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# Modeling of hydrogeologic conditions and ground water quality at an oil well reserve pit Richland County Montana

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# MODELING OF HYDROGEOLOGIC CONDITIONS AND GROUND WATER QUALITY AT AN OIL WELL RESERVE PIT, RICHLAND COUNTY, MONTANA

by

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# MODELING OF HYDROGEOLOGIC CONDITIONS AND GROUNDWATER QUALITY AT AN OIL WELL RESERVE PIT IN RICHLAND COUNTY, MONTANA

Director: Dr. William W. Woessner WWW 8-7-89

This study examined groundwater contamination in a shallow aquifer of the Yellowstone River Valley resulting from storage of oil-field brine and drilling fluid additives in a reserve pit. Results show brine seepage from the pit enters the shallow aquifer due to inadequate pit reclamation. Reserve pit mud is contaminated with ions and metals at concentrations one to three orders of magnitude greater than federal drinking water standards. Only certain ions and metals present in the pit mud reach the underlying shallow aquifer system at concentrations much less then in the pit mud.

Chloride concentrations up to 2800 mg/l are present in the shallow aquifer during spring and summer months as a result of the high water table intersecting the base of the reserve pit. In addition, precipitation generates wetting fronts which leach pit contaminants into the shallow aquifer. Chloride seepage declines in the fall through winter months as a result of a lowering water table and less recharge.

After entering the shallow aquifer, chloride migrates downgradient and enters a nearby return flow irrigation ditch. Maximum chloride concentrations measured in the ground water decrease from 2800 mg/l to approximately 600 mg/l at a distance of 350 feet (115 m) from the pit. High chloride concentrations are vertically limited to the upper five to six feet (2 m) of the 15 to 20 foot (6 m) thick sand and gravel aquifer. Lack of vertical mixing in the aquifer is probably a result of a high hydraulic conductivity or layering of strata in the horizontal direction.

Other constituents in the shallow aquifer detected at above background concentrations and attributed to brine seepage from the reserve pit are boron, lithium, barium, strontium, titanium, zinc, beryllium, calcium, magnesium, sodium, potassium, manganese, bicarbonate, sulfate, and nitrates.

Surface electromagnetic induction conductivity (EM) and resistivity were used to delineate the extent of brine contamination. Both methods produced similar results and delineated the brine contaminated area. EM was less cumbersome and time consuming to use compared to resistivity.

Transient groundwater flow modeling for one year of hydraulic head data using the PLASM 2-D numerical model successfully simulated the actual hydraulic heads. Solute transport modeling with Random-Walk successfully simulated chloride concentrations at some monitoring well locations but not at others. The simplicity of the groundwater flow model in conjunction with Random-Walk limitations yielded inaccurate simulated chloride concentrations.

# ACKNOWLEDGMENTS

This project is the result of many individual's time and effort. I am deeply indebted for their assistance, knowledge and information. Residents living in the study area were helpful and cooperative throughout the study. I appreciated their patience and willingness to permit monitor well drilling and water quality sampling on their property.

The following organizations provided technical help and data: The Montana Bureau of Mines and Geology, Richland County, the Montana State University Agricultural Experiment Station in Sidney, the U.S. Department of Agriculture in Sidney, the U.S. Soil Conservation Service in Sidney, the U.S. Geological Survey in Helena and The U.S. Forest Service in Missoula. It is my opinion that the staff members of these public agencies provided outstanding assistance and were accessible and helpful in all of my requests.

A special thanks is due for Randy Skov, my field technician, who braved winter days to collect water quality data and water levels. Joe Donovan of the Montana Bureau of Mines and Geology also deserves a special thanks for his help in the field.

Key individuals in the project were my thesis committee members: Drs. Woessner, Thompson, Potts, and Sonderegger, and project supervisor Jon Reiten of the Montana Bureau of Mines and Geology.

I am deeply indebted to Dr. Sonderegger who proposed and secured the funding for this project and Jon Reiten who directed this project. Jon provided field assistance and hydrogeological knowledge that was instrumental and a necessity to pull this project together. I can't thank him enough. Dr. Woessner provided the modeling and hydrogeologic background from which I have learned from and will benefit from in the future. Dr. Woessner's knowledge has made me a better hydrogeologist and I am grateful. I appreciate the other key individuals' patience and wisdom.

Last but certainly not least, I want to thank Ann who is my best friend and love. Ann's patience, understanding, and support made all the work in this project worthwhile. Without her it would have been difficult.

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## Chapter I

## INTRODUCTION

Groundwater contamination from an oil well reserve pit was studied in a shallow aquifer of the Yellowstone River Valley, eastern Montana. Significant contamination by chloride and other ions and metals was documented. The source of contamination is a buried reserve pit containing extremely elevated concentrations of the ions and metals. Computer modeling was used to simulating groundwater flow and solute transport of chloride contamination through the shallow aquifer. The following discussion will familiarize the reader with a reserve pit. That discussion is followed by a description of oil production in the Williston basin, goals and objectives of this study, location and description of the study site, and a discussion of previous work done at the study site.

Drilling fluids and brine water are contained in a reserve pit during drilling of oil and gas wells in the oil producing areas of the United States. Pit dimensions vary, but average 150 to 200 feet long (46 to 61 m), 60 to 70 feet wide (18 to 21 m), and 8 to 12 feet deep (2 to 4 m). Most reserve pits are lined with a synthetic or clay liner to protect underlying groundwater from brine seepage, however, in some instances pit liners are not used depending on the geologic setting and location. Contamination of shallow aquifers by reserve pits has been documented in Montana, Oklahoma, Alabama, North Dakota, Texas, Arkansas, Wyoming, Ohio, and Kansas (Beal, 1986; Beal and others, 1987; Collins, 1971; Dewey, 1984; Fryberger, 1975; Hicks, 1983a and 1983b; Knowels, 1965; Leonard, 1965; McMillion 1965; Murphy and Kehew, 1984; Murphy et. al., 1985, Novak and Yoram, 1988).

Techniques used to reclaim reserve pits usually involve removal of the brine water from the pit (disposed via injection well) and on site disposal of the more viscous drilling fluid or pit mud. On site mud disposal consists of digging trenches radially away form the reserve pit and pushing the pit mud into the trenches. Backhoes used to dig the trenches destroy the integrity of the existing pit liner. After the mud is pushed into the trenches, the site is resurfaced to ground level.

Surface recharge at a reclaimed reserve pit site may generate leachate and contaminate the underlying groundwater. In addition, high groundwater may come in contact with the bottom of the buried reserve pit or trenches and contaminate the groundwater.

Presently, drilling fluid wastes are designated as nonhazardous under the RCRA (Resource Conservation and Recovery Act). According to Kemblowski and Deeley (1987), this exemption is primarily based on the "...low toxicity of drilling fluid wastes". However, reserve pit studies in the last five to six years have shown that oil-field brine (Table 1) and drilling fluid additives (Appendix A) contain products that are a threat to water, soil and vegetation (Hicks 1983a).

### Oil production in the Williston Basin

As of 1982, there were over 4000 oil wells in the Williston Basin (Dewey, 1984). Chloride concentrations in brine and drilling fluids (Murphy and Kehew, 1984) are typically 300,000 ± 20,000 mg/l in north central North Dakota and 100,000 to 200,000 mg/l in eastern Montana (Dewey, 1984). Pit reclamation in the Williston Basin most often includes removal of brine water and on site mud disposal in excavated trenches (Dewey, 1984). Contamination of groundwater by brine seepage is reported at all reserve pit sites studied in the Williston Basin (Dewey, 1984; Murphy and Kehew, 1984; Hicks, 1983a and 1983b; and Beal, 1986). Dead or stunted vegetation has been documented at a number of these brine contaminated sites (Hicks, 1983a; Dewey, 1984). Many sites outside of Montana and North Dakota have also experienced dead or stunted vegetation in addition to contaminated drinking water and surface water in streams and rivers (Leonard, 1965; McMillion, 1965; Knowles, 1965).

The processes that leach reserve pit wastes into the shallow groundwater are poorly understood and regional impacts to eastern Montana groundwater are relatively unknown.

### Goals and objectives

Goals of this study are: 1) to characterize the mechanism(s) controlling reserve pit waste migration into the shallow aquifer, and if the process(es) is continuous or

TABLE 1. Comparison of dissolved solids in seawater and oil field brine (USEPA, 1972).

| Element | Seawater, mg/l. | Oil-field brine, mg/l. |
|---|---|---|
| Sodium | 10,600 | 12,000 to 150,000 |
| Potassium | 380 | 30 to 4,000 |
| Lithium | 0.2 | 1 to 50 |
| Rubidium | 0.12 | 0.1 to 7 |
| Cesium | 0.0005 | 0.01 to 3 |
| Calcium | 400 | 1,000 to 120,000 |
| Magnesium | 1,300 | 500 to 25,000 |
| Strontium | 8 | 5 to 5,000 |
| Barium | 0.03 | 0 to 1,000 |
| Chlorine | 19,000 | 20,000 to 250,000 |
| Bromine | 65 | 50 to 5,000 |
| Iodine | 0.05 | 1 to 300 |

episodic; 2) to determine if EM (electromagnetic induction conductivity) can be used to identify groundwater contaminated from brine seepage; 3) to estimate the aquifer parameters necessary to conduct a hydrogeologic model for the reserve pit area and predict contaminant dispersion behavior; 4) to characterize the chemistry of brine contaminated water and soil and 5) to suggest possible remediation measures. Objectives related to meeting the above goals consisted of measuring/determining the following parameters:

1) The soil and groundwater conductance/resistivity using EM and resistivity surface geophysics;
2) Groundwater and surface water quality;
3) The extent of brine contamination including related metal contamination;
4) The hydraulic properties of the unconfined aquifer;
5) The rate and direction of groundwater flow at the site;
6) The dispersion and dilution of contaminants in the unconfined aquifer;
7) Amount of chloride loaded into the groundwater;
8) Regional loading of chloride into the Yellowstone River;
9) The reclamation technique best suited to reverse soil contamination on site;

## Location and description of study site

The Iverson site is located approximately 3 miles north of Sidney, Montana in Section 15 of Township 23 north, Range 59 east in Richland County (Figures 1 and 2). The site is

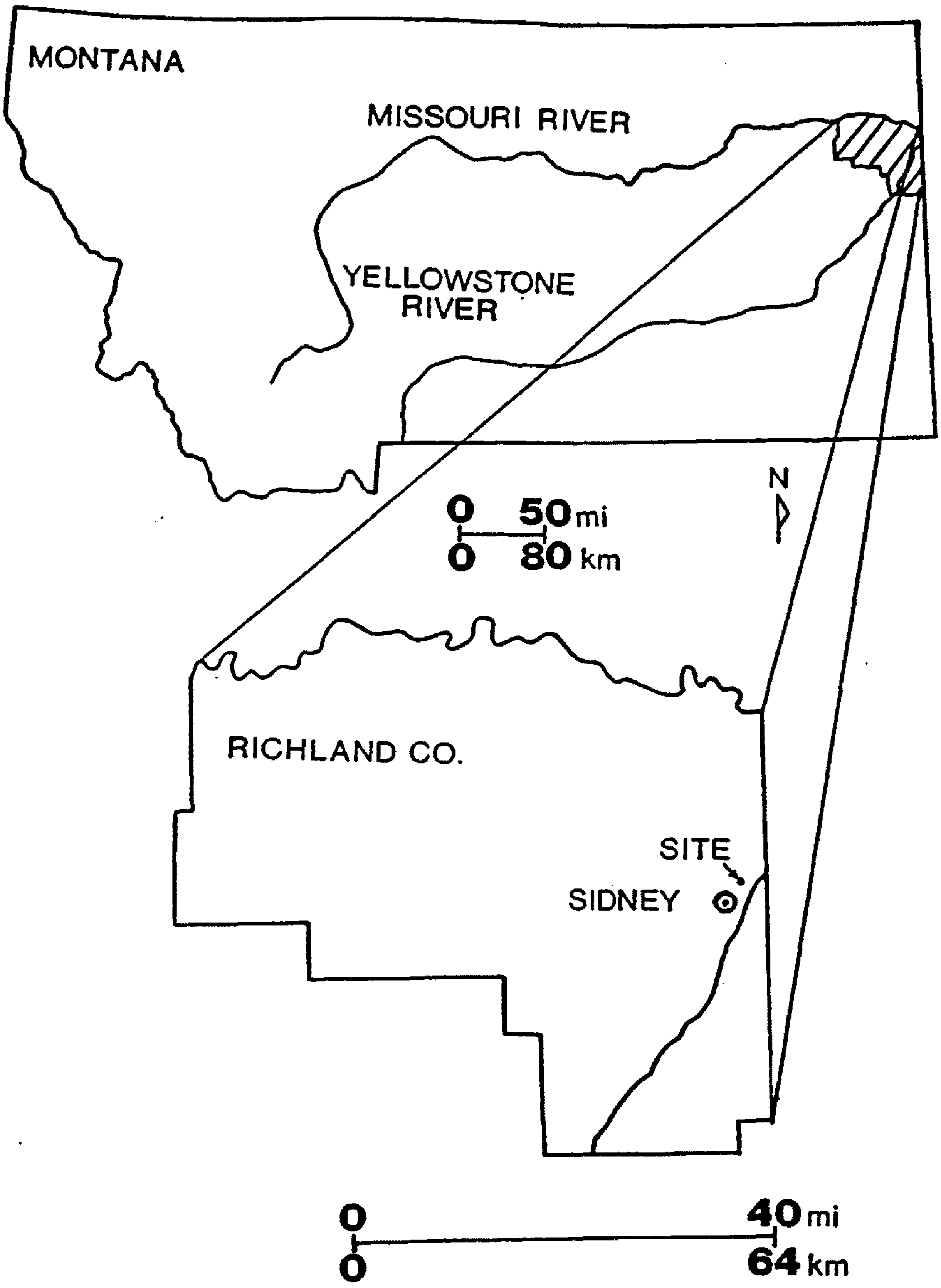


Figure 1. Site delieation in Richland County, Montana.

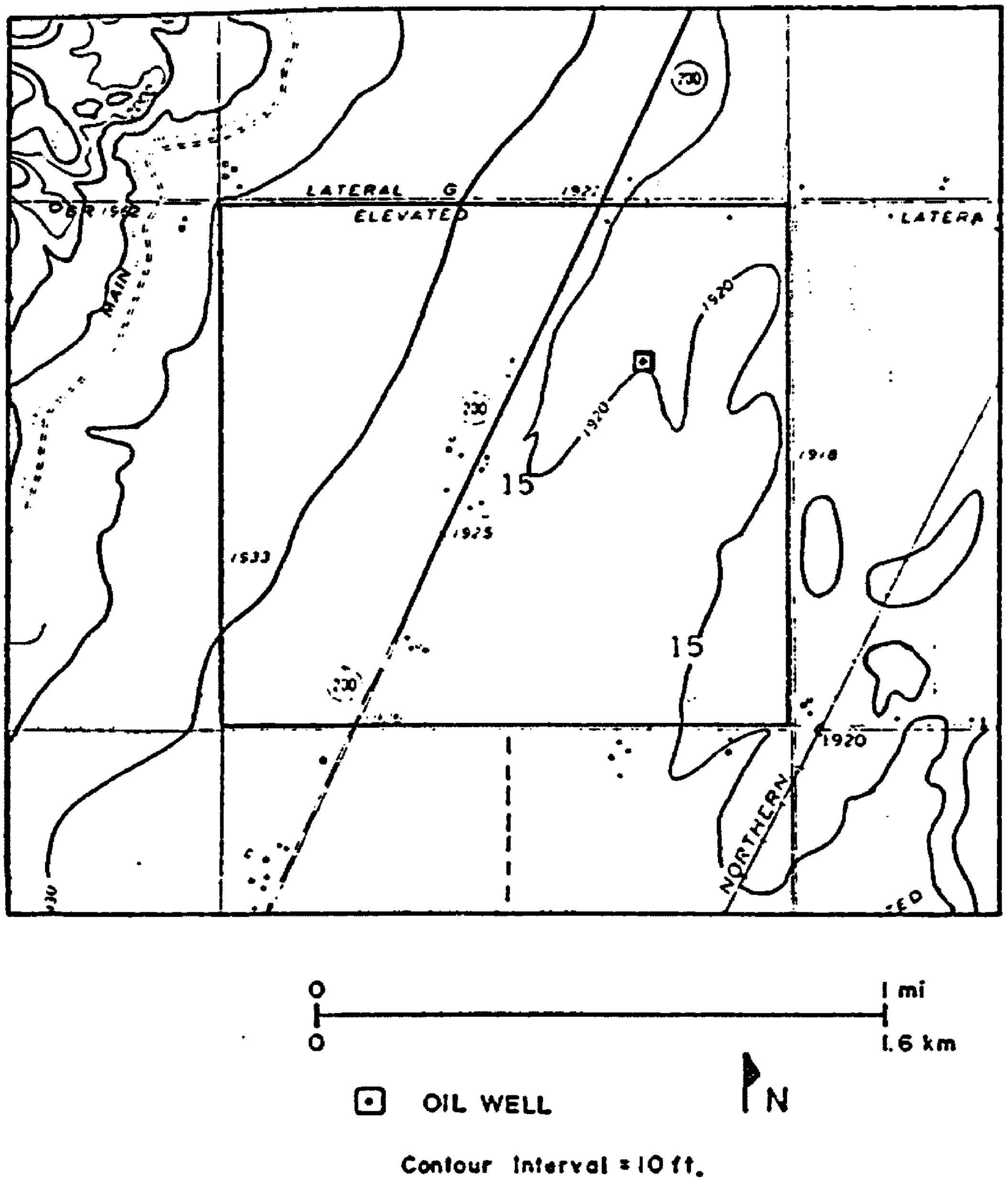


Figure 2. Topography of Section 15, T.23N., R.59E. and location of study site (adapted from Dewey, 1984).

situated on a terrace deposit on the western side of the Yellowstone River ("Crane Creek Gravel"), one mile (1.7 km) east of the western valley edge. The valley edge is composed of the Tongue River member of the Fort Union Formation which is 300 to 500 feet (120 m) higher in elevation than the valley bottom. The Yellowstone River Valley bottom is fairly level, except for a series of low terrace deposits.

At the study site an operating oil pumper and buried reserve pit are present (Figure 3). The reserve pit contained brine water and drilling mud, and was reclaimed in the summer of 1982 using the trenching method (Dewey, 1984). Brine water was removed from the pit and the drilling mud was disposed in both the reserve pit and trenches. According to Dewey (1984), initial groundwater contamination from brine seepage occurred within approximately 20 days after the pit was reclaimed. Wheat, corn, sugar beets, and alfalfa are grown on surrounding land and a return flow irrigation ditch abuts the west side of the oil pumper area. A number of small irrigation channels supply water for flood irrigation near the site.

### Climate

The climate is semiarid, characterized by cold, dry winters, moderately hot and dry summers, and cool, dry falls (Slagle, 1984a). Winters are often interrupted by warming trends, with summers dominated by hot days and cool nights. January is generally the coldest month and July the warmest. Glendive, Montana has a 14.9° F average January temperature

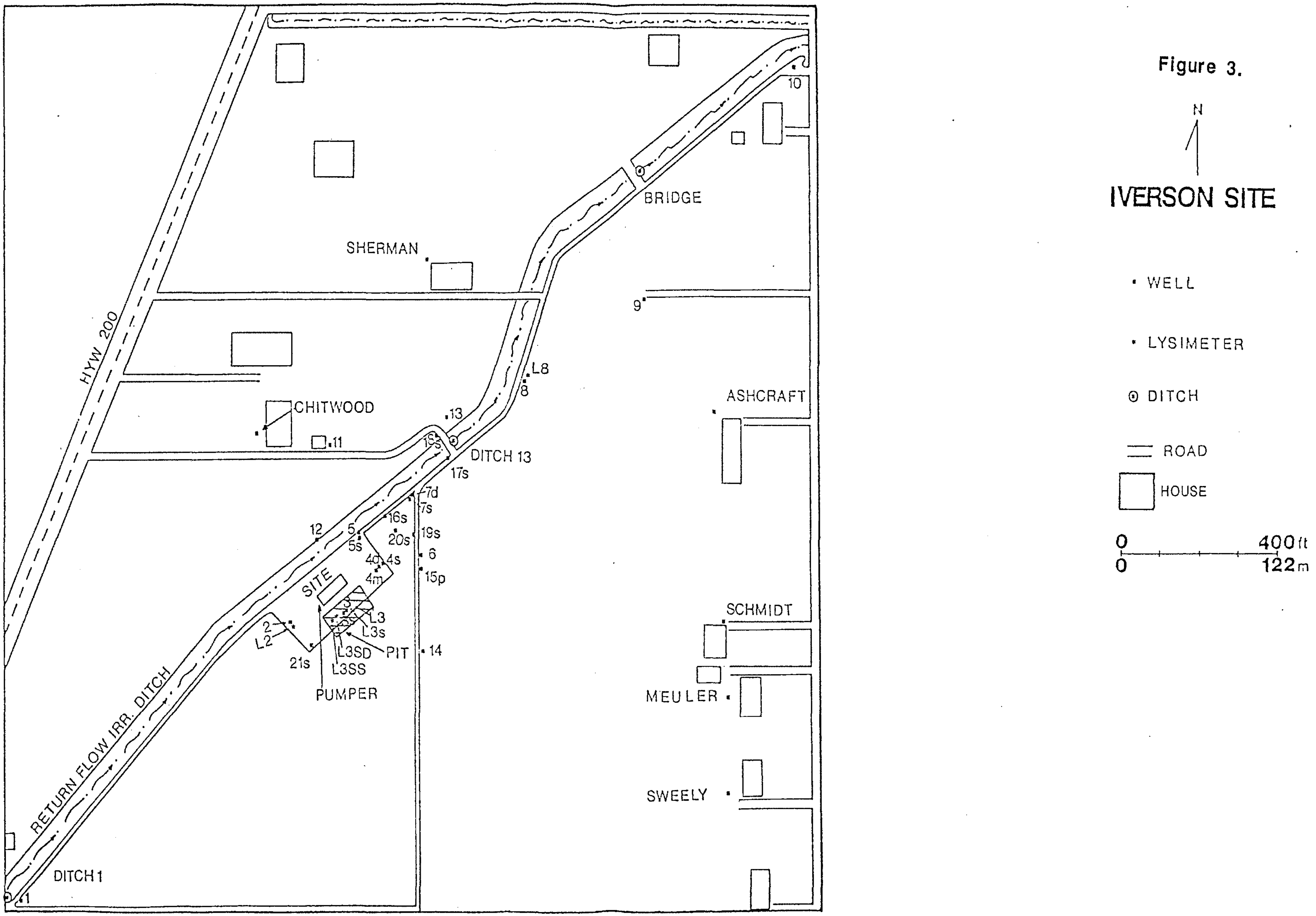


Figure 3.

IVERSON SITE

and a 74.0° F average temperature for July, -10°C and 23.3°C respectively (Slagle, 1984). Average annual precipitation at Sidney is approximately 14 inches/year (35.6 cm) with about 65 percent of the precipitation falling from May through August, and June being the wettest month (Slagle, 1984a).

## Regional hydrogeology of Richland County, Montana

Groundwater is present in eight major aquifer systems in Richland County from the Paleozoic Madison Group to the Quaternary alluvium. Aquifers present within 200 to 300 feet (61-91 m) of ground surface in Richland County are the Tongue River Member of the Tertiary Fort Union Formation and the Quaternary glacial, terrace and alluvial deposits. The water table in these aquifers usually reflects the land surface topography (Slagle, 1984a). Deeper aquifers, below 300 feet (91 m), have a regional flow direction towards the Yellowstone and Missouri Rivers.

Groundwater recharge generally occurs in the topographically high areas with discharge areas in the valley bottoms. Snow melt and precipitation are the major contributors of recharge in eastern Montana (Torry and Kohout, 1956), however, irrigation in Yellowstone River Valley contributes large quantities of water to the shallow aquifer(s). Groundwater recharge is greatest in the spring when snow melt and precipitation are at their peak and irrigation begins (Torry and Kohout, 1956).

Prior to this study, no aquifer property data were available for the Quaternary aquifer systems in Richland County, and only laboratory estimates of hydraulic conductivity were available for the Tongue River Member. Croft (1985) estimated hydraulic conductivities of the Tongue River claystone to be 0.15 to 0.099 ft/day ($8.45 \times 10^{-6}$ to $5.64 \times 10^{-6}$ cm/sec).

A detailed discussion on the regional hydrogeology is in Appendix B.

Previous work

The Iverson site was previously studied by Michelle Dewey of the University of Montana from August 1982 through June 1983. Dewey determined that a shallow sand and gravel aquifer underlies the site, average depth to the groundwater is nine feet and groundwater flows towards the north.

Dewey's chemical analyses and surface resistivity surveys led her to conclude that: 1) brine is seeping into the shallow groundwater from the reserve pit which produces increased levels of sodium and chloride; 2) the reclamation techniques used to reclaim reserve pits are inadequate to inhibit brine migration; 3) surface electrical resistivity is a good indicator of possible brine contamination at oil well sites; and 4) contaminants may be moving as fast as 22 feet per day through the shallow aquifer.

Numerous other authors have studied reserve pit brine migration in the oil producing areas of the United States. These studies demonstrate that chloride and other ions often contaminate shallow aquifers and surface water systems comparable to the reserve pit contamination in the shallow aquifer of the Williston Basin (Powell and others, 1963; Knowles, 1965; Fryberger, 1972 and 1975; Todd and McNulty, 1976; Vander Leeden and others, 1975; Latta, 1963; Leonard, 1964; Bryson and others, 1966; Kreiger and Henderickson, 1960; Miller and others, 1977; McMillion, 1965; Scalf and others, 1975; Shaw, 1966; Pettyjohn, 1971, 1973, and 1975; McMillion, 1965; Payne, 1966; Miller; 1980; Baker and Brendecke, 1983).

## Chapter II

## METHODS

Analytical methods were selected to determine the movement and chemical composition of groundwater and surface water. Monthly soil moisture and groundwater quality sampling methods were selected to determine how and when contaminants enter the groundwater. Computer modeling methods were selected to simulate groundwater flow and solute transport in two dimensions.

### Field methods - Geophysical techniques

#### Resistivity measurement

A Soiltest R-60 resistivity meter and Wenner electrode configuration with electrode a-spacings of 10, 20 and 30 feet (3.48 m, 6.1 m, and 9.57 m, respectively) were used to determine soil and groundwater resistivity. Figure 4 shows the location of resistivity stations. Standard operating procedures as described by Dejong and others (1979) and Soiltest (1976a and 1976b) were used to determine soil and groundwater resistivity.

#### EM measurement

A Geonics EM34-3 conductivity meter with 10, 20 and 40 metre coil spacings (32.8 ft, 65.6 ft, and 131.23 ft respectively) was used to determine soil and groundwater conductivity in both the horizontal and vertical EM modes. Location of EM stations are shown in Figure 5.

Use of two coil configurations (or modes) with the EM

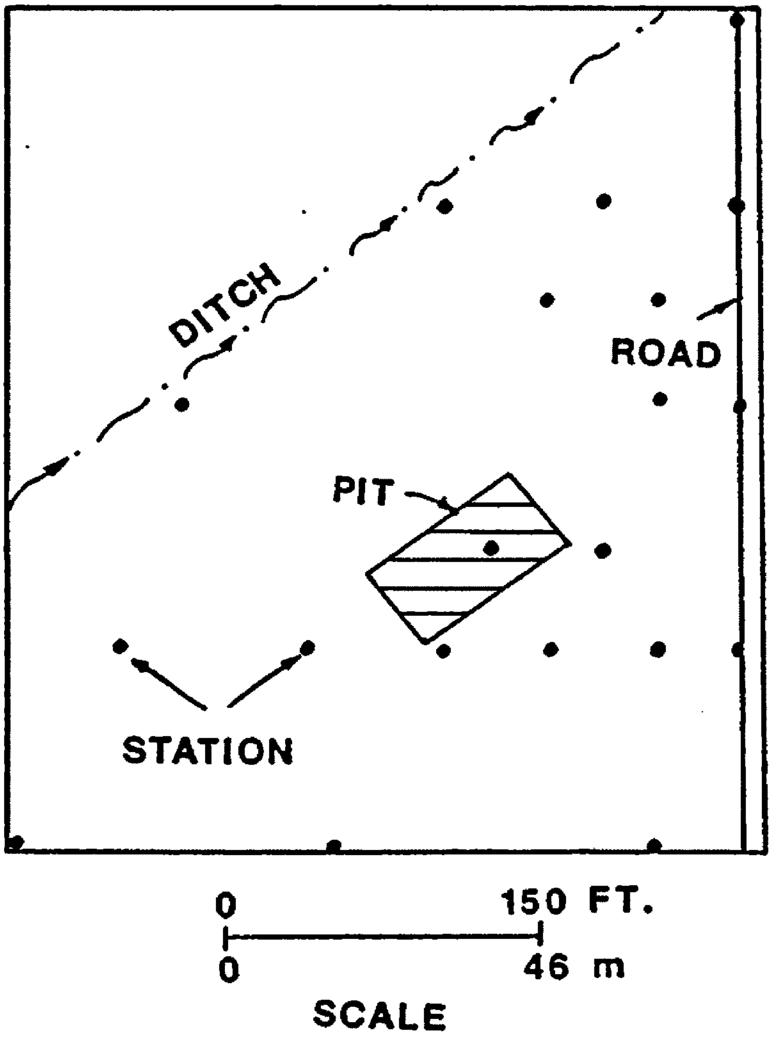
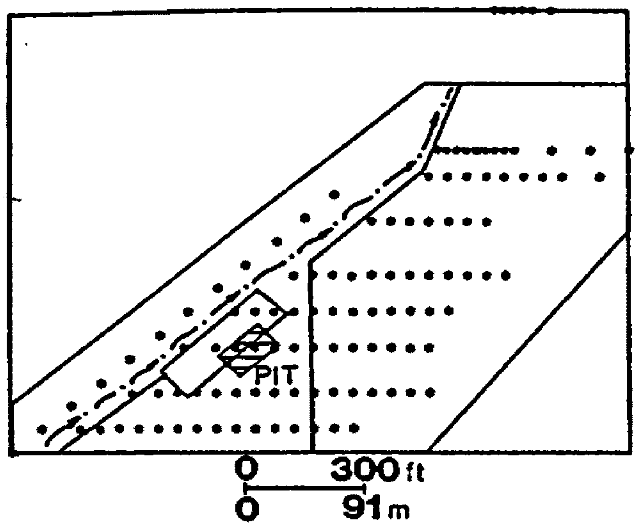
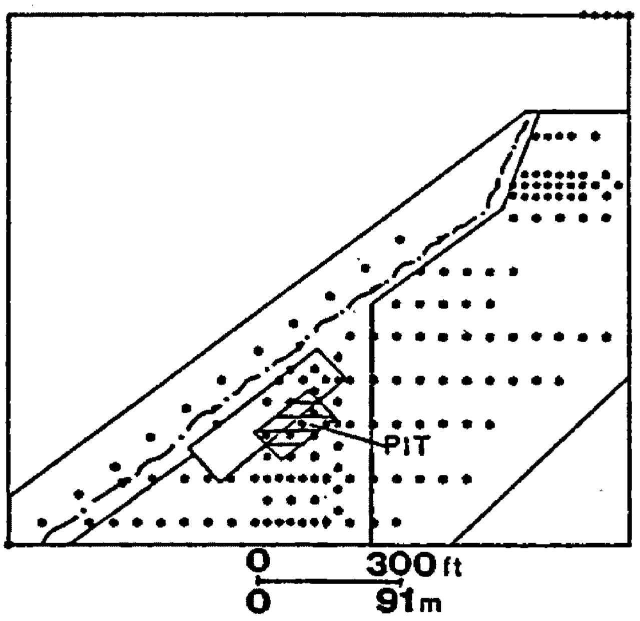


Figure 4. Resistivity grid (10, 20 and 30 ft. a-spacings).

STATION MAP FOR 20 METRE EM



STATION MAP FOR 10 METRE EM



STATION MAP FOR 40 METRE EM

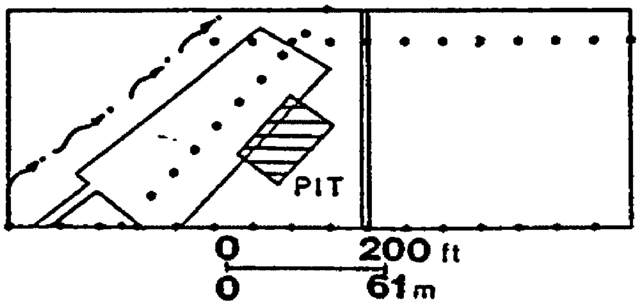


Figure 5. EM gird (10, 20 and 40 metre coil spacings).

equipment measures different depths of soil conductivity. Thehorizontal EM mode (vertical dipoles) measures soil conductivity to approximately 1.5 times the length of the coil spacing and is relatively insensitive to surface soil conductivity (McNeil, 1980c). The vertical EM mode (horizontal dipoles) measures soil conductivity from the surface to approximately .75 times the length of the coil spacing (McNeil, 1980c).

EM data were interpreted using standard procedures described by McNeil (1980a, 1980b, 1980c, 1985 and 1986).

Monitoring wells and lysimeters:

Figure 3 shows the location of monitoring wells and lysimeters. Appendix C details well and lysimeter construction. The monitoring wells were located on the basis of EM and resistivity results. Readings of large conductivity values and small resistivity values at geophysical survey points were interpreted to represent areas of reserve pit contamination. Monitoring wells were installed using the MBMG (Montana Bureau of Mines and Geology) Mobile-Drill 50 drill rig equipped with 6.5 inch OD (outer-diameter)/3.25 inch ID (inner-diameter) HSA (hollow-stem-auger) flights. One well, MW 15p, was installed using 10 inch OD/6.25 inch ID HSA flights.

The depth of bore holes varied from 10 to 37 feet (3 to 11 m), however, no monitoring wells were installed below 23 feet (7 m). All monitoring wells, except MW 15p, are 2-inch

ID diameter schedule 20 PVC with either a 20 or 30 slot (0.020 or 0.030 inch) well screen. Well MW 15p is a 4.5 inch ID schedule 40 PVC well with a 20 slot (0.020 inch) well screen. The wells are completed with a natural sand and gravel (hole collapse) and a surface bentonite plug. Both single and nested well sites were installed. Nested well sites consisted of two to three monitoring wells completed at different depths a few feet apart. Each well was developed with a hand bailer or pumped with a small surface pump until clear water was obtained. Soil samples and logs were collected from auger cuttings and a geologic log was prepared for each hole (Appendix D).

Monitoring wells installed in the pit area were completed with two bentonite seals. A second bentonite seal (below the surface bentonite) was installed below the bottom of the reserve pit mud to inhibit vertical brine migration along the well casing.

Lysimeters were installed from 3.5 to 6 feet (1 to 2 m) below ground surface. Lysimeters are 1.5 inch diameter schedule 26 PVC with a ceramic cup at the lower end of the casing. The lysimeters are completed with a saturated silica flour surrounding the ceramic cup, natural fill above the silica flour, and a surface bentonite seal.

Water levels were measured with either a steel tape or electric M-scope from a top-of-casing datum surveyed by the United States Soil Conservation Service in Sidney, Montana.

Water levels were measured monthly from July, 1987 to August 1988. Water level data were used to determine head at each well site and areal groundwater flow direction.

A stilling well was installed with a 30 day Stevens continuous water level recorder on the return flow irrigation ditch at site Ditch 1 (Figure 3). Two additional 30 day Stevens continuous recorders were installed on monitoring wells MW 1 and MW 3.

Aquifer testing:

The hydraulic conductivity of the shallow, unconfined sand and gravel aquifer was estimated from an aquifer test conducted at well MW 15p. The shallow aquifer was stressed using a 3 HP surface pump which sustained a constant discharge rate of 30 gpm (gallons/minute) for 4.5 hours. Discharge water was pumped through a pipe approximately 150 feet away to the southwest of the pumping well onto an alfalfa field. Drawdown and recovery were measured in the pumping well (MW 15p) and three monitor wells, 53 feet, 82 feet and 118 feet (16 m, 25 m and 36 m) from the pumping well (wells MW 6, MW 19s, and MW 20s, respectivley). Drawdown verses time data were first analyzed by assuming steady-state conditions (Driscoll, 1986). The data were also evaluated assuming transient conditions with delayed yield and partial well penetration (Boulton 1954a, 1954b, 1964, and Stallman, 1965).

Water quality sampling:

Measured field parameters include corrected SC (specific conductance), temperature, pH, and chloride. Chloride concentrations were measured using Quantabs (Appendix E), a small capillary tube that function as a chloride titrator. A single Quantab is lowered into a cup of water, after which water moves up the capillary passage on the Quantab to discolor the top. A value corresponding to the distance the sample water moved up the capillary passage is read off the side of the Quantab and converted into mg/l or percent chloride in solution (Appendix E). Field data were collected monthly and input into a computer data base.

Water samples for chemical analyses were collected on a quarterly basis. Sampling procedure included bailing water from monitoring wells until pH stabilized and rinsing sample bottles three times with sample water. Four samples were collected from each monitoring well site including one untreated, one filtered, and two filtered and acidified samples. Acidified samples were preserved with 2.5 milliliters of nitric acid per 500 ml of sample water. The filtered samples were pumped through a 0.45-micron filter. Decontamination of sampling equipment was accomplished with three rinses of deionized water.

Analyses for major ions and metals were done at the MBMG laboratory. Metals were also analyzed at the University of Montana Geology Department. Field quality control was checked with one deionized water sample filtered and preserved in the field, and analyzed at the MBMG laboratory. Sample water was stored in a cooler over ice for delivery to the MBMG laboratory in Butte and the University of Montana Geology Department in Missoula.

Lysimeters were also sampled quarterly. Vacuum was drawn on lysimeters five to 30 days prior to sampling, after which, the soil moisture was sucked out using a vacuum pump. Sample bottles were rinsed with deionized water. The sample water was filtered in the field and sometimes acidified in the field if sufficient sample water was available. Sample bottles were stored in coolers over ice and delivered to the MBMG laboratory and the University of Montana Geology Department.

### Laboratory methods - Chemical analyses:

Groundwater and soil moisture samples were analyzed at the MBMG laboratory for following ions and constituents including: calcium, magnesium, sodium, potassium, iron, manganese, silica, bicarbonate, carbonate, chloride, sulfate, nitrate, fluoride, phosphate, bromide, dissolved solids, sum of constituents, specific conductance, pH, hardness, alkalinity, Ryznar stability, Langlier saturation, and sodium absorption ratio. All MBMG laboratory procedures were EPA and USGS certified procedures (Reiten, 1988). Metals analyzed at the MBMG laboratory on an ICPS (inductively coupled plasma spectrometer) were: silver, aluminum, arsenic, boron, beryllium, cadmium, chromium, copper, lithium, molybdenum, barium, lead, nickel, strontium, titanium, vanadium, zinc, zirconium, and selenium.

Metal analyses at the University of Montana were also done on a ICPS. Groundwater, soil moisture, and soil samples were tested for: aluminum, arsenic, calcium, cadmium, copper, iron, potassium, magnesium, manganese, nickel, sodium, lead, phosphate, antimony, and titanium. Soil samples were acid extracted for total digestible metal content (Moore, 1988). Metal scans and sample preparation were accomplished using standard laboratory techniques done in accordance with USGS water analysis standards which included a 10 percent rerun of samples as duplicates (Moore, 1988).

### Sieve analysis:

Sieve analyses were performed on three different samples collected from monitoring well cuttings. The samples were sieved at the United States Forest Service Materials Testing Lab in Missoula, Montana. Standard laboratory techniques were used to determine the grain size distribution.

Aquifer porosity was determined by saturating a volume of oven dried aquifer material and measuring the volume of water needed to fill the empty void spaces.

### X-ray diffraction:

X-ray diffraction was used to identify the <2-micron size fraction clay mineralogy of mud samples taken from auger cuttings while drilling through the reserve pit. The samples were mixed with deionized water and centrifuged to separate the <2-micron size fraction. The <2-micron size fraction was put on glass slides as random, oriented, and glycol saturated clay particles for x-ray diffraction (Jennings and Thompson, 1986). Standard X-ray diffration techniques were used to identify the clay mineralogy of the pit mud.

Computer modeling:

The 2-dimensional PLASM groundwater flow model developed by Prickette and Lonnquist (1971) was used to model groundwater flow. Random-Walk, developed by Prickette, Naymik, and Lonnquist (1981), was used to model solute transport. PLASM is a finite difference model which can be used to simulate non-steady flow in a heterogeneous aquifer under unconfined and non-leaky, and leaky-confined conditions. PLASM estimates head using the alternating direction implicit numerical method to solve a set of finite difference equations. Input data will be discussed in detail in Chapter III.

Random-Walk is a 2-dimensional model that can simulate contaminant transport in an unconfined or confined aquifer (Prickette and others, 1981). The model takes into account groundwater velocity, convection, dispersion, and chemical reactions. The model simulates movement of a solute using a particles in a cell method, transported for a given time schedule. Particles are randomly dispersed according to model inputs by a statistical technique. The model has the ability to install sinks or sources, and can map solute as concentration or the number of particles for a given cell. The version of Random-Walk used in this study is linked with the PLASM groundwater flow model. Head data generated with PLASM is converted into a velocity vector field with a preprocessor for each simulated month. The velocity vector field is then linked to the Random-Walk model to move solute in accordance with the modeled potentiometric surface and dispersion coefficients.

## Chapter III

## RESULTS AND DISCUSSION

This chapter presents all data collected in this study. A short discussion will follow the data in each section.

### Site hydrogeology

Soil and fill (material used to cover the pumper area and roads) cover the top three feet (1 m) of land surface of the study area. From three to 26 feet (1 to 8 m) Quaternary sand and gravel of the oldest terrace deposit ("Crane Creek Gravel") of the Yellowstone River Valley is present. Included in the sand and gravel are local zones of well sorted sand, gravel, thin lenses of clay, layered silt and sand, layered clay and sand, and pit mud in the reserve pit area (see geologic cross sections in Appendix D). The depositional environment of the terrace deposit was apparently a fairly high energy system since coarse gravel was deposited with sand. Terrace deposition apparently took place during an interglacial time since till deposits are present stratigraphically above and below the terrace deposits about three miles (5 km) south of the study site (Prichard and Landis, 1975).

A sieve analysis on the sand and gravel material (Appendix D) shows an even distribution of particles, from fine sand to coarse gravel. This material is the dominant aquifer material encountered in the monitoring well bore holes. A sieve analyses on a sample collected from eight to

20 feet (2.5 to 6 m) at monitoring well MW 12 showed that 85% of the sample retained was sand size. A sieve analyses on a sample collected from 14 to 33 feet (4.5 to 10.5 m) at monitoring well MW 13 showed 75% of the sample retained was gravel size. Results of the sieve analyses indicate that the aquifer is relatively coarse grained and little silt and clay are present.

The Tongue River Member of the Fort Union Formation underlies the terrace deposits at approximately 26 to 28 feet (8 m) below ground surface. At the study site the Tongue River Member consists of a dense, low permeability grayish clay with sandy intervals.

The shallow aquifer is restricted to the sand and gravel terrace deposits. The shallow aquifer has a seven to 10 foot (3 m) unsaturated zone and a saturated thickness of about 17 feet (5 m). Below the shallow aquifer, clay of the Tongue River Member separates the shallow unconfined aquifer and the deeper confined aquifer. The upper clay of the Tongue River Member has a relatively low hydraulic conductivity, estimated to be 0.15 to 0.099 ft/day ($8.45 \times 10^{-6}$ to $5.64 \times 10^{-6}$ cm/sec) (Croft, 1985), which probably inhibits groundwater movement between the shallow and deep aquifers. Domestic wells in the study are completed in water bearing coal and sandy intervals of the Tongue River Member 35 to 45 feet (13 m) below land surface (as determined from domestic well logs).

In general, groundwater flow direction (Figure 6 and

Appendix F) is towards the northeast with some variations in flow direction along the return flow irrigation ditch. The ditch is recharged by groundwater in the spring, summer and fall and the water table is in contact with the ditch since it is above the ditch water level and a visible seepage face is present in the ditch channel. Estimated ditch flow in the summer months is approximately three to four cfs.

In the winter, groundwater flow (Appendix F) is parallel to the ditch, and water in the ditch apparently leaks into the underlying shallow aquifer since the measured ditch water levels are above the water table. The ditch bottom is comprised of mud and silt, and permeability of these sediments is estimated to be relatively low. The low permeability and small winter ditch flow (approximately .5 cfs) indicate that the ditch is most likely leaking water to the shallow aquifer and forming a small groundwater mound.

The Yellowstone Irrigation District shuts down the irrigation canals in the winter months, yet flow is present in the return flow ditch. The source of winter ditch water is probably from upgradient reaches where the water table intersects the ditch causing groundwater to discharge into the ditch.

### Precipitation and recharge

Precipitation and free water evaporation data collected at the Montana State University Agricultural Experiment Station in Sidney about two miles from the study area are in

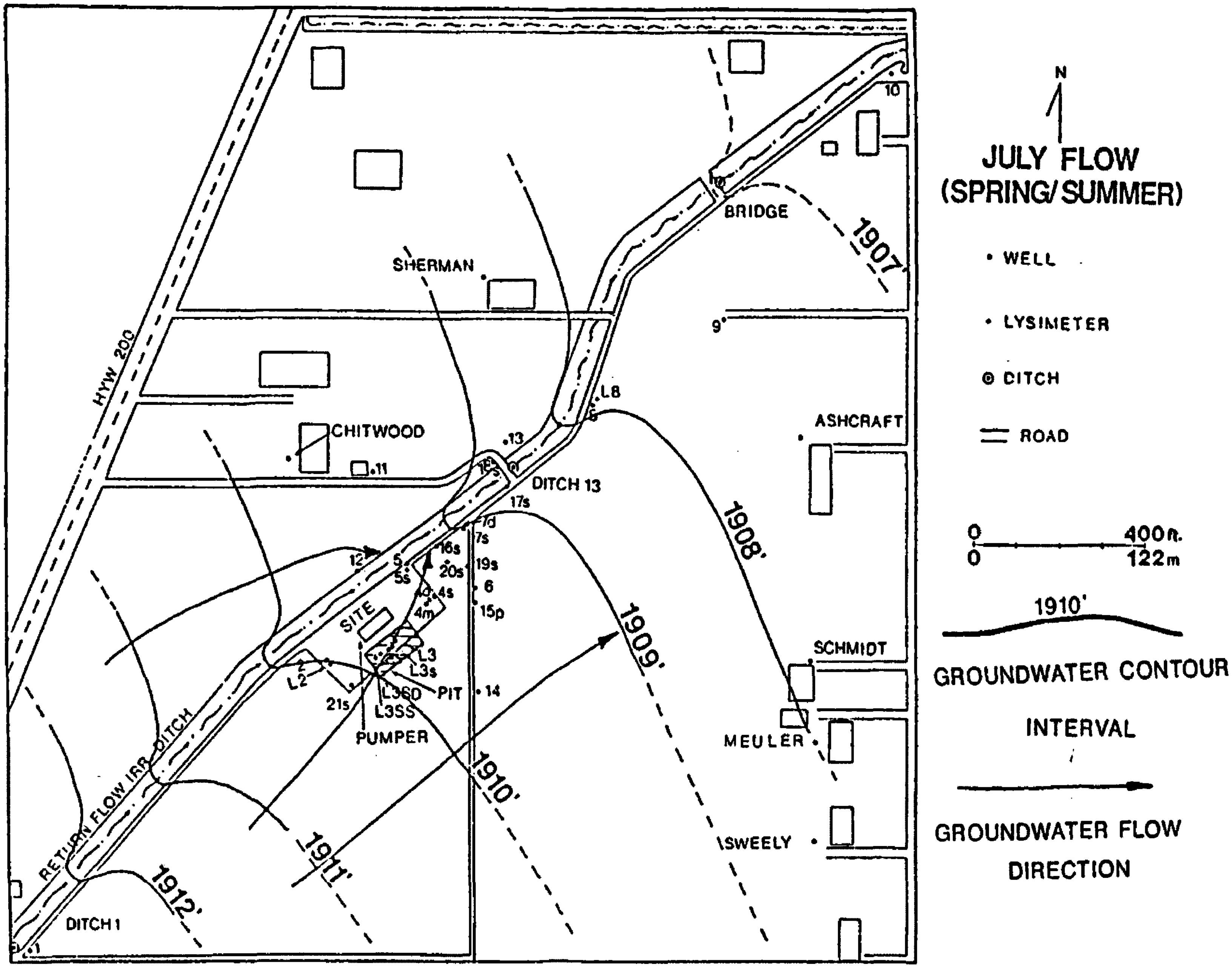


Figure 6. Groundwater flow map (spring and summer).

