a constant dispersion coefficient. Under steady state conditions the advection-dispersion equation can be expressed as:

$$D\frac{\partial^2 c}{\partial x^2} - \bar{V}\frac{\partial c}{\partial x} = \frac{\partial c}{\partial t}$$

D = Dispersion coeficient (constant)
$\bar{V}$ = Average linear velocity (constant)
c = concentrations of nonreactive ion
x = distance from contamination source

The boundary conditions for contaminant movement below the source are:



C_x = F(X) The concentration at any point X in a 1 dimensional flow field is a function of X

$\frac{\partial c}{\partial t} = 0$ steady state conditions

$C(X) = C_0$ X = 0 concentration of pit mud

$C(X) = 0$ X > L concentration of aquifer

Because of the steady state assumption the equation can be simplified to:

$$D = \frac{d^2 c}{dx^2} - \bar{V}\frac{dc}{dx} = 0$$

The equation is then integrated, keeping in mind we want to look at C (concentration) compared to X (distance).

$$D\int\frac{d^2 c}{dx^2} = \bar{V}\int\frac{dc}{dx}$$

D and $\bar{V}$ are constants in the steady state solution therefore can be pulled out of integral

$$D\frac{dc}{dx} = \bar{V} C$$

Solve the integral

$$D/c\ dc = \bar{V}\ dx$$

Rearrange the equation

$$\frac{1}{c}\ dc = \frac{\bar{V}}{D}\ dx$$

Put constants $\bar{V}$ and D together

$$\frac{1}{c}\ dc = Z\,dx$$

Simplify by letting $Z = \frac{\bar{V}}{D}$

$$\int \frac{1}{c}\,dc = \int z\,dx$$
$$\int \frac{1}{c}\,dc = z\int dx$$

Integrate

$$\ln C \Big|_{C_o}^{C_x} = Z X \Big|_{0}^{x}$$
$$\ln C_x - \ln C_o = Z(X-0)$$

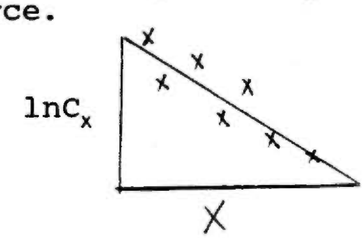
Evaluate from C_x to C_0 and from X_o to X_x

$$\ln C_x = Zx + \ln C_o$$

Set up in form y = mx + b

This means the natural log of concentration (with respect to depth) = Constant (Z) times (distance from source) + natural log of initial concentration.

We know that $\ln C_x$ = log of concentration of chloride at point X. We can then plot $\ln C_x$ versus X, with X being the distance from the source.



The solution indicates that under steady state saturated homogeneous conditions one would expect a good negative correlation between depth and the natural log of contaminant concentration. The unsaturated heterogeneous conditions of the Hunter site complicate the use of this equation because $\overline{V}$ and D are no longer constant. Therefore, a direct solution cannot be obtained with available data. The similar relationship of the depth to log chloride concentrations (Figure 17) and the theoretical depth to natural log chloride concentration shown above indicates similar processes causing the relationship.