Figure 7 and Appendix G. Precipitation is lower in the spring and summer of 1988 compared to the spring and summer of 1987. In addition, evaporation is greater in 1988 compared to 1987. The higher evaporation and lower precipitation in 1988 indicate there was less surface recharge available to move pit contaminants compared to 1987. Since the reserve pit area is not flood irrigated, precipitation is the only surface recharge factor for leaching brine to the water table.

Annual water level fluctuation at well MW 3 is about four feet in the 1987-1988 year (Figure 8). The water table rise and fall is coincident with the start of spring flood irrigation in May and irrigation shutdown in November surrounding the site. The crops grown on the surrounding farmland (alfalfa, corn and sugar beets) require 18 to 24 inches (46 to 61 cm) of water during the growing season (SCS, 1987), which is significantly greater than the average annual precipitation of 14 inches/year (36 cm). The irrigation water used to supplement the crops is an important source of recharge to the shallow aquifer.

The peak 1988 water table position (Figure 8) matches the peak 1987 water table position, yet precipitation is less and free water evaporation is greater in 1988 compared to 1987. This suggests that more flood irrigation water was applied in 1988 compared to 1987 to counter drought conditions.

All monitoring wells and ditch locations have a similar annual water level fluctuation (Appendix H), indicating water

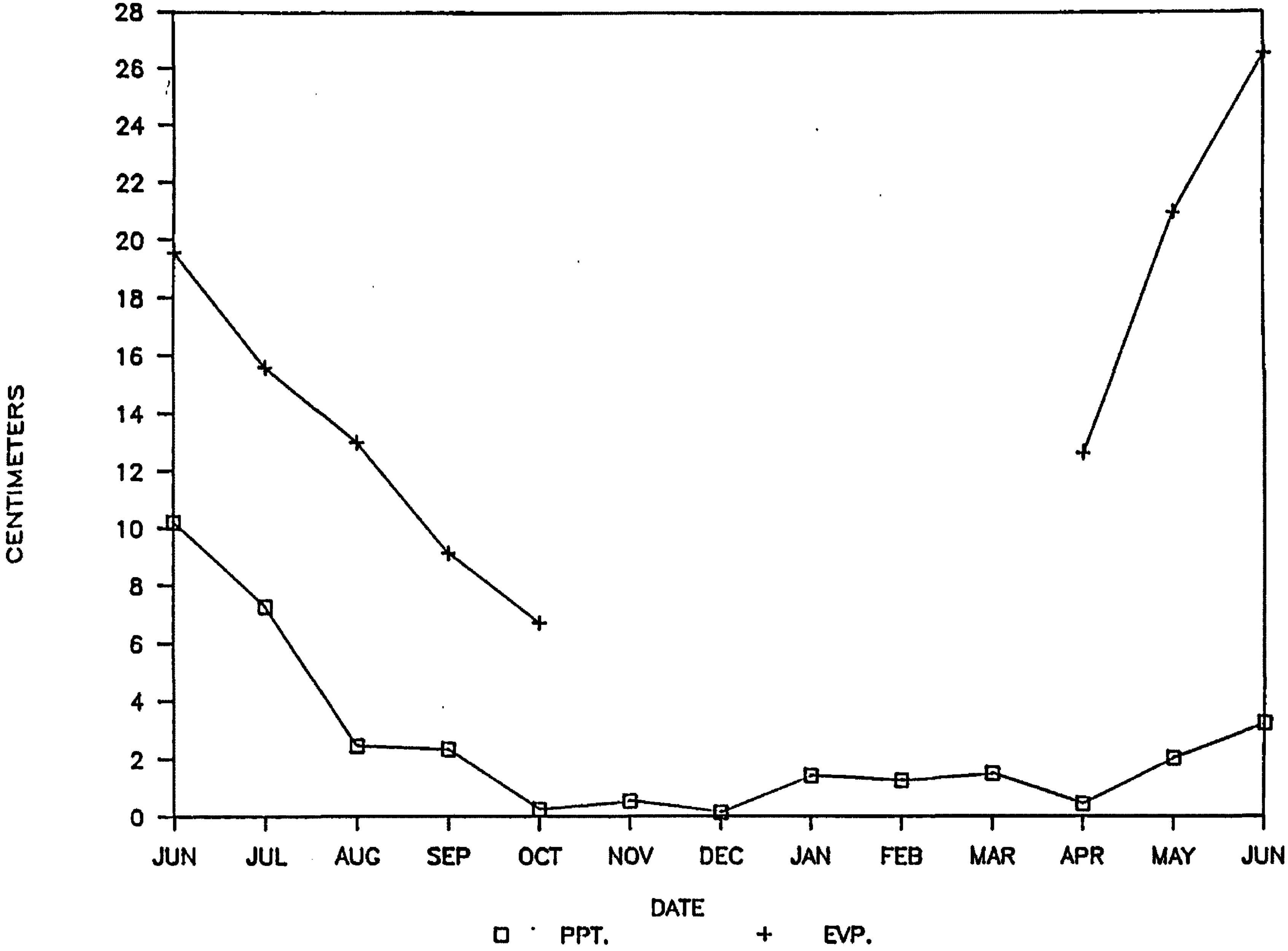


Figure 7. Annual precipitation and evaporation from June 1987 to June 1988 (Montana State University Agricultural Experiment Station Sidney, Montana).

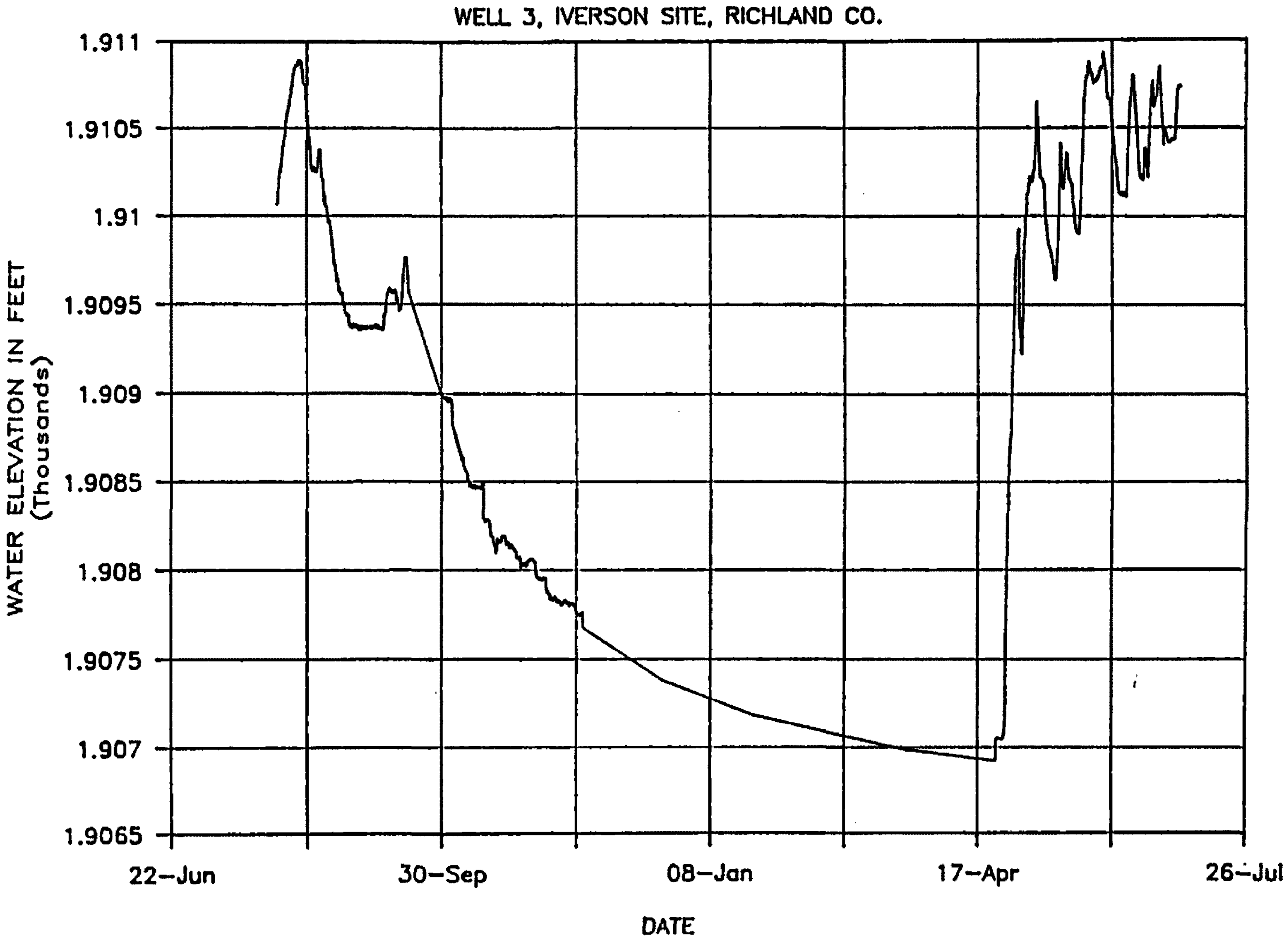


Figure 8. Annual water table fluctuation from August 1987 to July 1988.

level response to recharge is similar across the entire site.

Hydraulic conductivity and specific yield

One constant discharge aquifer test was used to estimate K (hydraulic conductivity) using both Boulton's partial penetration and delayed yield equations (Lohman, 1978). Delayed yield was evident in the pumping well (MW 15p) and one monitoring well (MW 6). The delayed yield method was employed to estimate K at these locations. Delayed yield was not evident in the other monitoring wells (MW 19s and MW 20s) and the partial penetration method was used to estimate K at these locations.

One foot of drawdown was measured at the end of the 4.5 hour aquifer test at the pumping well MW 15p (pumping 30 gpm), and only a few tenths of a foot drawdown were measured at the monitoring wells (Appendix I). Limited drawdown made K interpretation difficult. Hydraulic conductivity estimates ranged from 1,500 gal/day/ft$^2$ (7 x 10$^{-2}$ cm/sec) to 25,000 gal/day/ft$^2$ (1.0 cm/sec) depending on the well location and whether the delayed yield or the partial penetration method was employed. K is probably close to 4200 gal/day/ft$^2$ (.2 cm/sec) since the most accurate simulated drawdown in an aquifer test was modeled using this value (to be discussed later). Assuming a 17.5 feet thick aquifer, transmissivity is 73,500 gallons/day/ft.

Hydraulic conductivity was also estimated by using the Theim steady-state equations (Driscoll, 1986) since drawdown at the end of the aquifer test was small. Theim K estimates averaged one order of magnitude below K estimates calculated with the delayed yield and partial penetration methods. Transient K calculations probably represent a better estimate of K since steady-state conditions were not present at the end of the stress period.

A representative Sy (specific yield) for an unconfined sand and gravel aquifer was not calculated with the above methods. All calculated estimates were a number of orders of magnitude too low. Specific yield was estimated from 13 documented Sy values for sand and gravel aquifers (Turcan, 1963). Specific yield values ranged from 0.2 to 0.35, and .2 was chosen since it is a conservative estimate. Porosity of a repacked aquifer sample was determined to be .25 in the laboratory. To calculate groundwater velocity at the pit area (wells sites MW 3 and MW 7s) I used the following relationship:

$$V = \frac{K\,I}{7.48\,n}$$

where

V = velocity (ft/day)
K = hydraulic conductivity (4200 gal/day/ft$^2$ )
I = gradient (.0026 to .001 depending on which month)
n = porosity (.25)
7.48 = conversion factor for gallons to cubic feet

and calculated the following monthly groundwater velocities:

| | | | |
|---|---|---|---|
| 87' | July: | 5.6 ft/day | (1.70 m/day) |
| | August: | 5.3 ft/day | (1.62 m/day) |
| | September: | 4.7 ft/day | (1.43 m/day) |
| | October: | 4.5 ft/day | (1.37 m/day) |
| | November: | 3.2 ft/day | (.97 m/day) |
| | December: | 2.9 ft/day | (.88 m/day) |

| | | | |
|---|---|---|---|
| 88' | January: | 2.9 ft/day | (.88 m/day) |
| | February: | 2.8 ft/day | (.85 m/day) |
| | March: | 2.6 ft/day | (.79 m/day) |
| | April: | 2.4 ft/day | (.73 m/day) |
| | May: | 5.6 ft/day | (1.70 m/day) |
| | June: | 5.9 ft/day | (1.79 m/day) |

### Soil chemistry

Vadose zone soil analyses results are in Table 2 and Appendix K. Table 2 data represents the total acid digestible metal content for sodium, calcium and lead concentrations in samples collected from three reserve pit locations and three samples collected downgradient of the pit. Only sodium, calcium and lead are presented in the Table 2 since the other ions tested are at background concentrations. Chloride was not analyzed.

Table 2. Soil analyses (* less than detection)

| Sample site | Depth | % Na | % Ca | ppm Pb |
|---|---|---|---|---|
| PITMUD 1 | 6-8 ft. | 1.9 | 6.4 | 30.0 |
| PITMUD 2 | 6-8 ft. | 2.1 | 7.7 | 44.0 |
| MW 3 | 5-7 ft. | 1.6 | 3.8 | 21.9 |
| MW 4 | 6-12 ft. | 2.3 | 4.6 | 16.8 |
| MW 7 | 2-7 ft. | 0.8 | 2.6 | * |
| MW 7 (DUPLICATE) | 2-7 ft. | 0.9 | 2.9 | * |
| FT. UNION | 28 ft. | 0.7 | 7.8 | * |

Sodium, calcium, and lead results are elevated in pit samples PITMUD 1, PITMUD 2, and MW 3, and downgradient of the site at MW 4. Analyses indicate the pit mud results are approximately 50 to 75% greater than background analyses results (MW 7 and FT.UNION), with the exception of calcium in the Fort Union sample. MW 4 sample site is approximately 100 feet north of the pit area. The apparent soil contamination at monitoring site MW 4 is probably from pit mud being pushed into a reclamation trenches extending from the reserve pit.

### Groundwater and vadose water chemistry

#### Field measurements

Specific conductance (SC) and Quantab data (chloride concentrations) are in Figures 9 and 10, and Appendix J. Figure 9 shows Quantab and SC results for nested well site MW 4. The highest chloride and SC levels are present in upper four feet of the aquifer (MW 4s). Intermediate chloride and SC levels are present from four to eight feet below the water table (MW 4m). Background or near background chloride and SC levels are present in the lower half of the aquifer from eight feet below the water table to the top of the Fort Union Formation (MW 4d). Figure 9 also shows MW 4s chloride and SC levels in the summer of 1988 are less compared to chloride and SC levels in the summer of 1987.

Figure 10 shows Quantab and SC levels for monitoring wells MW 7s and MW 4m. Both wells are completed in the upper half of the shallow aquifer where brine contamination concentrates. Chloride and SC levels are significantly less in MW 7s than in MW 4m, and the peak timing of chloride and SC levels are approximately 2.5 to three months behind in MW 7s (which is down gradient of the MW 4 site). Contaminant loading in the spring and summer of 1988 appears to be less compared to the summer of 1987. Lower chloride and SC levels in 1988 are probably a result of less surface recharge and in

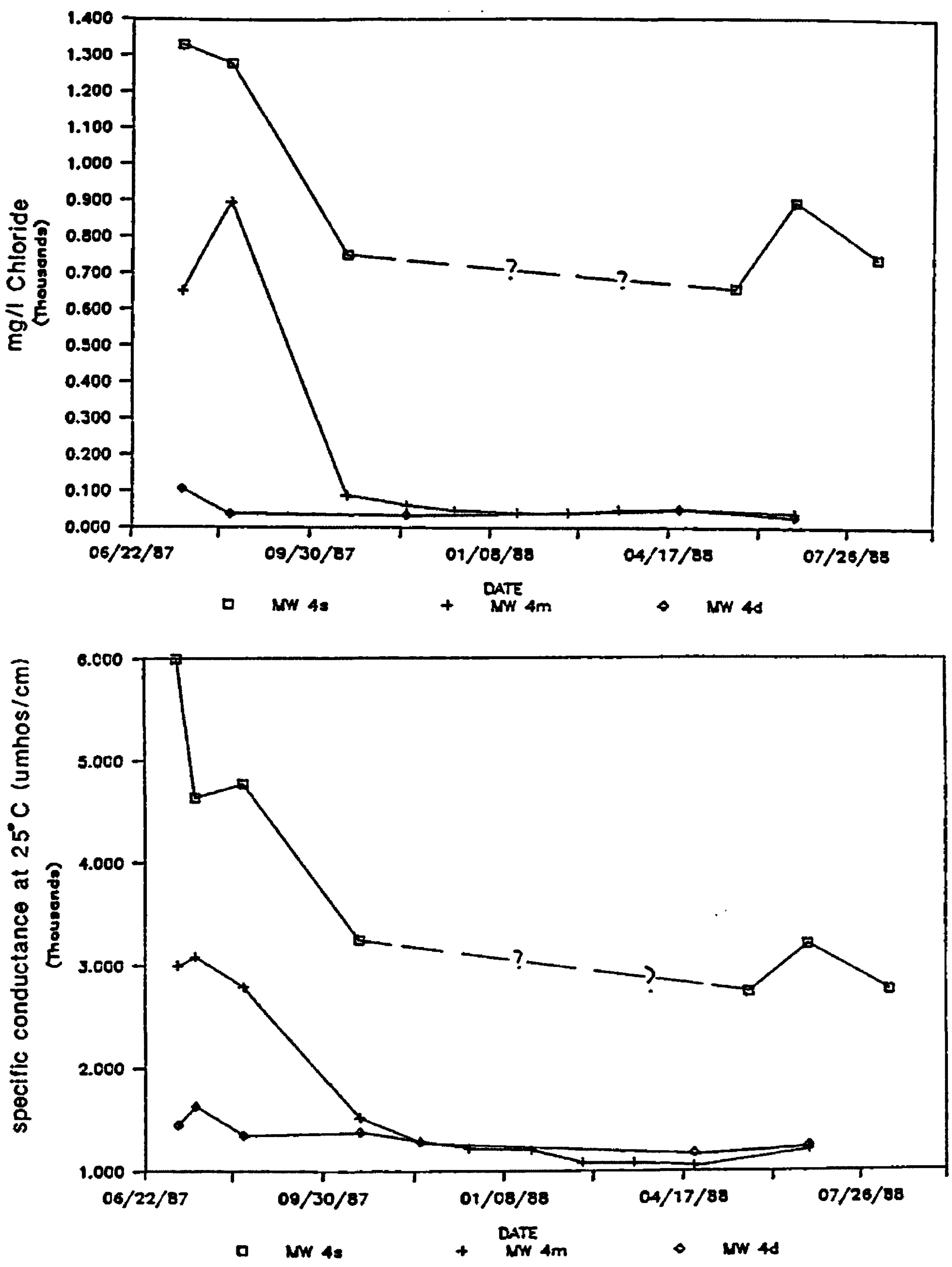
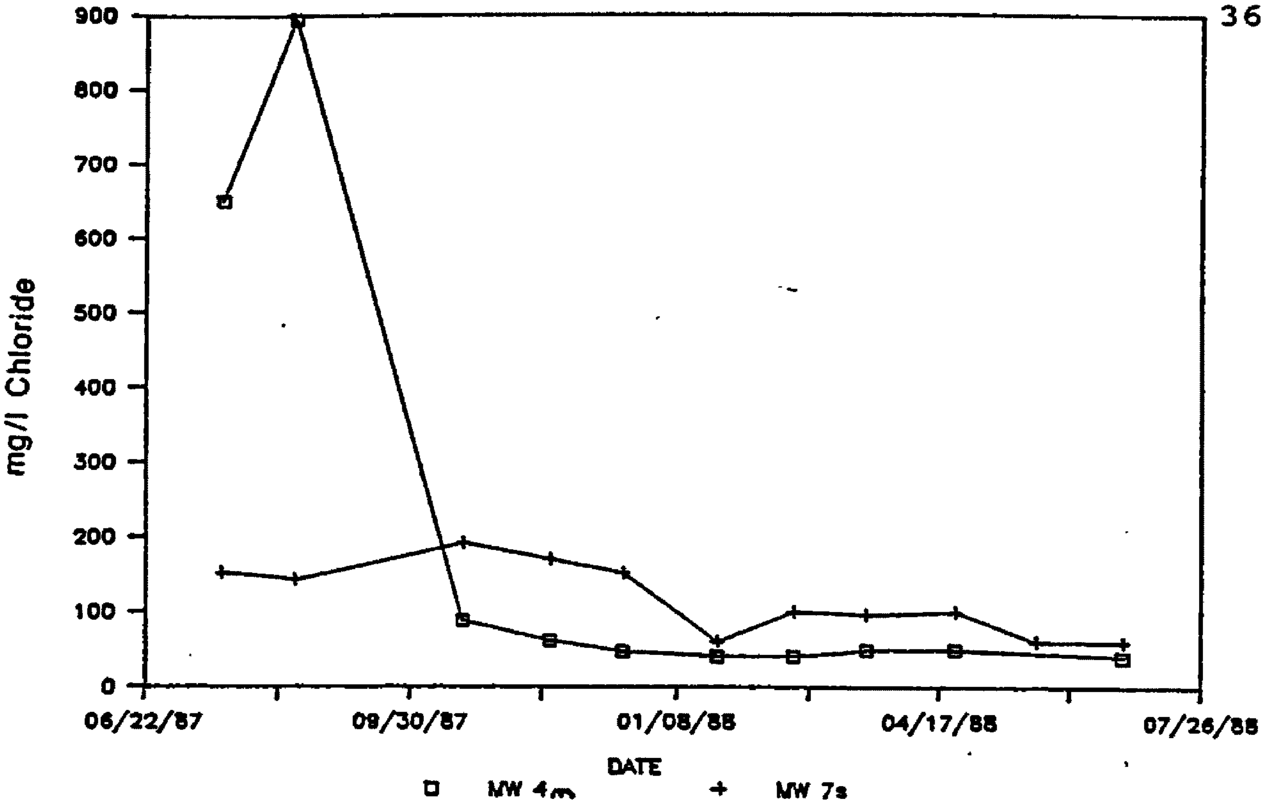


Figure 9. Annual chloride concentration and specific conductance at MW 4 nest.



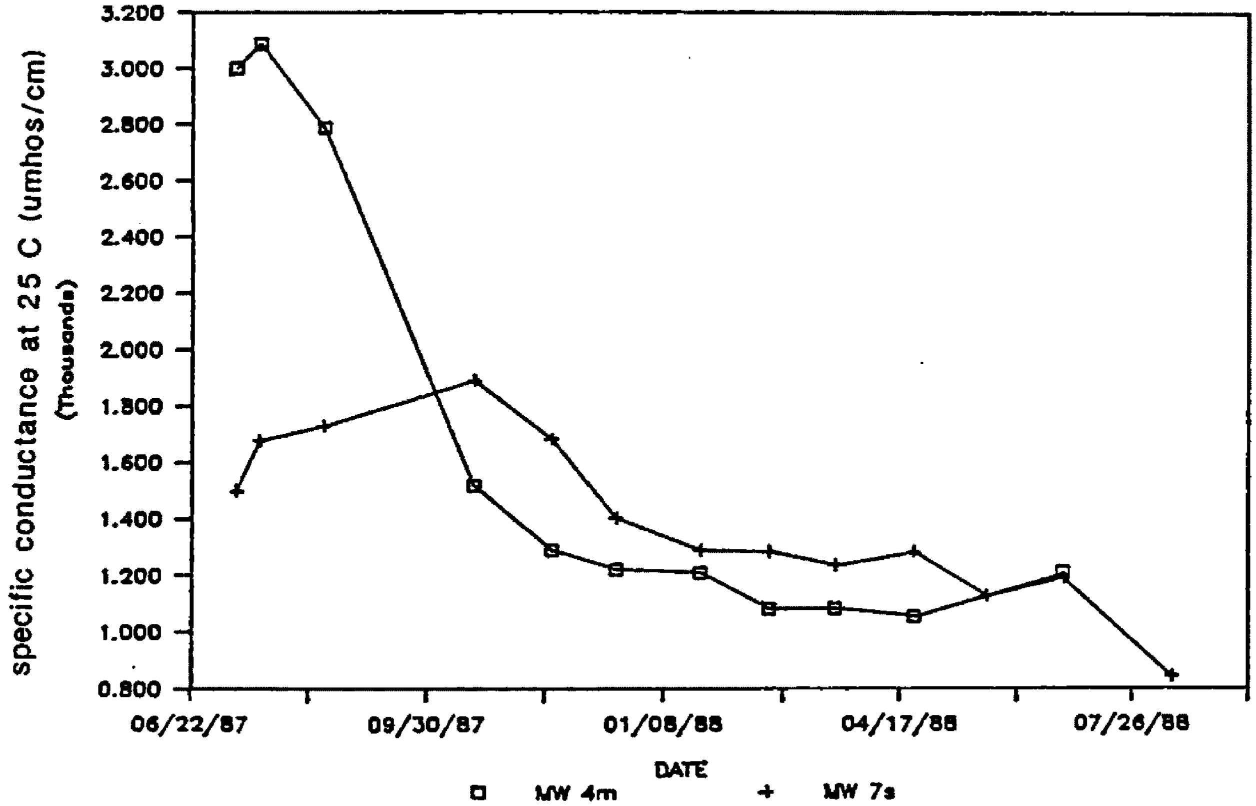


Figure 10. Annual chloride concentration and specific conductance at MW 4m and MW 7s.

turn less brine seepage into the underlying aquifer.

Field data indicate the brine contaminants tend to disperse near the top of the shallow aquifer. The lack of vertical contaminant migration suggests that K may be greater in the horizontal direction compared to the vertical direction and/or an upward flow component is keeping the pit contaminants near the top of the aquifer.

An approximation of groundwater velocity between the two well sites in Figure 10 indicates that contaminants move through the aquifer at approximately 3.3 ft/day to 4 ft/day. This was estimated by evaluating the time required for a chloride or SC peak at MW 4s to be measured at MW 7s. Figure 10 show a 2.5 to three month lag time between chloride and SC peaks which approximates the above velocities since the two sites are about 250 feet (80 m) apart.

Contaminants apparently enter the shallow aquifer by seepage from surface recharge and from contact between the water table and the pit mud. Monitoring well logs (Appendix D) show the that pit mud extends to a depth of about nine feet (3 m) below land surface at the pit area. The water table fluctuates from seven to ten feet (2 to 3 m) below land surface at MW 3. This demonstrates that the groundwater intersects the pit material. The water table apparently saturates the pit mud and in turn pit contaminants are released into the aquifer.

In 1987, pit wastes probably entered the shallow aquifer as a result of both seepage caused from precipitation and groundwater saturating the pit mud. Wetting fronts were less frequent in 1988 due to drought conditions, which apparently caused the lower chloride concentrations in the groundwater.

### Laboratory analyses

Tables 3 and 4 show suspect brine contaminants in the shallow aquifer. Groundwater contamination is indicated by annual changes in ion and metal concentrations above background concentrations. This change is characterized by high spring and summer concentrations, lower fall concentrations and very low winter or background concentrations. Background concentrations are present under the pit area in the winter months indicating contaminant loading temporarily stops. Up gradient control wells (MW 2 and MW 21) have lower concentrations compared to wells in and downgradient of the reserve pit year round.

Pit soil moisture analyses at lysimeter L3 indicate the pit material is contaminated with all metals and ions tested (except titanium and zinc) at concentrations sometimes a number of orders of magnitude above those in the groundwater.

Chloride and sodium are the two most elevated constituents detected in the reserve pit mud and groundwater. Other ions and metals were detected in the pit mud and groundwater but to a lesser degree compared to chloride and sodium. Constituents detected above the recommended federal drinking water standards are nitrates (>10 mg/l), Manganese

Table 3. Ions in the shallow aquifer attributed to brine seepage (dissolved ions reported as mg/l)*.

| | | LOCATION | | | | |
|---|---|---|---|---|---|---|
| PARAMETER | DATE | SITE 2/21 | SITE 3 | SITE 4 | MW 7s | L3 |
| Ca | 07/22/87 | 145 | 357 | 226 | 119 | 9510 |
| | 10/22/87 | 111 | 113 | 172 | 109 | |
| | 04/23/88 | 102 | 96.3 | 83.2 | 86.4 | 8350 |
| | 06/28/88 | 105 | 147 | 175 | 84.9 | 7310 |
| Mg | 07/22/87 | 31.2 | 90.7 | 50.6 | 53.6 | 1270 |
| | 10/22/87 | 34 | 35.8 | 44.5 | 53.2 | |
| | 04/23/88 | 32.4 | 37.4 | 42.6 | 42 | 1260 |
| | 06/28/88 | 37.2 | 38.7 | 43 | 43.3 | 1300 |
| Na | 07/22/87 | 63.5 | 1436 | 681 | 196 | 8470 |
| | 10/22/87 | 85.2 | 229 | 462 | 211 | |
| | 04/23/88 | 91.8 | 105 | 143 | 162 | 88600 |
| | 06/28/88 | 89.1 | 324 | 476 | 146 | 73500 |
| K | 07/22/87 | 3.8 | 25.4 | 28.4 | 8.2 | 1040 |
| | 10/22/87 | 4.5 | 8.1 | 18.7 | 8.8 | |
| | 04/23/83 | 3.3 | 4.5 | 0.6 | 6.3 | 1020 |
| | 06/28/88 | 5 | 14.4 | 19.2 | 7.3 | 885 |
| Cl | 07/22/67 | 31.9 | 2660 | 1060 | 217 | 14500 |
| | 10/22/87 | 19.7 | 221 | 678 | 224 | |
| | 04/23/88 | 21.1 | 24.4 | 28.2 | 70.7 | 156000 |
| | 06/28/88 | 23.2 | 411 | 680 | 60.6 | 130000 |
| Mn | 07/22/87 | <.001 | 5.01 | 0.29 | 0.003 | 42 |
| | 10/22/87 | <.001 | 0.4 | 0.085 | <.001 | |
| | 04/23/88 | 0.006 | 0.28 | 0.022 | 0.015 | 35.9 |
| | 06/28/88 | 0.001 | 0.077 | 0.001 | 0.002 | 30.9 |
| HCO3 | 07/22/87 | 349 | 532 | 589 | 476 | 220.8 |
| | 10/22/87 | 438 | 484 | 539 | 478 | |
| | 04/23/88 | 438 | 470 | 501 | 506 | 332 |
| | 06/28/88 | 382 | 441 | 508 | 448 | 268.4 |
| SO4 | 07/22/87 | 203 | 256 | 253 | 243 | 690 |
| | 10/22/87 | 187 | 208 | 227 | 227 | |
| | 04/23/88 | 213 | 233 | 251 | 267 | 1110 |
| | 06/28/88 | 209 | 243 | 260 | 234 | 223 |
| N | 07/22/87 | 22.7 | 2.61 | 9.14 | 4.03 | 25 |
| | 10/22/87 | 5.89 | 3.85 | 3.21 | 2.22 | |
| | 04/23/98 | 4.34 | 1.55 | 0.97 | 1.24 | <.04 |
| | 06/28/88 | 11 | 10.6 | 3.28 | 2.75 | 36 |

*See also Br Appendix L

Table 4. Metals in the shallow aquifer attributed to brine seepage (dissolved metals reported as ug/l).

| | | LOCATION | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PARAMETER | DATE | MW 21s | MW 3 | MW 3s | MW 4s | MW 16s | MW 20s | L3 |
| B | 07/21/87 | | 1030 | | | | | |
| | 10/22/87 | | 220 | | | | 570 | |
| | 04/23/88 | | 140 | | | | | 38000 |
| | 06/28/88 | 120 | | 400 | 820 | 600 | | 38000 |
| Li | 07/21/87 | | 370 | | | | | |
| | 10/22/87 | | 71 | | | | 160 | |
| | 04/23/88 | | 20 | | | | | 13100 |
| | 06/28/88 | 20 | | 130 | 190 | 100 | | 10000 |
| Ba | 07/21/87 | | 530 | | | | | |
| | 10/22/87 | | | | | | 92 | |
| | 04/23/88 | | 60 | | | | | 320 |
| | 06/28/88 | | | 110 | 100 | | | 270 |
| Sr | 07/21/87 | | 7300 | | | | | |
| | 10/22/87 | | 1020 | | | | 2510 | |
| | 04/23/88 | | 990 | | | | | 241000 |
| | 06/28/88 | 630 | | 2660 | 2780 | 940 | | 207000 |
| Ti | 07/21/87 | | 29 | | | | | |
| | 10/22/87 | | 3 | | | | 5 | |
| | 04/23/88 | | <1 | | | | | <1 |
| | 06/28/88 | 4 | | 6 | 8 | 5 | | <1 |
| Zn | 07/21/87 | | 14 | | | | | |
| | 10/22/87 | | 4 | | | | <3 | |
| | 04/23/88 | | <3 | | | | | 880 |
| | 06/28/88 | <3 | | <4 | 3 | <3 | | 430 |
| Be | 07/21/87 | | 21 | | | | | |
| | 10/22/87 | | | | | | | |
| | 04/23/88 | | <1 | | | | | 26 |
| | 06/28/88 | | | 1 | | | | 21 |

(>0.05 mg/l) and chloride (>250 mg/l). Nitrates and Manganese only exceed these standards in the spring and summer at the pit area; chloride is generally above the recommended drinking water standards year round.

Ions and metals at elevated concentrations in the pit mud but not detected in the groundwater are probably absorbed, bonded, precipitated and/or absorbed by the clay minerals of the pit material. An x-ray diffraction pattern of the pit mud (Appendix M) shows the drilling mud is rich in smectite (or bentonite, which is the common drilling mud used drill oil wells). Smectite is a 2:1 layer silicate clay mineral that will absorb hydrated ions in the interlayer spaces of the 2:1 structure (depending on the size and charge of the element or compound).

The ions that do not seep into the groundwater are identified by comparing the pit mud soil moisture analyses with the groundwater analyses. They are: nickel, vanadium, zirconium, aluminum, silver, cadmium, iron, chromium, copper, molybdenum, and lead (Appendix K and L). These are retained in the pit mud.

Figures 11 through 14 are chloride plume maps. Most contaminant loading occurs in the spring and summer as shown by high chloride concentrations originating from the pit area in Figures 11 and 12. Loading wanes in the fall and chloride concentrations drop (Figure 13). In the winter, the water table continues to lower and little surface recharge is

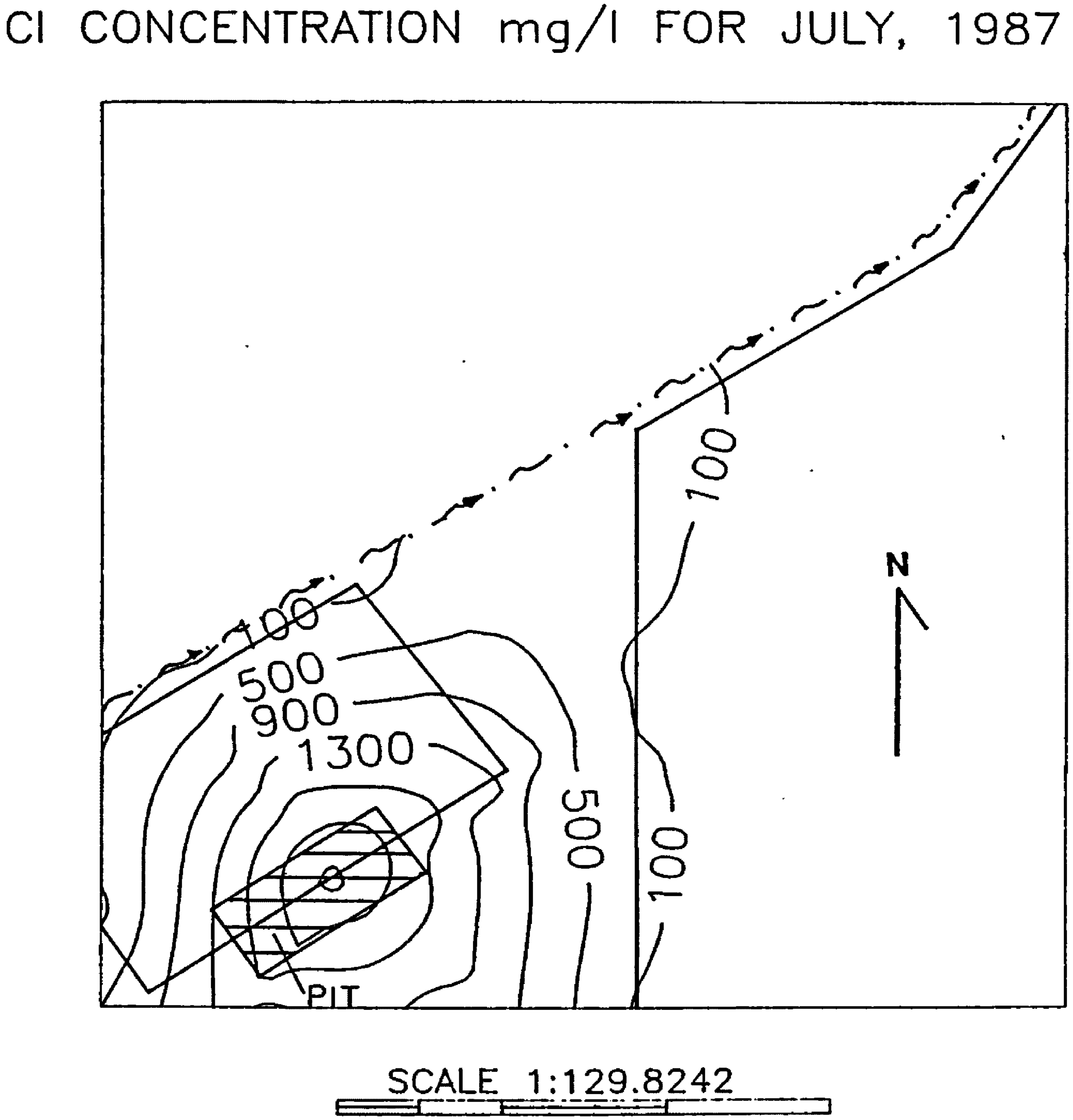


Figure 11. Chloride plume map July 1987 (CI = 400 mg/l).

Cl CONCENTRATION mg/l FOR OCT., 1987

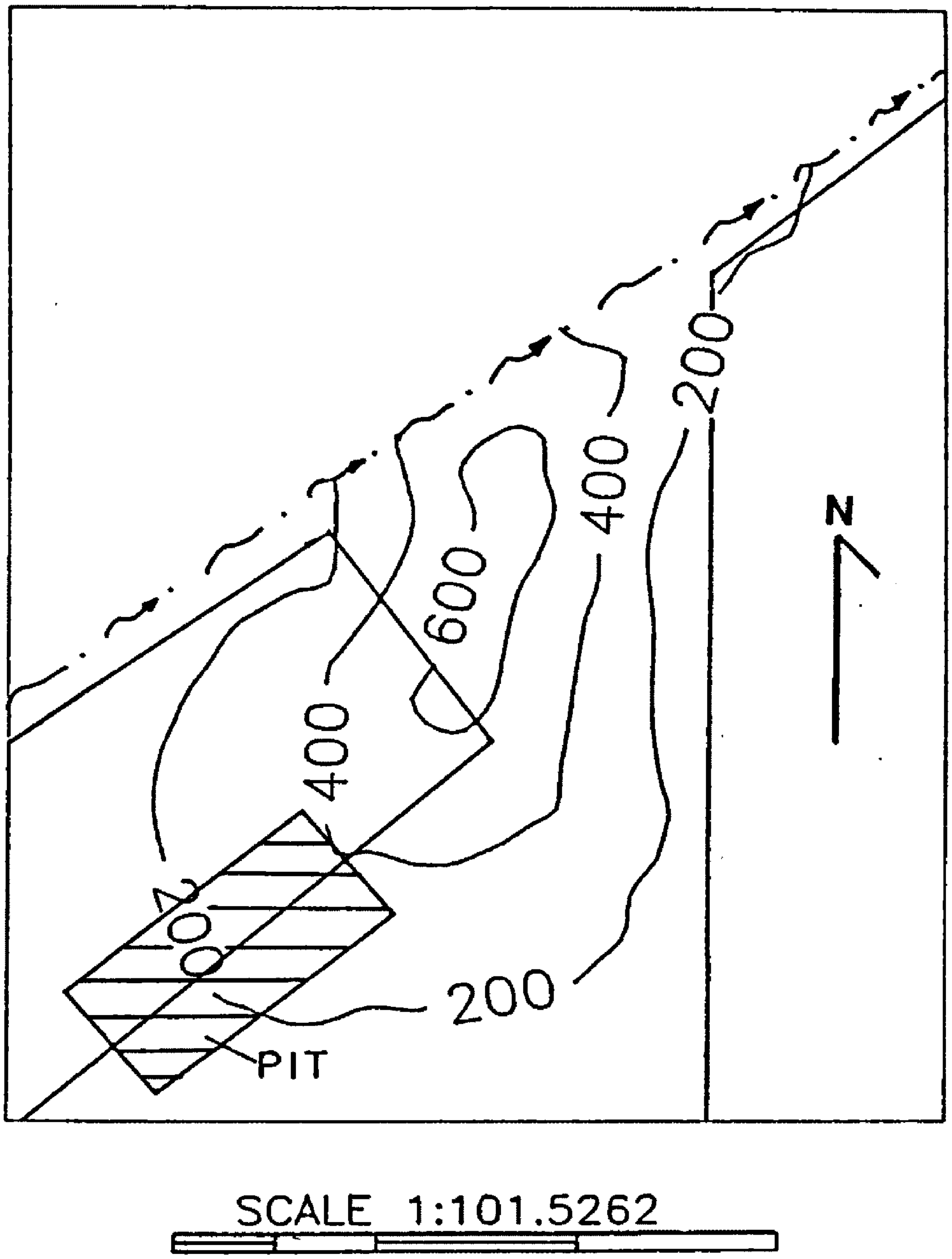


Figure 12. Chloride plume map October 1987 (CI = 200 mg/l).

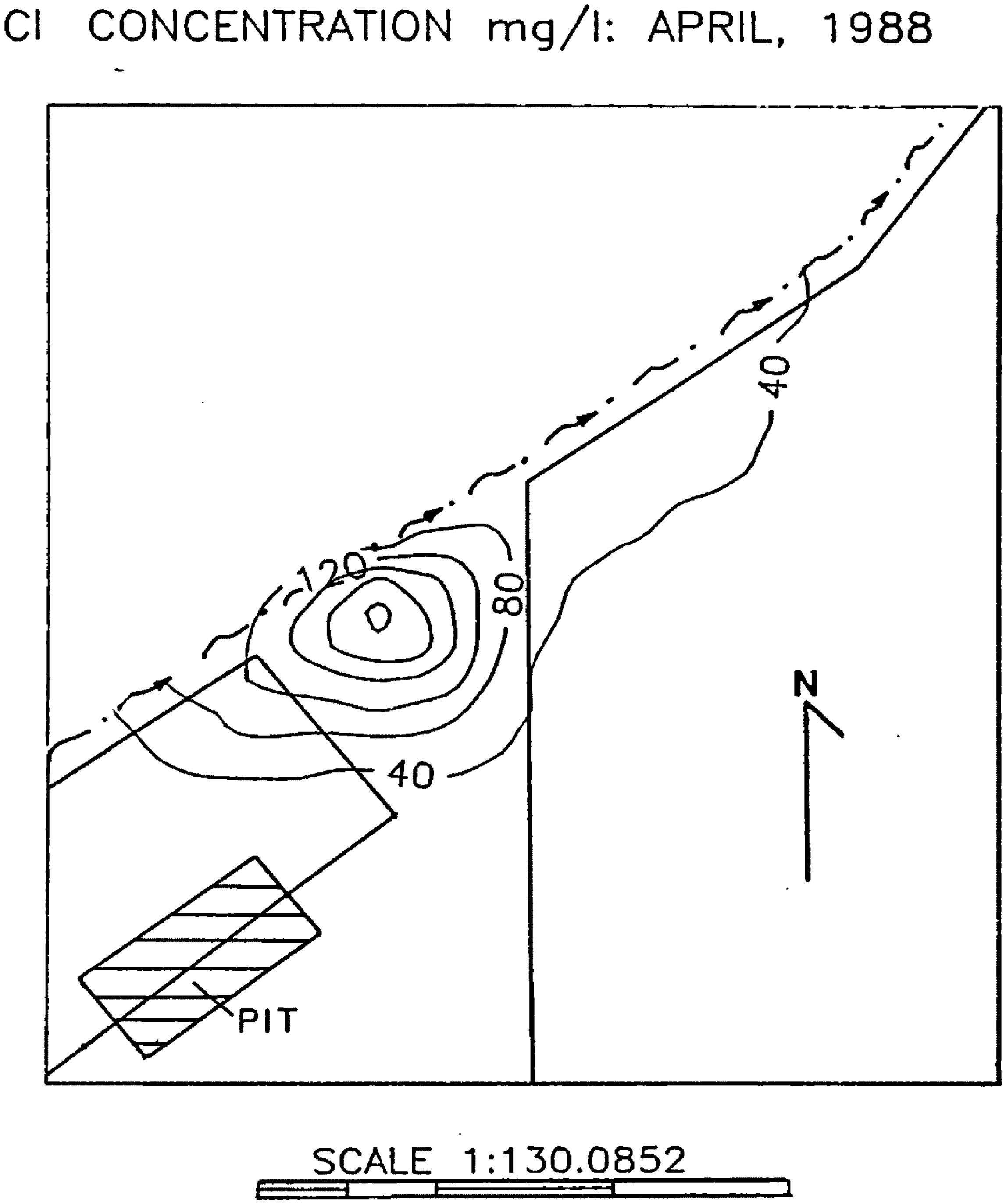


Figure 13. Chloride plume map April 1988 (CI = 40 mg/l).

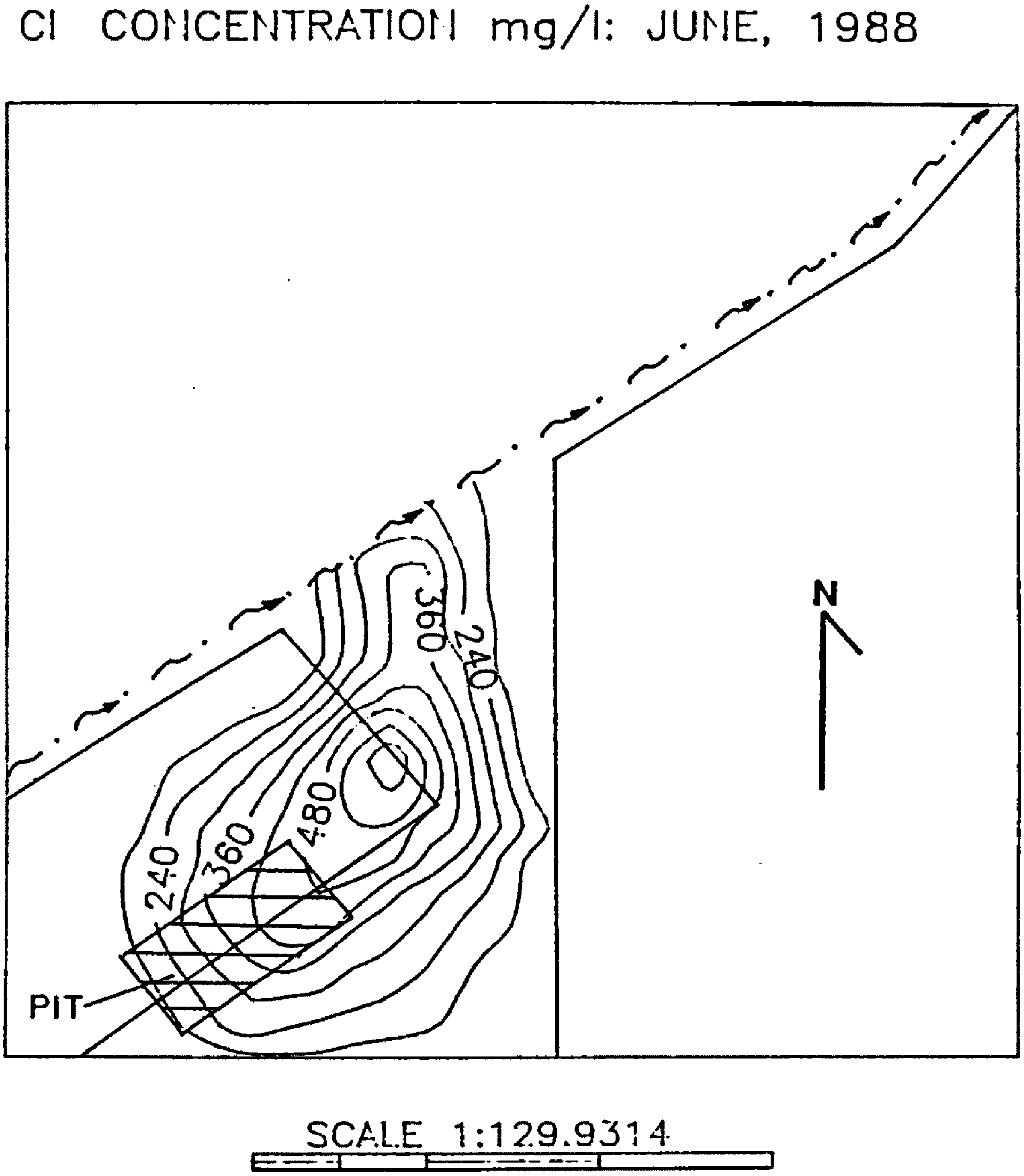


Figure 14. Chloride plume map June 1988 (CI = 60 mg/l).

available. Background chloride concentrations are present in the groundwater under the reserve pit at this time (Figure 14). In the spring, chloride concentrations increase at the pit area from the high water table intersecting the bottom of the pit and increased precipitation leaching pit contaminants into the groundwater.

Shallow groundwater discharges to the irrigation ditch in the spring, summer and fall since the ditch acts as a groundwater sink, removing chloride from the aquifer. In late winter, the ditch is influent and a small groundwater divide probably forms under the ditch causing chloride migration to be parallel to the ditch.

Figures 11 through 14 and Tables 3 and 4 show that contaminants load into the shallow aquifer in a annual cyclic fashion. In addition, Figures 11 through 14 show that the chloride concentrations decline dramatically over a short distance from the source (350 feet or 115 m), from 2800 mg/l under the pit to 600 mg/l at MW 16s.

Data plots for Figures 11 through 14 are in Appendix N, which also contains SC plume maps and data for the same locations and seasons.

Michelle Dewey of the University of Montana studied the same reserve pit site from 1982 to 1983. Dewey completed five monitoring wells in the shallow aquifer and collected water quality samples for major ion analysis. Chloride concentrations down gradient of the reserve pit at Dewey's wells 3 and 5 (Appendix O) have similar chloride concentrations as down gradient monitoring wells sampled in this study. Background chloride concentrations at Dewey's well 1 (Appendix O) also has similar chloride concentrations as background wells sampled in this study (with the exception of one anomalous peak in April, 1983).

A comparison of Dewey's data and data collected in this study indicate that brine seepage has not decreased significantly in the past four years, suggesting the pit will be a long term contaminant source. However, comparison of Dewey's data with this study is awkward since her wells were located at different points and completed differently. The comparison does show the pit mud on site may load brine wastes into the shallow aquifer for the next tens of years.

### Yellowstone River chemistry

Data provide by the United States Geological Survey shows no significant increase in chloride, sodium, sulfate, calcium, potassium, and magnesium concentrations occur in the chemistry of the Yellowstone River between Terry, Montana and Sidney, Montana (Slagle, 1983, 1984 and 1988) (Appendix O). Terry is approximately 90 miles (155 km) up stream of Sidney on the Yellowstone River. Many reserve pits are located along this stretch of the Yellowstone River in both valley fluvial deposits and the nearby Tertiary deposits. Brine from these reserve pits may seep into the underlying aquifers and in turn increase chloride and other ion concentrations in the

Yellowstone River (assuming groundwater velocity, time, dispersion and discharge will move the contaminants to the river). Chemical data collected from the Yellowstone River indicate dilution of brine contaminants in the groundwater or in the Yellowstone River are too great to measure an increase in concentration of ions analyzed or no increase occurs.

### Apparent Conductivity and resistivity

#### EM

Results of the EM 10 m horizontal and vertical mode surveys are in Figures 15 and 16. The EM 20 m and 40 m surveys show similar conductivities to those measured in the EM 10 m survey (Appendix P). All EM data were collected in July, 1987. Figures 15 and 16 show soil conductivity data measured near the reserve pit and do not include the conductance data measured over the entire EM 10 m grid in Figure 5. EM 10 m conductance data collected away from the pit were background readings and are plotted in Appendix P.

In Figure 15, the pit area is delineated by conductance values ranging from 40 to 110 mmhos/m compared to background readings of 20 to 25 mmhos/m. Only a limited area around the pit shows a high conductivity. Figure 16 accurately defines the pit area with conductivity values ranging from 90 to 160 mmhos/m, and appears to delineate a conductive zone (30 to 60 mmhos/m) in the shape of a plume downgradient of the pit, similar to the chloride plume map in Figure 14.

Water quality data for July, 1987 indicate that brine

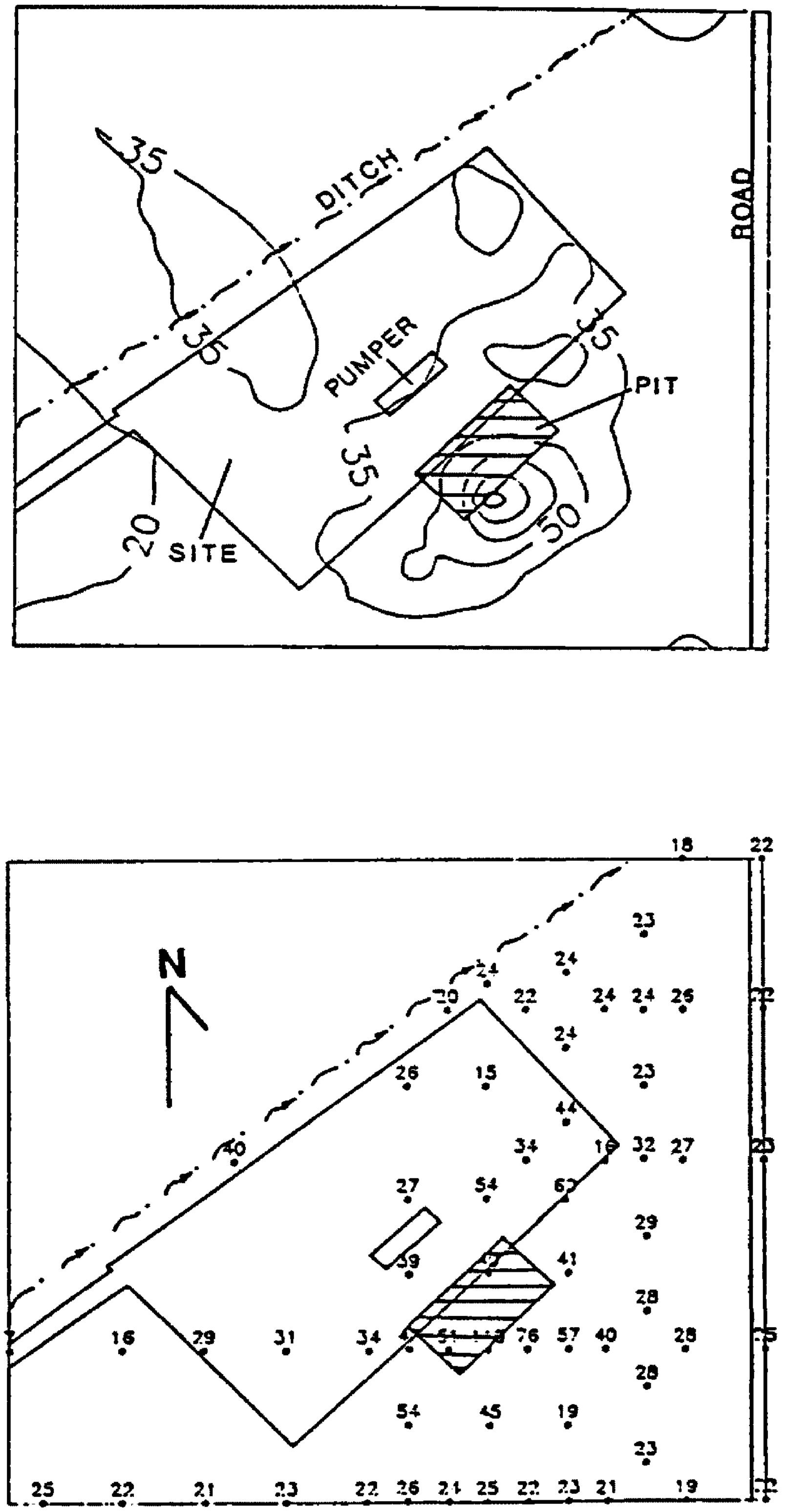


Figure 15. Contour map and data plot of EM 10m horizontal mode survey (CI = 15 mmhos/m) (July 1987).

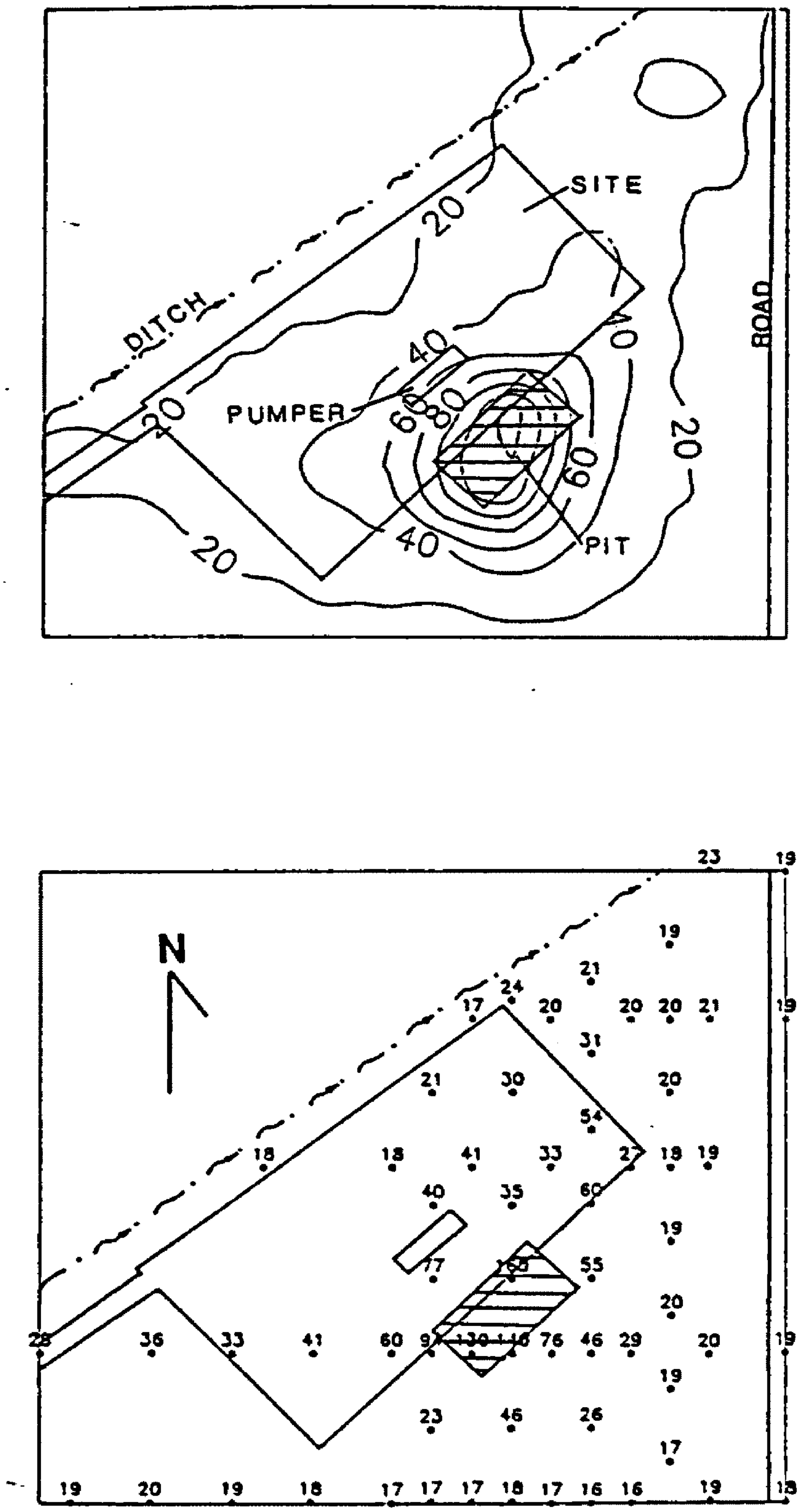


Figure 16. Contour map and data plot of EM 10m vertical mode survey (CI = 20 mmhos/m) (July 1987).

contamination was present downgradient of reserve pit. The presence of brine in the groundwater was apparently significant enough that the EM 10 m vertical mode could delineate the contaminated area. The EM survey may also have delineated soil contamination. This is indicated from lysimeter data at L2 which shows contaminated soil moisture approximately four to six feet below ground surface, 100 feet (30 m) west of the pit area. Soil chemistry data at the MW 4 site indicates that contaminated pit mud is present from approximately six to 12 feet (4 m) below land surface, 100 feet (30 m) north of the pit area.

The contrast between the EM data in Figures 15 and 16 is probably caused by a difference in EM depth penetration. The horizontal mode (Figure 15) is less influenced by the surface and near surface conductivity, probing soil approximately 1.5 times the coil spacing. The vertical EM mode (Figure 16) examines conductivity from the ground surface down to about .75 times the coil spacing. The shallower EM penetration (vertical mode) did a better job delineating brine contamination because the water table and reserve pit are within seven to nine feet of the ground surface. The "deeper" soil was not as affected by the brine contamination making the vertical EM mode a better tool to evaluate brine contamination at this site.

A comparison of EM conductivity values with chloride and SC levels collected in July 1987 show the EM highs are located in the same area as chloride and SC highs (Appendix M). A correlation of EM versus chloride or SC could not be determined with these data. Monthly EM data, collected during water quality sampling, is needed to quantitatively determine groundwater quality from EM conductivity.

Results indicate that EM is a valuable tool for locating brine contamination. Highly conductive pit mud and brine water are delineated with the equipment.

### Resistivity

Resistivity 10, 20 and 30 foot a-spacing data and plots support conductivity data collected with EM (Appendix N). Low resistivity values are present in the pit area extending northward in the same direction as groundwater flow away from the pit area. Operation of resistivity equipment was significantly more time consuming and cumbersome to use compared to the EM equipment.

Resistivity data collected in this study are very similar to Dewey's resistivity work in 1983, suggesting that contaminant concentrations have not significantly changed since the first resistivity surveys in 1983.

## Groundwater and solute transport modeling

### Flow modeling

Figure 17 displays the model area. Figure 18 displays the node location, boundary conditions, and site landmarks. K was set at 4200 gal/day/ft$^2$ for each node except those representing the irrigation ditch. The bottom of the ditch

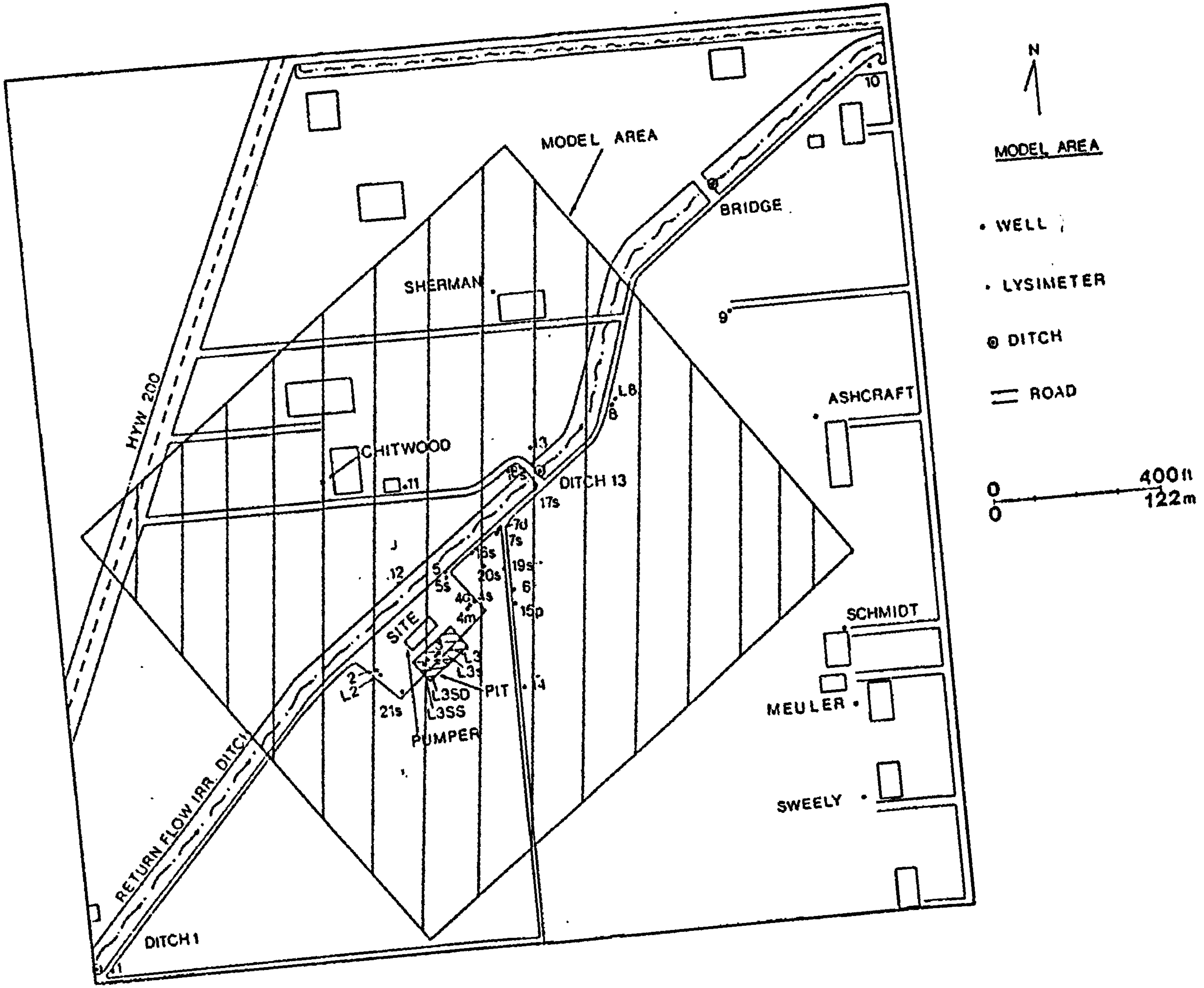
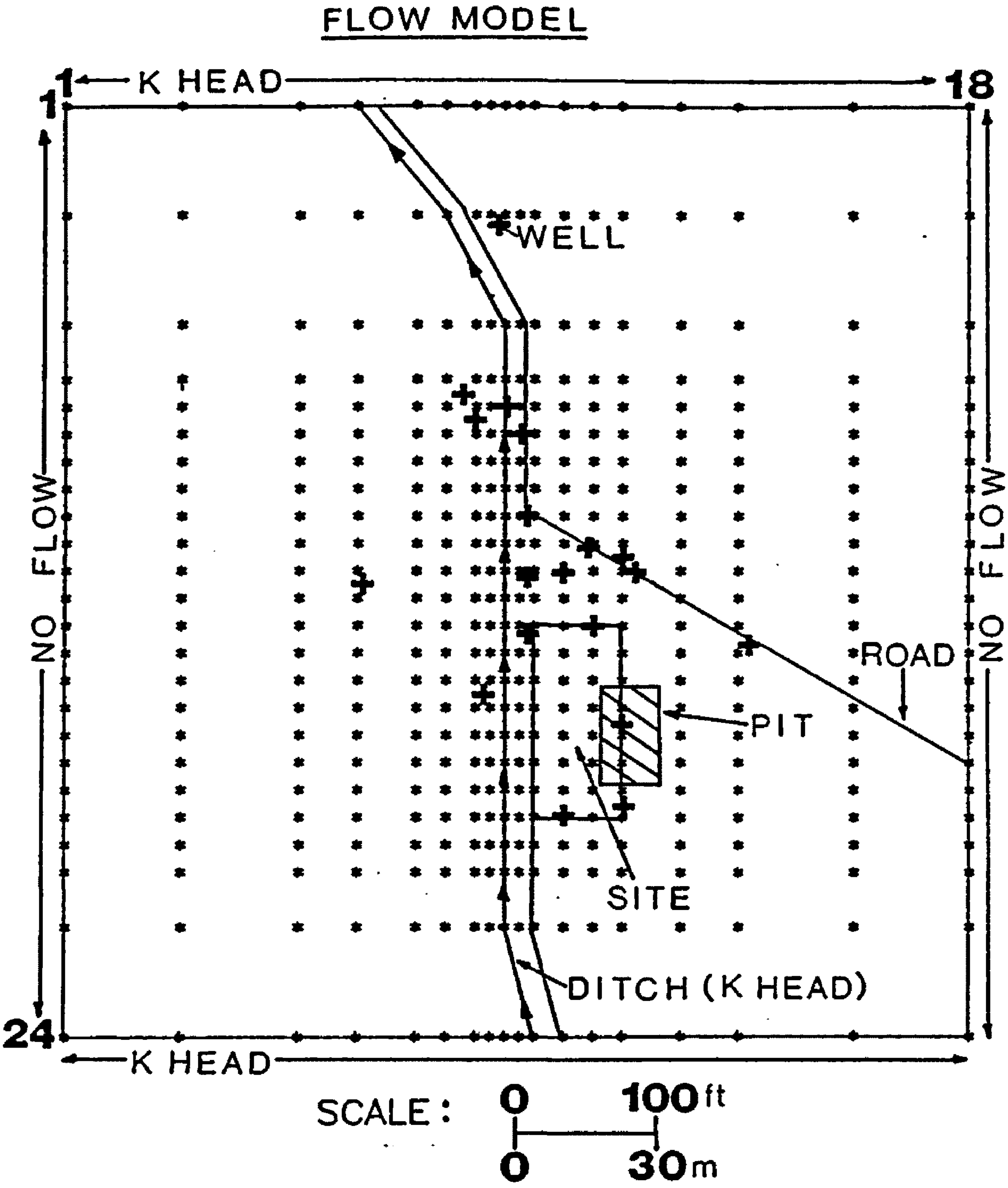


Figure 17. Model area.



KEY

K-HEAD = constant head boundary

\+ = well location

NO FLOW = no flow boundary

Figure 18. Boundary conditions.

is composed of mud and silt, and consequently is assumed to be less transmissive then the underlying sand and gravel. The actual K of the ditch bottom is unknown but probably is a number of orders of magnitude lower then the sand and gravel aquifer. Since PLASM is two dimensional model it interprets K to penetrate the entire aquifer thickness. To account for the lower K in the ditch, K was lowered in all ditch nodes to 420 gal/day/ft$^2$ which approximates the actual ditch K by averaging K in the ditch bottom and the aquifer. No other K zones were modeled. Specific yield was set at .2 for all nodes.

October, 1987 head data were used to calibrated a steady-state flow model simulation. Ten time steps were used, with a model error tolerance of .1 feet. Constant head data were varied until simulated head were within .1 to .2 feet of actual head data (see October data Appendix R and Appendix S).

Modeling groundwater flow alone, a wide range of K inputs could be used to simulate head within the .1 to .2 error tolerance using the same constant head data. To determine a more precise estimate of K, the aquifer test was simulated. In order to match the actual and simulated aquifer test drawdown, K had to be limited to approximately 3500 to 4500 gallons/day/ft$^2$ and Sy equal to .2 (Appendix T).

Simulated drawdown at the pumping well is off by approximately one foot. This is caused by the model removing water from a nodal area instead of discrete well diameter, which in turn caused the simulated drawdown at the pumping node to be less then actual well drawdown.

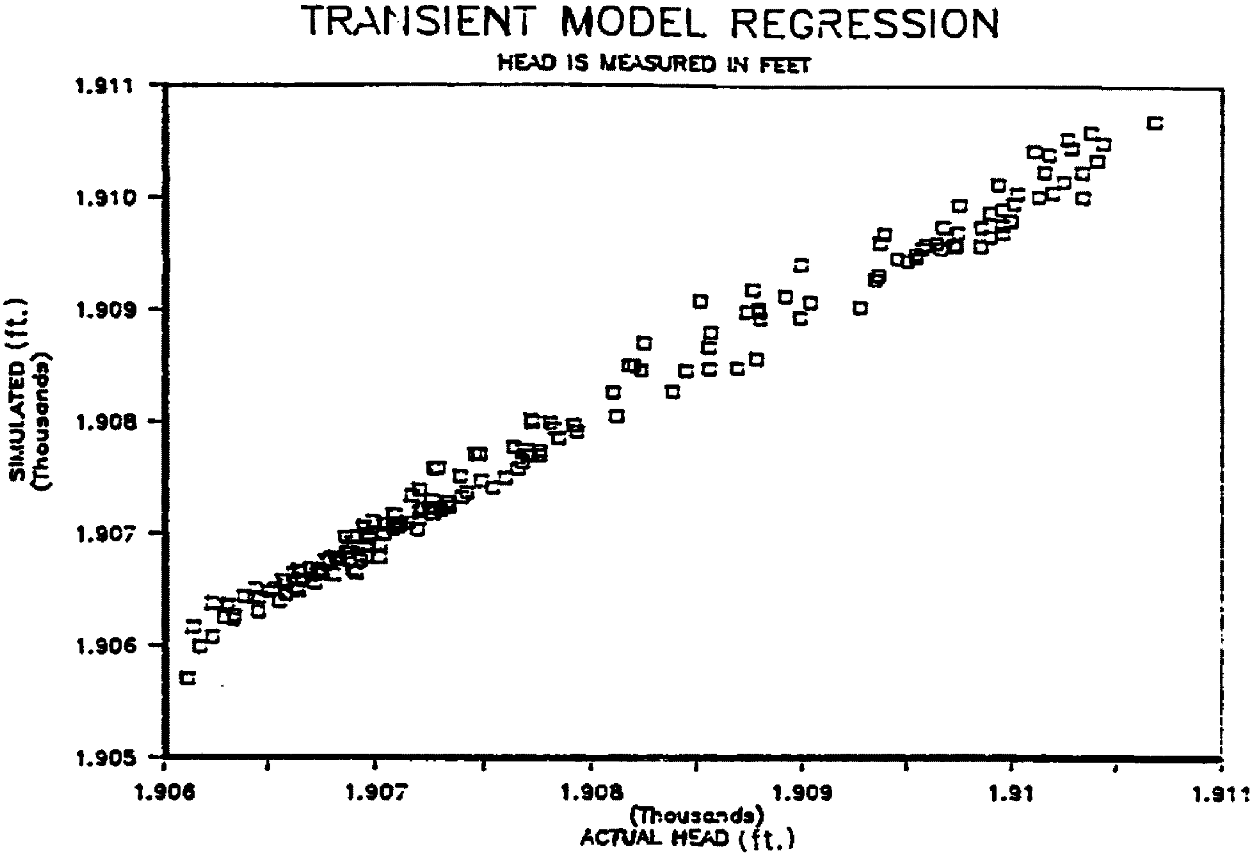
After achieving a steady-state simulation by adjusting constant head data and simulating the aquifer test, the same model and different constant head data were used to simulate 12 months of transient head data. Each month was modeled by reading a new constant head file (Appendix S) every thirty days and adjusting the constant head files until head was simulated within a .2 to .3 foot error tolerance.

An error tolerance of .2 to .3 feet was chosen after considering factors that might account for inaccuracies in the actual head data. These are: human error, survey elevations and accuracy of well location in the model.

Simulated monthly groundwater flow from July 1987 to June 1988 are in Appendix R. The accuracy of each monthly flow field is depicted in Figures 19 through 21 and Appendix T. Figure 19 is a regression plot of the actual and simulated head from both the transient (top diagram) and steady-state simulations (bottom diagram). Both regressions show a good correlation between the actual and simulated head.

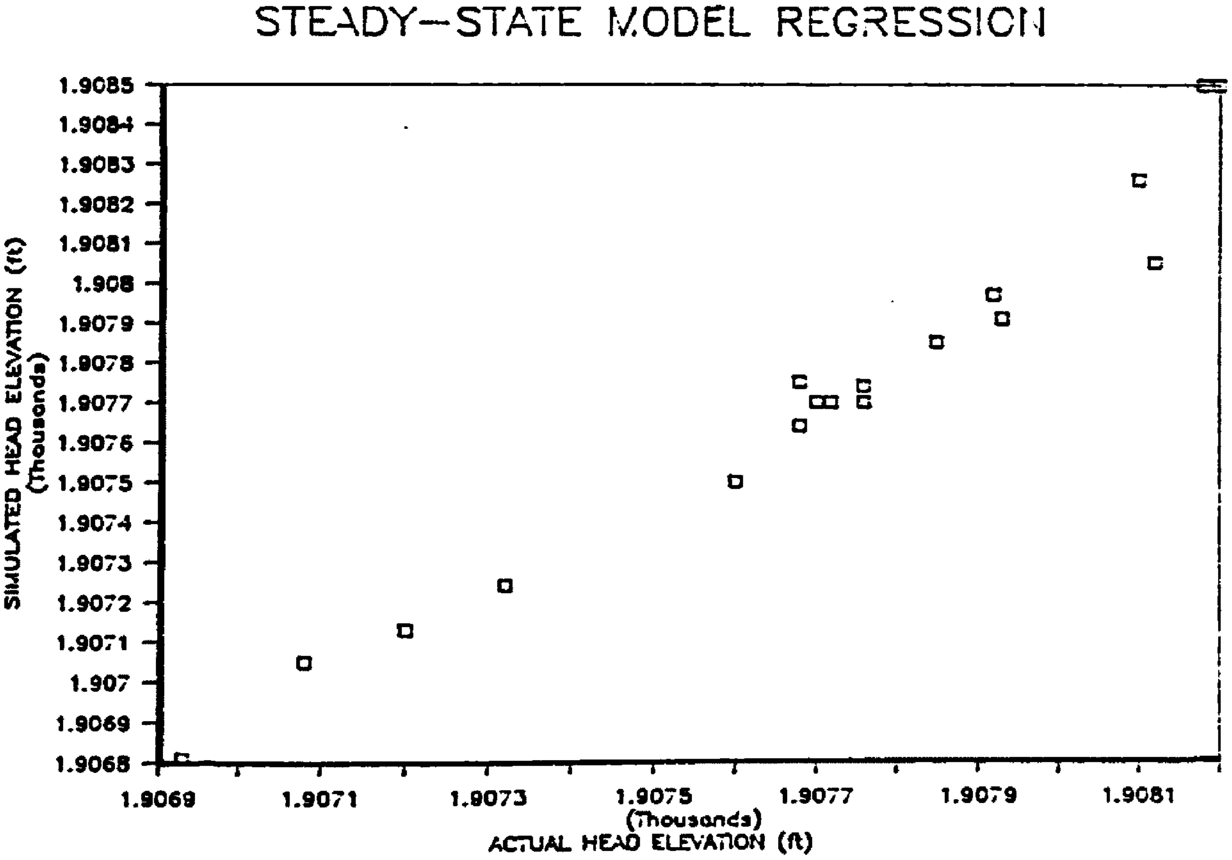
Figure 20 compares the actual and simulated head in monitoring wells MW 3 and MW 7. This figure shows a good correlation between actual and simulated head for one year of transient modeling.

Figure 21 is a variance plot of simulated head data. This figure shows that 85% of the simulated head are within



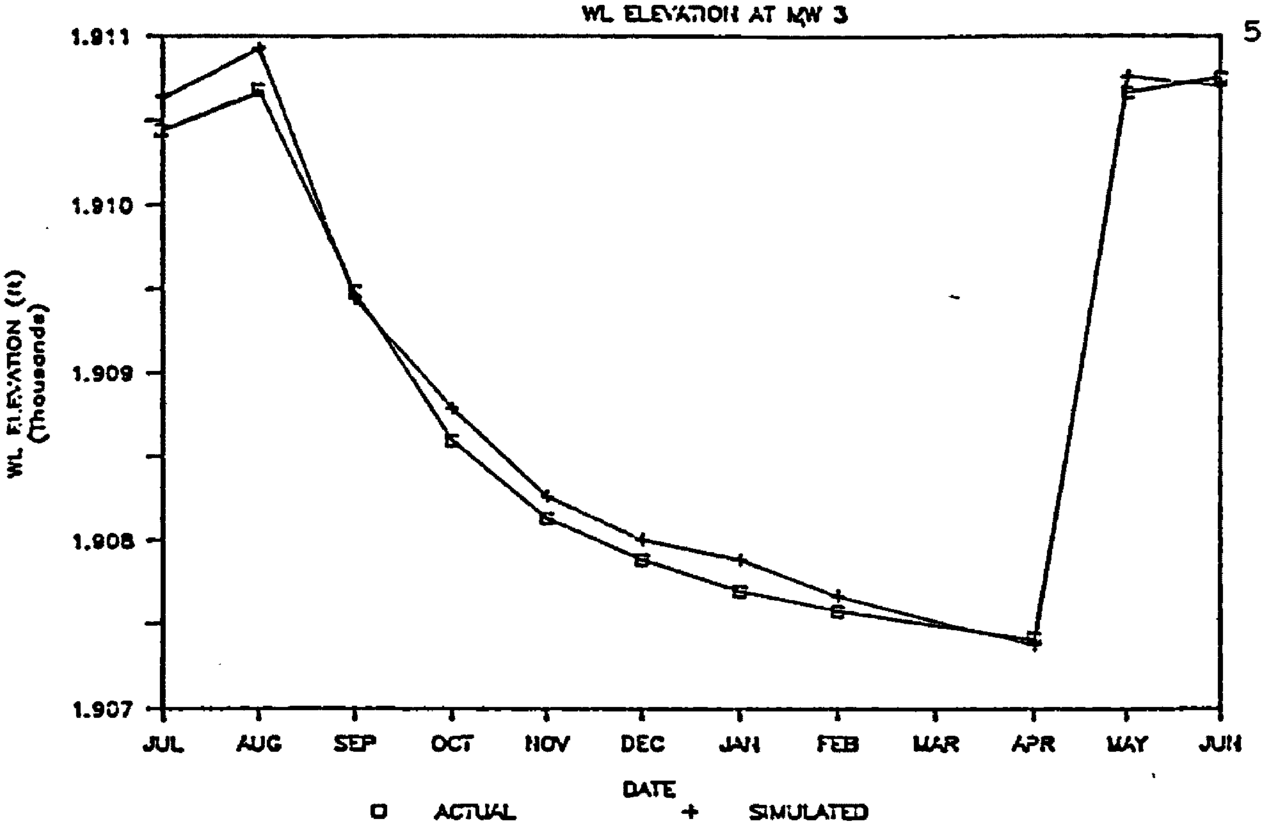
TRANSIENT MODEL REGRESSION

HEAD IS MEASURED IN FEET



STEADY-STATE MODEL REGRESSION

Figure 19. Regression plot of actual and simulated head.



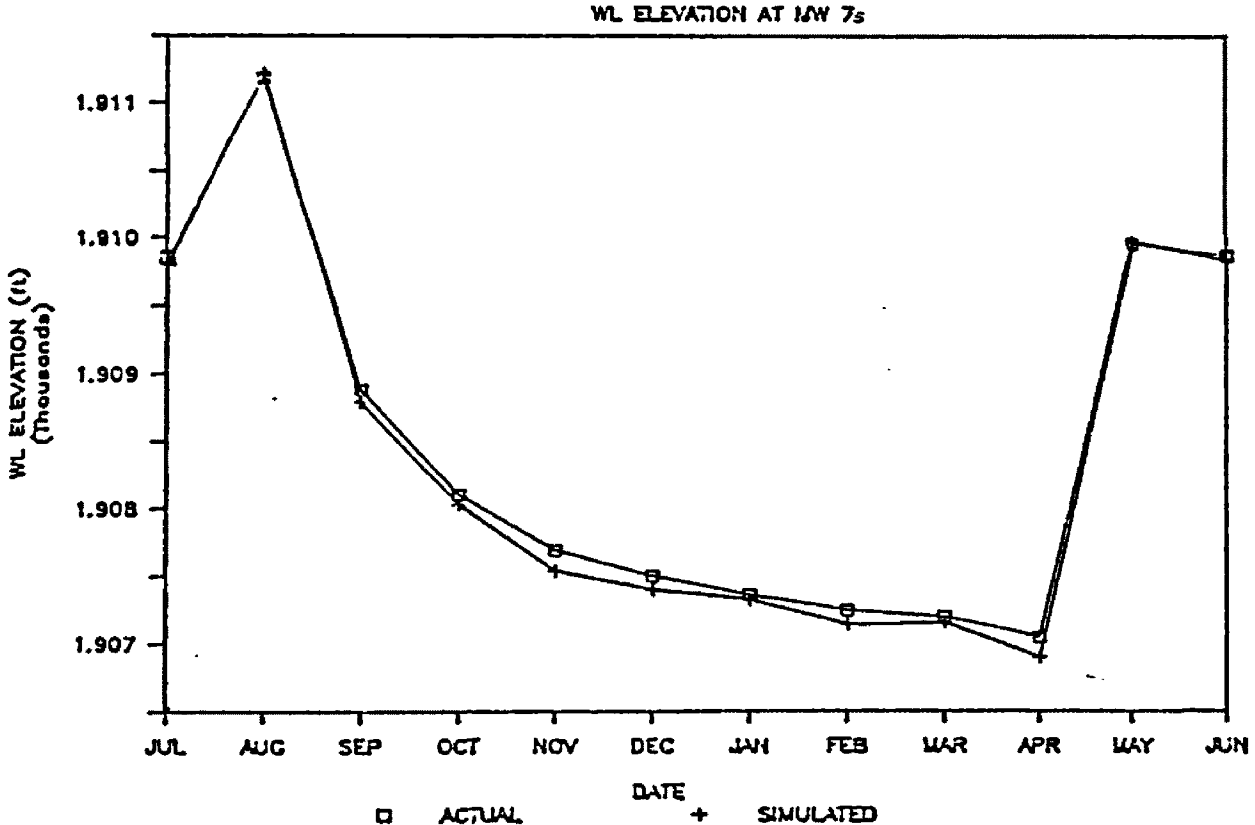


Figure 20. Comparison of actual and simulated water level at MW 3 and MW 7s.

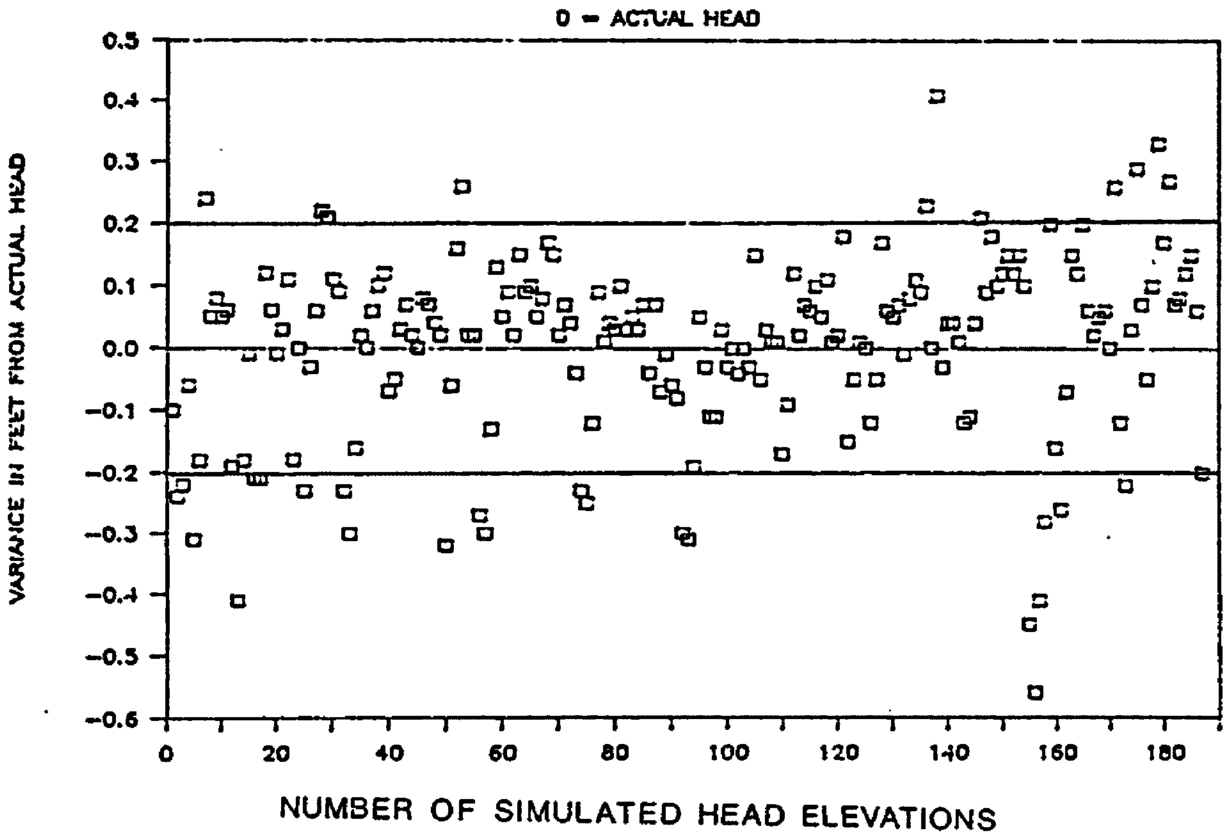


Figure 21. Variance plot of simulated head.

.2 feet of actual head, and greater than 95% of simulated head data are within .3 of actual head data. In addition, the PLASM water balance accounted for 99.9% of all water moving through the model over the duration of the transient simulation.

The modeled hydrogeologic parameters and boundary conditions comprise a relatively simple model in an aquifer that is not homogeneous and isotropic. Modeling head data is not an important factor by itself since monthly groundwater flow is approximate with available water level data. However, modeling different hydrogeologic parameters and boundary conditions provide a better understanding of the hydrogeologic system and were needed to generate flow fields for solute transport modeling.

### Solute transport

A preprocessor was used to convert simulated head data from PLASM into twelve groundwater flow velocity fields. They represented flow for each simulated month from July 1987 to June 1988. Chloride transport modeling was initiated in May 1988 since most of 1987 chloride is off site (via the return flow ditch), and a new chloride plume is present at the pit area. The drawback to this method is that chloride was simulated forward in time through July 1988 and then modeled with previous chloride concentration data (August 1987 through April 1988) in the model. This reasoning assumed that the previous year (1987) chloride data (and head distributions) were 1988 data.

Brine contamination is represented by loading particles into the model, where each particle represents 15 pounds of chloride. Most particles were input to the model during groundwater highs. Particle input was decreased during groundwater declines (Appendix U). In a few months, particle input deviated from the initial approach to increase or decrease chloride concentrations to improve the match of simulated and actual chloride concentrations.

Model input parameters consisted of: porosity (.25), longitudinal dispersivity (20 feet), transverse dispersivity (1 foot), and retardation (= 1; none). Particles were removed from the model if they migrated within a ditch node area since the ditch acts as a groundwater sink during most of the year. Figures 22 and 23 show simulated chloride and actual concentrations for four monitoring well sites. Appendix V contains simulated and actual chloride concentrations at each monitoring well site.

The comparison of actual chloride concentration in monitoring wells with the simulated chloride concentrations were done by comparing the highest chloride level for a specific date at each well site with the simulated value for that location. The chloride concentration at the well sites were assumed to represent the chemistry of the entire saturated thickness of the shallow aquifer (for this reason, only well site identification is presented in Figures 22 and

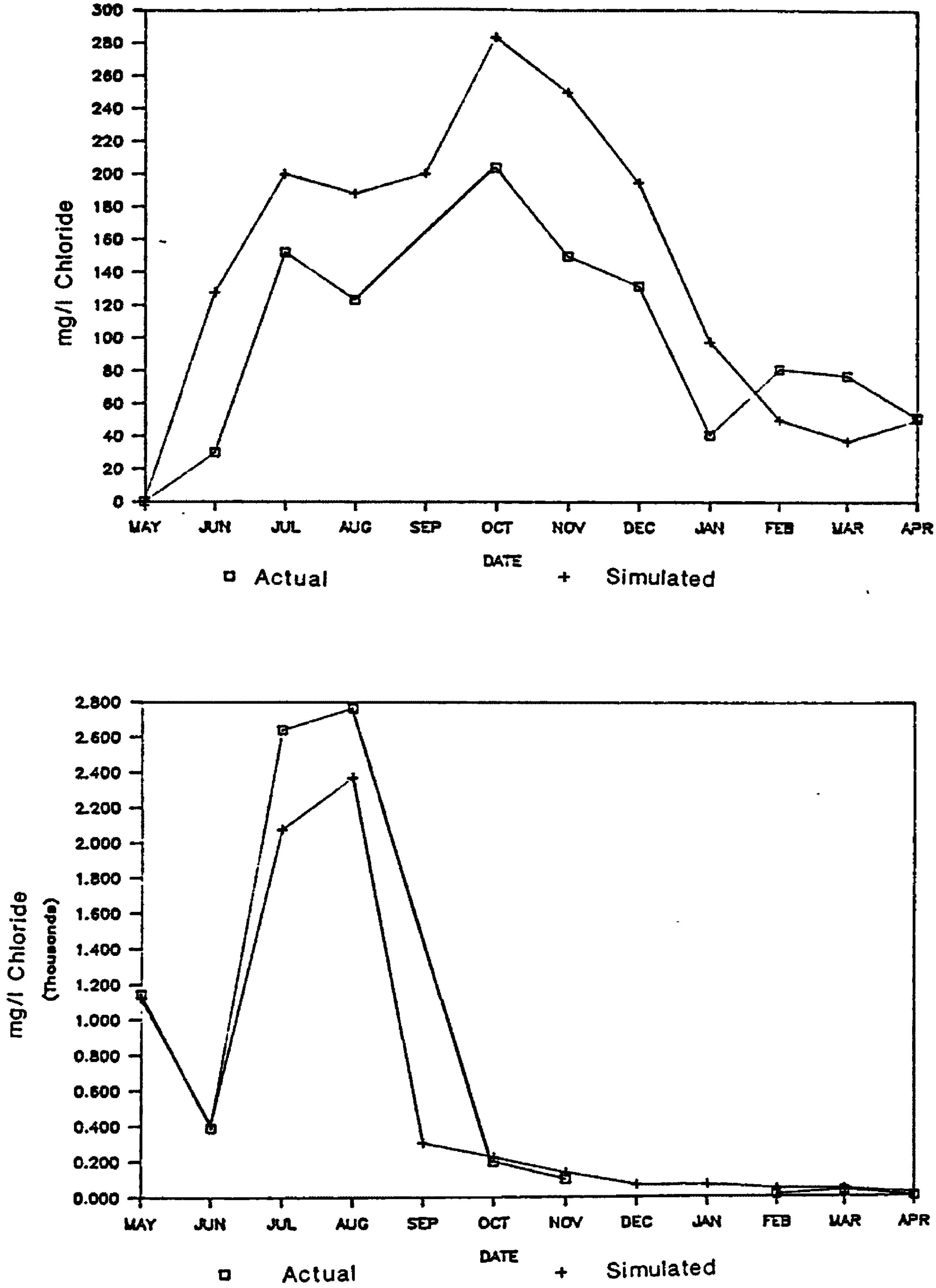
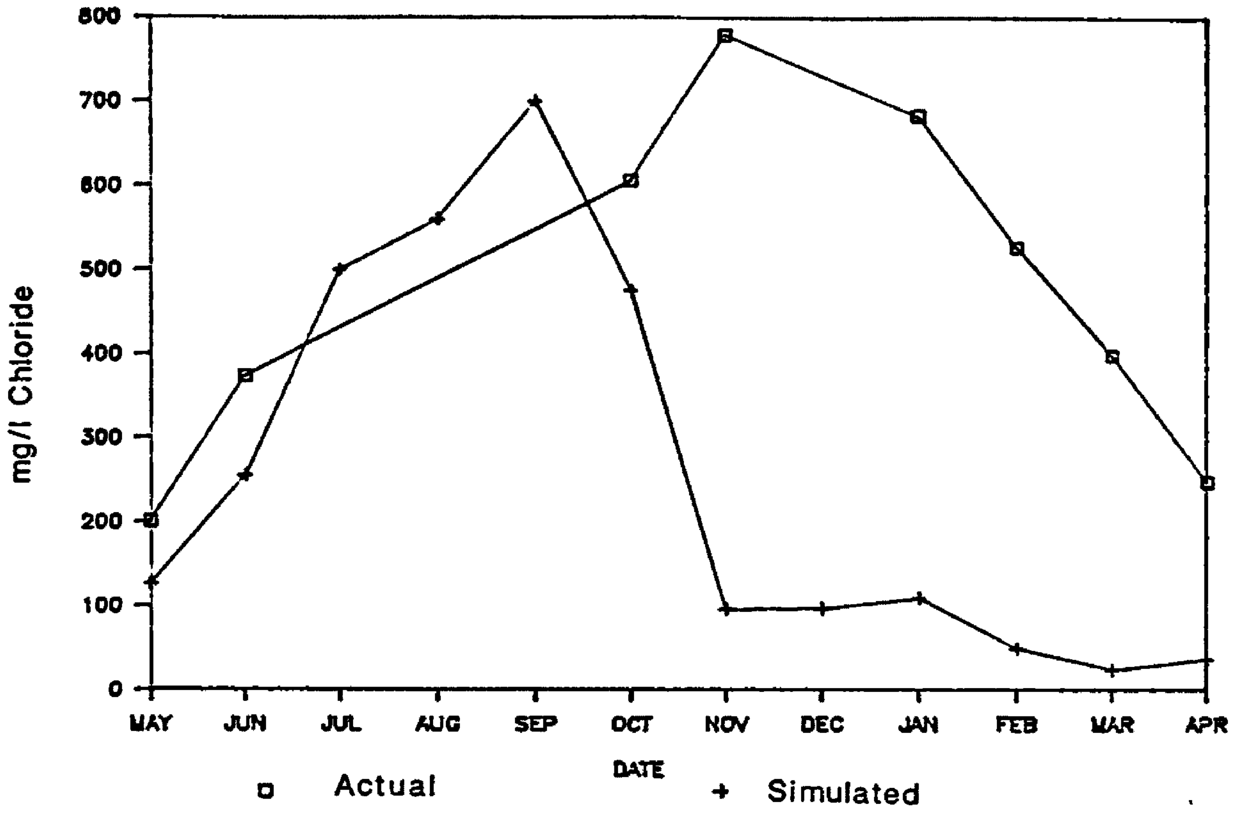


Figure 22. Comparison of actual verses simulated chloride concentrations at well sites MW 7 and MW 3.



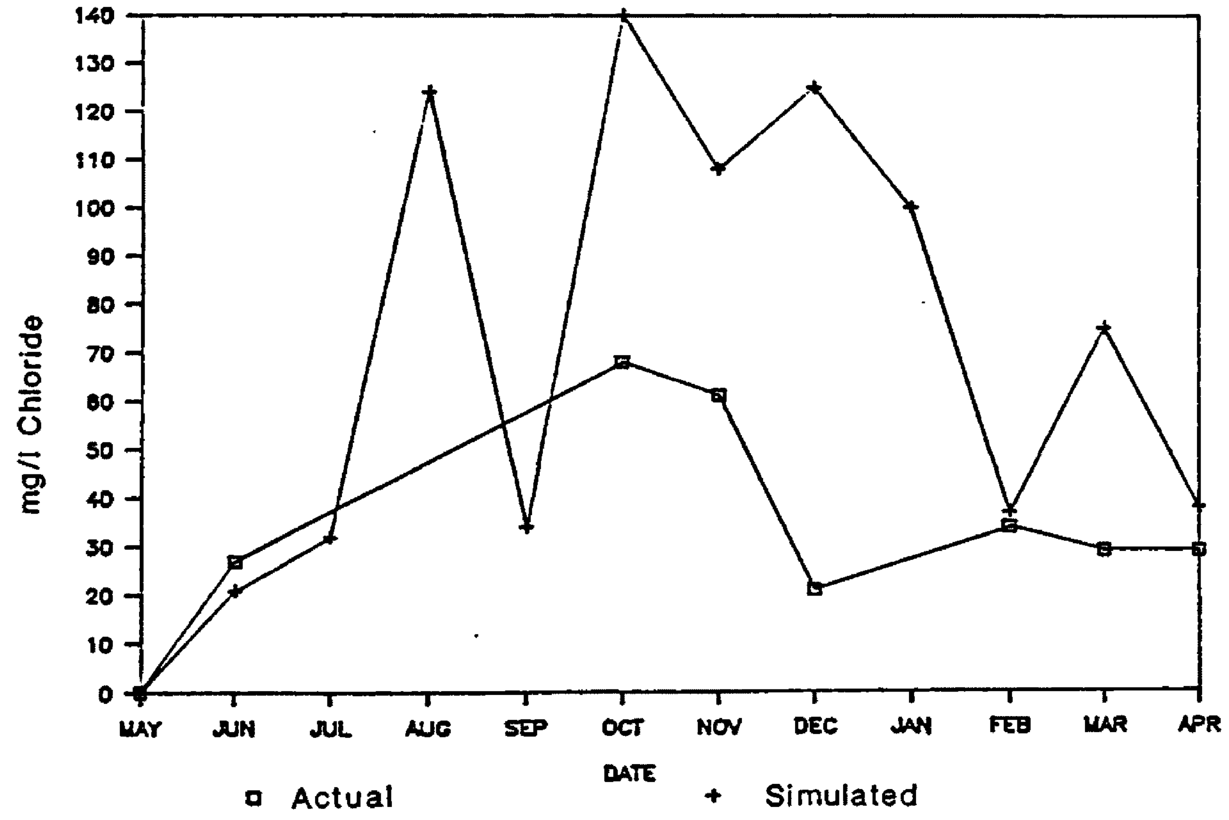


Figure 23. Comparison of actual verses simulated chloride concentrations at well sites MW 16 and MW 19.

23 and no deep or shallow well designations are used to identify well sites).

Figure 22 shows a good correlation between the simulated chloride concentrations at monitoring well sites MW 7 and MW 3. These data indicate simulated chloride concentrations are fairly close to the actual chloride concentrations. However, in Figure 23 the timing of actual versus simulated chloride concentrations at MW 16 and MW 19 is off by two to three months in both diagrams. In addition, the bottom diagram of Figure 23 shows that the simulated chloride concentrations are two to three times greater compared to the actual chloride concentrations. These data indicate the model did an inadequate job simulating chloride concentration through time at these sites. I explain the inaccurate simulated chloride concentrations in a number of ways:

1) I modeled my site in two dimensions when in reality it a three dimensional problem. Random-Walk assumes chloride concentration is evenly distributed throughout the entire aquifer thickness which was determined to not be true according to water quality data.

2) The flow field was calibrated within .2 to .3 feet error tolerance of actual groundwater elevations which may be insufficient to accurately move particles through the solute transport model.

3) Quantab chloride results were sometimes 10% to 50% different from the laboratory chloride concentrations.

4) The nodal scale in the model may be too large to accurately simulate head without creating a "blocky" velocity field to move particles in Random-walk.

5) Modeling 1988 chloride concentrations with 1987 groundwater flow data may poorly represent the

actual migration and chloride concentrations.

6) The flow model may be too simplistic in describing the geologic system. Actual aquifer geology is complected with variable K in three dimensions.

7) Solute modeling input parameters may be incorrect.

## Annual Chloride load

To calculate annual chloride loading, a cross section extending from MW 5 site, MW 4 site and MW 19s/MW 6 site was used to represent the shallow aquifer. The cross section was divided into blocks or zones vertically and horizontally throughout the saturated zone (Appendix W). Volumes of monthly chloride input from the reserve pit were calculated knowing the volume of groundwater moving through the cross sectional area and chloride concentrations at nested well sites. Monthly chloride data from Quantabs and laboratory chloride analyses were used to determine chloride concentrations. If no data were available, a monthly chloride concentration trend was used to estimate chloride concentrations for a well site.

Monthly chloride loading is in Table 5. Total annual chloride load from July 1987 to June 1988 is calculated to be 3,137 kg/yr from the pit, which is 3.7 times that of background chloride load (852.3 kg/yr chloride). Some error in the load calculations probably occur since about 35% of the chloride concentration data had to be estimated. Other factors which may affect the load accuracy are estimates of groundwater velocity and the area of contamination and

Table 5. Annual chloride load in groundwater (kilograms).

| | Pit Input | Background | Simulated |
|---|---|---|---|
| July: | 732.45 | 100.25 | 2503.9 |
| August: | 822.46 | 94.9 | 1564.9 |
| September: | 450.86 | 81.43 | 251.7 |
| October: | 242.06 | 80.56 | 149.7 |
| November: | 113.75 | 55.44 | 183.7 |
| December: | 70.56 | 51.9 | 45.0 |
| January: | 56.28 | 51.9 | 45.0 |
| February: | 40.71 | 45.28 | 44.5 |
| March: | 47.01 | 46.55 | 45.0 |
| April: | 44.66 | 41.58 | 45.0 |
| May: | 210.19 | 100.25 | 2245.3 |
| June: | 306.01 | 102.22 | 898.1 |
| TOTAL: | 3137 | 852.3 | 8021.9 |
| lbs/yr | 6915 | 1879 | 17658 |

chloride analyses/Quantab results.

The total simulated chloride load (Random-Walk simulation) appears to be high compared to the calculated chloride load. However, the model is only two dimensional and must assume the total saturated thickness of the simulated aquifer has the same chloride concentration. Chemical data show that only about half of the shallow aquifer is contaminated with chloride. This required the simulated load be twice as high as the field data in order to reproduce the measured values. The simulated annual chloride is therefore reasonable considering that the lower half of the aquifer is generally at background chloride concentrations and approximately 60% more chloride was input into the simulation compared to the calculated chloride load. The simulated chloride load is greater in the initial and ending months in comparison to the calculated monthly chloride load. This may be a results of improperly loading chloride in the model.

Elevated chloride concentrations in the ditch water were not detected by chemical analyses. The ditch water varied from approximately 20 to 35 mg/l chloride depending on the ditch flow rate. Chloride data from the up gradient ditch control site did not show any relative increase in chloride concentrations that could be attributed to brine seepage. In some instances the up gradient chloride concentrations were higher by a few mg/l than the down gradient control site where the brine enters the ditch.

Inability to measure the chloride input into the ditch is probably due to the relatively small amount of chloride loaded into the ditch from the reserve pit. This is demonstrated by calculating the chloride concentration which enters the ditch via groundwater (500 mg/l) and the groundwater flux into the ditch (two gpm or 7.57 l/minute). Using these values, 0.057 kg of chloride per minute enter the ditch which produces an increase in chloride concentration of .64 mg/l at an average flow rate of 3.5 cfs. This small amount of chloride loaded into the ditch is not detectable in chemical analyses since the analytical methods used to determine chloride concentration were not precise enough to measure chloride differences of .64 mg/l.

In the winter, when ditch flow is much less, the ditch is loses water to the shallow aquifer. For this reason chloride is not detected in the winter months.

The pit will continue to load chloride into the shallow aquifer system until the brine contaminants are purged from the pit material. The time necessary to remove available chloride is difficult to determine since controlling factors, including future climate condition, percolation rates and the amount of chloride available in the pit area, are poorly understood or unknown. However, for illustrative purposes an estimate will be attempted.

Parameters used in the attempt include assuming a pit volume (200 feet long by 70 feet wide by 12 feet deep or 61 m by 21 m by 4 m respectively) (Dewey, 1984) and a soil porosity (.25) since open void spaces will not contain chloride. Multiplying these values yields a hypothetical pit volume of 126,000 $ft^3$ or 3,565,800 l of soil. Assuming all chloride in the soil volume loads into the shallow aquifer system, the required time to purge the chloride can be calculated knowing annual chloride load.

Soil moisture analyses at lysimeter L-3 (located in the pit material) indicate the potential amount of removable chloride in the pit material. The largest chloride concentration at L-3 (156,000 mg/l) was used to calculate the volume of removable chloride (where 3,565,800 l x 156,000 mg/l = $5.5626 \times 10^{11}$ mg or 55,626 Kg of available chloride in the pit material). This value represents the volume of chloride that would take the longest to purge from the pit material.

Assuming the 1987-1988 calculated loading values are the average future chloride loading values, approximately 3,000 kg of chloride are loaded into the shallow aquifer per year. This value is divided into 55,626 kg total available chloride which equals 18.5 years or about 20 years until most of the chloride is removed from the pit from 1988.

The 20 year estimate is probably conservative since it represents a chloride loading pattern similar to the 1987-1988 year for the next 20 years. In reality more time will probably be required to purge all chloride from the pit materials. The "less easily removed" chloride (i.e., small concentrations held up by soil and chemical reactions) will require more leaching action and/or groundwater contact to be removed. This indicates chloride concentrations may be measurable in the shallow groundwater for more than 20 years.

The annual chloride load from the numerous reserve pit sites in the region is probably dependant on the oil-field brine encountered during drilling and the volume and type of drilling additives used during drilling. In addition, not all reserve pit sites may seep brine contaminant into the underlying aquifer. Without knowing the site specific information it is difficult to determine what regional chloride loading impacts will occur in the Yellowstone River Valley as a result of brine seepage from reserve pits.

### Reclamation practices and remediation

This and other studies document that reserve pit reclamation techniques are inadequate. Synthetic or clay liners used to protect the underlying groundwater are intended to inhibit brine seepage. However, when pit liners are ripped or punctured as a result of reclamation, a pathway for brine seepage into the groundwater is created. New cost effective reclamation methods are needed to stop brine from entering the groundwater.

A technique used in some areas is replacement of permanent on site reserve pits with mobil reserve pits. Mobil pits may be more cost effective depending on disposal costs (Reiten, 1988). Drilling fluids can be disposed of by injection wells and solid wastes can be buried at a drilling mud disposal site (properly designed to handle the wastes).

Pit solidification with fly ash has been used for several years in states other than Montana to stop brine seepage from reserve pits. The fly ash causes the mud to be fairly impermeable, limiting brine seepage into the underlying groundwater. This process may be effective, however, it needs to be tested at reserve pits located in the Williston Basin.

Other methods include pumping or evaporating the liquid fraction off the reserve pits and excavating the solid fraction. Brine water can be injected back into saline aquifers and the solid fraction shipped to a central disposal site for burial.

### Remediation

Remediation at reserve pit sites with excessive brine contamination would require one or more of the following:

1) The reserve pit and trenches be cleared of mud to eliminate the source.
2) A cap over the pit and trenches be installed to limit wetting fronts and slow brine migration (would not affect mud below the water table).
3) installation of brine removal pump(s) in severe cases of groundwater contamination.

These are expensive measures and not the only solution to localized brine contamination. Most reserve pit sites are probably similar to the Iverson site and will require little or no remediation. However, highly contaminated sites which threaten vegetation and water supplies need to be cleaned up. Improved pit reclamation techniques could significantly decrease the need to curb brine seepage from reserve pits.

# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

1) Groundwater quality analyses indicated elevated concentrations of calcium, magnesium, sodium, potassium, chloride, manganese, bicarbonate, sulfate, nitrate, boron, lithium, barium, strontium, titanium, zinc, beryllium and possibly bromide are present in the shallow aquifer at the Iverson site. These contaminants apparently enter the shallow aquifer as a result of wetting fronts moving through the contaminated pit mud and the high water table intersecting the base of the reserve pit.

2) Analyses of pit mud show that high concentrations of all constituents detected in the groundwater are in the pit mud in addition to nickel, vanadium, zirconium, aluminum, silver, cadmium, iron, chromium, copper, molybdenum, and lead. These ions were at concentrations a number of orders of magnitude above background levels detected in soil water and groundwater analyses.

3) Nitrates and Mn concentrations in the groundwater exceed federal drinking water standards near the pit area in the spring and summer months. Chloride concentrations exceed recommended federal drinking water concentrations year around at the pit area and down gradient of the pit.

4) Rising groundwater at the pit area in the spring and summer months, accompanied by greater precipitation, generate high concentrations of brine contaminants in the groundwater. Lowering of the water table in the fall and winter months, accompanied with less precipitation, slows the contaminant loading processes producing lower concentrations at those times.

5) High horizontal hydraulic conductivity limits vertical contaminant migration to approximately the upper five to ten feet of the shallow aquifer. Dispersion and dilution appear to lower chloride concentrations by a factor of five at a point 350 feet (115 m) down gradient of the pit.

6) The reserve pit will be a groundwater contaminant source for at least 20 years and possibly more.

7) Local groundwater flow direction in the spring, summer and fall is partly controlled by the ditch. Groundwater flows is towards the ditch during these months. During winter, groundwater flow is approximately parallel to the ditch. Winter ditch levels are slightly above that of the groundwater, which produces a small groundwater divide below the ditch.

8) No water supplies are threatened by brine contamination at this site since groundwater discharge to the ditch removes chloride and other pit contaminants from the shallow aquifer.

9) Cumulative groundwater contamination impacts are difficult to measure. However, broad scale regional brine loading impacts to the quality of the Yellowstone River appear to be insignificant. Local brine contamination from oil well sites could have serious local effects on water supplies and vegetation depending on the geology, groundwater flow direction and contaminant loading rate. The potential of these effects should be considered when siting and reclaiming reserve pits.

10) EM is a valuable tool to delineate brine contamination and plume migration at oil well sites. EM equipment can be used to survey a site quickly and easily to determine the extent of brine contamination. Resistivity delineates brine contamination as accurately as EM but it is cumbersome and time-consuming to use.

11) Groundwater flow and solute transport modeling are important tools to improve the understanding and characterization of the hydrogeologic system, aquifer

parameters, and contaminant migration.

12) Flow modeling accurately simulated flow direction, head and groundwater velocities.

13) The accuracy of simulated chloride concentrations were limited by the simplicity of the groundwater flow model, Random-Walk limitations of dispersion and dilution, boundary conditions and model inputs. Results show chloride concentrations were accurately simulated at some locations and inadequately simulated at other locations.

14) Current reclamation practices in Montana are inadequate to prevent brine contamination in shallow alluvial aquifers.

## Recommendations

Individuals pursuing research involving reserve pit contamination should consider the following topics:

1) Determine whether organic contamination is a potential threat to groundwater quality at oil well sites drilled with oil based mud or mud containing diesel fuel additives. Volatile, semi-volatile and long chain organic compounds are potential contaminants not examined in current reserve pit literature.

2) Perform EM work needed to located contaminated oil well sites in eastern Montana, and correlate chloride concentrations in the groundwater with EM conductance values.

3) Determine cost effective measures that can be implemented to replace current reclamation techniques to stop or reduce brine contamination.

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# APPENDIX A

# FUNCTION AND GENERAL PURPOSE OF DRILLING FLUIDS ADDITIVES

Function and general purpose of drilling fluid additives (adapted from Murphy and Kewhew, 1985)

| Function | General Purpose | Common Additives |
|---|---|---|
| Weighting Material | Control formation pressure, check caving, facilitate pulling dry pipe, and well completion operations | Barite, lead compounds, iron oxides |
| Viscosifier | Viscosity builders for fluids, for a high viscosity-solids relationship | Bentonite, attapulgite clays, all colloids, fibrous asbestos |
| Thinner Dispersant | Modify relationship between the viscosity and percentage of solids, vary gel strength, deflocculant | Tannins (Quebracho), polyphosphates, lignitic materials |
| Filtrate Reducer | Cut the loss of the drilling fluid's liquid phase into the formation | Bentonite clays, sodium carboxymethyl cellulose (CMC), pregelatinized starch, various lignosulfonates |
| Lost Circulation Material | Primary function is to plug the zone of loss | Walnut shells, shredded cellophane flakes, thixotropic cement, shredded cane fiber, pig hair, chicken feathers, etc. |
| Alkalinity, pH Control | Control the degree of acidity or alkalinity of a fluid | Lime, caustic soda, bicarbonate of soda |
| Emulsifier | Create a heterogeneous mixture of two liquids | lignosulfonates, mud detergent, petroleum sulfonate |
| Surfactant | Used to the degree of emulsification, aggregation, dispersion, interfacial tension, foaming, and defoaming (surface active agent) | Include additives used under emulsifier foamers, defoamers, and flocculators |
| Corrosion Inhibitor | Materials attempt to decrease the presence of such corrosive compounds as oxygen, carbon dioxide, and hydrogen sulfide | Copper carbonate, sodium chromate, chromate-zinc solutions, chrome lignosulfonates, organic acids and amine polymers, sodium arsenite |
| Defoamer | Reduce foaming action especially in salt-water-based muds | Long chain alcohols, silicones, sulfonated |
| Foamer | Surfactants which foam in the presence of water and thus permit air or gas drilling in formations producing water | Organic sodium and sulfonates, alkyl benzene sulfonates |
| Flocculants | Used commonly for increases in gel strength | Salt, hydrated lime, gypsum, sodium tetraphosphates |
| Bactericides | Reduce bacteria count | Starch preservative, paraformaldehyde, caustic soda, lime, sodium pentachloraphenate |
| Lubricants | Reduce torque and increase horsepower at the bit by reducing the coefficient of friction | Graphite powder, soaps, certain oils |
| Calcium Remover | Prevent and overcome the contamination effects of anhydrite and gypsum | Caustic soda (NaOH), soda ash, bicarbonate of soda, barium carbonate |
| Shale Control Inhibitors | Used to control caving by swelling or hydrous disintegration | Gypsum, sodium silicate, calcium lignosulfonates, lime, salt |

# APPENDIX B

# DISCUSSION ON THE REGIONAL HYDROGEOLOGY

The site is located on the western flank of the Williston Basin (Exhibit 1) in Richland County, Montana which is a deep structural depression containing 14,000 to 15,000 feet (4500 m) of sedimentary rock overlying a gneissic precambrian basement (Carlson, 1985).

As of 1982 oil removed from the Williston basin in Montana had totaled 21,923,760 barrels from 1,360 wells (Dewey, 1984). Major oil producing zones 9,000 to 13,000 feet (2700 to 4000 m) below ground surface include the Paleozoic Mission Canyon Limestone and Red River formation (Prichard and Landis, 1975). The Spearfish Evaporite sequence is above the oil producing zones and marks the Permian boundary (Carlson, 1985).

The Regional surficial geology encompasses the Tertiary Fort Union Formation to the Quaternary alluvial and fluvial deposits. Exhibit 2 shows a geologic cross section of the area and Exhibit 3 describes the Mesozoic through the Quaternary stratigraphy. The Fort Union formation has four members, however, only the Tongue River member is significant to this study. The Tongue River Member is a light grayish to brown layered sand, silt, and clay deposit with .25 to five feet thick coal beds and clinker zones. Gypsum layers and iron nodules are found in many of the silt and clay layers. Most beds are massive with local crossbedding, and weathered to a yellowish buff color. Cementation is weak in most rock layers making the Tongue River Member soft. The depositional environment was probably similar to a terrestrial flood plain, marsh, or swamp setting (Prichard and Landis, 1975). The Tongue River Member generally yields approximately 10 gpm of water from

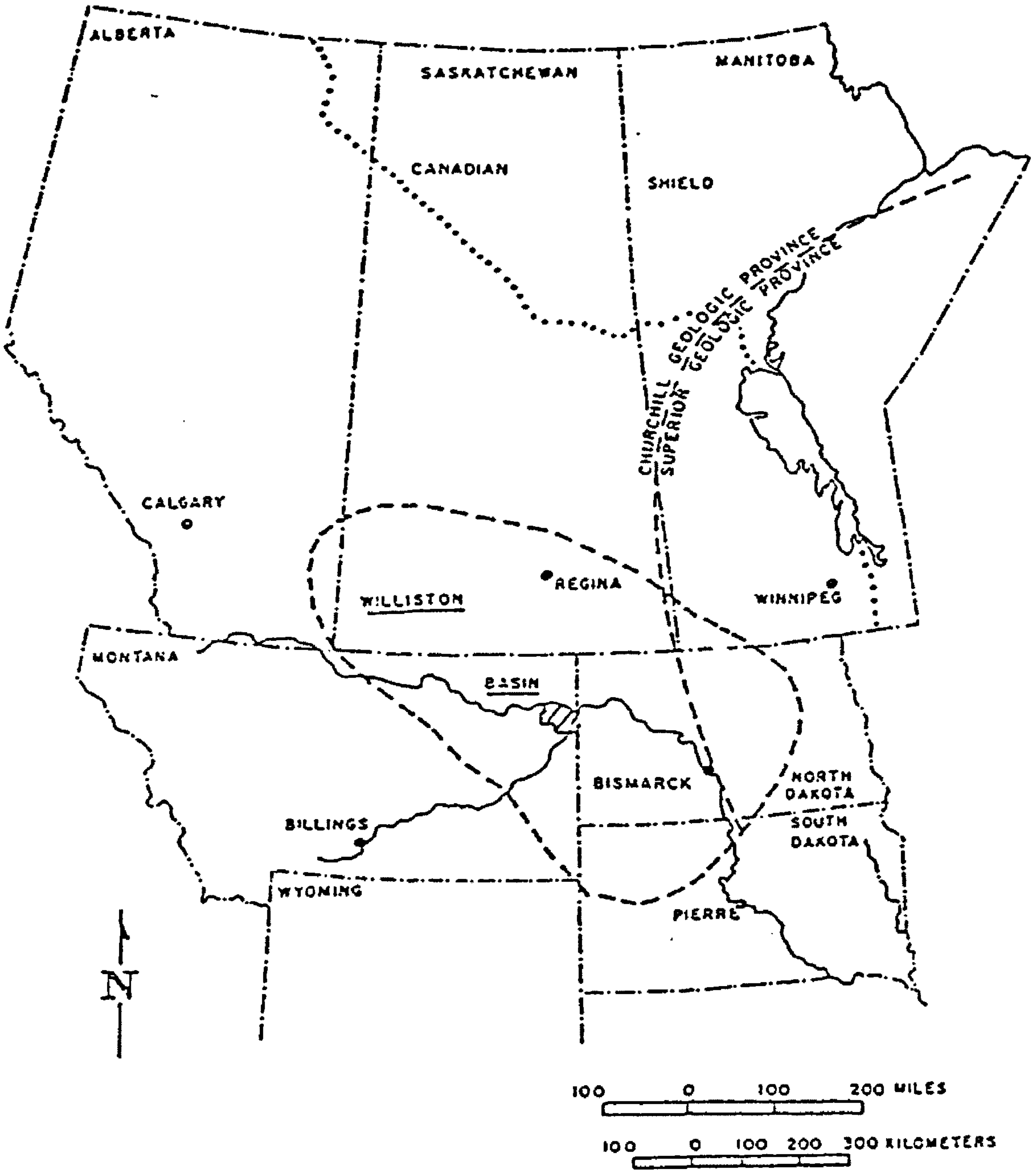


Exhibit 1. Location of Richland County Montana, Montana in the Williston basin shown by hatched lines (adapted from Dewey, 1984).

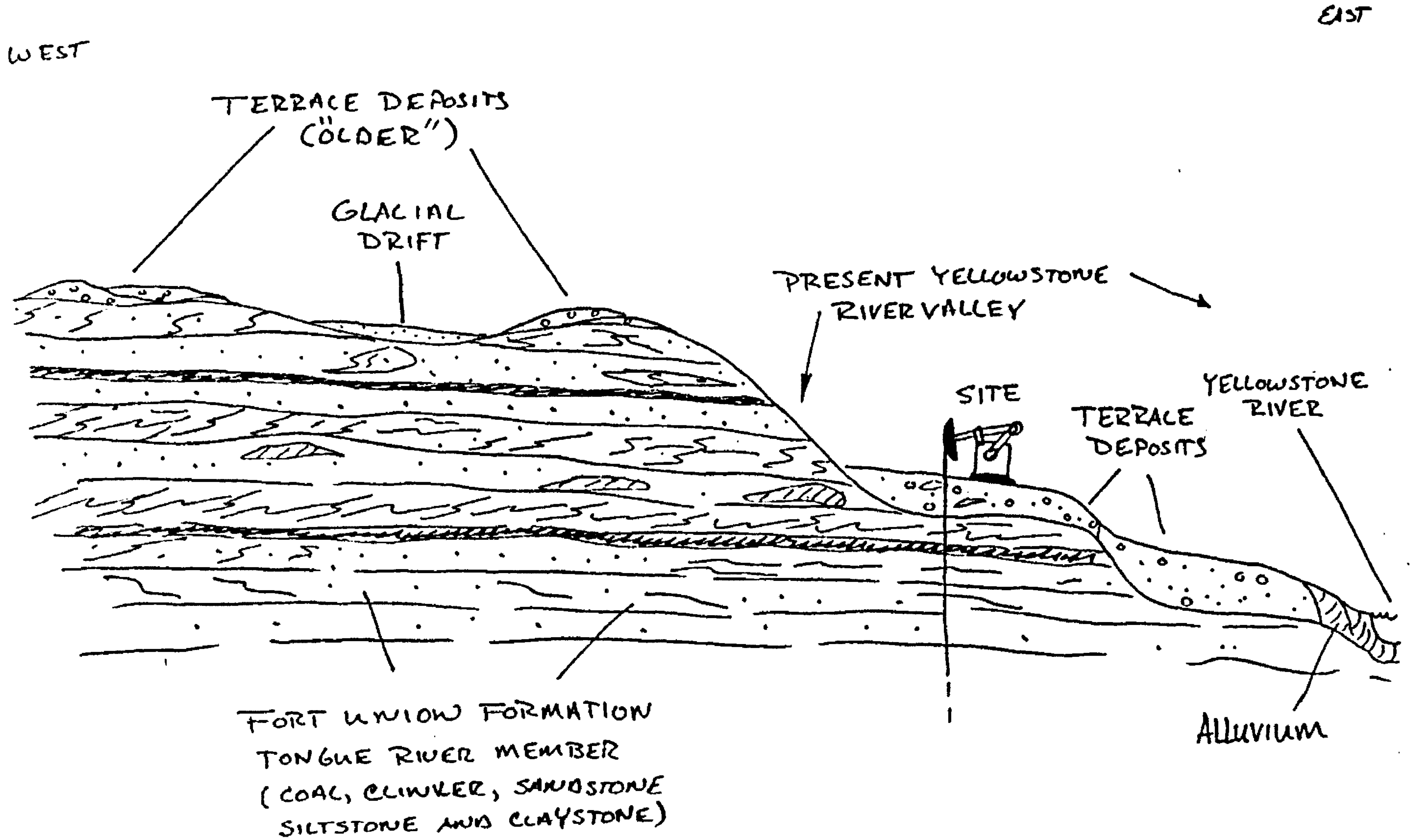


Exhibit 2. Geologic cross section of the study area (diagrammatic).

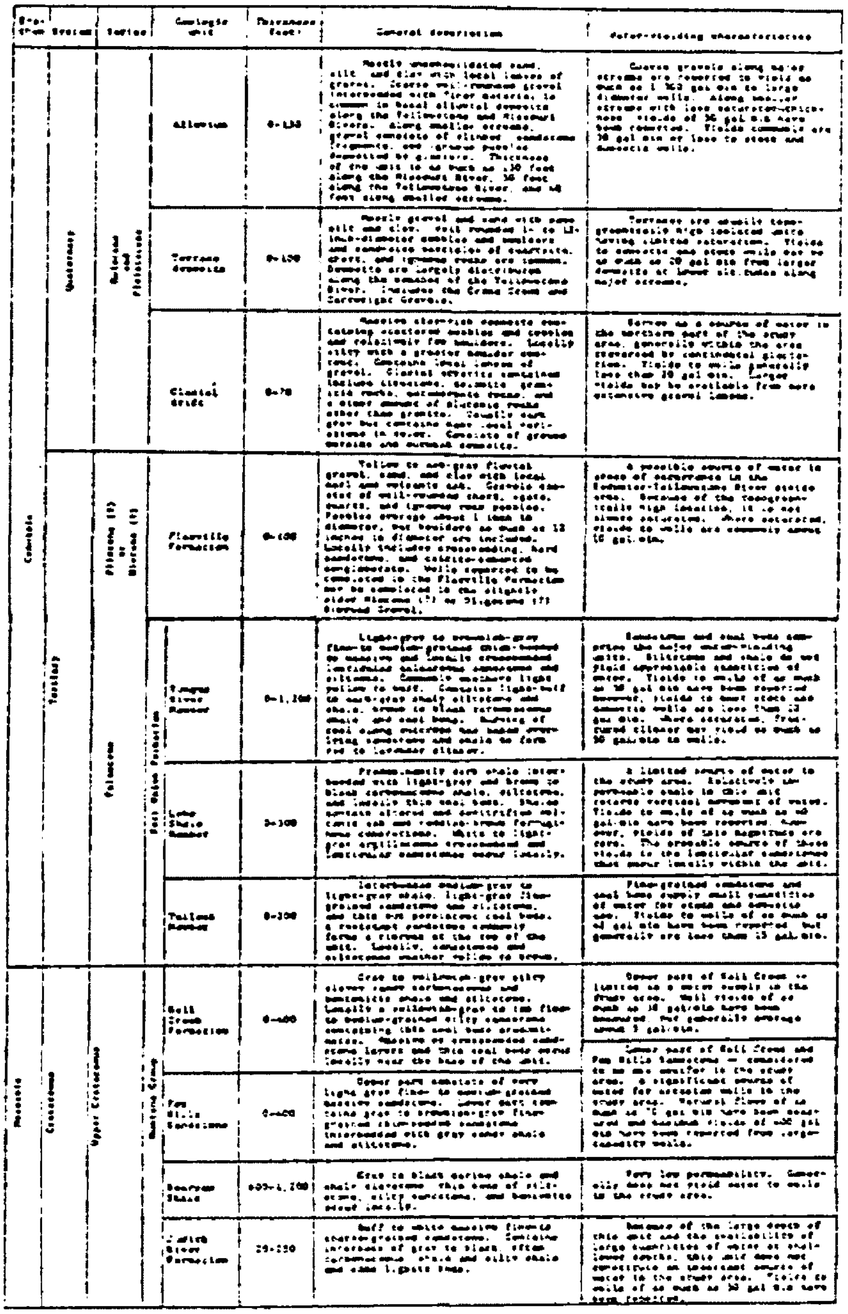


Exhibit 3. Stratigraphic column for Richland County, Montana (from Slagle, 1981)

wells, most of which is derived from coal beds. Many wells are completed in the Tongue River Member since the water tends to be softer then other near surface water supplies and wells are generally not deeper then 75 feet.

The Yellowstone River deposited terrace gravel upon the Fort Union formation. These gravel were previously named the "Flaxville Gravel" which has now been abandoned. The oldest terrace deposits as reported by Howard (1960) are Miocene or Pliocene and may have a surface younger than Pliocene. The gravel cap the Fort Union highs and are composed of coarse gravel and cobbles in a coarse to fine sand matrix, and in some instances, the deposits are weakly cemented with calcite.

The Yellowstone River cut into the oldest terrace deposits and formed the Missouri Plateau peneplain, on which a younger terrace gravel were deposited (previously named the Cartwright Gravel). These gravel deposits are early Pleistocene age laid down by the ancestral Missouri and Yellowstone Rivers (Howard, 1960) and found on topographically high Fort Union banks as erosional remnants of a once extensive gravel blanket. These terrace deposits ("Cartwright Gravel") are lithologically similar to the older terrace deposits ("Flaxville Gravel"), and may in fact be reworked terrace deposits (Alden, 1932). Both of these deposits ("Cartwright and Flaxville") generally do not yield more than 10 gpm and the quality of the water is often poor due to a high TDS and hardness.

Another period of erosion and aggradation period deposited a younger terrace gravel sequence (previously named the Crane Creek

Gravel). These gravel exhibit a similar lithology and texture as the two older terrace deposits and hence, thought to be in part derived from these deposits (Prichard and Landis, 1975). The major difference between the two older terrace gravel and the younger terrace gravel ("Crane Creek Gravel") is that the younger it is constrained to the present Yellowstone drainage, and is not preserved on plateaus and broad interstream uplands of the ancestral Missouri and Yellowstone Rivers. Howard (1960) correlates these gravel as pre-Wisconsin Pleistocene or Yarmonth Interglaciation. These younger terrace deposits produce up to 1,000 gpm in the major river valleys and are recharged by irrigation and channel seepage in addition to precipitation.

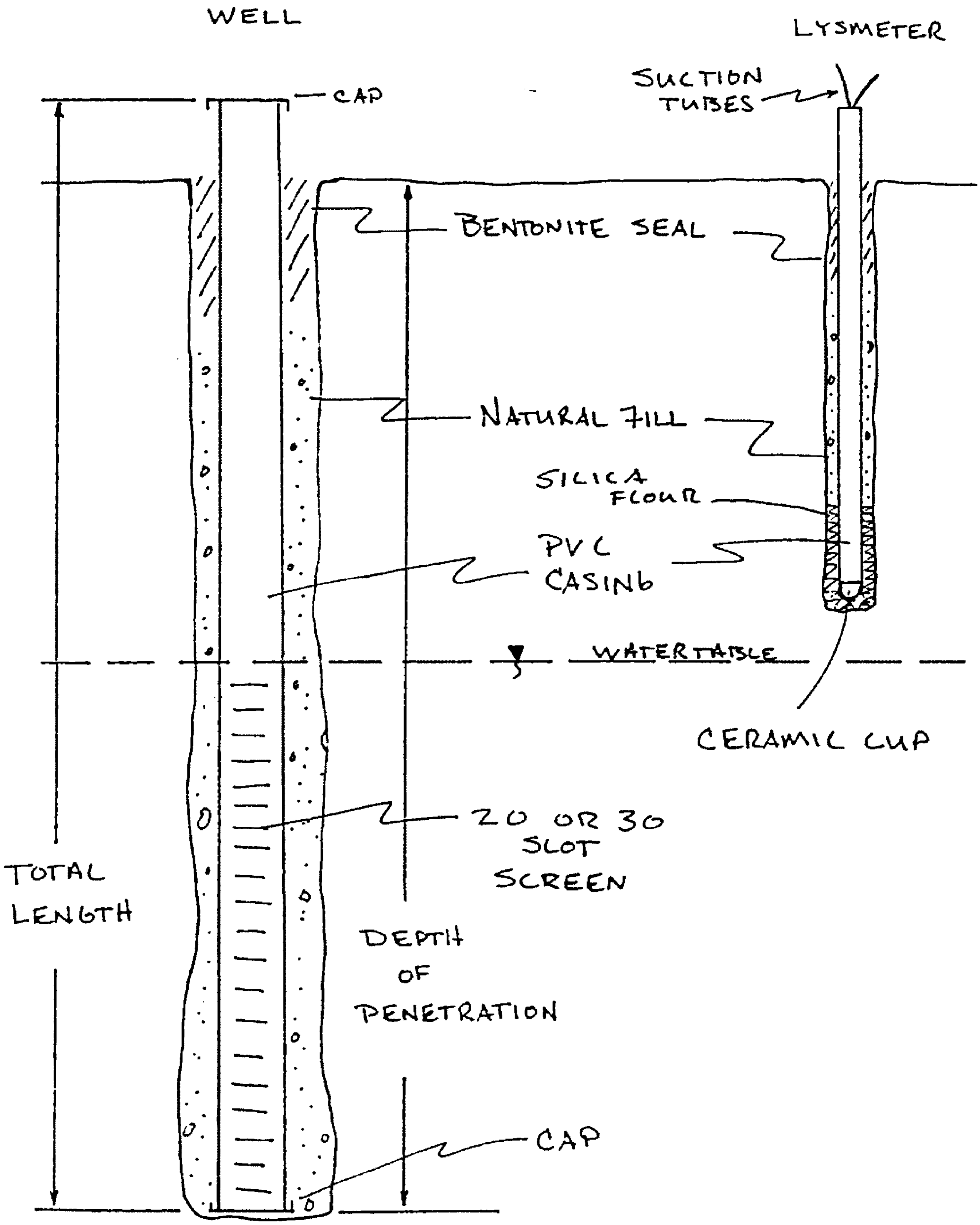
These younger terrace deposits ("Crane Creek Gravel") are infrequently covered by Glacial till, but do show evidence of continental glaciation after deposition. Glacial drift is early Wisconsin (?) according to Howard (1960) and Iowan or Illinoian (?) according to Alden (1932). Glacial deposits include ground moraines, stratified drift, till, melt-water and diversion-channel deposits, eskers, and kames (Prichard and Landis, 1975). The exact number of ice advances and glacial interims is disputed and not discussed in this text (see Alden, 1932; Carlson, 1985; Howard, 1960; and Prichard and Landis, 1975). Glacial deposits are reported to produce 20 gpm of water from wells but are seldom utilized.

Alluvium in the Yellowstone River Valley is mapped as two older flood plain terraces and alluvium deposited within the river channel. Alluvial deposits are predominately Holocene age deposited after an erosional period, which topographically has changed little since deposition of the older alluvium (Howard, 1960). Exhibit 3 is a stratigraphic column of units discussed above which also reviews water-yielding characteristics of each geologic unit. Alluvial deposits generally yield 10 gpm.

# APPENDIX C

# WELL CONSTRUCTION

# TYPICAL LYSIMETER AND WELL CONSTRUCTION



## WELL CONSTRUCTION INFORMATION

| WELL # | ELEVATION | CASING | SCREEN SLOT/LENGTH | TOTAL LENGTH | DEPTH OF PENETRATION |
|---|---|---|---|---|---|
| MW 1 | 1922.1’ | 2"PVC | #20/3.0’ | 21.75’ | 20.0’ |
| MW 2 | 1920.14’ | 2"PVC | #20/5.0’ | 20.0’ | 18.0’ |
| MW 3 | 1920.14’ | 2"PVC | #20/5.0’ | 20.0’ | 18.17’ |
| MW 3s | 1920.89’ | 2"PVC | #30/2.25’ | 14.0’ | 11.4’ |
| MW 4s | 1921.09’ | 2"PVC | #30/2.0’ | 14.0’ | 12.33’ |
| MW 4m | 1919.74’ | 2"PVC | #30/2.0’ | 16.0’ | 14.17’ |
| MW 4d | 1922.24’ | 2"PVC | #30/2.0’ | 22.0’ | 19.75’ |
| MW 5 | 1919.59’ | 2"PVC | #30/5.0’ | 20.0’ | 18.08’ |
| MW 5s | 1919.34’ | 2"PVC | #20/3.0’ | 13.5’ | 11.5’ |
| MW 6 | 1921.14’ | 2"PVC | #30/5.0’ | 22.0’ | 19.0’ |
| MW 7s | 1919.84’ | 2"PVC | #30/1.5’ | 15.3’ | 13.8’ |
| MW 7d | 1919.69’ | 2"PVC | #30/2.0’ | 24.0’ | 22.17’ |
| MW 8 | 1915.72’ | 2"PVC | #20/3.0’ | 22.0’ | 20.5’(?) |
| MW 9 | 1920.48’ | 2"PVC | #30/2.0’ | 22.2’ | 19.62’ |
| MW 10 | 1916.67’ | 2"PVC | #30/3.0’ | 23.0’ | 20.17’ |
| MW 11 | 1919.74’ | 2"PVC | #30/3.0’ | 23.0’ | 21.75’ |
| MW 12 | 1917.77’ | 2"PVC | #20/3.0’ | 22.0’ | 20.0’ |
| MW 13 | 1919.09’ | 2"PVC | #20/3.0’ | 22.0’ | 19.5’ |
| MW 14 | 1921.54’ | 2"PVC | #20/5.0’ | 23.0’ | 21.33’ |
| MW 15D | 1919.84’ | 4.5"PVC | #20/14.0’ | 21.1’ | 18.6’ |
| MW 16s | 1919.87’ | 2"PVC | #20/6.0’ | 14.0’ | 12.0’ |
| MW 17s | 1918.18’ | 2"PVC | #20/3.0’ | 15.0’ | 12.6’ |
| MW 18s | 1917.75’ | 2"PVC | #20/3.0’ | 13.0’ | 11.0’ |
| MW 19s | 1920.74’ | 2"PVC | #20/6.0’ | 17.0’ | 14.8’ |
| MW 20s | 1917.96’ | 2"PVC | #20/3.5’ | 13.5’ | 12.8’ |
| MW 21s | 1920.64’ | 2"PVC | #20/3.0’ | 15.0’ | 12.4’ |

## LYSIMETER CONSTRUCTION INFORMATION

| LYSIM. # | CASING | TOTAL DEPTH | DEPTH OF PENETRATION | |
|---|---|---|---|---|
| L2 | 1.5"PVC | 5.17’ | 3.59’ | |
| L3 | 1.5"PVC | 6.83’ | 6.41’ | |
| L3s | 1.5"PVC | 4.25’ | 2.92’ | |
| L3SD | (NONFUNCTIONAL) | | | |
| L3SS | (NONFUNCTIONAL) | | | |
| L8 | 1.5"PVC | 5.42’ | 3.84’ | (DESTROYED 10/87) |

# APPENDIX D

# MONITOR WELL LOGS, SIEVE ANALYSES AND SITE GEOLOGY

# LITHOLOGY KEY

| | |
|---|---|
| SO | SO - Blackish tan/dark brown soil, fine to coarse sands with 5 to 15% silt and clay, and 5 to 20% gravel, moist, moderate to poorly sorted, rounded and subangular. |
| SO | SO - Blackish tan to green soil, fine grained sand with 25 to 35% silt and clay, moist, moderately well sorted, subrounded to subangular, a few gravel bits and clay lenses. |
| FL | FL - Blackish red fill soil and debris, coarse to fine sand, gravel and silts with 5 to 10% clay (?), v. poorly sorted, subrounded gravel and cobbles, 5% coarse clinker bits, trace wood and plastic debris. |
| FL | FL - Blackish brown and grayish fill soil, medium to v. fine sand with 10% coarse grains and 20 to 30% silts and clays, 5 to 15% gravel, poorly sorted, subrounded to subangular, 5% clinker bits. |
| SD | SD - Tan brown to green clean sand, medium to fine grained with 3 to 5% gravel, fairly well to well sorted, subrounded to subangular, Qtz rich with 5 to 10% dolomite and clinker, 2% mica, and trace coal bits. |
| SD | SD - Tan brown fairly clean sand, medium grained with 10 to 20% pea gravel, fine and coarse sand, moderately sorted, subrounded to subangular sand and subrounded gravel, Qtz rich, 5% clinker, dolomite, agates, and coal bits. |
| SD&GR | SD&GR - Brownish sand and gravel. fine to coarse sand with .5 to 3 inch gravel, 5% cobbles, 2 to 10% silt and clay, v. poorly sorted, subangular sand and subrounded gravel, Qtz rich with siltstone, granite, gneiss, dolomite, sandstone, and agate clasts, common aquifer material for site. |
| GR | GR - Brownish clean gravel, 1 to 2 inch gravel with 10 to 20% smaller and larger, 5 to 10% cobbles, 2 to 5% fines, moderately to poorly sorted, subrounded to subangular, Qtz rich with siltstone, granite, gneiss, dolomite, sandstone, and agate clasts, channel cut deposit (?). |
| CL | CL - Dark green to gray pit mud, silty/clayey fine sand with a few clinker bits and pea gravel, 30% silt and 20% clay, moderately sorted, rounded to subrounded clasts, moist, oily smell (diesel?). |
| SL&CL | SL&CL - Gray to dark green clayey silt, trace gravel, moderately sorted. rounded to subrounded clasts, v. moist, oily smell near pit area-possibly a trench dug from the reserve pit(?), more tan colored away from the pit. |
| CL/SD | CL/SD - Brown interlayered clay and sand with 20% gravel. v. poorly sorted sands and fairly sorted clays. subrounded. Qtz rich, trace clinker bits. |
| SL/SD | SL/SD - Brown interlayered silt and sand with 15 to 20% gravel, poorly sorted sands and fairly sorted silts, subrounded, Qtz rich. |
| SL/GR | SL/GR - Gray to Brown clayey-silty sand with 5 to 10% pea gravel, 50% silt and clay, medium to coarse sand, moderate to poorly sorted, moist, till(?). |
| FU | FU - Fort Union bedrock, thick layers of gray silty clay and black coal beds, 20% fine sandy lenses and trace pea gravel in silty clay, fairly well sorted, rounded to subangular, v. moist to wet, v. dense "siltstone". |

ETMAR Trilobites STRATCOL

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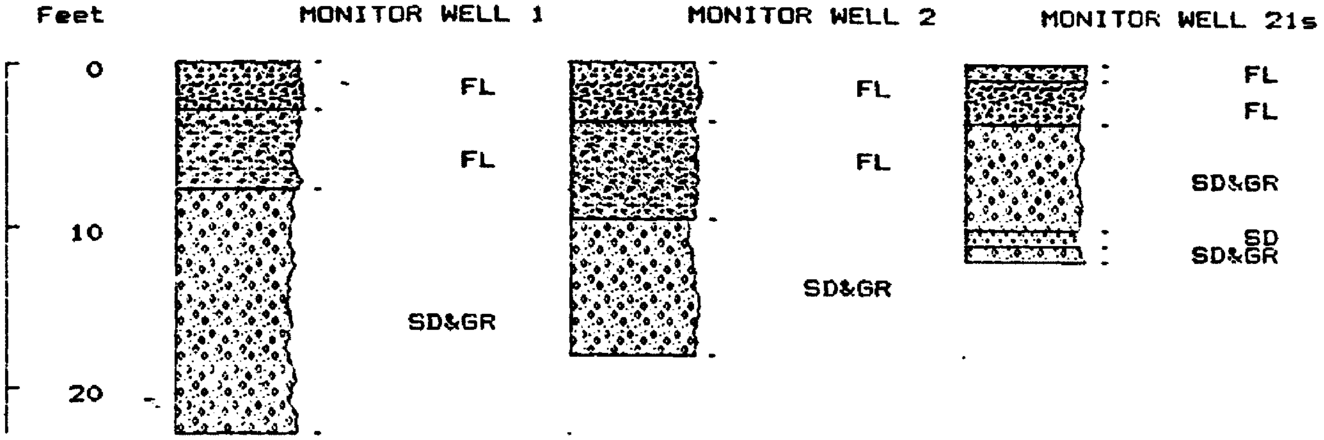

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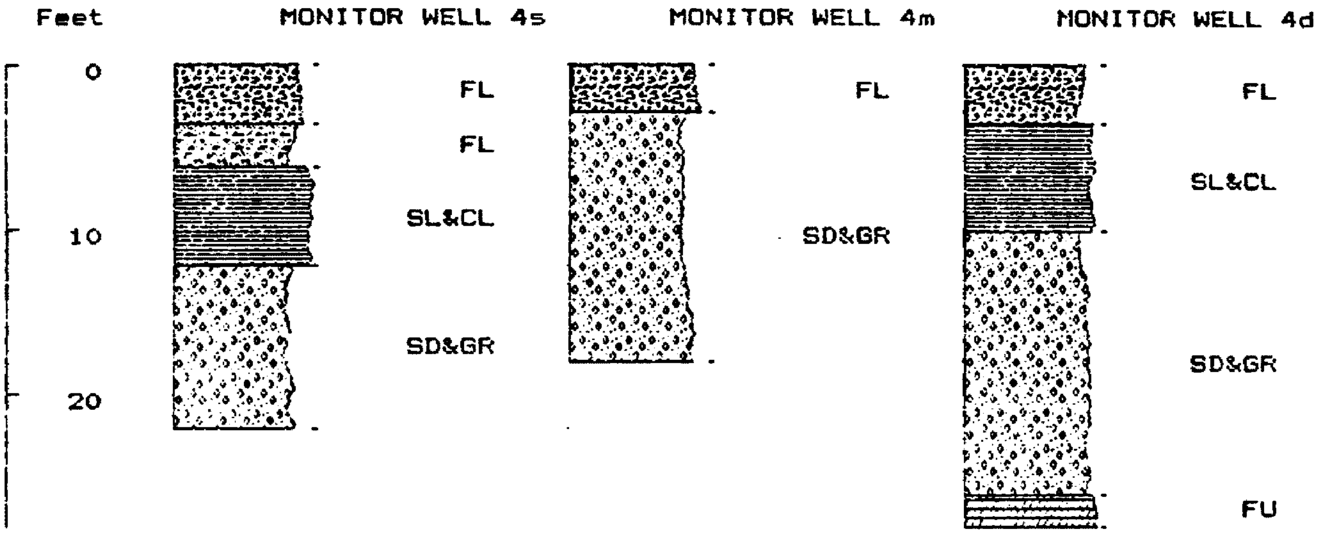

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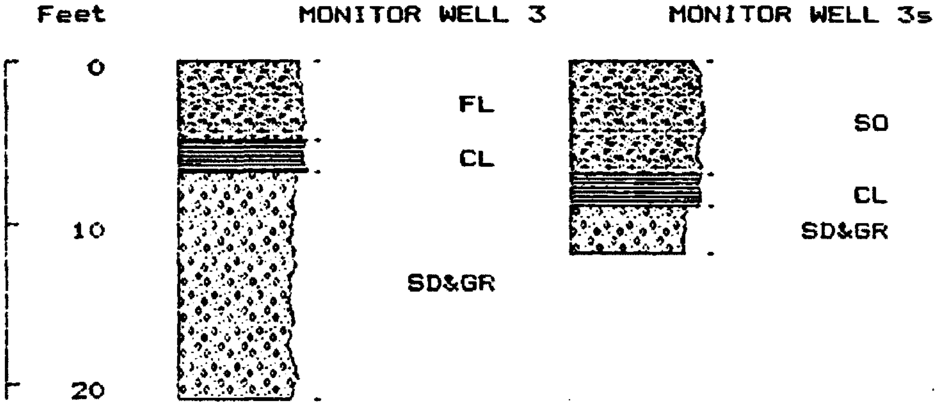

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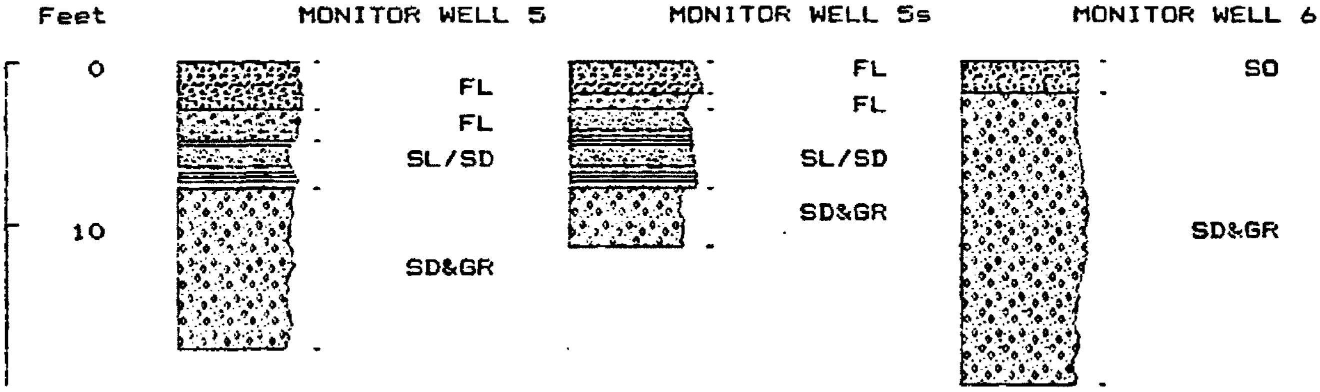

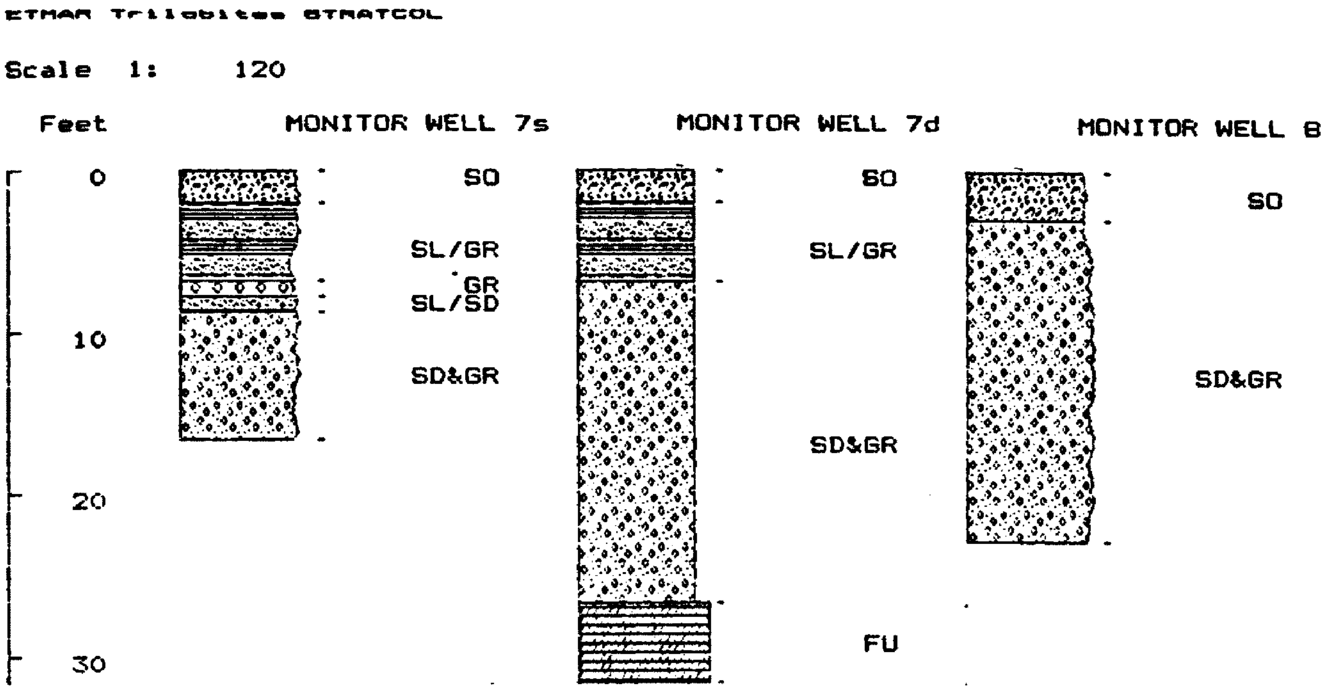
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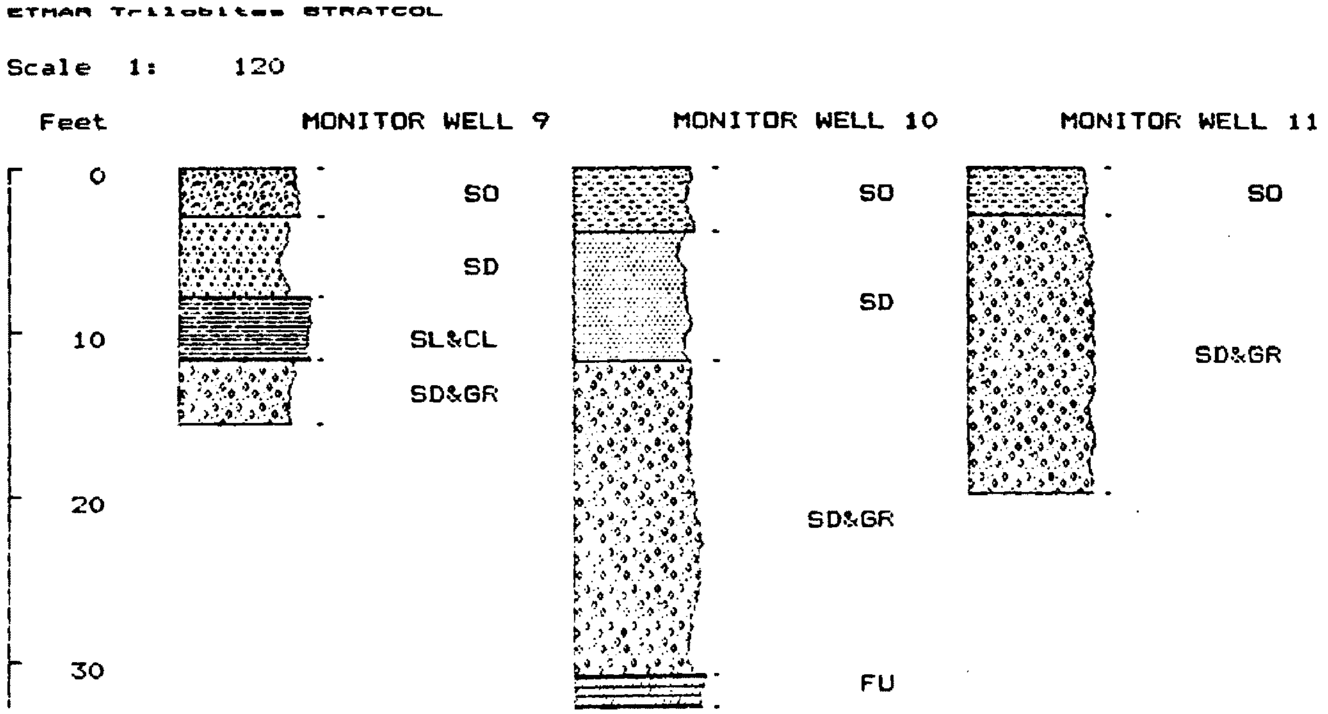
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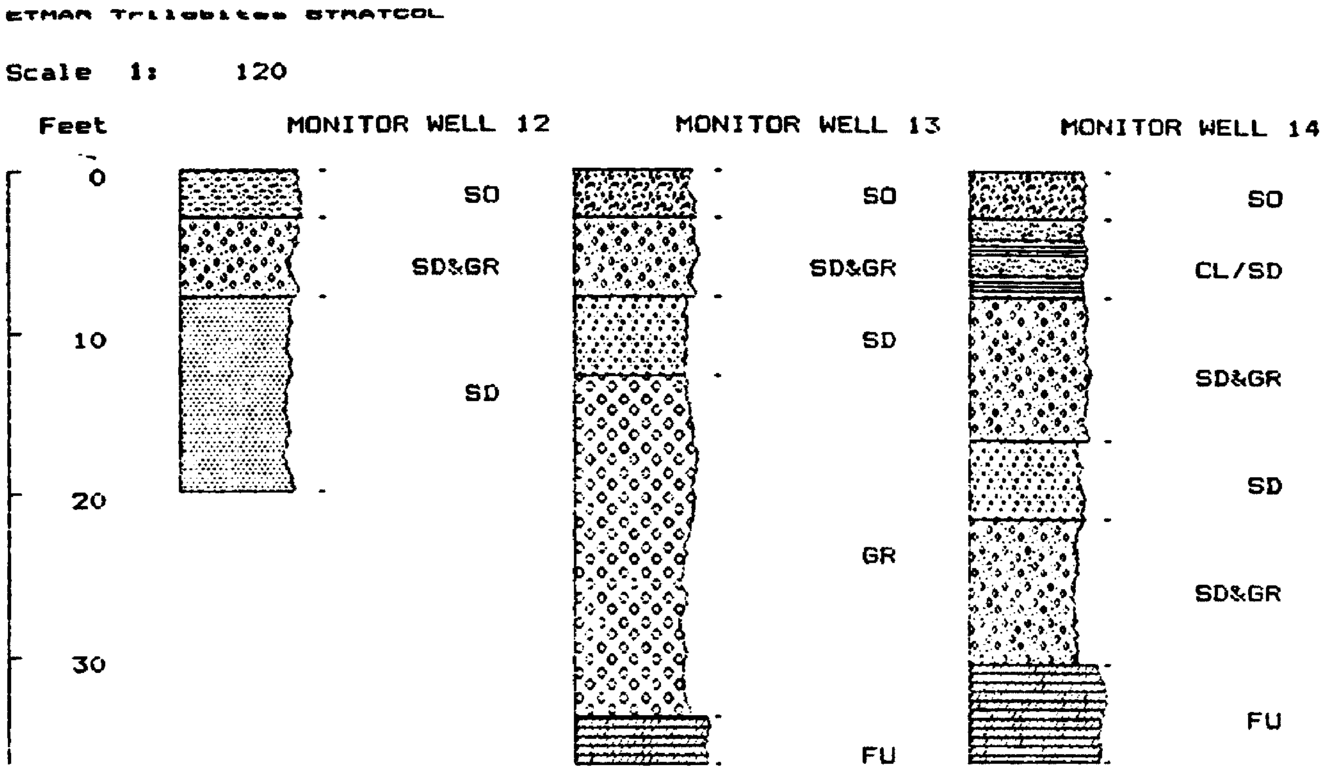
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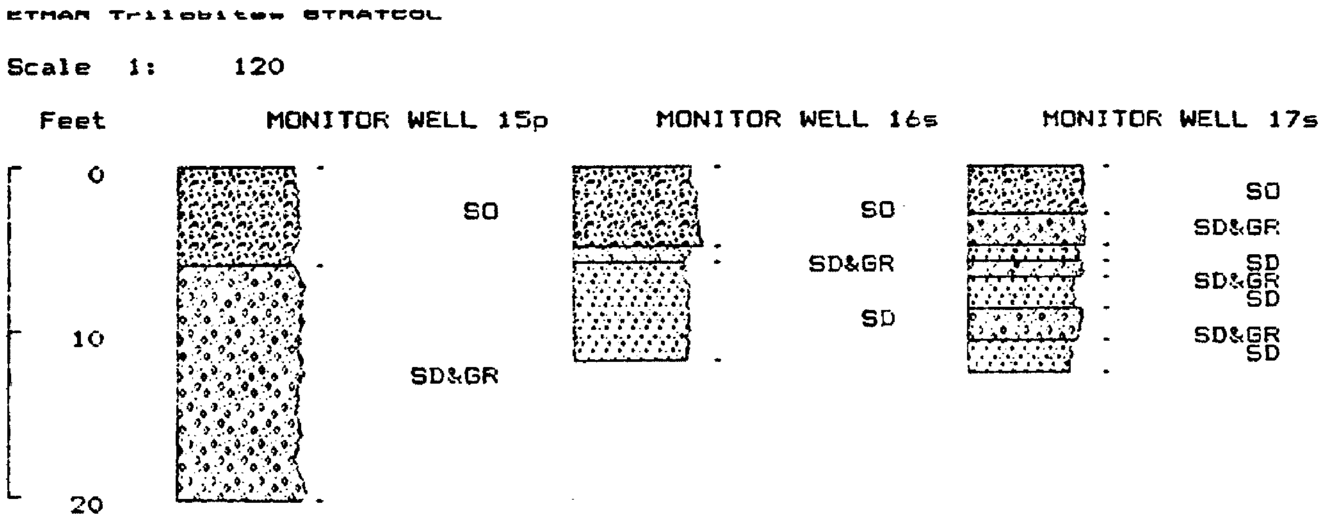
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STMAR Trilobites STRATCOL

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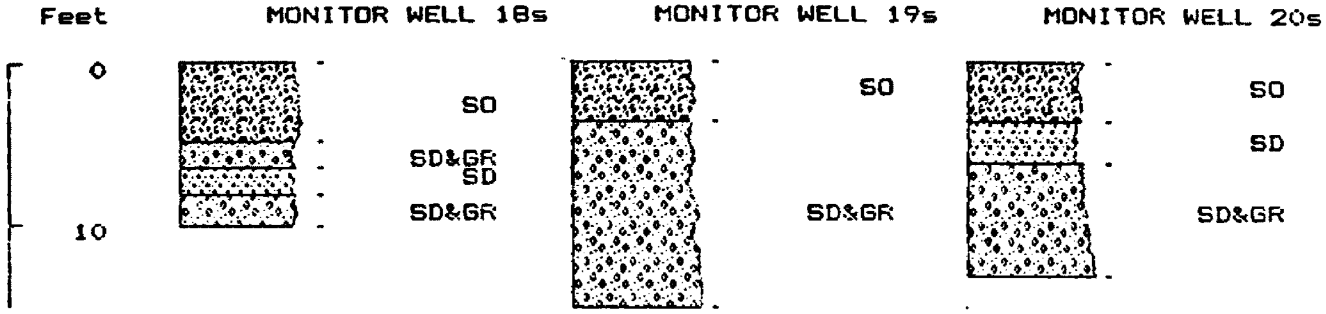


SAND SAMPLE (MW 12)

# SIEVE ANALYSIS OF SOIL AND AGGREGATE

USDA FOREST SERVICE REGION 1

FOREST —

FIELD NO. SAND LAB NO. —

PROJECT IVERSON

LOCATION RICHLAND, CO.

| SIEVE SIZE | WEIGHT RETAINED | % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| 3" (75.0mm) | 0 | 0 | 100 | |
| 2" (50.0mm) | 0 | 0 | 100 | |
| 1-1/2" (37.5mm) | 0 | 0 | 100 | |
| 1" (25.0mm) | 0 | 0 | 100 | |
| 3/4" (19.0 mm) | 0 | 0 | 100 | |
| 1/2" (12.5 mm) | 51.5 g | 4.43 | 95.57 | |
| 3/8" (9.5 mm) | 12.0 g | 1.03 | 94.54 | |
| #4 (4.75mm) | 44.0 g | 3.78 | G 90.76 | |
| PAN | 1055.0 g | 90.75 | | |
| TOTAL | 1162.0 g | | | |
| Sieve Loss or Gain | -3 g | | | |

WEIGHT OF ORIGINAL SAMPLE 1165.5 g

| SIEVE SIZE | Weight Retained X $\frac{G}{H}$ = | % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| #8 (2.36mm) | 13.6 | 3.15 | 87.61 | |
| #10 (2.00mm) | | | | |
| #16 (1.18mm) | 13.8 | 3.20 | 84.41 | |
| #30 (.600mm) | 20.1 | 4.66 | 79.75 | |
| #40 (.425 mm) | | | | |
| #50 (.300mm) | 39.9 | 9.25 | 70.5 | |
| #100 (.150 mm) | 139.0 | 32.24 | 38.26 | |
| #200 (.075mm) | 109.4 | 25.37 | 12.89 | |
| Total Minus #200 | E 55.5 | 12.87 | | |
| TOTAL | H 391.3 | | | |
| Sieve Loss or Gain | H-A .8 | | | |

MINUS #40 MATERIAL IS:

PLASTIC ☐

NON-PLASTIC ☒

TOTAL DRY WEIGHT BEFORE WASHING A 390.5

TOTAL DRY WEIGHT AFTER WASHING, BEFORE SIEVING B 347.6

MINUS #200 WASHED OUT (A-B) C 42.9

MINUS #200 FROM SIEVING PAN D 12.6

TOTAL MINUS #200 (C+D) E 55.5

MINUS #4 CORRECTION FACTOR, $\frac{G}{H}$ = .23194

REMARKS

| FORM NO. | OPERATOR | DATE | CHECKED BY | DATE |
|---|---|---|---|---|
| 51-7100 MTL-2 2/80 | SP | 11/87 | | |

SAND AND GRAVEL SAMPLE

# SIEVE ANALYSIS OF SOIL AND AGGREGATE

USDA FOREST SERVICE REGION 1

FOREST ——
FIELD NO. SAND & GRAVEL | LAB NO. —
PROJECT IVERSON
LOCATION RICHLAND, CO.

| SIEVE SIZE | WEIGHT RETAINED | % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| 3" (75.0mm) | 0 | 0 | 100 | |
| 2" (50.0mm) | 0 | 0 | 100 | |
| 1-1/2" (37.5mm) | 157.0 g | 2.57 | 97.43 | |
| 1" (25.0mm) | 104.0 g | 1.70 | 95.73 | |
| 3/4" (19.0 mm) | 264.0 g | 4.31 | 91.42 | |
| 1/2" (12.5 mm) | 444.5 g | 7.26 | 84.16 | |
| 3/8" (9.5 mm) | 287.5 g | 4.70 | 79.46 | |
| #4 (4.75mm) | 621.0 g | 10.15 | G 69.31 | |
| PAN | 4242.0 g | 69.31 | | |
| TOTAL | 6120.0 g | | | |
| Sieve Loss or Gain | — 1 g | | | |

WEIGHT OF ORIGINAL SAMPLE 6121.0 g

| SIEVE SIZE | Weight Retained X $\frac{G}{H}$ | = % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| #8 (2.36mm) | 55.4 g | 6.77 | 62.54 | |
| #10 (2.00mm) | | | | |
| #16 (1.18mm) | 67.4g | 8.23 | 54.31 | |
| #30 (.600mm) | 95.1 g | 11.61 | 42.7 | |
| #40 (.425 mm) | | | | |
| #50 (.300mm) | 84.1 g | 10.27 | 32.43 | |
| #100 (.150 mm) | 144.9 g | 17.70 | 14.73 | |
| #200 (.075mm) | 59.9 g | 7.31 | 7.42 | |
| Total Minus #200 | E 60.7 g | 7.41 | | |
| TOTAL | H 567.5 g | | | |
| Sieve Loss or Gain | H-A —.9 g | | | |

MINUS #40 MATERIAL IS:
PLASTIC ☐
NON-PLASTIC ☒

TOTAL DRY WEIGHT BEFORE WASHING A 568.4
TOTAL DRY WEIGHT AFTER WASHING, BEFORE SIEVING B 513.8
MINUS #200 WASHED OUT (A-B) C 54.6
MINUS #200 FROM SIEVING PAN D 6.1
TOTAL MINUS #200 (C+D) E 60.7
MINUS #4 CORRECTION FACTOR, $\frac{G}{H}$ = .12213

REMARKS

| | | | | |
|---|---|---|---|---|
| FORM NO. 51-7100 MTL-2 2/80 | OPERATOR SP | DATE 11/87 | CHECKED BY | DATE |

GRAVEL (MW 13) SAMPLE

# SIEVE ANALYSIS OF SOIL AND AGGREGATE

USDA FOREST SERVICE REGION 1

FOREST —

FIELD NO. GRAVEL

LAB NO. —

PROJECT IVERSON

LOCATION RICHLAND, CO.

| SIEVE SIZE | WEIGHT RETAINED | % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| 3" (75.0mm) | 0 | 0 | 100 | |
| 2" (50.0mm) | 0 | 0 | 100 | |
| 1-1/2" (37.5mm) | 253.5 g | 12.03 | 87.97 | |
| 1" (25.0mm) | 305.5 g | 14.49 | 73.48 | |
| 3/4" (19.0 mm) | 361.5 g | 17.15 | 56.33 | |
| 1/2" (12.5 mm) | 464.0 g | 22.01 | 34.32 | |
| 3/8" (9.5 mm) | 254.0 g | 12.05 | 22.27 | |
| #4 (4.75mm) | 132.5 g | 6.29 | G 15.98 | |
| PAN | 337.5 g | 16.01 | | |
| TOTAL | 2108.0 g | | | |
| Sieve Loss or Gain | − 11.5 g | | | |

WEIGHT OF ORIGINAL SAMPLE 2119.5 g

| SIEVE SIZE | Weight Retained X $\frac{G}{H}$ | = % RETAINED | % PASSING | SPEC. GRADATION |
|---|---|---|---|---|
| #8 (2.36mm) | 43.5 g | 2.05 | 13.93 | |
| #10 (2.00mm) | | | | |
| #16 (1.18 mm) | 41.7 g | 1.97 | 11.96 | |
| #30 (.600mm) | 51.1 g | 2.41 | 9.55 | |
| #40 (.425 mm) | | | | |
| #50 (.300mm) | 39.5 g | 1.86 | 7.68 | |
| #100 (.150 mm) | 52.6 g | 2.48 | 5.21 | |
| #200 (.075mm) | 42.0 g | 1.98 | 3.23 | |
| Total Minus #200 | E 68.5 g | 3.23 | | |
| TOTAL | H 338.9 g | | | |
| Sieve Loss or Gain | H-A − 1.4 g | | | |

MINUS #40 MATERIAL IS:
PLASTIC ☐
NON-PLASTIC ☒

TOTAL DRY WEIGHT BEFORE WASHING A 337.5
TOTAL DRY WEIGHT AFTER WASHING, BEFORE SIEVING B 276.8
MINUS #200 WASHED OUT (A - B) C 60.7
MINUS #200 FROM SIEVING PAN D 7.8
TOTAL MINUS #200 (C + D) E 68.5
MINUS #4 CORRECTION FACTOR, $\frac{G}{H}$ = .047153

REMARKS

| FORM NO. | OPERATOR | DATE | CHECKED BY | DATE |
|---|---|---|---|---|
| 51-7100 MTL-2 2/80 | SP | 11/87 | | |

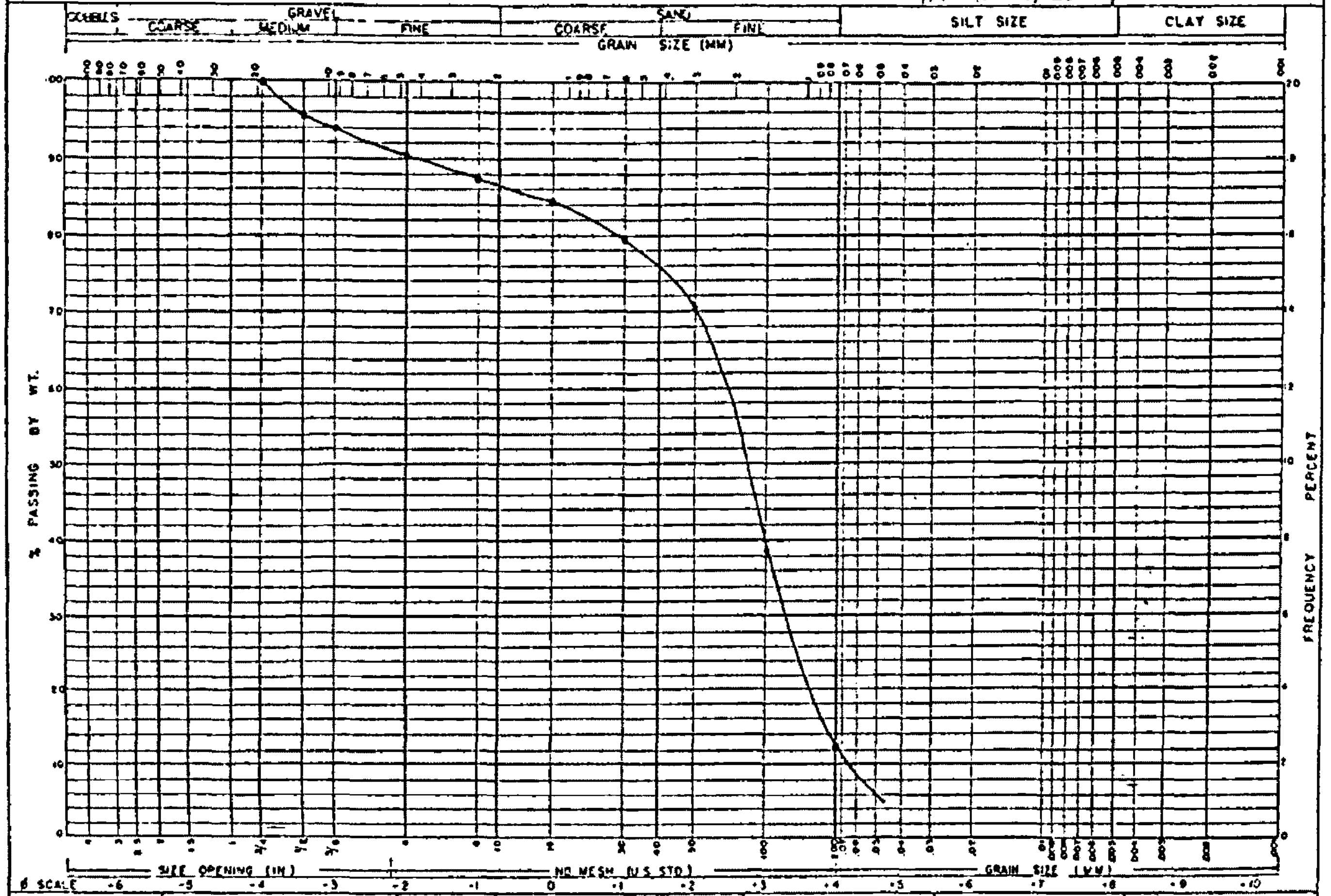
SAND (MW 12) SAMPLE

# REGION I MATERIALS TESTING LABORATORY

## U.S. FOREST SERVICE

## SOIL AGGREGATE GRADING CHART

| | |
|---|---|
| FOREST —— | PROJECT IVERSON |
| FIELD SAMPLE NO SAND | LAB SERIAL NO. —— |
| LOCATION RICHLAND, CO | DATE 7/87 |



| | | | | | |
|---|---|---|---|---|---|
| LL<br>PL | H R B CLASSIFICATION | UNIFIED CLASSIFICATION SP | PLOTTED BY SP | CHECKED BY | DATE 7/1/87 |

FORM NO. 24-7/00-MTL-13

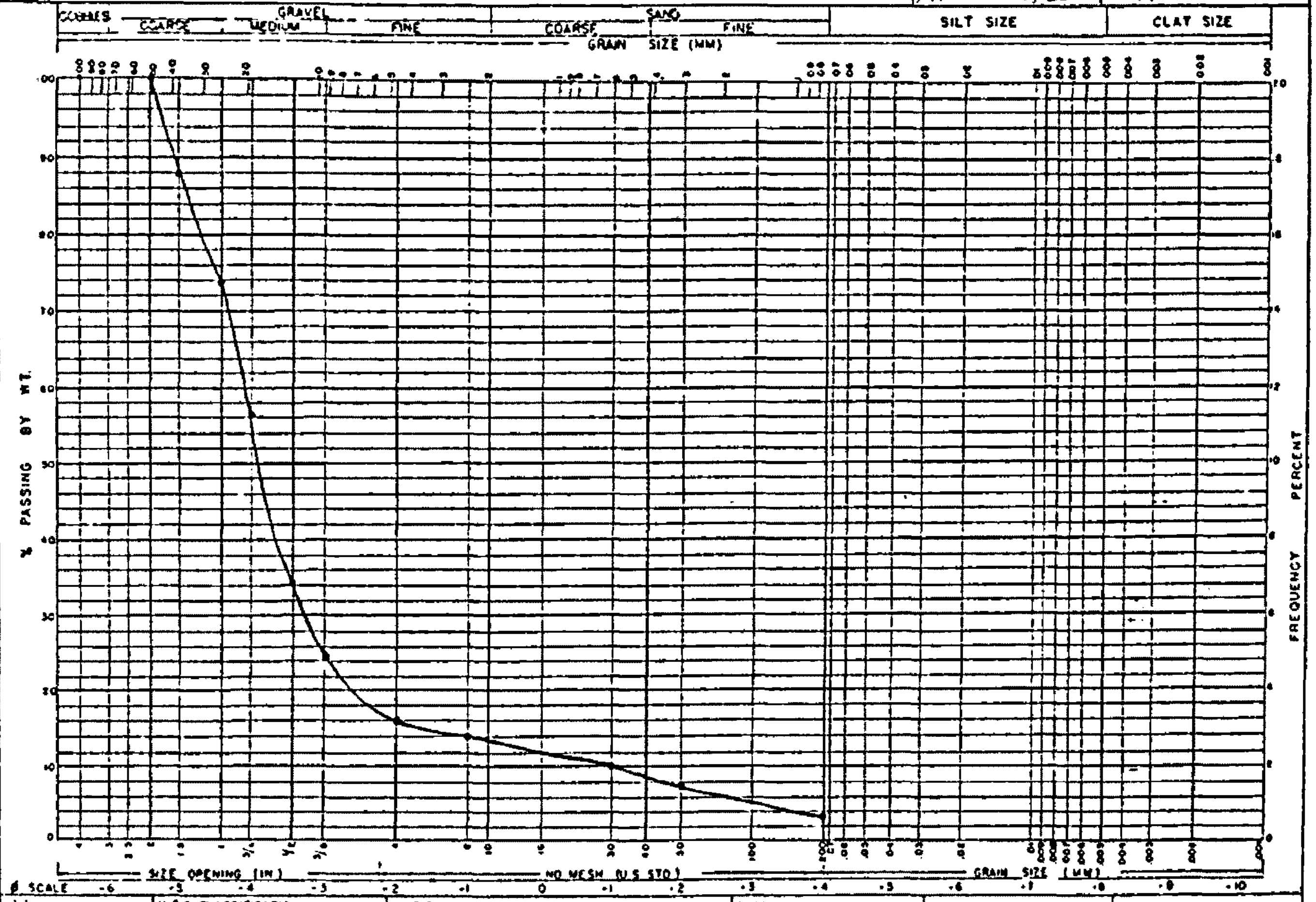
GRAVEL (MW 13) SAMPLE

# REGION I MATERIALS TESTING LABORATORY

## U.S. FOREST SERVICE

## SOIL AGGREGATE GRADING CHART

| | |
|---|---|
| FOREST<br>— | PROJECT<br>IVERSON |
| FIELD SAMPLE NO.<br>GRAVEL | LAB SERIAL NO.<br>— |
| LOCATION<br>RICHLAND, CO. | DATE<br>7/88 |



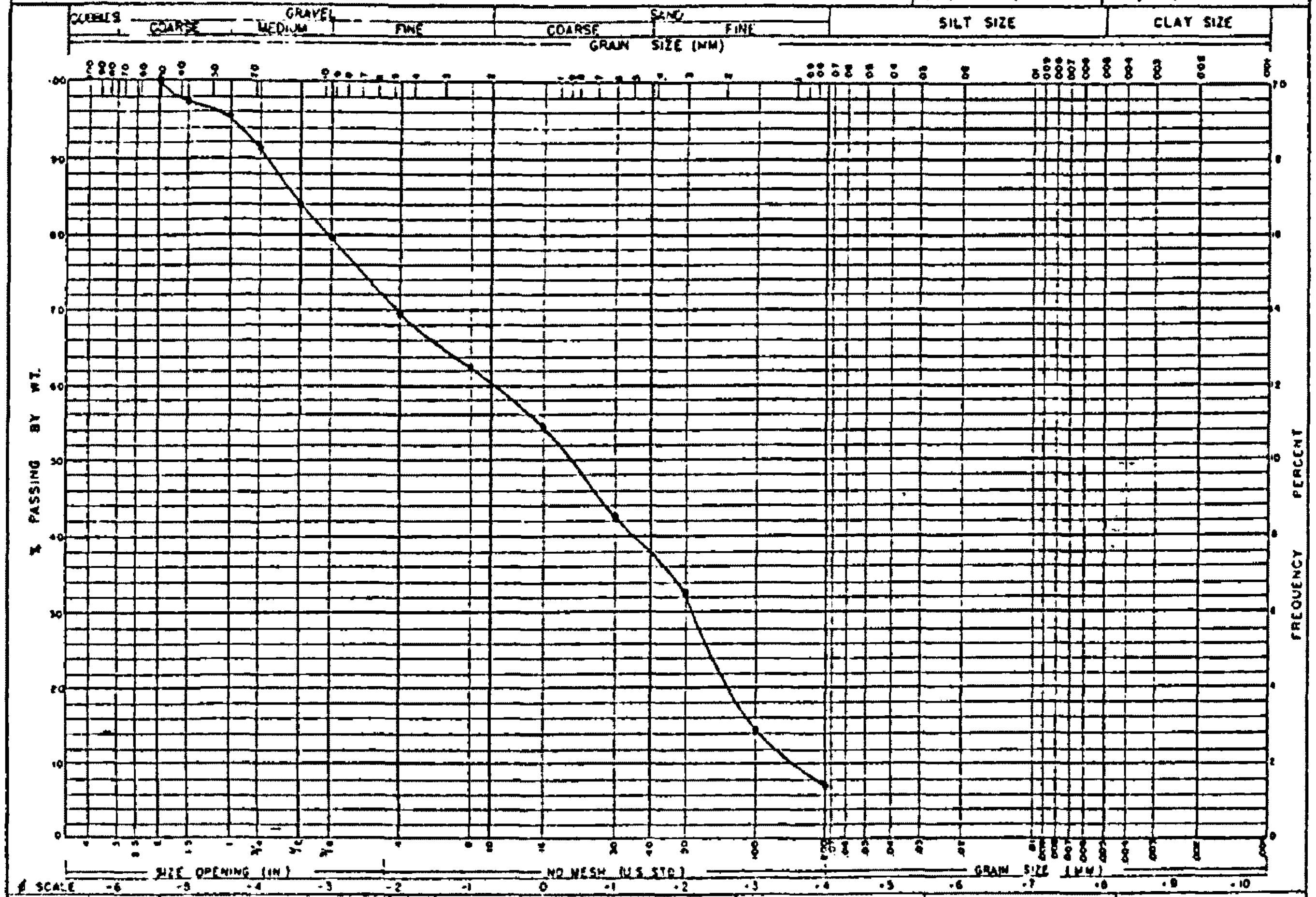
| | | | | | |
|---|---|---|---|---|---|
| LL | H R B CLASSIFICATION | UNIFIED CLASSIFICATION<br>GP | PLOTTED BY<br>SP | CHECKED BY | DATE 11/87 |
| PL | | | | | |

FORM NO. 24-7/00-MTL-13

SAND AND GRAVEL SAMPLE

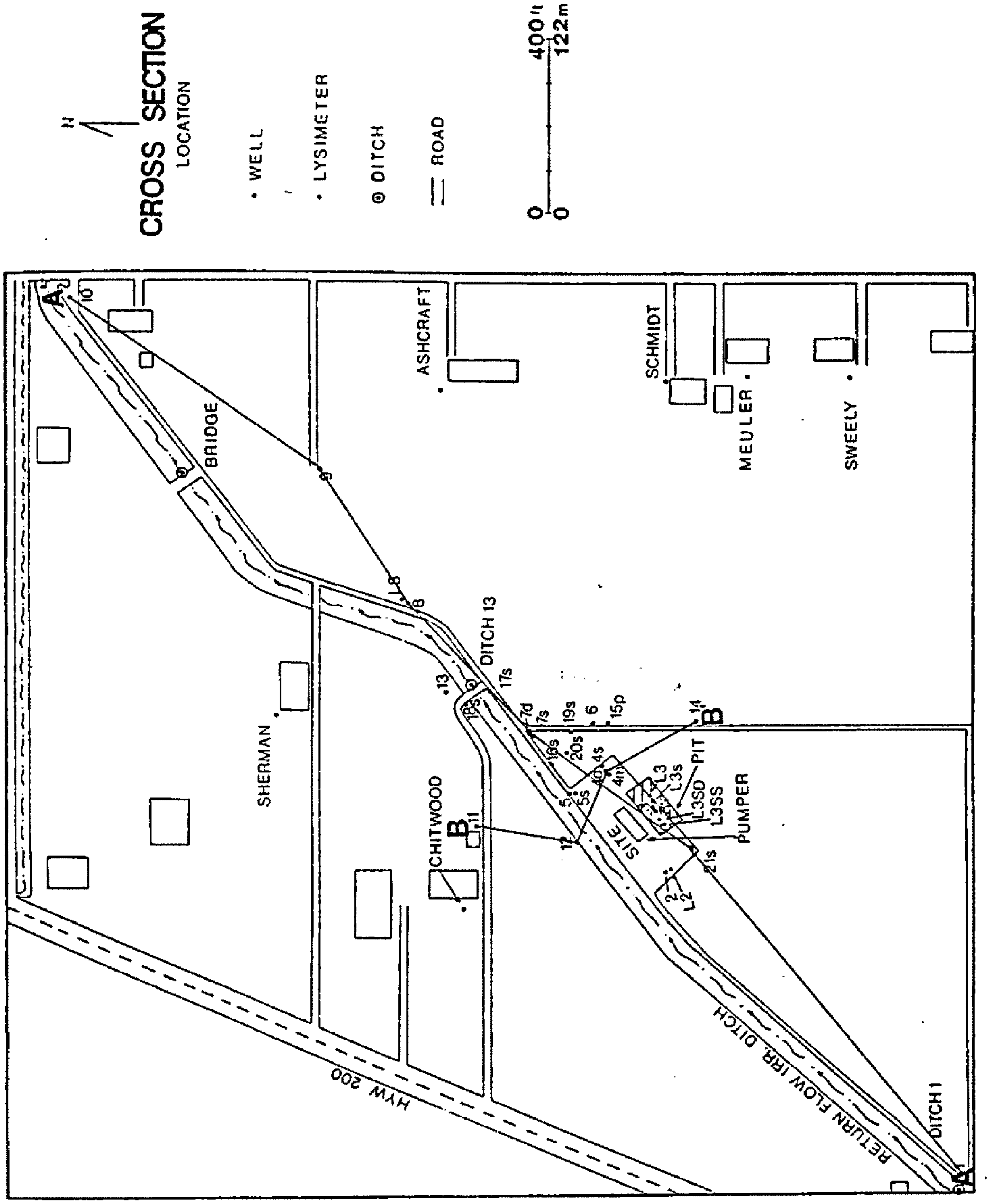
## REGION I MATERIALS TESTING LABORATORY
## U.S. FOREST SERVICE
## SOIL AGGREGATE GRADING CHART

| | |
|---|---|
| FOREST<br>— | PROJECT<br>IVERSON |
| FIELD SAMPLE NO<br>SAND & GRAVEL | LAB SERIAL NO. |
| LOCATION<br>RICHLAND, CO | DATE<br>7/87 |



| | | | | | |
|---|---|---|---|---|---|
| LL<br>PL | H R B CLASSIFICATION | UNIFIED CLASSIFICATION<br>GW & SW | PLOTTED BY<br>SP | CHECKED BY | DATE<br>7/87 |

FORM NO. 24-7/00-MTL-13


N
CROSS SECTION
LOCATION
• WELL
• LYSIMETER
⊙ DITCH
═ ROAD
0 400 ft
0 122 m
A
A'
10
BRIDGE
ASHCRAFT
9
L8
8
DITCH 13
SCHMIDT
MEULER
SWEELY
SHERMAN
.13
18s
17s
7d
7s
19s
6
15p
14
B'
16s
20s
4s
4D
4m
5
5s
L3
L3s
PIT
L3SD
L3SS
PUMPER
SITE
CHITWOOD
B
11
12
21s
2
L2
RETURN FLOW IRR. DITCH
HYW 200
DITCH 1

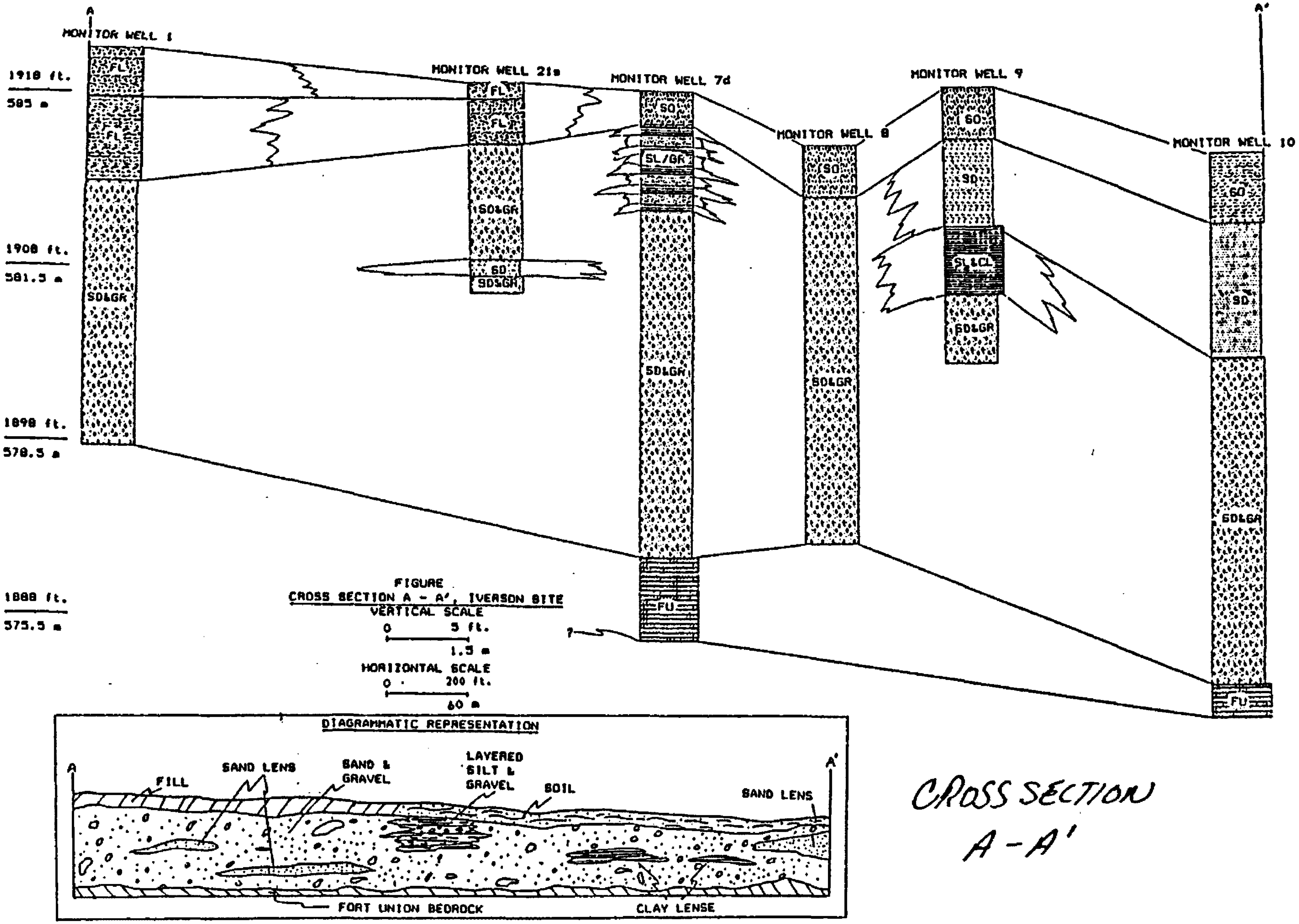


FIGURE
CROSS SECTION A - A', IVERSON SITE

CROSS SECTION
A-A'

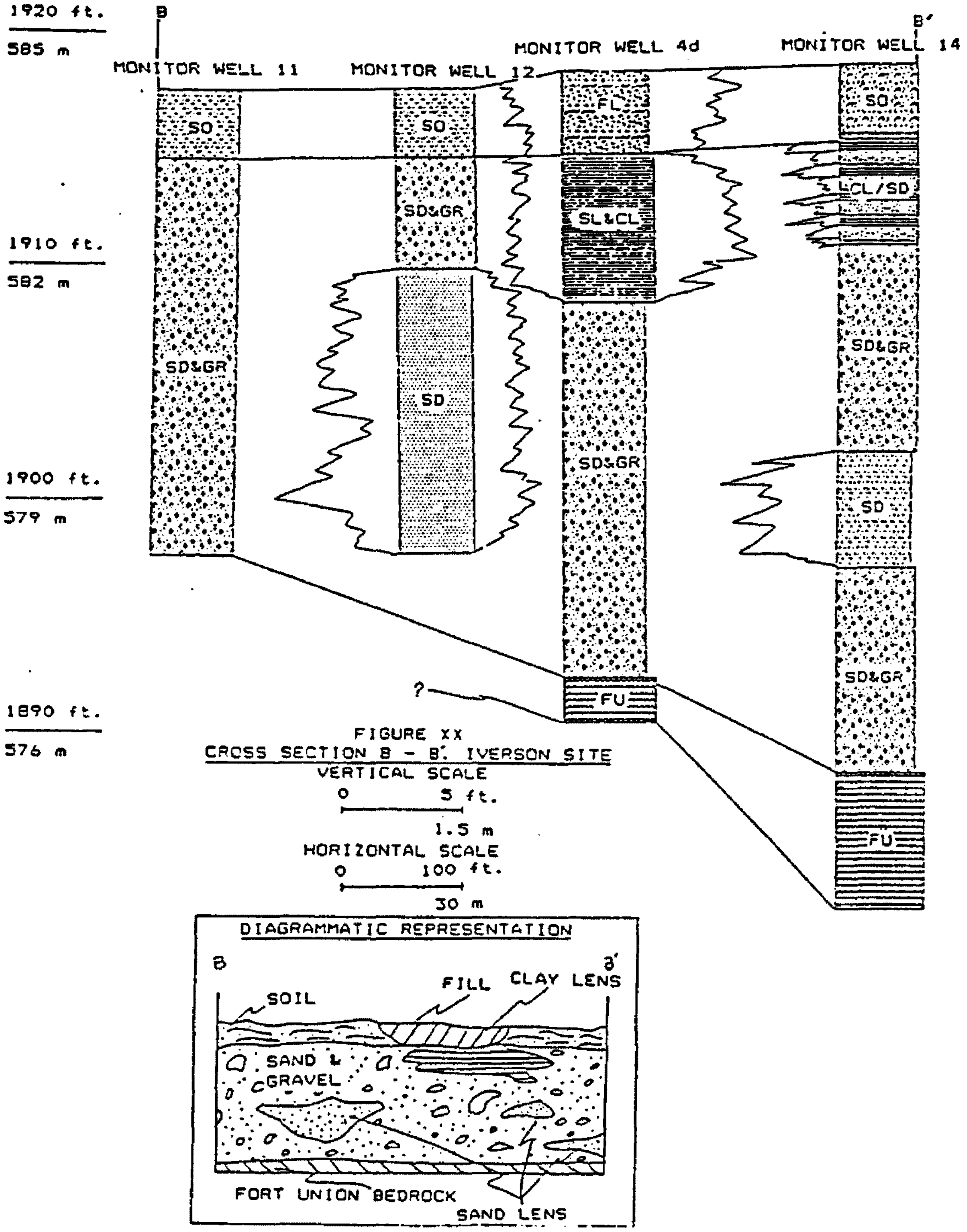


FIGURE XX
CROSS SECTION B - B'. IVERSON SITE

CROSS SECTION B-B'

# APPENDIX E

# QUANTAB DISCUSSION

# 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 in the approximate ranges from .01% (60 ppm $Cl^-$) to saturation of NaCl. QUANTAB Titrators are self-acting and provide recorded objective results which are easy to read and interpret into meaningful answers where monitoring salt concentration is important.

| PRODUCT IDENTIFICATION | APPROXIMATE TITRATION RANGE |
|---|---|
| QUANTAB Chloride Titrator No. 1175 | .01% to 0.08% NaCl<br>60 to 480 ppm. $Cl^-$ |
| QUANTAB Chloride Titrator No. 1176 | .05% to 0.6% $NaCl^-$<br>300 to 3,600 ppm $Cl^-$<br>(With dilution/extraction procedure up to 6.0% NaCl or 36,000 ppm $Cl^-$) |
| QUANTAB Chloride Titrator No. 1177 | 0.6% to 6.4% $NaCl^-$<br>3,600 to 38,400 ppm $Cl^-$<br>(Up to saturation with dilution.) |

APPLICATIONS: The QUANTAB method for measuring chlorides employs a direct interaction of chloride with silver dichromate. Dichromate is a frequently employed indicator for titration of chloride with silver salts.

QUANTAB Chloride Titrators may be used whenever salt (chloride) measurement for control is important.

Listed below are three industries in which QUANTAB is being used successfully:

1. Chemical
2. Food
3. Petroleum

Additional use or application information is available upon request.

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 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.)
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. This usually requires about 20 minutes.
3. Results may be read from 30 seconds to 5 minutes after complete signal color change occurs. (Strip excess fluid out open end to make test result permanent.)

INTERPRETATION OF REACTION

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 on the reverse side.
3. If sample has been diluted, multiply result on calibration table by dilution factor to obtain salt content of sample.

### TECHNICAL

CHEMISTRY: QUANTAB Chloride Titrators consist of a thin, chemically inert plastic strip. Laminated within the strip is a capillary column impregnated with silver dichromate. When QUANTAB Chloride Titrators are placed in aqueous solutions, fluid will rise in the column by capillary action and continue to progress as long as chloride solution enters the column. 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 and the chloride concentration has then been measured as silver chloride. The reaction that takes place in this measurement can be explained by the chemical equation:

$$\underset{\text{(Brown)}}{Ag_2Cr_2O_7} + 2NaCl \longrightarrow Na_2Cr_2O_7 + \underset{\text{(White)}}{2AgCl}$$

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

SPECIFICITY: For the application described, QUANTAB Chloride Titrators are specific for chlorides. Bromides, Iodides, Sulfides, 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.

## PERFORMANCE TIPS

Good Results may be expected using the QUANTAB according to the directions. Occasionally unusual results may occur. The following ideas will help resolve problems which may arise.

| | |
|---|---|
| **Low Results** | Caused by incomplete extraction of salt, plugged wick, variable product.<br>Resolved by more complete mixing, filtering, pin hole in signal (yellow area), and recalibration. |
| **High Results.** | Caused by variable product or over easy extraction.<br>Resolved by recalibration, or using 10% more water for extraction. |
| **Slow Reaction or No Completion.** | Caused by sample plugging, sealed off signal, or compressed wick.<br>Resolved by filtering and/or larger dilution, pin hole in signal, hot water. |
| **Inaccurate High Readings:** | Readings above 7 on the QUANTAB scale will cover a broad, sometimes unacceptable spread.<br>Always read results below 7.0 by choosing appropriate QUANTAB or diluting. |
| **Variable Results** | Non-representative samples or variable product. Be sure sample and mixture are correct. Recalibrate batch. |

If technical questions arise, write or call Venture Systems, Ames Division, Miles Laboratories, Inc., 1127 Myrtle Street, P.O. Box 70 Elkhart, Indiana 46515 U.S.A. Telephone (219) 264-8534

### CALIBRATION TABLE

Be sure control number for table corresponds to bottle label control number. This table is made from representative samples of the batch. Small variations from table may be noted within any batch. For greater accuracy recalibration by user is suggested.

**QUANTAB CHLORIDE TITRATOR** 1176 **CONTROL NO.** 0192119A

Calibration at time of manufacture

| QUANTAB Reading | NaCl in solution as % NaCl | ppm $Cl^-$ mg $Cl^-$/L | QUANTAB Reading | NaCl in solution as % NaCl | ppm $Cl^-$ mg $Cl^-$/L | QUANTAB Reading | NaCl in solution as % NaCl | ppm $Cl^-$ mg $Cl^-$/L |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 0.025 | 148 | 4.0 | 0.189 | 1130 | 7.0 | 0.61 | 3630 |
| 1.2 | 0.032 | 190 | 4.2 | 0.21 | 1230 | 7.2 | 0.65 | 3910 |
| 1.4 | 0.039 | 233 | 4.4 | 0.22 | 1340 | 7.4 | 0.70 | 4220 |
| 1.6 | 0.046 | 279 | 4.6 | 0.24 | 1450 | | | |
| 1.8 | 0.055 | 329 | 4.8 | 0.26 | 1570 | | | |
| 2.0 | 0.064 | 384 | 5.0 | 0.28 | 1700 | | | |
| 2.2 | 0.074 | 441 | 5.2 | 0.31 | 1840 | | | |
| 2.4 | 0.084 | 501 | 5.4 | 0.33 | 1980 | | | |
| 2.6 | 0.094 | 564 | 5.6 | 0.36 | 2140 | | | |
| 2.8 | 0.105 | 630 | 5.8 | 0.38 | 2310 | | | |
| 3.0 | 0.117 | 700 | 6.0 | 0.41 | 2490 | | | |
| 3.2 | 0.130 | 780 | 6.2 | 0.45 | 2680 | | | |
| 3.4 | 0.144 | 860 | 6.4 | 0.48 | 2900 | | | |
| 3.6 | 0.158 | 950 | 6.6 | 0.52 | 3130 | | | |
| 3.8 | 0.173 | 1040 | 6.8 | 0.56 | 3370 | | | |

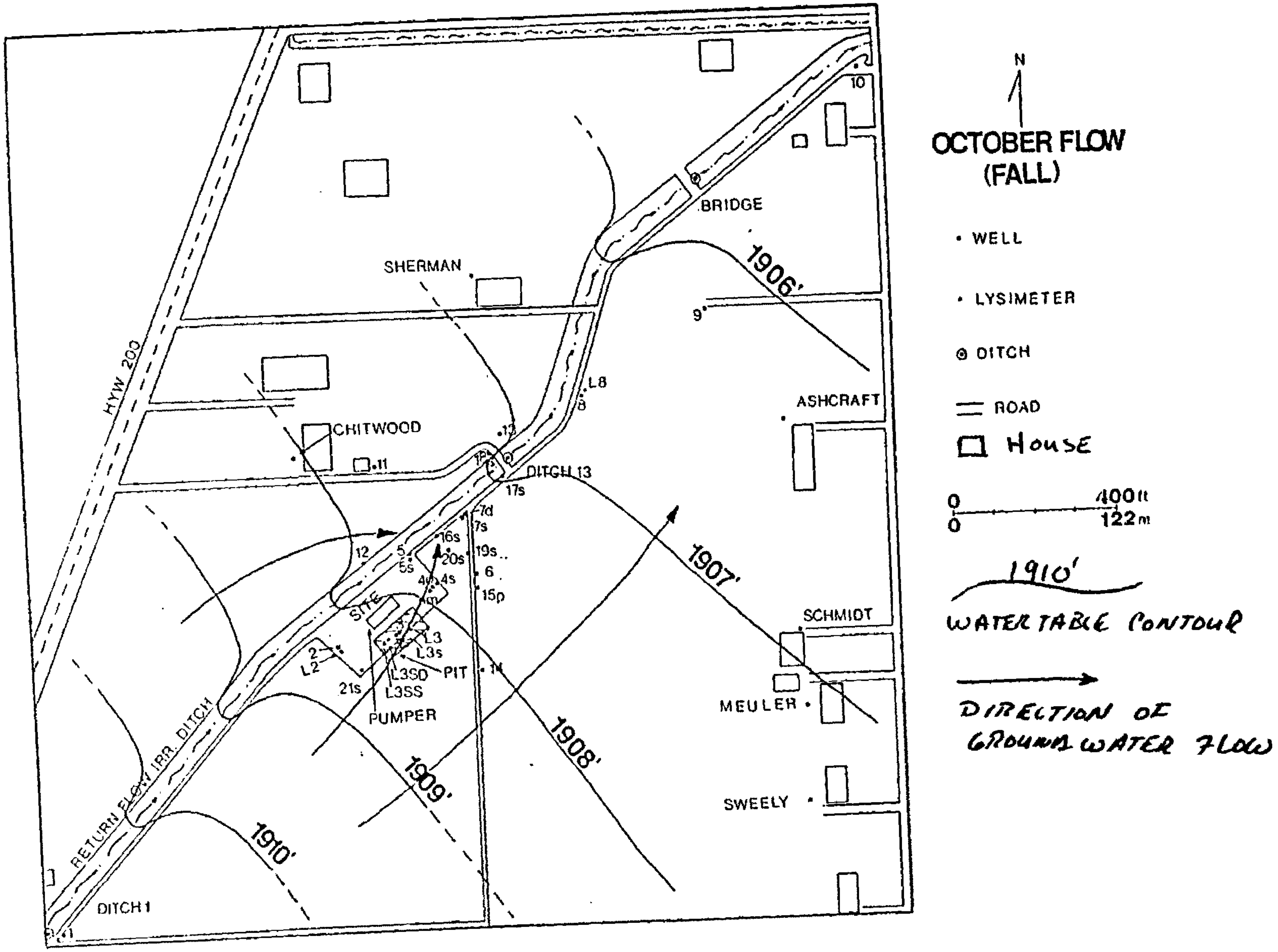
11/15/79

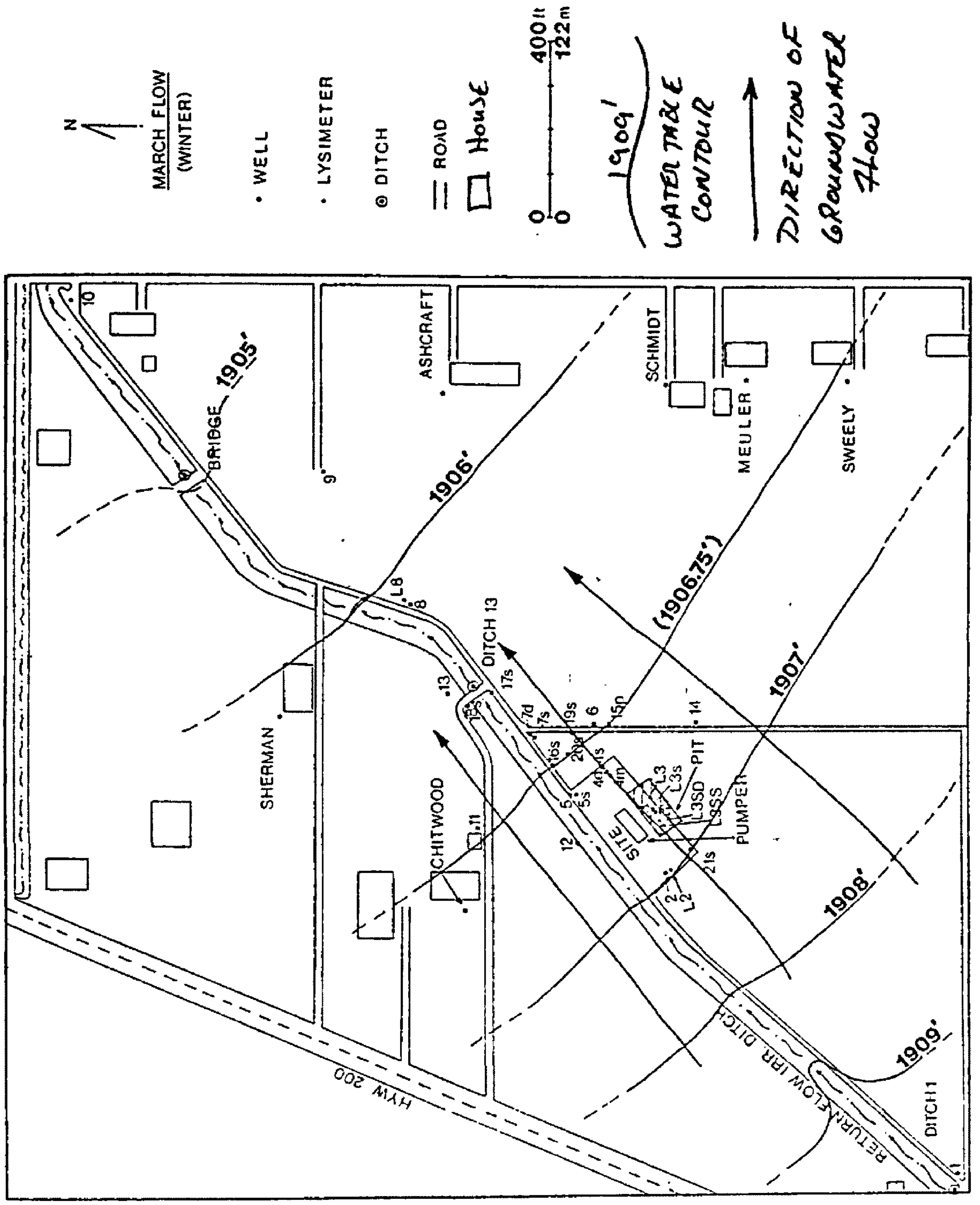
Ames Division MILES

Ames Division, Miles Laboratories, Inc., PO Box 70, Elkhart, Indiana 46515

# APPENDIX F

## FALL AND WINTER GROUND WATER FLOW MAP


OCTOBER FLOW
(FALL)
N
• WELL
• LYSIMETER
⊚ DITCH
ROAD
House
0 400 ft
0 122 m
1910'
WATER TABLE CONTOUR
DIRECTION OF GROUNDWATER FLOW
1906'
1907'
1908'
1909'
1910'
BRIDGE
SHERMAN
CHITWOOD
ASHCRAFT
SCHMIDT
MEULER
SWEELY
HYW 200
RETURN FLOW IRR. DITCH
DITCH 13
DITCH 1
SITE
PIT
PUMPER
L8
L2
L3
L3s
L3SD
L3SS
10
9
8
11
12
13
17s
7d
7s
16s
20s
19s
6
15p
5
5s
4d
4s
4m
14
2
21s


N
MARCH FLOW
(WINTER)
• WELL
• LYSIMETER
⊙ DITCH
═ ROAD
☐ House
0 400ft
0 122m
1909'
WATER TABLE CONTOUR
DIRECTION OF GROUNDWATER FLOW
1905'
1906'
(1906.75')
1907'
1908'
1909'
BRIDGE
ASHCRAFT
SCHMIDT
MEULER
SWEELY
SHERMAN
CHITWOOD
DITCH 13
DITCH 1
SITE
PIT
PUMPER
RETURN FLOW IRR DITCH
HWY 200
10
9
L8
8
13
15s
17s
7d
7s
19s
6
15D
14
16s
20s
4s
4D
4m
L3
L3s
L3SD
L3SS
5
5s
12
11
21s
2
L2
1

# APPENDIX G

## CLIMATE DATA

CLIMATE DATA FOR THE SIDNEY AREA (MONTANA STATE UNIVERSITY EXPERIMENT STATION)

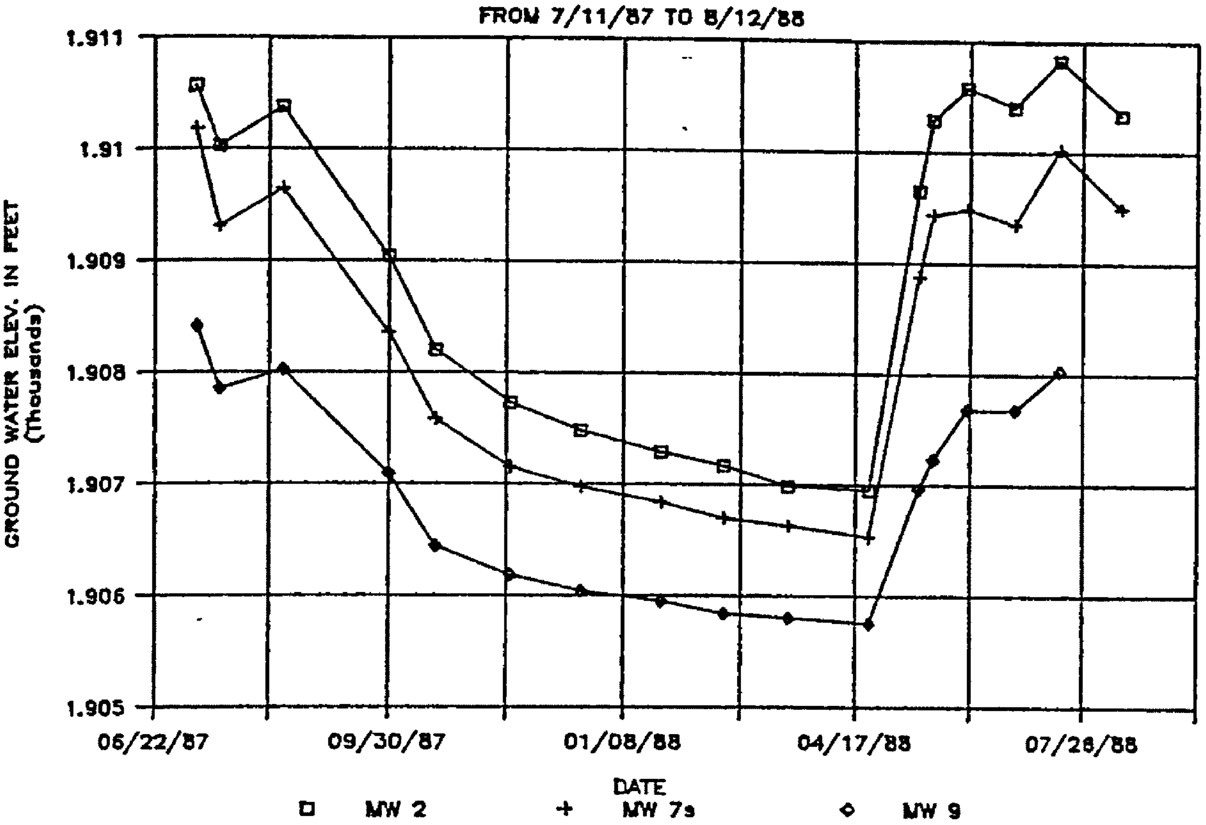
| | (F) | (C) | (F) | (C) | (F) | (C) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| DATE | AV.MAX T | | AV.MIN T | | AVERG. T | | INCH PPT | (cm) | INCH EVP | (cm) |
| Jun-87 | 84.6 | 29.22221 | 53 | 11.66666 | 68.9 | 20.49999 | 4.02 | 10.21075 | 7.71 | 19.58332 |
| Jul-87 | 85.9 | 29.94444 | 56.7 | 13.72222 | 71.3 | 21.83333 | 2.87 | 7.289770 | 6.14 | 15.59553 |
| Aug-87 | 80.5 | 26.94444 | 51.4 | 10.77777 | 66 | 18.99999 | 0.97 | 2.463790 | 5.11 | 12.97934 |
| Sep-87 | 77 | 24.99999 | 43.3 | 6.277777 | 60.2 | 15.66666 | 0.92 | 2.336790 | 3.59 | 9.118563 |
| Oct-87 | 60.3 | 15.72222 | 31 | -0.55555 | 45.7 | 7.611110 | 0.1 | 0.253998 | 2.63 | 6.680173 |
| Nov-87 | 50.2 | 10.11111 | 24.2 | -4.33333 | 37.2 | 2.888888 | 0.21 | 0.533397 | | |
| Dec-87 | 37.3 | 2.944444 | 15.1 | -9.38888 | 26.2 | -3.22222 | 0.05 | 0.126999 | | |
| Jan-88 | 25.1 | -3.83333 | -1.1 | -18.3888 | 12 | -11.1111 | 0.56 | 1.422394 | | |
| Feb-88 | 32.9 | 0.499999 | 5.8 | -14.5555 | 19.3 | -7.05555 | 0.49 | 1.244595 | | |
| Mar-88 | 51.4 | 10.77777 | 22.8 | -5.11111 | 37.1 | 2.833333 | 0.58 | 1.473194 | | |
| Apr-88 | 67.6 | 19.77777 | 28.6 | -1.88888 | 48.1 | 8.944443 | 0.17 | 0.431798 | 4.97 | 12.6238 |
| May-88 | 82.1 | 27.83333 | 46.4 | 7.999999 | 64.2 | 17.88888 | 0.79 | 2.006591 | 8.24 | 20.9296 |
| Jun-88 | 94.7 | 34.83332 | 61.4 | 16.33333 | 78.1 | 25.61110 | 1.27 | 3.225787 | 10.44 | 26.5176 |

# APPENDIX H

# ANNUAL WATER TABLE FLUCTUATION

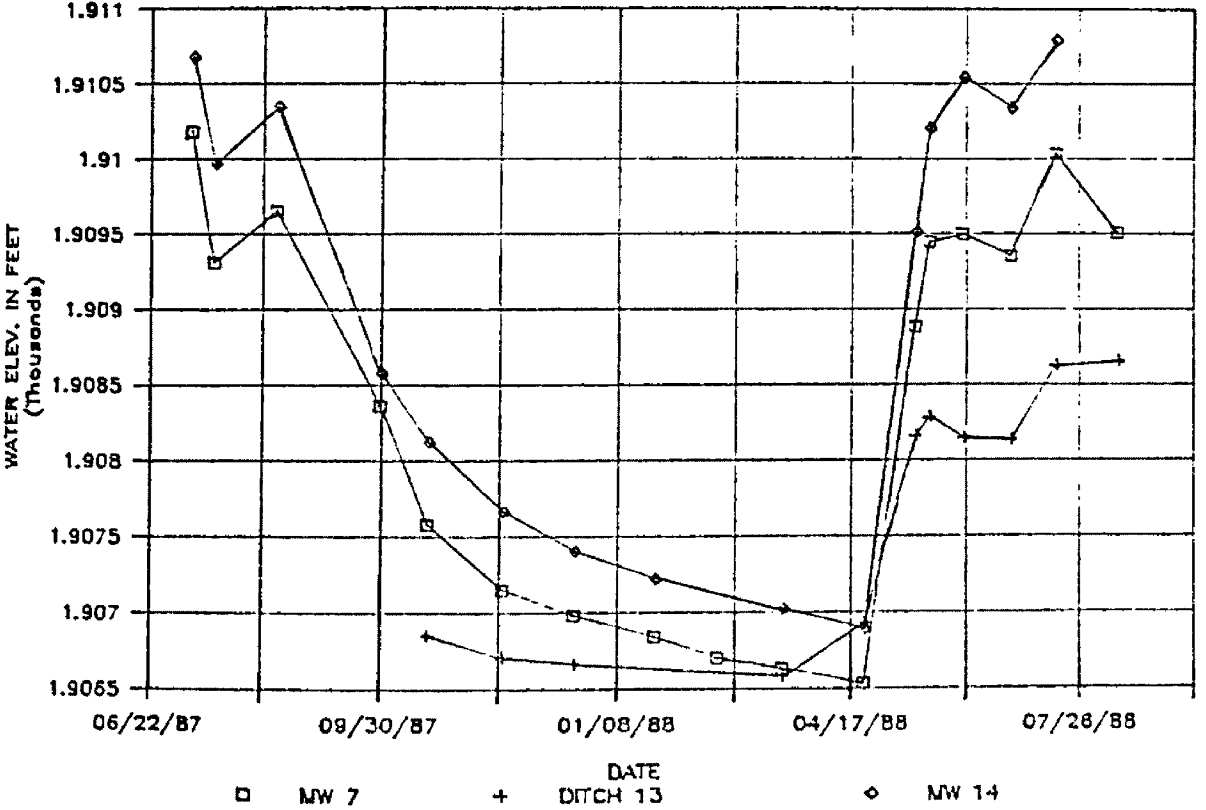
COMPARISON OF ANNUAL WL IN THREE WELLS

FROM 7/11/87 TO 8/12/88



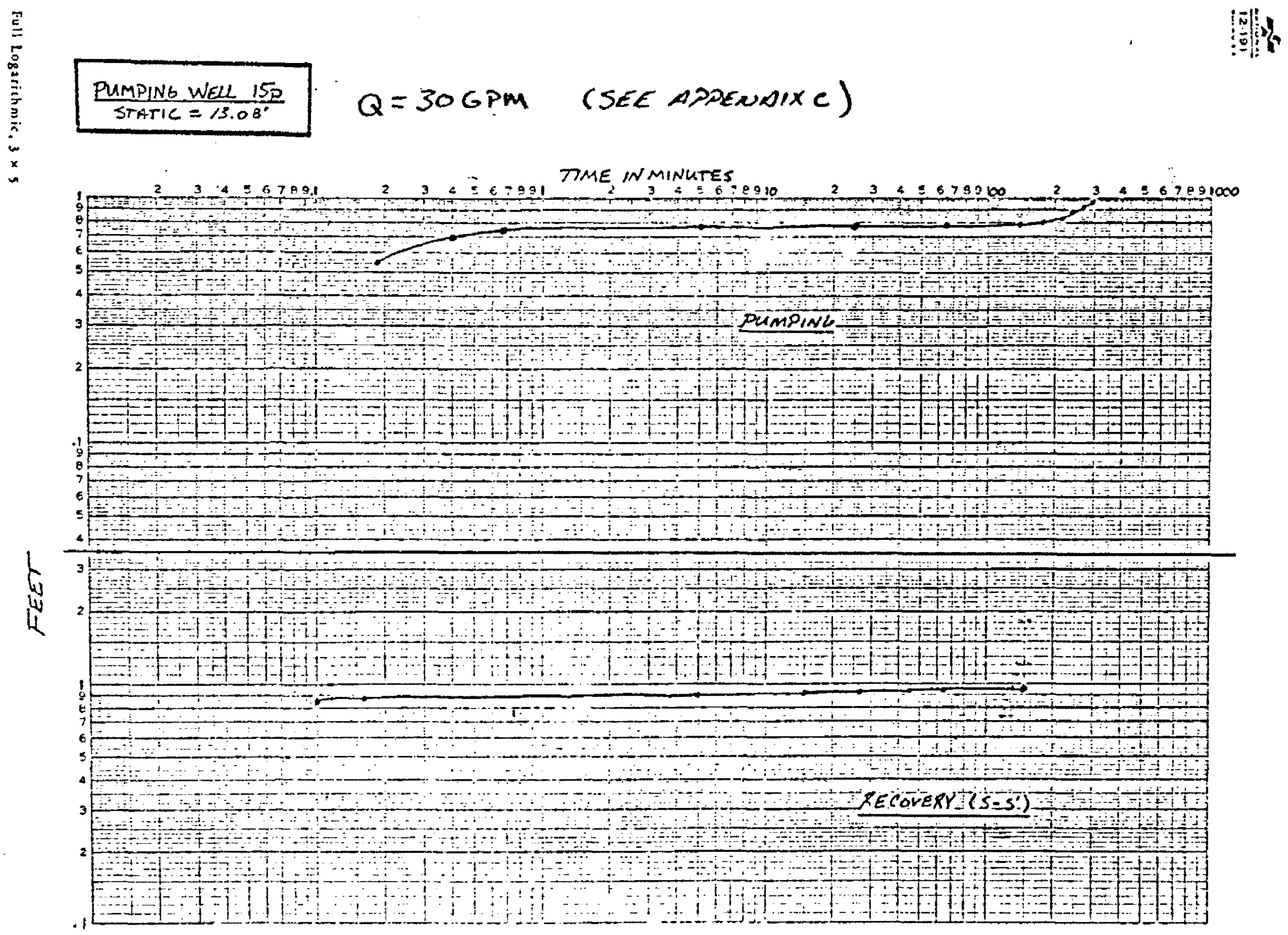
COMPARISON OF DITCH WL AND WELL WL

FROM 7/11/87 TO 8/12/88



# APPENDIX I

# AQUIFER TEST DRAWDOWN AND RECOVERY

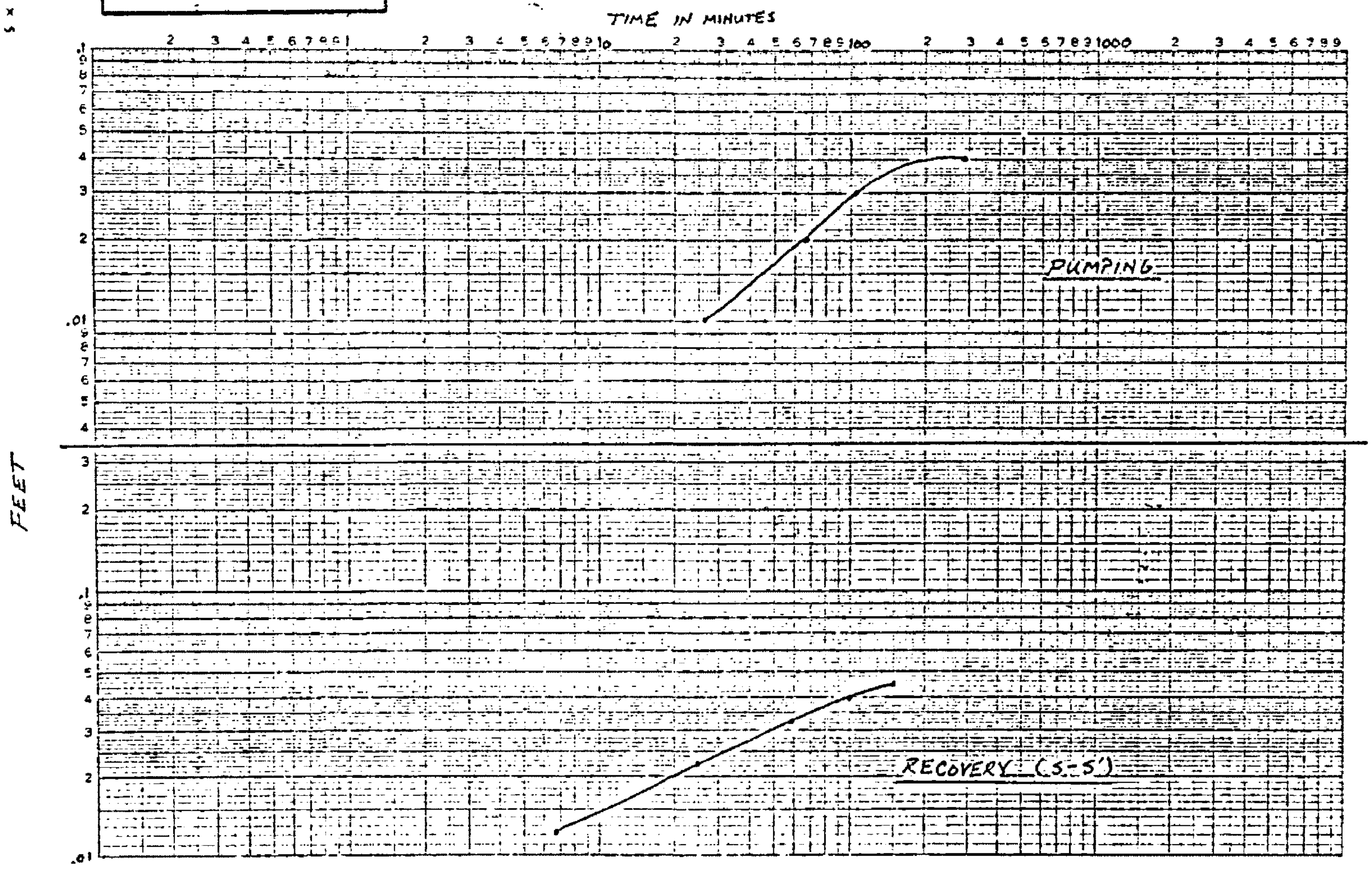


"Page 122 omitted in numbering."

12-191

MONITOR WELL 19s
STATIC = 13.16'

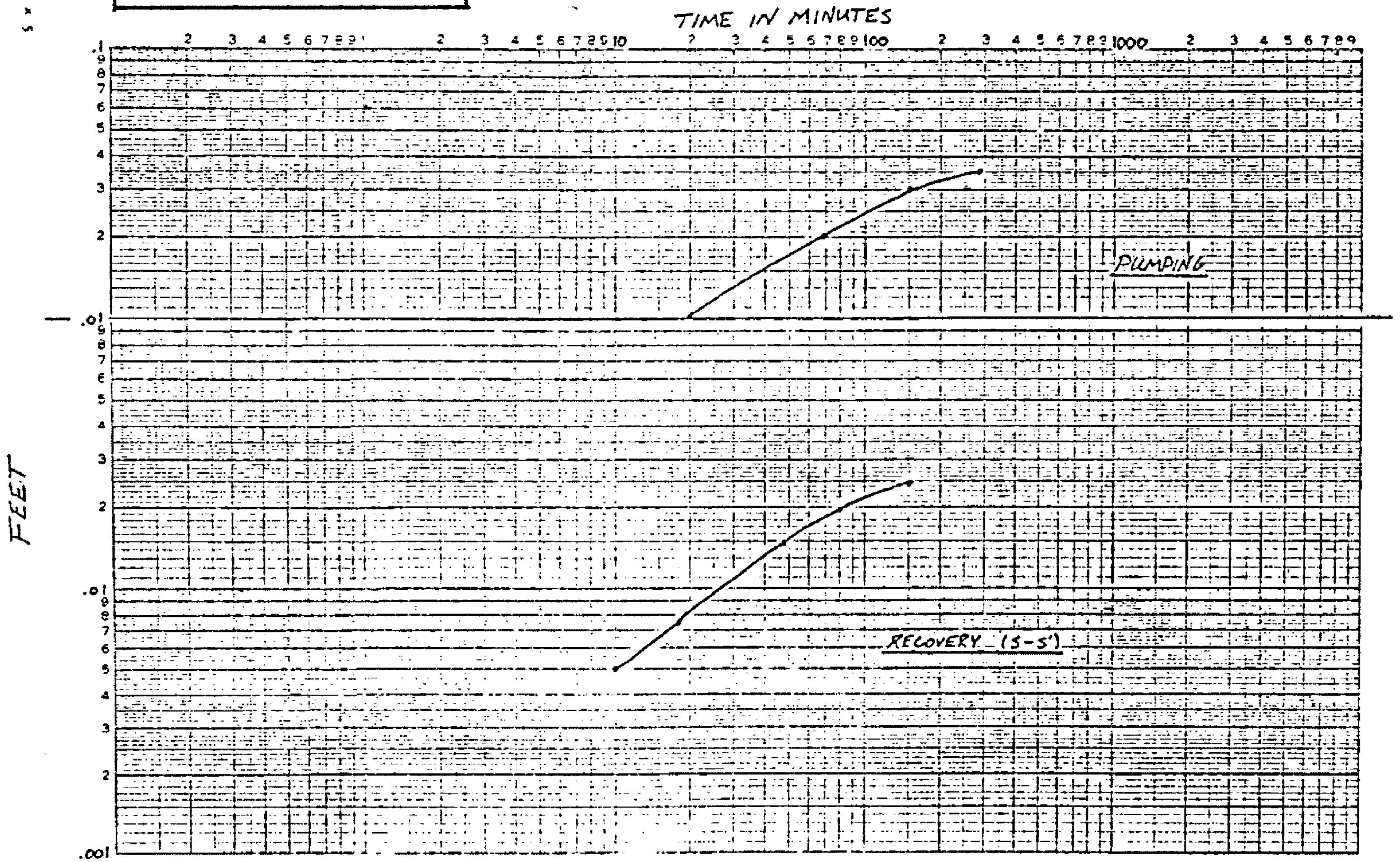
r = 82 ft.



Full Logarithmic, 3 × 5

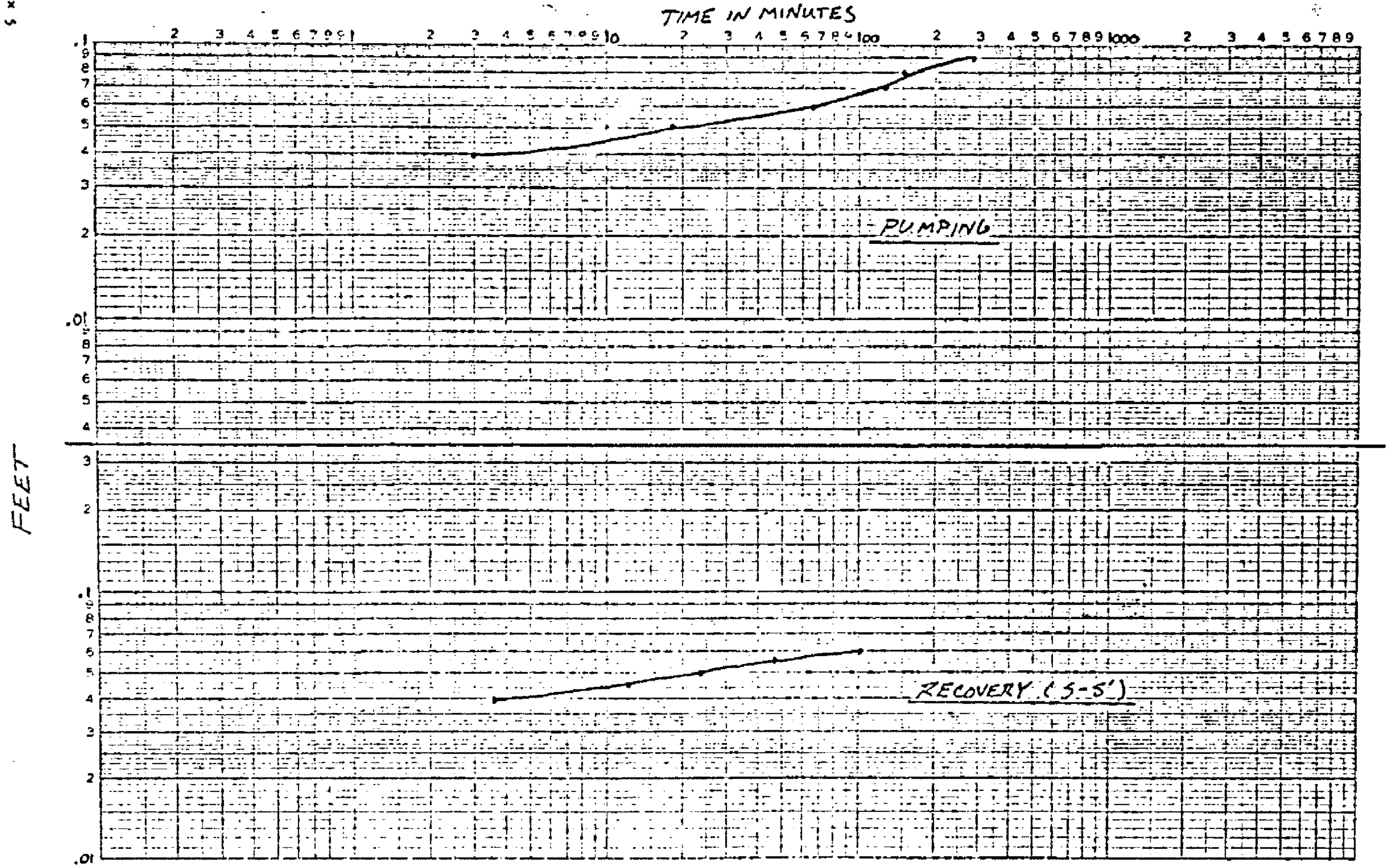
MONITOR WELL 20s
STATIC = 13.325'

r = 118 ft.



MONITOR WELL 6
STATIC = 13.52'

r = 35 ft.



# APPENDIX J

# FIELD DATA

QUANTAB RESULTS OF ppm Cl IN WATER AT THE IVERSON SITE, RICHLAND, CO.

| Well # DATE | 07/11/87 | 07/21/87 | 08/17/87 | 10/20/87 | 11/22/87 | 12/19/87 | 01/23/88 | 02/21/88 | 03/20/88 | 04/23/88 | 05/24/88 | 06/26/88 | 08/12/88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | <36 | <36 | | | | | | | 50 | | <50 | |
| 2 | | <36 | <36 | | <34 | | | | | | | <50 | 30 |
| 21 | | | | | | | 41 | | | 34 | <34 | <50 | |
| 3 | | 2447 | 2784 | 365 | | | | 34 | 60 | 50 | | 74 | |
| 3s | | | | 61 | <34 | | | | | | 1154 | 547 | 1212 |
| 4s | | 1330 | 1279 | 750 | | | | | | | 658 | 875 | 740 |
| 4d | | 126 | 36 | | 34 | | | | | 50 | | <50 | |
| 4m | | 650 | 875 | 89 | 61 | 47 | 41 | 41 | 47 | 50 | | <50 | |
| 5 | | <36 | 52 | | 34 | | | 41 | | 50 | | <50 | |
| 5s | | | | 174 | 170 | | | | | 293 | 34 | 101 | |
| 6 | | <36 | <36 | | <34 | | | | | 34 | | <50 | |
| 16 | | | | 703 | 799 | | 703 | 547 | 415 | 340 | 456 | 436 | |
| 20 | | | | 750 | 547 | 425 | 425 | 365 | 277 | 241 | | | |
| 19 | | | | 88 | 81 | 41 | | 54 | 54 | 81 | 47 | 60 | |
| 15 | | | | <36 | <34 | | | | | | | <50 | |
| 7s | | 152 | 143 | 192 | 170 | 152 | 61 | 101 | 97 | 101 | 61 | 60 | |
| 7d | | 58 | 47 | | 81 | | | | | 61 | | <50 | |
| 17 | | | | 110 | 142 | 54 | | 111 | 111 | 142 | <34 | <50 | |
| 18 | | | | 115 | 122 | | | | | 87 | <34 | <50 | |
| 8 | | <36 | 36 | | | | | 47 | 55 | 60 | <34 | <50 | |
| 9 | | <36 | <36 | | | | | | | <34 | | <50 | |
| 10 | | <36 | <36 | | | | | | | | | <50 | |
| 11 | | <36 | <36 | | 34 | | | | | 50 | | | |
| 12 | | <<36 | <36 | | | | | | | 34 | | <50 | |
| 13 | | 53 | 53 | | 111 | | | 54 | 54 | | | <50 | |
| 14 | | <<36 | <36 | | | | | | | <34 | | <50 | |
| ASHCRAFT | | <<36 | <36 | | | | | | | | | | |
| SCHMIDT | | | | | | | | | | | | | |
| MEULER | | 93 | 79 | | | | | | | | | | |
| SWEELY | | <<36 | <36 | | | | | | | <34 | | <50 | |
| LOMAN | | <36 | | | | | | | | | | | |
| SHERMAN | | | | | | | | | | | | | |
| CHITWOOD | | <<36 | <36 | | | | | | | | | | |
| L2 | | >6000 | >6000 | >6000 | | | | | | | | | |
| L3s | | >6000 | >6000 | | | | | | | | | | |
| L3 | | >6000 | >6000 | | | | | | | >6000 | | | |
| L8 | | <36 | <<36 | | | | | | | | | | |
| DITCH 13 | | <<36 | <36 | | <34 | <34 | | | <34 | | | <50 | 30 |
| DITCH 1 | N/A | | <35 | <36 | <34 | 41 | <34 | | <34 | <34 | | <50 | |

CONDUCTANCE OF WATER IN umhos/cm AT THE IVERSON SITE, RICHLAND, CO. (CORRECTED TO 25°C)

| Well # DATE | 07/11/87 | 07/21/87 | 08/17/87 | 10/20/87 | 11/22/87 | 12/19/87 | 01/23/88 | 02/21/88 | 03/20/88 | 04/23/88 | 05/24/88 | 06/26/88 | 08/12/88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1600 | 1597 | 1597 | 1563 | | | | | | 1085 | | 743 | |
| 2 | 925 | 1146 | 1061 | 1137 | 1006 | | | | | | | 999 | 823 |
| 21 | | | | 1100 | 1089 | | 939 | | | 1026 | 1008 | 1037 | |
| 3 | 5250 | 6215 | 9914 | 2213 | | | | 944 | 1057 | 1053 | (4181) | 1135 | 942 |
| 3s | | | | 1381 | 1173 | | | | | | 4181 | 2351 | 3159 |
| 4s | 6000 | 4635 | 4770 | 3245 | | | | | | | 2741 | 3206 | 2759 |
| 4d | 1450 | 1631 | 1349 | 1379 | 1286 | | | | | 1178 | | 1250 | |
| 4a | 3000 | 3087 | 2788 | 1519 | 1289 | 1221 | 1209 | 1082 | 1095 | 1056 | (2741) | 1215 | |
| 5 | 900 | 1272 | 1309 | 1355 | 1242 | | | 1111 | | 1187 | | 987 | |
| 5s | | | | 1672 | 1570 | | | | | 1497 | 947 | 1305 | 1262 |
| 6 | 1075 | 1461 | 1199 | 1192 | 1170 | | | | | 1082 | | 990 | |
| 16 | | | | 3315 | 3317 | | 2324 | 2339 | 1989 | 1729 | 2401 | 2284 | 1878 |
| 20 | | | | 3528 | 2311 | 1999 | 1844 | 1910 | 1635 | 1655 | | | |
| 19 | | | | 1417 | 1296 | 1117 | | 1149 | 1170 | 1193 | 1196 | 1129 | 942 |
| 15 | | | | 1170 | 1061 | | | | | | | 671 | |
| 7s | 1500 | 1679 | 1730 | 1691 | 1683 | 1401 | 1290 | 1294 | 1237 | 1285 | 1121 | 1174 | 845 |
| 7d | | 1288 | 1317 | 961 | 1372 | | | | | 1088 | | 1223 | |
| 17 | | | | 1467 | 1479 | 1346 | | 1307 | 1298 | 1302 | 746 | 807 | 811 |
| 18 | | | | 1623 | 1593 | | | | | 1254 | 927 | 1099 | |
| 8 | 1200 | 1127 | 1220 | 1265 | 1157 | | | 1114 | 1146 | 1207 | 1031 | 456 | |
| 9 | 1100 | 1051 | 1127 | 1209 | 1115 | | | | | 1069 | | 711 | |
| 10 | 950 | 883 | 1021 | 1105 | 1041 | | | | | | | 1095 | |
| 11 | 1300 | 1311 | 1541 | 1644 | 1485 | | | | | 1363 | | | |
| 12 | 810 | 672 | 1145 | 1226 | 1257 | | | | | 1190 | | 1012 | |
| 13 | 1200 | 1200 | 1433 | 1392 | 1481 | | | 1017 | 1174 | | | 1050 | |
| 14 | 900 | 710 | 867 | 1125 | 1086 | | | | | 1045 | | 1000 | |
| ASHCRAFT | | 834 | 914 | | | | | | | | | | |
| SCHMIDT | | | 723 | 536 | 487 | | | | | | | | |
| MEULER | | 1525 | 1534 | | | | | | | | | | |
| SHEELY | | 814 | 962 | 1044 | 990 | | | | | 937 | | 896 | |
| LOMAN | | 918 | | | | | | | | | | | |
| SHERMAN | | | | | | | | | | | | | |
| CHITWOOD | | 1302 | 1372 | 1523 | 1542 | | | | | | | | |
| L2 | | 15994 | 29997 | | | | | | | | | | |
| L3s | | >50000 | | | | | | | | | | | |
| L3 | | >50000 | >50000 | | >50000 | | | | | >50000 | | | |
| L8 | | 3720 | 3100 | | | | | | | | | | |
| DITCH 13 | | 946 | 904 | 1458 | 1739 | 1182 | | | 1085 | | | 836 | 735 |
| DITCH 1 | | | 877 | 1521 | 1413 | 1681 | 1142 | | 1012 | 861 | | 759 | |

TEMPERATURE OF WATER IN CENTIGRADE AT THE IVERSON SITE. RICHLAND, CO.

| Well # DATE | 07/11/87 | 07/21/87 | 08/17/87 | 09/25/87 | 10/20/87 | 11/22/87 | 12/19/87 | 01/23/88 | 02/21/88 | 03/20/88 | 04/23/88 | 05/24/88 | 06/26/88 | 08/12/88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 14.4 | 12.9 | 14.8 | | 12.5 | | | | | | 7.1 | | 16 | |
| 2 | 10.0 | 10.9 | 12.2 | | 9.5 | 6.5 | | | | | | | 13.9 | 16.9 |
| 21 | | | | | 10.5 | 8.9 | | 9.9 | | | 8 | 11.9 | 13.9 | |
| 3 | 15.6 | 13.0 | 14.2 | | 12 | | | | 5.9 | 6.9 | 7.9 | | 15.9 | 16.9 |
| 3s | | | | | 12 | 9 | | | | | | 11.9 | 15.1 | 16.1 |
| 4s | 12.8 | 13.2 | 15.0 | | 12 | | | | | | | 13.3 | 13.5 | 15.9 |
| 4d | 12.8 | 10.8 | 13.8 | | 10.5 | 9.1 | | | | | 7.9 | | 11.9 | |
| 4m | 17.8 | 11.8 | 12.8 | | 10.5 | 9 | 11.1 | 11.5 | 7.1 | 7 | 8 | | 13.5 | |
| 5 | 11.1 | 12.9 | 13.8 | | 10 | 9.1 | | | 6.1 | | 8.1 | | 11.1 | |
| 5s | | | | | 10.5 | 9.2 | | | | | 8 | 11.1 | 12.3 | 14.9 |
| 6 | 11.7 | 12.4 | 12.5 | | 11 | 9.1 | | | | | 7.1 | | 13.2 | |
| 16 | | | | | 10.5 | 9 | | 11 | 5 | 8.9 | 8.9 | 11.1 | 13.1 | 15.1 |
| 20 | | | | | 10 | 9.1 | 10.1 | 10.1 | 5.9 | 6.9 | 7.9 | | | |
| 19 | | | | | 11 | 9.1 | 10.9 | | 6.9 | 7.5 | 7.9 | 10.1 | 15.2 | 16.9 |
| 15 | | | | | 10.5 | 9.9 | | | | | | | 15.9 | |
| 7s | 11.7 | 12.9 | 12.0 | | 11 | 9.9 | 9.9 | 8.1 | 6.9 | 7 | 9.1 | 10.9 | 12.9 | 17 |
| 7d | | 12.4 | 11.1 | | 10.5 | 9.1 | | | | | 6.9 | | 11.9 | |
| 17 | | | | | 11.5 | 8.2 | 8.2 | | 5 | 7 | 6.9 | 15.1 | 17.1 | 18.1 |
| 18 | | | | | 12 | 9 | | | | | 6.5 | 13.1 | 15.9 | |
| 8 | 14.4 | 13.9 | 12.9 | | 11 | 10 | | | 6 | 7 | 7 | 11 | 18.9 | |
| 9 | 22.2 | 13.1 | 13.9 | | 11.5 | 10 | | | | | 7 | | 17.9 | |
| 10 | 13.9 | 13.9 | 13.0 | | 11.8 | 8 | | | | | | | 15.1 | |
| 11 | 12.2 | 12.1 | 12.9 | | 11.1 | 9.9 | | | | | 6.9 | | | |
| 12 | 11.1 | 12.7 | 13.9 | | 10.5 | 9.1 | | | | | 8 | | 14.9 | |
| 13 | 23.9 | 14.0 | 16.1 | | 11.5 | 8.9 | | | 8.9 | 6.1 | | | 15.9 | |
| 14 | 12.2 | 16.5 | 15.0 | | 13 | 11 | | | | | 6.9 | | 14.9 | |
| ASHCRAFT | | 11.9 | 12.5 | | | | | | | | | | | |
| SCHMIDT | | | 15.0 | | 13 | 11.1 | | | | | | | | |
| MEULER | | 14.2 | 14.3 | | | | | | | | | | | |
| SWEELY | | 14.8 | 16.0 | | 13.6 | 9.9 | | | | | 6.8 | | 15.1 | |
| LOMAN | | 15.8 | | | | | | | | | | | | |
| SHERMAN | | | | | | | | | | | | | | |
| CHITWOOD | | 24.9 | 19.1 | | 11.1 | 9.9 | | | | | | | | |
| L2 | | 17.0 | 20.0 | | | | | | | | | | | |
| L3s | | 18.2 | 20.5 | | | | | | | | | | | |
| L3 | | 16.7 | 17.0 | | | 5.2 | | | | | | | | |
| L8 | | 18.0 | | | | | | | | | | | | |
| DITCH 13 | | 16.7 | | | 8.5 | 6 | 3.9 | | | 7 | | | 15.1 | 21.1 |
| DITCH 1 | | | 15.1 | | 9 | 6 | 3.9 | 5.1 | | 4 | 12.5 | | 23.1 | |

## pH OF WATER AT THE IVERSON SITE, RICHLAND, CO.

| Well # DATE | 07/11/87 | 07/21/87 | 08/17/87 | 09/25/87 | 10/20/87 | 11/22/87 | 12/19/87 | 01/23/88 | 02/21/88 | 03/20/88 | 04/23/88 | 05/24/88 | 06/26/88 | 08/12/88 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | 7.7 | | 6.9 | | | | | | 7.1 | | | |
| 2 | | | 5.3 | | 7 | 6.89 | | | | | | | | |
| 21 | | | | | 7 | 6.7 | | 7.1 | | | 7.5 | | | |
| 3 | | | 6.8 | | 7.2 | | | | 6.4 | 6.9 | 7.1 | | | |
| 3s | | | | | 6.8 | 6.1 | | | | | | | | |
| 4s | | | 4.5 | | 6.8 | | | | | | | | | |
| 4d | | | 6.7 | | 7.3 | 7 | | | | | 7.3 | | | |
| 4a | | | 4.8 | | 7.3 | 6.4 | 7.49 | 7.1 | 6.8 | 7.2 | 7.3 | | | |
| 5 | | | 6 | | 7.1 | 7.2 | | | 7.2 | | 7.3 | | | |
| 5s | | | | | 7 | 6.8 | | | | | 7.2 | | | |
| 6 | | | 6.3 | | 7.1 | 7.1 | | | | | 7.1 | | | |
| 16 | | | | | 7.3 | 7 | | 6.8 | 6.9 | 7.4 | 7.4 | | | |
| 20 | | | | | 7.3 | 7 | 7.41 | | 6.7 | 6.6 | 7.1 | | | |
| 19 | | | | | 7.1 | 6.9 | 6.6 | | 6.8 | 6.9 | 7.1 | | | |
| 15 | | | | | 7.2 | 7.2 | | | | | | | | |
| 7s | | | 4.9 | | 7.2 | 7.2 | 6.9 | 7.1 | 6.8 | 6.7 | 7.1 | | | |
| 7d | | | 5.5 | | 7.4 | 7.5 | | | | | 7.9 | | | |
| 17 | | | | | 7.1 | 7.1 | 6.9 | | 6.8 | 7 | 7.2 | | | |
| 18 | | | | | 7.2 | 7.3 | | | | | 7.4 | | | |
| 8 | | | 5.3 | | 7.2 | 6.7 | | | 7.1 | 7.1 | 7.3 | | | |
| 9 | | | 7.5 | | 7.15 | 6.9 | | | | | 7.3 | | | |
| 10 | | | 7.3 | | 7.2 | 6.8 | | | | | | | | |
| 11 | | | 5.5 | | 7.2 | 6.9 | | | | | 7.2 | | | |
| 12 | | | 6.5 | | 7.2 | 7 | | | | | 7 | | | |
| 13 | | | 5.5 | | 7.2 | 6.9 | | | 7.3 | 7.2 | | | | |
| 14 | | | 5.8 | | 7.1 | 6.9 | | | | | 7.3 | | | |
| ASHCRAFT | | | 7.7 | | | | | | | | | | | |
| SCHMIDT | | | | | | | | | | | | | | |
| MEULER | | | 7 | | | | | | | | | | | |
| SWEELY | | 8 | 6.8 | | 7.5 | | | | | | 6.8 | | | |
| LOMAN | | 8 | | | | | | | | | | | | |
| SHERMAN | | | | | | | | | | | | | | |
| CHITWOOD | | | 7.8 | | | | | | | | | | | |
| L2 | | 6.9 | 6.4 | | 6.7 | | | | | | | | | |
| L3s | | <6.0 | 6.6 | | | | | | | | | | | |
| L3 | | 9.5 | 6.1 | | | | | | | | | | | |
| L8 | | 7.6 | 7.6 | | | | | | | | | | | |
| DITCH 13 | | | 5.5 | | 8.1 | 7.9 | 7.9 | | | 8.1 | | | | |
| DITCH 1 | N/A | | 8 | | 7.8 | 6.81 | 7.7 | 7.5 | | 6.8 | 8 | | | |

DEPTH BELOW GROUND SURFACE TO THE WATER TABLE AND GROUND WATER ELEVATION AT THE IVERSON SITE, RICHLAND. CC.

| WELL | MP ELEVA. | NEW MP | DATE | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | IN ft. | ELEV. | 07/11/87 | 07/21/87 | 08/17/87 | 09/30/87 | 10/20/87 | 11/21/87 | 12/21/87 | 01/24/88 | 02/20/88 | 03/19/88 | 04/23/89 | 05/15/88 | 05/21/88 | 06/05/88 | 06/26/88 | 07/16/88 | 08/12/88 |
| 1 | 1922.1 | | 8.82 | 8.60 | 8.58 | 9.58 | 10.35 | 10.87 | 11.26 | 11.57 | 11.8 | 11.96 | 12.14 | | 8.96 | | 8.8 | 8.37 | |
| | WL ELEV. | | 1913.28 | 1913.5 | 1913.52 | 1912.52 | 1911.75 | 1911.23 | 1910.84 | 1910.53 | 1910.3 | 1910.14 | 1909.96 | | 1913.14 | | 1913.3 | 1913.73 | |
| 2 | 1920.14 | | 9.57 | 10.11 | 9.76 | 11.10 | 11.94 | 12.41 | 12.66 | 12.85 | 12.97 | 13.15 | 13.19 | 10.49 | 9.85 | 9.56 | 9.73 | 9.31 | 9.3 |
| | WL ELEV. | | 1910.57 | 1910.03 | 1910.38 | 1909.04 | 1908.2 | 1907.73 | 1907.48 | 1907.29 | 1907.17 | 1906.99 | 1906.95 | 1909.65 | 1910.29 | 1910.58 | 1910.41 | 1910.83 | 1910.34 |
| 21 | 1920.64 | | | | | | 12.46 | 12.92 | 13.18 | 13.37 | | 13.6 | 13.7 | 11 | 10.37 | 10.07 | 10.2 | 9.77 | |
| | WL ELEV. | | | | | | 1908.18 | 1907.72 | 1907.46 | 1907.27 | | 1907.04 | 1906.94 | 1909.64 | 1910.27 | 1910.57 | 1910.44 | 1910.87 | |
| 3 | 1920.14 | | 9.65 | 10.20 | 9.96 | 11.15 | 12.01 | 12.48 | 12.73 | | | | 13.22 | | 9.96 | | 9.85 | 9.38 | 9.87 |
| | WL ELEV. | | 1910.49 | 1909.94 | 1910.18 | 1908.99 | 1908.13 | 1907.66 | 1907.41 | | | | 1906.92 | | 1910.18 | | 1910.29 | 1910.76 | 1910.27 |
| 3s | 1920.89 | | | | | | 12.82 | 13.28 | 13.52 | 13.69 | 13.81 | DRY | DRY | 11.39 | 10.75 | 10.5 | 10.67 | 10.21 | 10.66 |
| | WL ELEV. | | | | | | 1908.07 | 1907.61 | 1907.37 | 1907.2 | 1907.08 | | | 1909.5 | 1910.14 | 1910.39 | 1910.22 | 1910.68 | 1910.23 |
| 4s | 1921.09 | | 9.75 | 11.33 | 10.96 | 12.31 | 13.12 | DRY | DRY | DRY | DRY | DRY | DRY | 11.71 | 11.1 | 10.91 | 11.13 | 10.61 | 11.06 |
| | WL ELEV. | | 1910.34 | 1909.76 | 1910.13 | 1908.78 | 1907.97 | | | | | | | 1909.38 | 1909.99 | 1910.18 | 1909.96 | 1910.48 | 1910.03 |
| 4d | 1920.24 | | 9.91 | 10.46 | 10.13 | 11.48 | 12.29 | 12.72 | 12.95 | 13.1 | 13.23 | 13.33 | 13.44 | 10.89 | 10.27 | 10.08 | 10.3 | 9.76 | |
| | WL ELEV. | | 1910.33 | 1909.76 | 1910.11 | 1908.76 | 1907.95 | 1907.52 | 1907.29 | 1907.14 | 1907.01 | 1906.91 | 1906.8 | 1909.35 | 1909.99 | 1910.16 | 1909.94 | 1910.48 | |
| 4m | 1919.74 | | 9.41 | 9.94 | 9.59 | 10.93 | 11.75 | 12.18 | 12.42 | 12.57 | 12.7 | 12.79 | 12.91 | 10.35 | 9.72 | 9.54 | 9.75 | 9.23 | |
| | WL ELEV. | | 1910.33 | 1909.8 | 1910.15 | 1908.81 | 1907.99 | 1907.56 | 1907.32 | 1907.17 | 1907.04 | 1906.95 | 1906.83 | 1909.39 | 1910.02 | 1910.2 | 1909.99 | 1910.51 | |
| 5 | 1919.59 | | 8.99 | 9.92 | 9.58 | 10.90 | 11.71 | 12.13 | 12.35 | 12.5 | 12.64 | 12.72 | 12.83 | 10.29 | 9.7 | 9.6 | 9.82 | 9.22 | |
| | WL ELEV. | | 1910.61 | 1909.67 | 1910.01 | 1908.69 | 1907.89 | 1907.46 | 1907.24 | 1907.09 | 1906.95 | 1906.87 | 1906.76 | 1909.3 | 1909.89 | 1909.99 | 1909.77 | 1910.37 | |
| 5s | 1919.34 | | | | | | 11.53 | 11.95 | 12.17 | 12.34 | 12.45 | 12.53 | 12.64 | 10.11 | 9.5 | 9.44 | 9.65 | 9.05 | 9.53 |
| | WL ELEV. | | | | | | 1907.81 | 1907.39 | 1907.17 | 1907 | 1906.89 | 1906.81 | 1906.7 | 1909.23 | 1909.84 | 1909.9 | 1909.69 | 1910.29 | 1909.91 |
| 6 | 1921.14 | | 10.81 | 11.59 | 11.24 | 12.58 | 13.38 | 13.8 | 14.03 | 14.17 | 14.31 | 14.39 | 14.5 | 12.06 | 11.44 | 11.22 | 11.47 | 10.93 | |
| | WL ELEV. | | 1910.33 | 1909.55 | 1909.9 | 1908.56 | 1907.76 | 1907.34 | 1907.11 | 1906.97 | 1906.83 | 1906.75 | 1906.64 | 1909.08 | 1909.7 | 1909.92 | 1909.67 | 1910.21 | |
| 16 | 1919.87 | | | | | | 12.17 | 12.57 | 12.79 | 13.04 | 13.05 | 13.14 | 13.25 | 10.8 | 10.22 | 10.15 | 10.36 | 9.71 | 10.21 |
| | WL ELEV. | | | | | | 1907.7 | 1907.3 | 1907.08 | 1906.83 | 1906.83 | 1906.73 | 1906.62 | 1909.07 | 1909.65 | 1909.72 | 1909.51 | 1910.16 | 1909.66 |
| 20 | 1917.96 | | | | | | 10.24 | 10.71 | 10.87 | 11.1 | 11.14 | 11.22 | 11.34 | DESTROYED | | | | | |
| | WL ELEV. | | | | | | 1907.72 | 1907.25 | 1907.09 | 1906.86 | 1906.82 | 1906.74 | 1906.62 | | | | | | |
| 19 | 1920.74 | | | | | | 13.06 | 13.47 | 13.7 | 13.85 | 13.96 | 14.04 | 14.16 | 11.74 | 11.14 | 11 | 11.19 | 10.62 | 11.05 |
| | WL ELEV. | | | | | | 1907.69 | 1907.27 | 1907.04 | 1906.89 | 1906.78 | 1906.7 | 1906.58 | 1909 | 1909.6 | 1909.74 | 1909.55 | 1910.12 | 1909.69 |
| 15 | 1919.84 | | | | | | 12.08 | 12.51 | 12.72 | 12.88 | 13.03 | 13.09 | 13.21 | 10.75 | 10.09 | 9.87 | 10.11 | 9.6 | |
| | WL ELEV. | | | | | | 1907.76 | 1907.33 | 1907.12 | 1906.96 | 1906.81 | 1906.75 | 1906.63 | 1909.09 | 1909.75 | 1909.97 | 1909.73 | 1910.24 | |
| 7s | 1919.84 | | 9.66 | 10.53 | 10.19 | 11.48 | 12.26 | 12.65 | 12.86 | 13 | 13.14 | 13.21 | 13.31 | 10.96 | 10.4 | 10.35 | 10.49 | 9.81 | 10.34 |
| | WL ELEV. | | 1910.19 | 1909.31 | 1909.65 | 1908.36 | 1907.58 | 1907.15 | 1906.98 | 1906.84 | 1906.7 | 1906.63 | 1906.53 | 1908.88 | 1909.44 | 1909.49 | 1909.35 | 1910.03 | 1909.5 |
| 7d | 1919.69 | | 9.77 | 10.30 | 9.98 | 11.28 | 12.07 | 12.46 | 12.68 | 12.81 | 12.94 | 13.01 | 19.12 | 10.78 | 10.2 | 10.1 | 10.3 | 9.73 | |
| | WL ELEV. | | 1910.12 | 1909.39 | 1909.71 | 1908.41 | 1907.62 | 1907.23 | 1907.01 | 1906.88 | 1906.75 | 1906.68 | 1906.57 | 1908.91 | 1909.49 | 1909.59 | 1909.39 | 1909.96 | |
| 17 | 1918.18 | | | | | | 10.86 | 11.22 | 11.44 | 11.56 | 11.68 | 11.75 | 11.85 | 9.68 | 9.14 | 9.21 | 9.26 | | |
| | WL ELEV. | | | | | | 1907.32 | 1906.96 | 1906.74 | 1906.62 | 1906.5 | 1906.43 | 1906.33 | 1908.5 | 1909.04 | 1909.11 | 1908.92 | | |
| 18 | 1917.75 | | | | | | 10.5 | 10.84 | 11.09 | 11.18 | 11.29 | 11.36 | 11.46 | 9.44 | 8.98 | 8.88 | 9.8 | 8.04 | |
| | WL ELEV. | | | | | | 1907.25 | 1906.91 | 1906.66 | 1906.57 | 1906.46 | 1906.39 | 1906.29 | 1908.31 | 1908.77 | 1908.87 | 1908.95 | 1909.71 | |
| 8 | 1916.78 | (1915.72) | 7.54 | 8.82 | 7.99 | | 8.79 | 9.41 | 9.27 | 9.38 | 9.49 | 9.55 | 9.61 | 8.03 | 7.47 | DESTROYED | | | |
| | WL ELEV. | | 1909.24 | 1907.96 | 1908.79 | | 1906.93 | 1906.31 | 1906.45 | 1906.34 | 1906.23 | 1906.17 | 1906.11 | 1907.69 | 1908.25 | | | | |

| WELL | MP ELEVA. | NEW MP | DATE | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LOCATION | IN ft. | ELEV. | 07/11/87 | 07/21/87 | 08/17/87 | 09/30/87 | 10/20/87 | 11/21/87 | 12/21/87 | 01/24/88 | 02/29/88 | 03/19/88 | 04/23/88 | 05/15/88 | 05/21/88 | 06/05/88 | 06/26/88 | 07/16/88 | 08/12/88 |
| 9 | 1920.48 | | 12.07 | 12.63 | 12.46 | 13.39 | 14.04 | 14.3 | 14.44 | 14.53 | 14.64 | 14.68 | 14.73 | 13.51 | 13.25 | 12.8 | 12.8 | 12.45 | |
| | WL ELEV. | | 1908.41 | 1907.85 | 1908.02 | 1907.09 | 1906.44 | 1906.18 | 1906.04 | 1905.95 | 1905.84 | 1905.8 | 1905.75 | 1906.97 | 1907.23 | 1907.68 | 1907.68 | 1908.03 | |
| 10 | 1916.67 | | 9.22 | 9.92 | 9.80 | 10.89 | 11.65 | 11.85 | 11.94 | 11.67 | 12.05 | 12.1 | 12.07 | 11.06 | 10.88 | 10.84 | 10.63 | 10.11 | |
| | WL ELEV. | | 1907.45 | 1906.75 | 1906.87 | 1905.78 | 1905.02 | 1904.82 | 1904.73 | 1905 | 1904.61 | 1904.57 | 1904.6 | 1905.61 | 1905.79 | 1905.83 | 1906.04 | 1906.56 | |
| 11 | 1919.74 | | 9.42 | 10.36 | 9.98 | 11.29 | 12.06 | 12.49 | 12.7 | 12.82 | 12.95 | 13.04 | 13.16 | 10.86 | 10.34 | 10.16 | 10.16 | 9.45 | |
| | WL ELEV. | | 1910.32 | 1909.38 | 1909.76 | 1908.45 | 1907.68 | 1907.25 | 1907.04 | 1906.92 | 1906.79 | 1906.7 | 1906.58 | 1908.88 | 1909.4 | 1909.58 | 1909.58 | 1910.29 | |
| 12 | 1917.77 | | 7.12 | 8.09 | 7.74 | 9.04 | 9.85 | 10.28 | 10.51 | 10.68 | 10.8 | 10.89 | 11 | 8.41 | 7.81 | 7.71 | 7.91 | 7.37 | |
| | WL ELEV. | | 1910.65 | 1909.68 | 1910.03 | 1908.73 | 1907.92 | 1907.49 | 1907.26 | 1907.09 | 1906.97 | 1906.88 | 1906.77 | 1909.36 | 1909.96 | 1910.06 | 1909.86 | 1910.4 | |
| 13 | 1919.09 | | 7.59 | 10.35 | 10.09 | 11.28 | 12.01 | 12.37 | 12.56 | 12.65 | 12.79 | 12.86 | 12.95 | 11 | 10.57 | 10.41 | 10.29 | 9.54 | |
| | WL ELEV. | | 1911.5 | 1908.74 | 1909 | 1907.81 | 1907.08 | 1906.72 | 1906.53 | 1906.44 | 1906.3 | 1906.23 | 1906.14 | 1908.09 | 1908.52 | 1908.68 | 1908.8 | 1909.55 | |
| 14 | 1921.54 | | 10.87 | 11.58 | 11.20 | 12.57 | 13.42 | 13.88 | 14.14 | 14.32 | | 14.52 | 14.65 | 12.03 | 11.34 | 11 | 11.2 | 10.75 | |
| | WL ELEV. | | 1910.67 | 1909.96 | 1910.34 | 1908.57 | 1908.12 | 1907.66 | 1907.4 | 1907.22 | | 1907.02 | 1906.89 | 1909.51 | 1910.2 | 1910.54 | 1910.34 | 1910.79 | |
| ASHCRAFT | 1919.37 | | | | 11.5 | | 12.97 | 13.28 | 13.43 | 13.55 | 13.64 | 13.66 | 13.75 | | | | | | |
| | WL ELEV. | | | | 1907.87 | | 1906.4 | 1906.09 | 1905.94 | 1905.82 | 1905.73 | 1905.71 | 1905.62 | | | | | | |
| SCHMIDT | 1917.45 | | | 9.53 | 9.25 | 10.12 | 10.61 | 10.95 | 11.1 | 11.12 | 11.24 | 11.29 | 11.41 | 10.42 | 9.89 | | | | |
| | WL ELEV. | | | 1907.92 | 1908.2 | 1907.33 | 1906.82 | 1906.5 | 1906.35 | 1906.33 | 1906.21 | 1906.16 | 1906.04 | 1907.03 | 1907.57 | | | | |
| MEULER | 1918.47 | | | | 9.83 | 10.73 | 11.22 | 11.57 | 11.72 | 11.74 | 11.83 | 11.96 | 12.11 | | 10.24 | 9.5 | | 9.52 | |
| | WL ELEV. | | | | 1908.64 | 1907.74 | 1907.25 | 1906.9 | 1906.75 | 1906.73 | 1906.64 | 1906.51 | 1906.36 | | 1908.23 | 1908.97 | | 1908.95 | |
| SWEELY | 1917.99 | | | | 9.15 | 10 | 10.45 | 10.81 | 10.98 | 10.9 | 11.01 | 11.14 | 11.41 | | 11.21 | 9.18 | 9.5 | 8.54 | |
| | WL ELEV. | | | | 1908.84 | 1907.99 | 1907.54 | 1907.18 | 1907.01 | 1907.09 | 1906.98 | 1906.85 | 1906.58 | | 1906.78 | 1908.81 | 1908.49 | 1909.45 | |
| SHERMAN | 1918.49 | | | 9.61 | 9.58 | | DRY | | | | | | | | | | | | |
| | WL ELEV. | | | 1908.88 | 1908.91 | | | | | | | | | | | | | | |
| CHITWOOD | 1918.43 | | | 9.76 | 8.08 | | 7.9 | 8.82 | 8.74 | 9.81 | 10.75 | 9.82 | 9.55 | 6.91 | 10.5 | 26.41 | 6.14 | 7.66 | |
| | WL ELEV. | | | 1908.67 | 1910.35 | | 1910.53 | 1909.61 | 1909.69 | 1908.62 | 1907.68 | 1908.61 | 1908.88 | 1911.52 | 1907.93 | 1892.02 | 1912.29 | 1910.77 | |
| DITCH13 | 1907.81 | | | | | | XX | 1.11 | 1.15 | FROZE | FROZE | 1.24 | 0.88 | 0.65 | 0.53 | 0.67 | 0.68 | XX | XX |
| | 1908.36 | | | | | | 1.51 | XX | XX | FROZE | FROZE | 1.79 | XX | XX | XX | XX | XX | XX | XX |
| | 1913.98 | | | | | | XX | XX | XX | FROZE | FROZE | XX | XX | XX | XX | XX | XX | 5.36 | 5.33 |
| | WL ELEV. | | | | | | 1906.85 | 1906.7 | 1906.66 | | | 1906.57 | 1906.93 | 1908.16 | 1908.28 | 1909.14 | 1908.13 | 1908.62 | 1908.65 |
| BRIDGE | 1913.51 | | | | 6.76 | 7.75 | 8.31 | 8.45 | 8.46 | 8.63 | 8.65 | 8.6 | 8.16 | 7.96 | 7.79 | 7.95 | 7.84 | 6.86 | |
| | WL ELEV. | | | | 1906.75 | 1905.76 | 1905.2 | 1905.06 | 1905.05 | 1904.88 | 1904.86 | 1904.91 | 1905.35 | 1905.55 | 1905.72 | 1905.56 | 1905.67 | 1906.65 | |
| DITCH 1 | 1919.3 | (1918.2) | | | 5.56 | XX | XX | XX | XX | XX | XX | XX | XX | XX | XX | XX | XX | XX | |
| | 1915.63 | | | | XX | 3.55 | 3.92 | 3.98 | 3.99 | 4.24 | 4.15 | 3.85 | 3.62 | 3.5 | 2.95 | 3.45 | 3.72 | 3.12 | |
| | WL ELEV. | | | | 1912.74 | 1912.08 | 1911.71 | 1911.65 | 1911.64 | 1911.39 | 1911.48 | 1911.78 | 1912.01 | 1912.13 | 1912.68 | 1912.18 | 1911.91 | 1912.51 | |

# APPENDIX K

## METAL ANALYSES
## (UNIVERSITY OF MONTANA ICP)

# DISSOLVED METALS

(NEGATIVE INDICATES LESS THAN DETECTION LIMIT).

METAL ANALYSES FOR WATER SAMPLES AT THE IVERSON SITE, RICHLAND, CO.

| LOC. | DATE | ppm Al | ppm As | ppm Ca | ppm Cd | ppm Cu | ppm Fe | ppm K | ppm Mg | ppm Mn | ppm Na | ppm Ni | ppm Pb | ppm Sb | ppm P | ppm Si | ppm Ti | ppm Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MW 2 | 06/28/88 | 0.020 | 0.002 | 129.900 | -0.001 | 0.001 | 0.010 | 3.600 | 29.700 | 0.001 | 64.500 | 0.001 | -0.629 | 0.061 | 0.035 | 9.370 | 0.001 | 0.007 |
| MW 3 | 10/22/87 | 0.000 | 0.003 | 106.800 | 0.001 | 0.000 | 0.010 | 6.500 | 35.500 | 0.001 | 233.300 | 0.005 | -0.014 | 0.072 | 0.051 | 12.550 | 0.002 | 0.003 |
|  | 04/23/88 | 0.020 | 0.006 | 97.600 | -0.001 | -0.001 | 0.040 | 3.600 | 39.000 | 0.300 | 110.000 | 0.006 | -0.012 | 0.092 | 0.073 | 10.710 | -0.001 | 0.001 |
| (s) | 06/28/88 | 0.020 | 0.008 | 129.200 | 0.000 | 0.001 | 0.010 | 12.700 | 32.900 | 0.074 | 353.900 | 0.004 | -0.007 | 0.089 | 0.062 | 12.360 | 0.003 | 0.001 |
| (DUP.) | 10/22/87 | 0.110 | 0.017 | 112.900 | 0.000 | 0.002 | 0.030 | 11.600 | 35.100 | 0.409 | 218.200 | 0.500 | 0.018 | 0.080 | 0.130 | 12.710 | 0.002 | 0.005 |
| MW 4 (s) | 10/22/87 | 0.060 | 0.090 | 163.500 | 0.000 | 0.011 | 0.020 | 18.300 | 43.900 | 0.090 | 454.700 | 0.007 | -0.006 | 0.093 | 0.088 | 12.410 | 0.001 | 0.006 |
| (e) | 04/23/88 | 0.040 | 0.005 | 80.600 | -0.001 | 0.000 | 0.020 | 6.600 | 42.000 | 0.023 | 140.900 | 0.004 | -0.001 | 0.093 | 0.114 | 9.510 | 0.000 | 0.001 |
| (s) | 06/28/88 | 0.020 | 0.020 | 159.200 | -0.001 | 0.003 | 0.030 | 16.900 | 39.400 | 0.004 | 463.900 | 0.001 | -0.010 | 0.075 | 0.118 | 12.040 | 0.002 | 0.002 |
| MW 5s | 10/22/87 | 0.030 | 0.021 | 145.000 | 0.000 | -0.001 | 0.010 | 4.200 | 54.400 | 0.001 | 146.200 | 0.001 | -0.004 | 0.106 | 0.161 | 13.080 | 0.003 | 0.002 |
|  | 04/23/88 | 0.050 | 0.019 | 116.500 | 0.000 | 0.000 | 0.010 | 5.500 | 59.100 | 0.011 | 137.200 | 0.005 | 0.005 | 0.115 | 0.218 | 10.599 | -0.001 | 0.003 |
|  | 06/28/88 | 0.050 | 0.019 | 115.000 | 0.000 | 0.000 | 0.010 | 5.100 | 43.600 | 0.002 | 125.600 | 0.004 | 0.009 | 0.091 | 0.152 | 11.650 | 0.002 | 0.001 |
| MW 7s | 10/22/87 | 0.040 | 0.022 | 107.200 | -0.001 | -0.001 | 0.010 | 8.900 | 51.500 | 0.001 | 294.500 | 0.002 | 0.008 | 0.097 | 0.193 | 10.710 | 0.003 | -0.001 |
|  | 04/23/88 | 0.050 | 0.020 | 84.500 | 0.000 | 0.000 | 0.020 | 6.700 | 40.500 | 0.002 | 156.700 | 0.004 | 0.007 | 0.080 | 0.108 | 8.980 | -0.001 | -0.001 |
|  | 06/28/88 | 0.130 | 0.010 | 84.200 | 0.001 | 0.001 | 0.060 | 9.300 | 49.400 | 0.004 | 137.500 | 0.002 | 0.016 | 0.084 | 0.146 | 10.440 | 0.002 | 0.002 |
| (DUP.) | 04/23/88 | -0.010 | 0.014 | 81.000 | -0.001 | 0.000 | 0.010 | 5.100 | 40.300 | 0.001 | 158.900 | 0.002 | -0.012 | 0.080 | 0.100 | 8.770 | -0.001 | -0.001 |
| MW 8 | 04/23/88 | 0.130 | 0.015 | 88.900 | 0.000 | -0.001 | 0.050 | 7.500 | 44.700 | 0.065 | 122.700 | 0.006 | 0.076 | 0.104 | 0.182 | 10.020 | -0.001 | 0.000 |
|  | 06/28/88 | 0.090 | 0.019 | 55.400 | 0.000 | -0.001 | 0.040 | 9.500 | 41.200 | 0.177 | 143.000 | 0.003 | 0.022 | 0.070 | 0.184 | 9.700 | 0.003 | 0.002 |
| MW 16s | 10/22/87 | 0.020 | 0.013 | 170.800 | 0.001 | -0.002 | 0.010 | 13.100 | 108.500 | 0.004 | 370.200 | 0.005 | -0.004 | 0.192 | 0.268 | 14.390 | 0.002 | 0.003 |
|  | 04/23/88 | 0.070 | 0.012 | 110.000 | 0.002 | 0.013 | 0.176 | 6.400 | 63.700 | 0.026 | 261.200 | 0.006 | 0.040 | 0.134 | 0.177 | 12.180 | 0.002 | 0.025 |
|  | 06/28/88 | 0.040 | 0.021 | 90.500 | 0.000 | -0.002 | 0.020 | 10.700 | 72.900 | 0.000 | 317.400 | 0.001 | 0.006 | 0.145 | 0.200 | 13.620 | 0.002 | 0.001 |
| MW 17s | 10/22/87 | 0.020 | 0.014 | 87.600 | 0.000 | -0.005 | 0.010 | 6.600 | 49.300 | 0.001 | 164.200 | 0.001 | -0.002 | 0.107 | 0.107 | 10.220 | 0.003 | 0.000 |
|  | 04/23/88 | 0.010 | 0.016 | 83.500 | 0.001 | -0.001 | 0.020 | 5.000 | 46.200 | 0.002 | 177.400 | 0.003 | 0.001 | 0.086 | 0.098 | 9.690 | 0.000 | 0.001 |
|  | 06/28/88 | 0.040 | 0.011 | 62.700 | 0.001 | -0.002 | 0.020 | 4.100 | 35.500 | 0.002 | 87.800 | 0.001 | 0.000 | 0.089 | 0.091 | 10.470 | 0.002 | 0.002 |
| MW 18s | 10/22/87 | 0.040 | 0.017 | 97.300 | 0.001 | -0.002 | 0.916 | 8.100 | 53.600 | 0.001 | 183.600 | 0.003 | 0.006 | 0.121 | 0.135 | 9.830 | 0.004 | 0.000 |
|  | 04/23/88 | 0.070 | 0.016 | 80.200 | 0.002 | -0.001 | 0.090 | 5.600 | 47.000 | 0.007 | 161.400 | 0.002 | 0.005 | 0.102 | 0.109 | 9.190 | 0.002 | 0.001 |
|  | 06/28/88 | 0.009 | -0.001 | 69.800 | 0.001 | -0.004 | 0.010 | 5.600 | 41.200 | 0.001 | 135.200 | -0.003 | -0.008 | 0.079 | 0.093 | 9.770 | 0.002 | 0.001 |
| MW 19s | 10/22/87 | -0.030 | 0.019 | 98.200 | -0.001 | 0.000 | 0.060 | 3.600 | 45.300 | 0.060 | 141.500 | -0.002 | -0.021 | 0.083 | 0.117 | 11.940 | 0.003 | 0.000 |
|  | 04/23/88 | -0.050 | 0.010 | 42.600 | -0.002 | 0.001 | 0.000 | 1.300 | 48.900 | 0.306 | 155.200 | 0.017 | -0.015 | 0.085 | 0.147 | 9.180 | 0.000 | 0.091 |
|  | 06/28/88 | -0.020 | 0.009 | 101.000 | -0.002 | -0.001 | 0.000 | 3.100 | 36.800 | 0.001 | 113.300 | 0.000 | -0.010 | 0.067 | 0.111 | 11.920 | 0.002 | 0.001 |
| MW 20s | 10/22/87 | 0.000 | 0.008 | 160.700 | -0.001 | 0.000 | 0.010 | 14.500 | 50.400 | 0.001 | 448.500 | 0.003 | -0.006 | 0.603 | 0.163 | 12.376 | 0.001 | -0.001 |
|  | 04/23/88 | 0.010 | 0.008 | 109.200 | 0.000 | -0.001 | 0.010 | 6.000 | 35.600 | 0.001 | 230.700 | 0.002 | -0.009 | 0.053 | 0.140 | 9.730 | -0.003 | 0.000 |
| MW 21s | 10/22/87 | 0.090 | 0.011 | 108.500 | 0.000 | -0.001 | 0.010 | 0.400 | 33.290 | 0.001 | 81.500 | 0.003 | -0.005 | 0.048 | 0.057 | 11.050 | 0.001 | 0.006 |
|  | 04/23/88 | 0.070 | 0.010 | 101.700 | 0.001 | 0.001 | 0.130 | 1.700 | 32.800 | 0.014 | 89.200 | 0.005 | 0.006 | 0.039 | 0.084 | 9.610 | 0.002 | 0.004 |
|  | 06/28/88 | 0.030 | 0.007 | 95.900 | 0.000 | -0.002 | 0.010 | 5.300 | 33.300 | 0.001 | 80.000 | 0.005 | -0.003 | 0.045 | 0.059 | 9.976 | 0.001 | -0.002 |
| (DUP.) | 10/22/87 | -0.040 | 0.008 | 107.400 | 0.000 | -0.002 | 0.000 | 1.200 | 33.600 | 0.001 | 82.600 | -0.001 | -0.013 | 0.049 | 0.057 | 11.020 | 0.001 | 0.003 |
| DITCH 1 | 10/22/87 | -0.010 | 0.010 | 84.800 | 0.001 | -0.002 | 0.010 | 7.200 | 69.800 | 0.058 | 155.400 | 0.002 | -0.007 | 0.115 | 0.125 | 10.380 | 0.002 | 0.015 |
| DITCH 13 | 10/22/87 | -0.220 | 0.007 | 0.400 | 0.001 | -0.007 | -0.050 | -3.300 | 0.200 | 0.000 | 0.800 | -0.007 | -0.057 | -0.026 | 0.069 | -0.080 | -0.002 | -0.004 |
|  | 04/23/88 | 0.050 | 0.009 | 55.700 | 0.000 | 0.001 | 0.100 | 2.100 | 36.900 | 0.018 | 102.100 | -0.001 | -0.017 | 0.049 | 0.089 | 4.080 | 0.004 | 0.090 |
|  | 06/28/88 | -0.070 | 0.014 | 48.700 | 0.001 | -0.003 | -0.010 | -0.100 | 30.200 | 0.036 | 74.800 | -0.003 | -0.025 | 0.038 | 0.097 | 6.720 | 0.003 | -0.004 |
| (DUP.) | 10/22/87 | -0.060 | 0.010 | 63.100 | 0.000 | -0.003 | 0.000 | 5.790 | 69.100 | 0.039 | 154.500 | 0.003 | -0.017 | 0.116 | 0.127 | 10.060 | 0.003 | -0.004 |
| L3 | 04/23/88 | 77.50 | 1.60 | 8470.00 | -1.05 | 0.00 | 368.50 | 4870.00 | 1300.00 | 37.35 | 37445.00 | 1.70 | 19.05 | -5.20 | 15.55 | 47.00 | -0.60 | 0.15 |
|  | 06/28/88 | 23.00 | 4.80 | 7305.00 | 0.55 | -1.10 | 312.50 | 1180.00 | 1240.00 | 32.60 | 35085.00 | 0.80 | 3.45 | 5.30 | 15.30 | 14.00 | -0.10 | -0.35 |
| L2 | 10/22/87 | 0.970 | -0.001 | -0.100 | 0.004 | 0.003 | 0.150 | 8.600 | -0.290 | 0.075 | -0.300 | 0.040 | 0.115 | 1.131 | 0.746 | 25.420 | -0.066 | 0.028 |
|  | 06/28/88 | 0.950 | 0.013 | -0.100 | 0.004 | 0.255 | 0.150 | 8.000 | -0.260 | 0.036 | -0.300 | 0.033 | 0.120 | 1.097 | 0.800 | 29.000 | -0.065 | 0.403 |

METAL ANALYSES FOR SEDIMENT SAMPLES AT THE IVERSON SITE, RICHLAND, CO. (TOTAL DIGESTABLE METALS IN SEDIMENT) (TOTAL RECOVERABLE)

| LOC. | DEPTH | % Al | % Ca | % Fe | % K | % Na | % Si | ppm As | ppm Cd | ppm Cu | ppm Mg | ppm Mn | ppm Ni | ppm Pb | ppm Sb | ppm P | ppm Ti | ppm Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PITMUD 1 | 6-8 ft. | 3.773 | 6.379 | 2.101 | 1.960 | 1.083 | 30.330 | -26.006 | 1.800 | 18.800 | 1.447 | 397.200 | 18.000 | 36.000 | 42.000 | 0.045 | 1293.990 | 49.090 |
| PITMUD 2 | 6-8 ft. | 3.402 | 7.706 | 2.199 | 1.572 | 2.103 | 25.446 | -16.016 | 1.001 | 20.229 | 1.733 | 411.512 | 106.106 | 44.044 | 55.055 | 0.049 | 1423.323 | 59.051 |
| MW 3 | 5-7 ft. | 4.121 | 3.837 | 2.301 | 2.191 | 1.630 | 32.211 | -30.876 | 1.494 | 14.940 | 6.942 | 434.661 | 84.661 | 21.912 | 21.912 | 0.040 | 1533.765 | 56.574 |
| MW 4 | 6-12 ft. | 4.318 | 4.599 | 2.902 | 2.077 | 2.258 | 29.690 | -24.728 | 1.060 | 40.752 | 1.682 | 459.050 | 156.281 | 16.815 | 45.500 | 0.069 | 2208.124 | 91.998 |
| MW 7 | 2-7 ft. | 3.360 | 2.634 | 3.504 | 2.055 | 0.026 | 25.935 | -56.376 | 1.191 | 15.285 | 9.750 | 632.159 | 31.762 | -30.769 | -14.888 | 0.050 | 1547.295 | 57.965 |
| MW 7(DUP) | 2-7 ft. | 3.779 | 2.918 | 4.106 | 2.233 | 0.072 | 32.010 | -17.866 | 1.290 | 17.469 | 1.050 | 740.844 | 32.754 | -13.896 | 29.777 | 0.064 | 1777.568 | 67.593 |
| FI.UNIUM | 20 ft. | 3.755 | 7.823 | 1.028 | 1.042 | 6.737 | 30.525 | -21.901 | 0.896 | 13.041 | 3.217 | 435.341 | 173.221 | -20.966 | 97.561 | 0.059 | 1443.396 | 46.391 |

(NEGATIVE INDICATES LESS THAN DETECTION LIMIT).

# APPENDIX L

## BASIC ION AND METAL ANALYSES
## (MBMG LAB)

WATER ANALYSES RESULTS FOR THE IVERSON SITE, RICHLAND. CO. (DISSOLVED)

| PARAMETER | DATE | LOCATION<br>QA/QC | MW 2 | MW 21s | MW 3 | MW 3s | MW 4s | MW 4m | MW 4d | MW 5s | MW 6 | MW 7s | MW 9 | MW 13 | MW 16s | MW 17s | MW 18s | MW 19s | MW 20s | L3 | DITCH 13 | DITCH 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ppm Ca | 07/22/87 | <.1 | 145 |  | 357 |  | 226 |  | 80.7 |  | 84.9 | 119 | 61 | 71.5 |  |  |  |  |  | 9510 | 62.2 |  |
|  | 10/22/87 |  |  | 111 | 113 |  | 172 |  |  | 148 |  | 109 |  |  | 185 | 91.6 | 94.6 | 98.9 | 167 |  | 65.3 | 66.8 |
|  | 04/23/89 |  |  | 102 | 96.3 |  |  | 83.2 |  | 115 |  | 86.4 | 62.4 |  | 118 | 78.3 | 75.9 | 88 | 108 | 9350 | 62.2 |  |
|  | 06/28/89 |  |  | 105 |  | 147 | 175 |  |  | 119 |  | 84.9 | 60.7 |  | 98.6 | 66.6 | 73 | 110 |  | 7310 | 53.2 |  |
| ppm Mg | 07/22/87 | <.1 | 31.2 |  | 90.7 |  | 50.6 |  | 54.9 |  | 45.8 | 53.6 | 45.2 | 45.6 |  |  |  |  |  | 1270 | 34.7 |  |
|  | 10/22/87 |  |  | 34 | 35.8 |  | 44.5 |  |  | 55.6 |  | 53.2 |  |  | 112 | 50.3 | 53.2 | 44.4 | 50.2 |  | 72.4 | 73.1 |
|  | 04/23/88 |  |  | 32.4 | 37.4 |  |  | 42.5 |  | 58 |  | 42 | 47.4 |  | 65.5 | 42.3 | 44.3 | 45.2 | 35.3 | 1260 | 40.7 |  |
|  | 06/28/98 |  |  | 37.2 |  | 38.7 | 43 |  |  | 46.7 |  | 43.3 | 47.5 |  | 77.6 | 38.5 | 43.9 | 40 |  | 1300 | 33.2 |  |
| ppm Na | 07/22/87 | <.1 | 63.5 |  | 1436 |  | 681 |  | 192 |  | 112 | 196 | 156 | 144 |  |  |  |  |  | 8470 | 97.2 |  |
|  | 10/22/87 |  |  | 85.2 | 229 |  | 462 |  |  | 145 |  | 211 |  |  | 370 | 162 | 177 | 135 | 437 |  | 161 | 163 |
|  | 04/23/88 |  |  | 91.8 | 105 |  |  | 143 |  | 136 |  | 162 | 147 |  | 257 | 161 | 149 | 131 | 232 | 88600 | 121 |  |
|  | 06/29/89 |  |  | 89.1 |  | 324 | 476 |  |  | 130 |  | 146 | 161 |  | 327 | 89.6 | 134 | 116 |  | 73500 | 81.6 |  |
| ppm K | 07/22/87 | <.1 | 3.8 |  | 25.4 |  | 28.4 |  | 6.9 |  | 5 | 8.2 | 5.7 | 6.5 |  |  |  |  |  | 1040 | 5.2 |  |
|  | 10/22/87 |  |  | 4.5 | 8.1 |  | 18.7 |  |  | 6.4 |  | 8.8 |  |  | 13.5 | 6.7 | 7.7 | 6.7 | 15 |  | 10 | 10.2 |
|  | 04/23/89 |  |  | 3.3 | 4.5 |  |  | 0.6 |  | 6.1 |  | 6.3 | 5.2 |  | 8.6 | 5.3 | 5.5 | 5.4 | 8.8 | 1020 | 7.2 |  |
|  | 06/29/88 |  |  | 5 |  | 14.4 | 19.2 |  |  | 5.6 |  | 7.3 | 7.1 |  | 11 | 5.9 | 7.3 | 6.7 |  | 885 | 6.3 |  |
| ppm Fe | 07/22/87 | 0.003 | <.002 |  | <.002 |  | 0.004 |  | <.002 |  | <.002 | 0.005 | <.002 | 0.007 |  |  |  |  |  | 399 | 0.072 |  |
|  | 10/22/87 |  |  | <.002 | <.002 |  | <.002 |  |  | <.002 |  | <.002 |  |  | <.002 | <.002 | <.002 | <.002 | <.002 |  | <.002 | 0.002 |
|  | 04/23/88 |  |  | 0.012 | 0.11 |  |  | 0.014 |  | 0.016 |  | 0.066 | 0.35 |  | 0.023 | 0.051 | 0.044 | 0.28 | 0.099 | 358 | 0.04 |  |
|  | 06/29/88 |  |  | <.002 |  | <.002 | 0.002 |  |  | <.002 |  | <.001 | 0.005 |  | <.002 | <.002 | <.002 | <.002 |  | 329 | 0.006 |  |
| ppm Mn | 07/22/87 | <.001 | <.001 |  | 5.01 |  | 0.29 |  | 0.053 |  | <.001 | 0.003 | 0.5 | 0.25 |  |  |  |  |  | 42 | 0.022 |  |
|  | 10/22/87 |  |  | <.001 | 0.4 |  | 0.085 |  |  | <.001 |  | <.001 |  |  | 0.001 | <.001 | <.001 | <.001 | <.001 |  | 0.039 | 0.058 |
|  | 04/23/88 |  |  | 0.006 | 0.23 |  |  | 0.022 |  | 0.015 |  | 0.015 | 0.21 |  | 0.02 | 0.016 | 0.009 | 0.065 | 0.006 | 35.9 | 0.017 |  |
|  | 06/28/89 |  |  | 0.001 |  | 0.077 | 0.001 |  |  | 0.001 |  | 0.002 | 0.19 |  | <.001 | 0.001 | <.001 | 0.001 |  | 30.9 | 0.037 |  |

(DISSOLVED)

| PARAMETER | DATE | QA/QC | MW 2 | MW 21s | MW 3 | MW 3s | MW 4s | MW 4m | MW 4d | MW 5s | MW 6 | MW 7s | MW 8 | MW 13 | MW 16s | MW 17s | MW 18s | MW 19s | MW 20s | L3 | DITCH 13 | DITCH 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ppm F | 07/22/97 | <.1 | 0.2 |  | 0.2 |  | 0.3 |  | 0.8 |  | 0.6 | 0.6 | 0.7 | 0.7 |  |  |  |  |  | 10 | 0.4 |  |
|  | 10/22/87 |  |  | 0.4 | 0.6 |  | 0.6 |  |  | 0.4 |  | 0.7 |  |  | 0.4 | 0.6 | 0.6 | 0.6 | 0.6 |  | 0.6 | 0.6 |
|  | 04/23/88 |  |  | 0.6 | 0.7 |  |  | 0.8 |  | 0.5 |  | 0.3 | 1 |  | 0.5 | 0.4 | 0.8 | 0.8 | 0.4 | 2 | 0.3 |  |
|  | 06/28/88 |  |  | 0.6 |  | 0.5 | 0.6 |  |  | 0.5 |  | 0.8 | 1.1 |  | 0.5 | 0.7 | 0.7 | 0.7 |  | <30 | 0.2 |  |
| ppm Br | 07/22/87 | <.1 | <.1 |  | 6.1 |  | 2.5 |  | 0.4 |  | <.1 | 0.5 | <.1 | 0.2 |  |  |  |  |  | 110 | <.1 |  |
|  | 10/22/87 |  |  | <.1 | <.1 |  | 0.6 |  |  | 0.1 |  | 0.4 |  |  | 0.4 | 0.2 | 0.3 | 0.1 | 0.7 |  | <.1 | <.1 |
|  | 04/23/89 |  |  | <.1 | <.1 |  |  | <.1 |  | <.1 |  | <.1 | <.1 |  | <.1 | <.1 | <.1 | <.1 | <.1 | 0.2 | <.1 |  |
|  | 06/28/89 |  |  | <.1 |  | <.1 | <.1 |  |  | <.1 |  | <.1 | <.1 |  | <.1 | <.1 | <.1 | <.1 |  | <1. | <.1 |  |
| ppm P | 07/22/87 | <.1 | <.1 |  | <.1 |  | 0.2 |  | <.1 |  | <.1 | <.1 | <.1 | <.1 |  |  |  |  |  | <.1 | <.1 |  |
|  | 10/22/97 |  |  | <.1 | <.1 |  | <.1 |  |  | <.1 |  | <.1 |  |  | <.1 | <.1 | <.1 | <.1 | <.1 |  | <.1 | <.1 |
|  | 04/23/89 |  |  | <.1 | <.1 |  |  | <.1 |  | <.1 |  | <.1 | <.1 |  | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 | <.1 |  |
|  | 06/28/88 |  |  | <.1 |  | <.1 | <.1 |  |  | <.1 |  | <.1 | <.1 |  | <.1 | <.1 | <.1 | <.1 |  | <.1 | <.1 |  |
| DS | 07/22/87 | 0.3 | 693.72 |  | 5113.98 |  | 2629.98 |  | 969.16 |  | 744.43 | 1100.22 | 786.92 |  |  |  |  |  |  |  | 624.3 |  |
|  | 10/22/87 |  |  | 688.85 | 1086.67 |  | 1899.51 |  |  | 1039.72 |  | 1095.28 |  |  | 1950.49 | 915.58 | 982.82 | 843.58 | 1837.07 |  | 955.73 | 966.39 |
|  | 04/23/89 |  |  | 706.62 | 760 |  |  | 825 |  | 954 |  | 907 | 800 |  | 1285 | 898 | 846 | 827 | 1146 |  | 715 |  |
|  | 06/28/88 |  |  | 692.07 |  | 1435.81 | 1935.42 |  |  | 882.77 |  | 823.84 | 789.89 |  | 1459.43 | 596.69 | 757.88 | 782.35 |  |  | 513.15 |  |
| SUM DISS | 07/22/87 | 0.4 | 870.8 |  | 5383.92 |  | 2928.83 |  | 1223.36 |  | 973.27 | 1341.73 | 1022.35 |  |  |  |  |  |  |  | 762.31 |  |
|  | 10/22/97 |  |  | 911.09 | 1332.35 |  | 2172.99 |  |  | 1293.42 |  | 1337.82 |  |  | 2260 | 1155.58 | 1225.36 | 1080.03 | 2100.92 |  | 1209.93 | 1213.49 |
|  | 04/23/88 |  |  | 928.9 | 998 |  |  | 1079 |  | 1199 |  | 1164 | 1047 |  | 1580 | 1158 | 1102 | 1077 | 1407 |  | 866 |  |
|  | 06/28/88 |  |  | 885.9 |  | 1659.57 | 2193.18 |  |  | 1123.79 |  | 1051.15 | 1021.77 |  | 1717.7 | 778.34 | 969.97 | 987.95 |  |  | 645.89 |  |
| LAB SC | 07/22/87 | 2.9 | 1178.9 |  | 8445.8 |  | 5059.1 |  | 1602.2 |  | 1187.1 | 1860.9 | 1276.1 | 1277.2 |  |  |  |  |  | 113502 | 1037.3 |  |
|  | 10/22/87 |  |  | 1139 | 1921 |  | 3194 |  |  | 1726 |  | 1942 |  |  | 3534 | 1555 | 1681 | 1421 | 3362 |  | 1573 | 1584 |
|  | 04/23/88 |  |  | 1125 | 1165 |  |  | 1269 |  | 1612 |  | 1418 | 1244 |  | 2192 | 1440 | 1345 | 1242 | 1794 | 100000 | 1544 |  |
|  | 06/28/88 |  |  | 1067 |  | 2445 | 3313 |  |  | 1432 |  | 1317 | 1213 |  | 2413 | 934.9 | 1179 | 1234 |  |  | 796.3 |  |

(DISSOLVED)

| PARAMETER | DATE | QA/QC | MW 2 | MW 21s | MW 3 | MW 3s | MW 4s | MW 4m | MW 4d | MW 5s | MW 6 | MW 7s | MW 8 | MW 13 | MW 16s | MW 17s | MW 18s | MW 19s | MW 20s | L3 | DITCH 13 | DITCH 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ppm SiO2 | 07/22/87 | 0.1 | 20.5 |  | 19 |  | 31.1 |  | 19.9 |  | 23.8 | 24.3 | 21.5 | 21.3 |  |  |  |  |  | 8.3 | 14.4 |  |
|  | 10/22/87 |  |  | 25.4 | 28.5 |  | 27.9 |  |  | 29.6 |  | 23.9 |  |  | 32.1 | 22.8 | 21.5 | 26 | 26.6 |  | 22.8 | 22.3 |
|  | 04/23/88 |  |  | 22.3 | 24.8 |  |  | 22.1 |  | 23.9 |  | 21.8 | 20.4 |  | 29 | 21 | 19.7 | 22.6 | 23.8 | 7.5 | 9.2 |  |
|  | 06/29/88 |  |  | 23.9 |  | 29.3 | 28.1 |  |  | 27.3 |  | 23.5 | 22.6 |  | 31.9 | 24 | 21.8 | 27.6 |  | 1.3 | 15.7 |  |
| ppm HCO3 | 07/22/87 | 0.2 | 349 |  | 532 |  | 589 |  | 501 |  | 451 | 476 | 464 | 453 |  |  |  |  |  | 220.8 | 272 |  |
|  | 10/22/87 |  |  | 438 | 484 |  | 539 |  |  | 500 |  | 478 |  |  | 610 | 473 | 478 | 466 | 520 |  | 501 | 487 |
|  | 04/23/88 |  |  | 438 | 470 |  |  | 501 |  | 493 |  | 506 | 486 |  | 583 | 512 | 505 | 492 | 514 | 332 | 299 |  |
|  | 06/29/88 |  |  | 382 |  | 441 | 508 |  |  | 475 |  | 448 | 457 |  | 509 | 358 | 418 | 405 |  | 268.4 | 261.6 |  |
| ppm CO3 | 07/22/87 | 0 | 0 |  | 0 |  | 0 |  | 0 |  | 0 | 0 | 0 | 0 |  |  |  |  |  | 0 | 0 |  |
|  | 10/22/87 |  |  | 0 | 0 |  | 0 |  |  | 0 |  | 0 |  |  | 0 | 0 | 0 | 0 | 0 |  | 0 | 14.6 |
|  | 04/23/88 |  |  | 0 | 0 |  |  | 0 |  | 0 |  | 0 | 0 |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  |
|  | 06/29/88 |  |  | 0 |  | 0 | 0 |  |  | 0 |  | 0 | 0 |  | 0 | 0 | 0 | 0 |  | 0 | 0 |  |
| ppm Cl | 07/22/87 | 0.1 | 31.9 |  | 2660 |  | 1060 |  | 117 |  | 37.4 | 217 | 31 | 51.8 |  |  |  |  |  | 14500 | 25.9 |  |
|  | 10/22/87 |  |  | 19.7 | 221 |  | 678 |  |  | 186 |  | 224 |  |  | 626 | 119 | 146 | 87.9 | 646 |  | 33.8 | 30.9 |
|  | 04/23/88 |  |  | 21.1 | 24.4 |  |  | 28.2 |  | 130 |  | 70.7 | 31.4 |  | 268 | 71.3 | 44.4 | 49.4 | 220 | 156000 | 21.4 |  |
|  | 06/28/88 |  |  | 23.2 |  | 411 | 680 |  |  | 83.7 |  | 60.6 | 29.2 |  | 393 | 20.8 | 30.2 | 56.1 |  | 130000 | 17.7 |  |
| ppm SO4 | 07/22/87 | <.1 | 203 |  | 256 |  | 253 |  | 250 |  | 210 | 243 | 236 | 224 |  |  |  |  |  | 690 | 2249 |  |
|  | 10/22/87 |  |  | 187 | 208 |  | 227 |  |  | 213 |  | 227 |  |  | 295 | 227 | 244 | 211 | 234 |  | 340 | 342 |
|  | 04/23/88 |  |  | 213 | 233 |  |  | 251 |  | 238 |  | 267 | 245 |  | 247 | 265 | 255 | 240 | 262 | 1110 | 305 |  |
|  | 06/28/88 |  |  | 209 |  | 243 | 260 |  |  | 231 |  | 234 | 235 |  | 259 | 172 | 240 | 218 |  | 223 | 174 |  |
| ppm N | 07/22/87 | <.02 | 22.7 |  | 2.61 |  | 9.14 |  | 0.11 |  | 2.77 | 4.03 | 0.75 | 0.23 |  |  |  |  |  | 25 | 1.22 |  |
|  | 10/22/87 |  |  | 5.89 | 3.85 |  | 3.21 |  |  | 9.42 |  | 2.22 |  |  | 16 | 2.59 | 2.76 | 3.53 | 4.52 |  | 33 | 2.93 |
|  | 04/23/88 |  |  | 4.34 | 1.55 |  |  | 0.97 |  | 8.3 |  | 1.24 | 0.85 |  | 5.25 | 1.25 | 1.15 | 1.78 | 2.3 | <.04 | 0.67 |  |
|  | 06/28/88 |  |  | 11 |  | 10.6 | 3.28 |  |  | 4.98 |  | 2.75 | 0.38 |  | 10.1 | 2.24 | 1.07 | 7.75 |  | 36 | 2.35 |  |

| PARAMETER | DATE | QA/QC | MW 2 | MW 21s | MW 3 | MW 3s | MW 4s | MW 4m | MW 4d | MW 5s | MW 6 | MW 7s | MW 8 | MW 13 | MW 16s | MW 17s | MW 18s | MW 19s | MW 20s | L3 | DITCH 13 | DITCH 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LAB pH | 07/22/97 | 5.05 | 7.52 |  | 7.39 |  | 7.17 |  | 7.69 |  | 7.74 | 7.56 | 7.71 | 7.71 |  |  |  |  |  | 5.25 | 8.06 |  |
|  | 10/22/97 |  |  | 7.48 | 7.54 |  | 7.01 |  |  | 7.5 |  | 7.47 |  |  | 7.64 | 7.68 | 7.32 | 7.34 | 7.32 |  | 8.3 | 8.35 |
|  | 04/23/88 |  |  | 7.29 | 7.51 |  |  | 7.59 |  | 7.71 |  | 7.71 | 7.43 |  | 7.9 | 7.7 | 7.71 | 7.52 | 7.48 | 5.49 | 8.04 |  |
|  | 06/28/88 |  |  | 7.86 |  | 7.48 | 7.6 |  |  | 7.85 |  | 7.62 | 7.89 |  | 7.89 | 7.83 | 8.07 | 7.91 |  | 4.98 | 7.92 |  |
| HARDNESS | 07/22/87 | 0 | 490.48 |  | 1264.75 |  | 772.59 |  | 427.47 |  | 400.5 | 517.76 | 338.36 |  |  |  |  |  |  | 28973.79 | 298.13 |  |
|  | 10/22/87 |  |  | 417.11 | 429.51 |  | 612.64 |  |  | 598.4 |  | 491.14 |  |  | 922.93 | 435.76 | 455.18 | 429.7 | 623.62 |  | 461.05 | 467.67 |
|  | 04/23/88 |  |  | 388.05 | 394 |  |  | 383 |  | 526 |  | 369 | 351 |  | 564 | 370 | 372 | 406 | 415 | 26036 | 323 |  |
|  | 06/28/88 |  |  | 415.3 |  | 526.34 | 613.96 |  |  | 489.36 |  | 390.21 | 347.07 |  | 565.6 | 324.76 | 362.97 | 439.31 |  | 23603.87 | 269.49 |  |
| ALKALIN | 07/22/87 | 0.16 | 286.23 |  | 436.33 |  | 483.08 |  | 410.9 |  | 369.89 | 390.4 | 380.55 |  |  |  |  |  |  | 181.09 | 223.08 |  |
|  | 10/22/87 |  |  | 359.23 | 396.96 |  | 442.07 |  |  | 410 |  | 392.04 |  |  | 500.3 | 387.94 | 392.04 | 382.19 | 426.48 |  | 410.9 | 423.77 |
|  | 04/23/88 |  |  | 359.23 | 385 |  |  | 411 |  | 396 |  | 415 | 399 |  | 478 | 420 | 414 | 404 | 422 | 272.29 | 245 |  |
|  | 06/28/88 |  |  | 313.3 |  | 361.69 | 416.64 |  |  | 389.58 |  | 367.43 | 374.81 |  | 417.46 | 293.62 | 342.83 | 332.16 |  | 220.13 | 214.55 |  |
| ION BAL | 07/22/87 | 0.055 | -.640 |  | 0.498 |  | -.413 |  | -.877 |  | 0.145 | 560 | -.758 | -.517 |  |  |  |  |  |  | 0.604 |  |
|  | 10/22/87 |  |  | -0.315 | 0.091 |  | 0.204 |  |  | 0.367 |  | -0.382 |  |  | 0.117 | 0.361 | 0.749 | 0.502 | 0.094 |  | 0.035 | -0.003 |
|  | 04/23/88 |  |  | 2.525 | 2.663 |  |  | 0.995 |  | 1.63 |  | 2.934 | 1.675 |  | -0.049 | 4.571 | 2.919 | 2.098 | 4.253 |  | 0.032 |  |
|  | 06/28/88 |  |  | -0.78 |  | -0.823 | -0.592 |  |  | -0.732 |  | -0.56 | -2.747 |  | -0.51 | -1.198 | -1.551 | -2.13 |  |  | -2.179 |  |

METAL ANALYSES OF WATER SAMPLES AT THE IVERSON SITE, RICHLAND, CO. (DISSOLVED)

| PARAMETER | DATE | LOCATION<br>MW 21s | MW 3 | MW 3s | MW 4s | MW 16s | MW 20s | L3 |
|---|---|---|---|---|---|---|---|---|
| ppb Al | 07/21/87 | | <30 | | | | | |
| | 10/22/87 | | <30 | | | | <30 | |
| | 04/23/88 | | <30 | | | | | 80 |
| | 06/28/88 | <30 | | <30 | <30 | <30 | | 160 |
| ppb Ag | 07/21/87 | | <2 | | | | | |
| | 10/22/87 | | <2 | | | | <2 | |
| | 04/23/88 | | <2 | | | | | 44 |
| | 06/28/88 | <2 | | <2 | <2 | <2 | | 94 |
| ppb B | 07/21/87 | | 1030 | | | | | |
| | 10/22/87 | | 220 | | | | 570 | |
| | 04/23/88 | | 140 | | | | | 38000 |
| | 06/28/88 | 120 | | 400 | 820 | 600 | | 38000 |
| ppb Cd | 07/21/87 | | <2 | | | | | |
| | 10/22/87 | | <2 | | | | <2 | |
| | 04/23/88 | | <2 | | | | | 16 |
| | 06/28/88 | <2 | | <2 | <2 | <2 | | 30 |
| ppb Cr | 07/21/87 | | <2 | | | | | |
| | 10/22/87 | | <2 | | | | <2 | |
| | 04/23/88 | | <2 | | | | | 14 |
| | 06/28/88 | <2 | | <2 | <2 | <2 | | 12 |
| ppb Cu | 07/21/87 | | <2 | | | | | |
| | 10/22/87 | | 4 | | | | <2 | |
| | 04/23/88 | | <2 | | | | | 1920 |
| | 06/28/88 | <2 | | <2 | 11 | <2 | | 890 |
| ppb Li | 07/21/87 | | 370 | | | | | |
| | 10/22/87 | | 71 | | | | 160 | |
| | 04/23/88 | | 20 | | | | | 13100 |
| | 06/28/88 | 20 | | 130 | 190 | 100 | | 10000 |
| ppb Mo | 07/21/87 | | <20 | | | | | |
| | 10/22/87 | | <20 | | | | <20 | |
| | 04/23/88 | | <20 | | | | | 50 |
| | 06/28/88 | <20 | | <20 | <20 | <20 | | 20 |
| ppb Ba | 07/21/87 | | 530 | | | | | |
| | 10/22/87 | | | | | | 92 | |
| | 04/23/88 | | 60 | | | | | 320 |
| | 06/28/88 | | | 110 | 100 | | | 270 |
| ppb Pb | 07/21/87 | | <40 | | | | <40 | |
| | 10/22/87 | | | | | | | |
| | 04/23/88 | | <40 | | | | | 350 |
| | 06/28/88 | | | <40 | <40 | | | 270 |

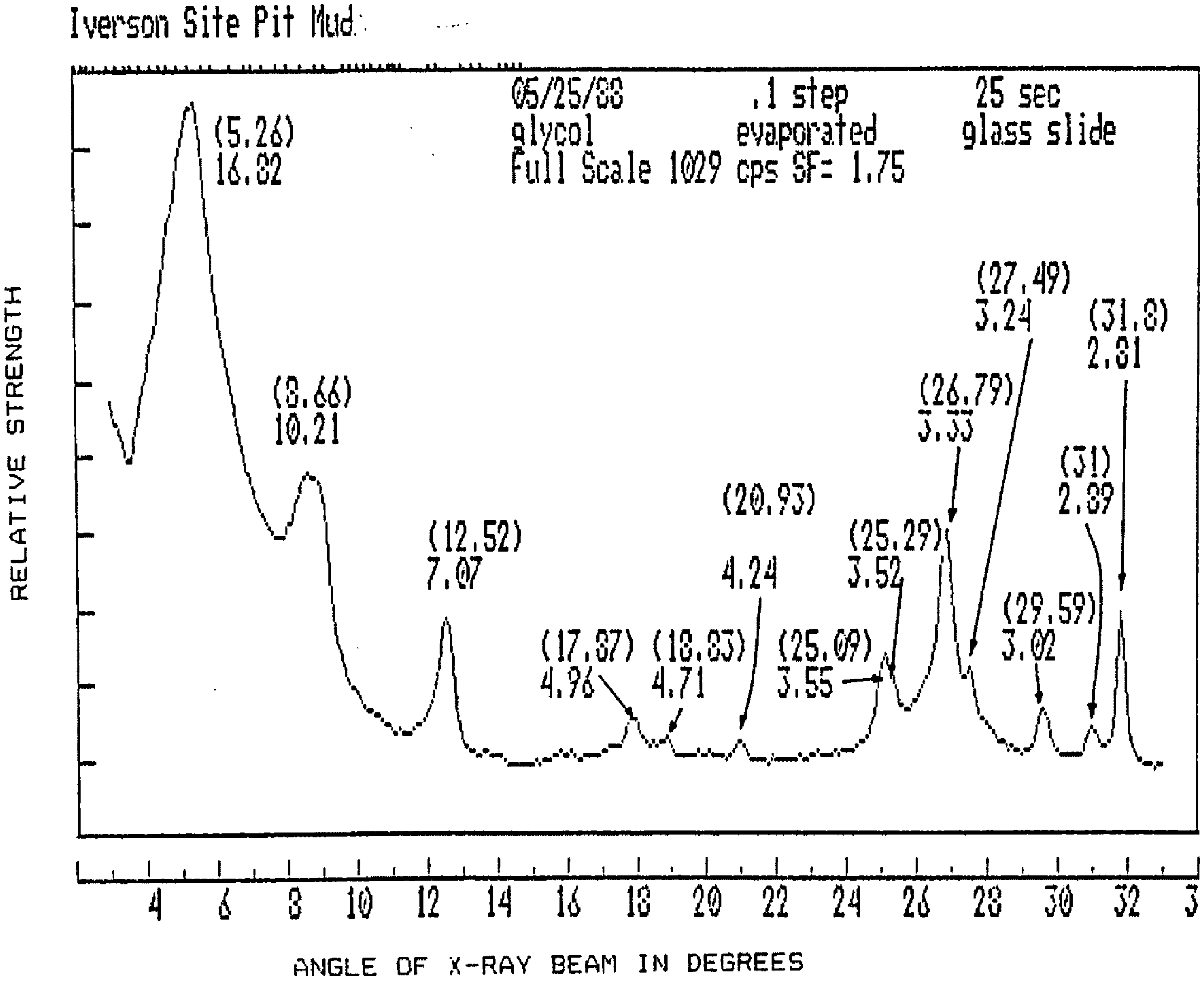
CoNT.

| PARAMETER | DATE | MW 21s | MW 3 | MW 3s | MW 4s | MW 16s | MW 20s | L3 |
|---|---|---|---|---|---|---|---|---|
| ppb Ni | 07/21/87 | | <10 | | | | | |
| | 10/22/87 | | <10 | | | | <10 | |
| | 04/23/88 | | <10 | | | | | 160 |
| | 06/28/88 | <10 | | <10 | <10 | <10 | | 160 |
| ppb Sr | 07/21/87 | | 7300 | | | | | |
| | 10/22/87 | | 1020 | | | | 2510 | |
| | 04/23/88 | | 990 | | | | | 241000 |
| | 06/28/88 | 630 | | 2660 | 2780 | 940 | | 207000 |
| ppb Ti | 07/21/87 | | 29 | | | | | |
| | 10/22/87 | | 3 | | | | 5 | |
| | 04/23/88 | | <1 | | | | | <1 |
| | 06/28/88 | 4 | | 6 | 8 | 5 | | <1 |
| ppb V | 07/21/87 | | <1 | | | | | |
| | 10/22/87 | | <1 | | | | <1 | |
| | 04/23/88 | | <1 | | | | | 51 |
| | 06/28/88 | <1 | | <1 | <1 | <1 | | 15 |
| ppb Zn | 07/21/87 | | 14 | | | | | |
| | 10/22/87 | | 4 | | | | <3 | |
| | 04/23/88 | | <3 | | | | | 880 |
| | 06/28/88 | <3 | | <4 | 3 | <3 | | 430 |
| ppb Zr | 07/21/87 | | <4 | | | | | |
| | 10/22/87 | | <3 | | | | <4 | |
| | 04/23/88 | | <4 | | | | | 66 |
| | 06/28/88 | <4 | | <4 | <4 | <4 | | 66 |
| ppb As | 07/21/87 | | 0.5 | | | | | |
| | 10/22/87 | | | | | | 0.5 | |
| | 04/23/88 | | 0.7 | | | | | 0.3 |
| | 06/28/88 | | | <.1 | | | | 2 |
| ppb Se | 07/21/87 | | | | | | | |
| | 10/22/87 | | | | | | 1 | |
| | 04/23/88 | | 1.2 | | | | | 0.6 |
| | 06/28/88 | | | | | | | 2.2 |
| ppb Be | 07/21/87 | | 21 | | | | | |
| | 10/22/87 | | | | | | | |
| | 04/23/88 | | <1 | | | | | 26 |
| | 06/28/88 | | | 1 | | | | 21 |

# APPENDIX M

# CLAY MINERALOGY

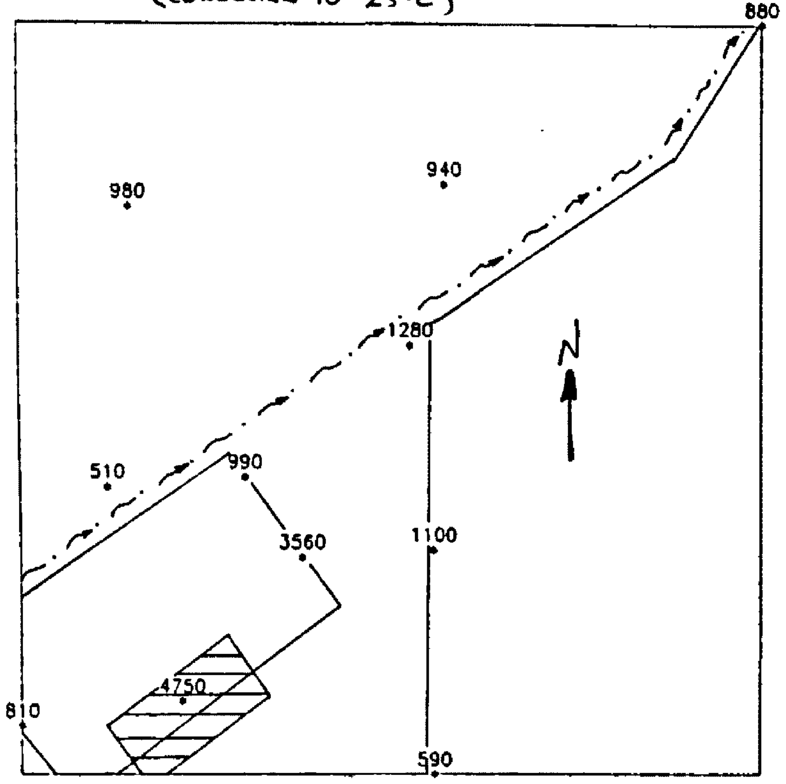
| ANGSTROMS | INTERPRETATION |
|---|---|
| 16.82 | SMECTITE 001 |
| 10.21 | ILLITE 001 |
| 7.07 | KAOLINITE 001 OR CHLORITE 002 |
| 4.96 | ILLITE 002(?) |
| 4.71 | ILLITE 002(?) |
| 4.24 | SMECTITE 002(?) |
| 3.55 | CHLORITE 003 |
| 3.52 | KAOLINITE 002 |
| 3.33 | QUARTZ |
| 3.24 | K-SPAR(?) |
| 3.02 | CALCITE |
| 2.89 | DOLOMITE |
| 2.81 | HALITE |



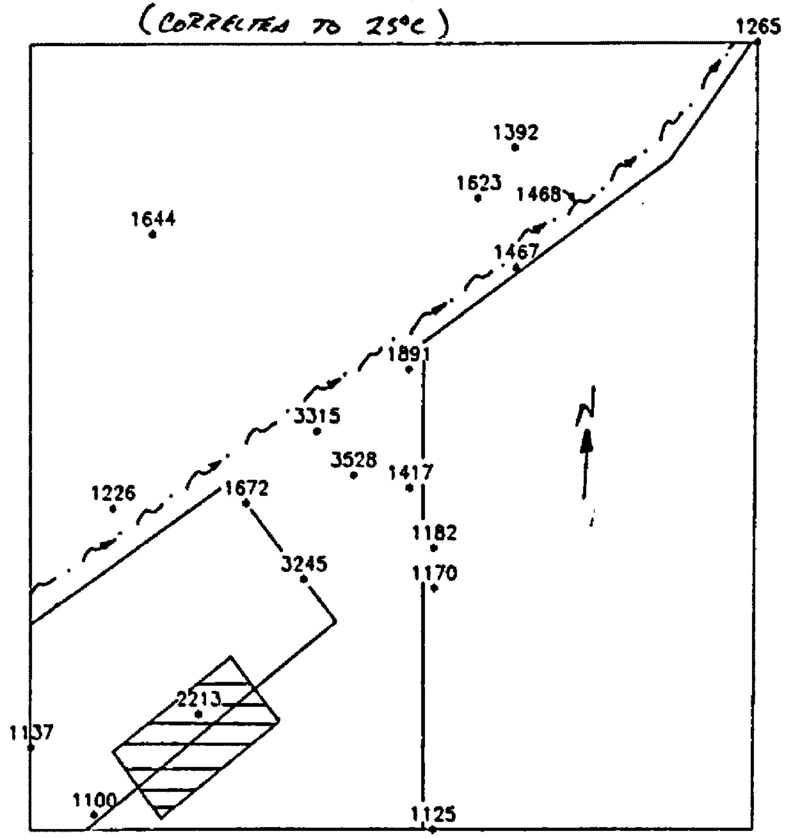
# APPENDIX N

# CHLORIDE DATA AND SC DATA/PLOTS

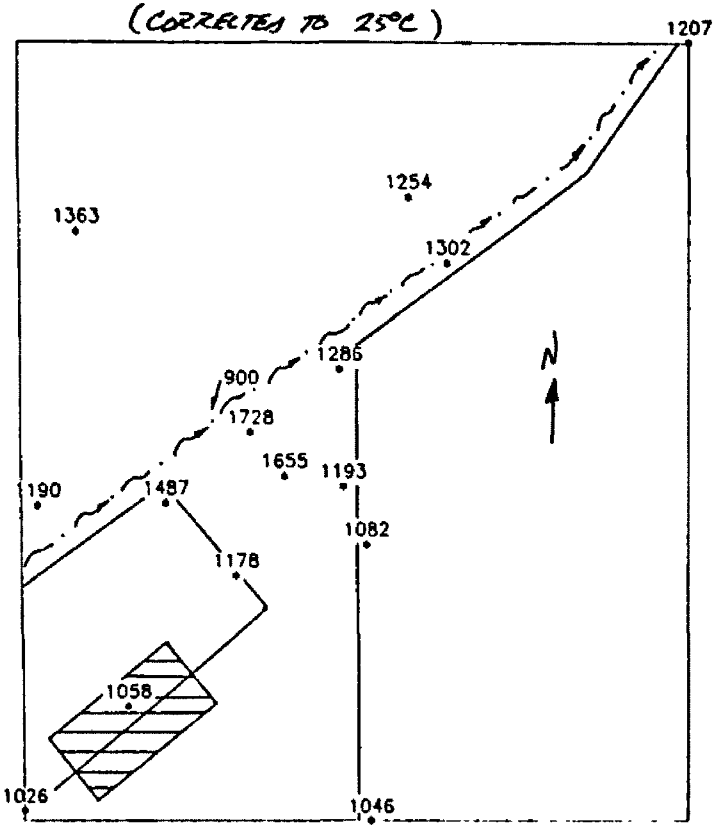
SPECIFIC
CONDUCTANCE umohs/cm: JULY, 1987
- (CORRECTED TO 25°C)



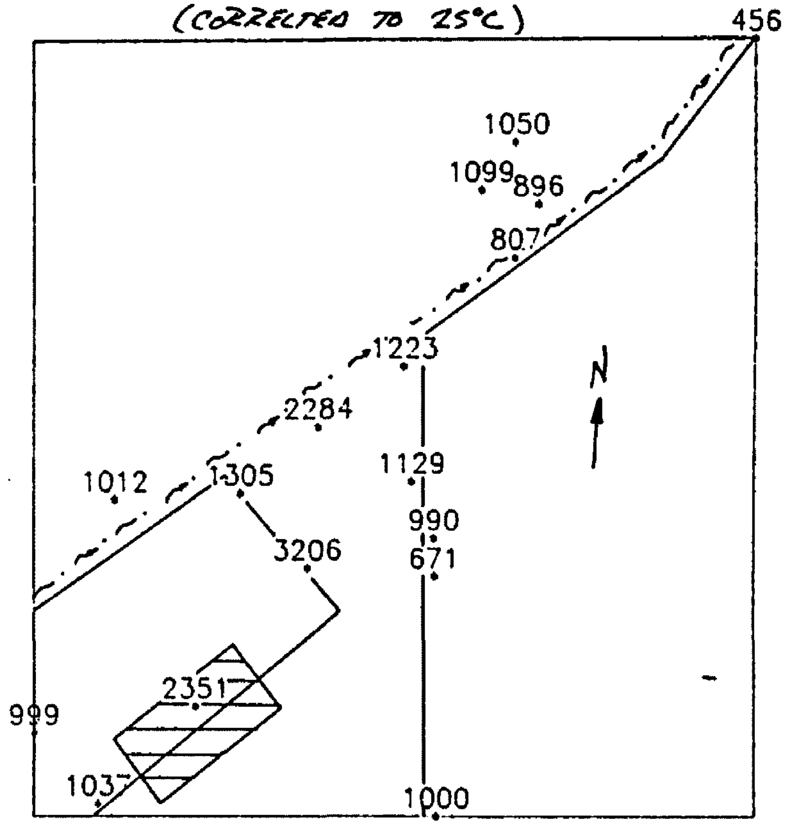
SPECIFIC
CONDUCTANCE umohs/cm: OCT., 1987
(CORRECTED TO 25°C)



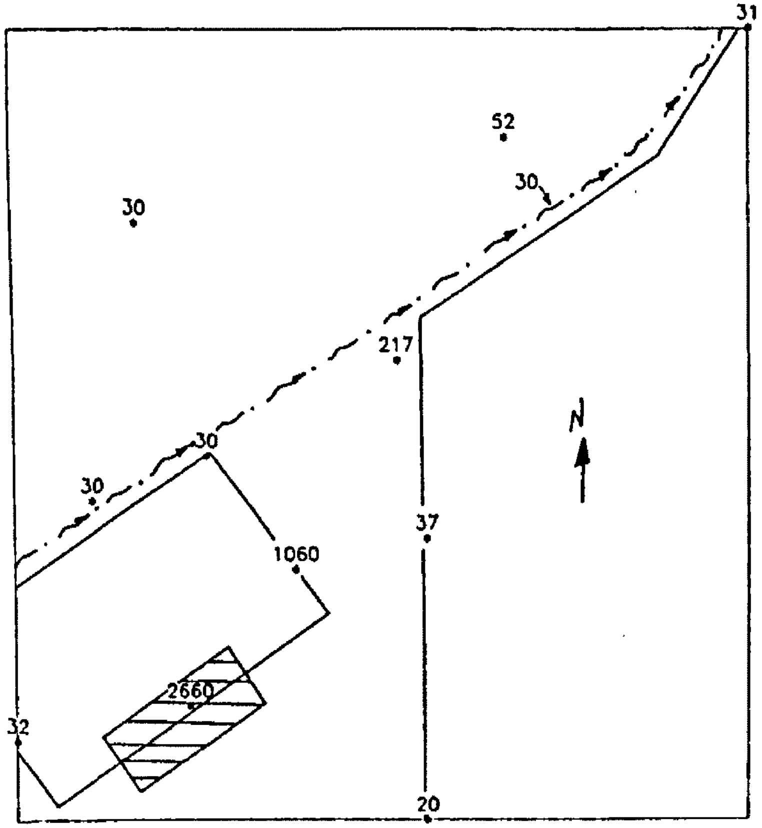
SPECIFIC
CONDUCTANCE umohs/cm: APRIL, 1988
(CORRECTED TO 25°C)



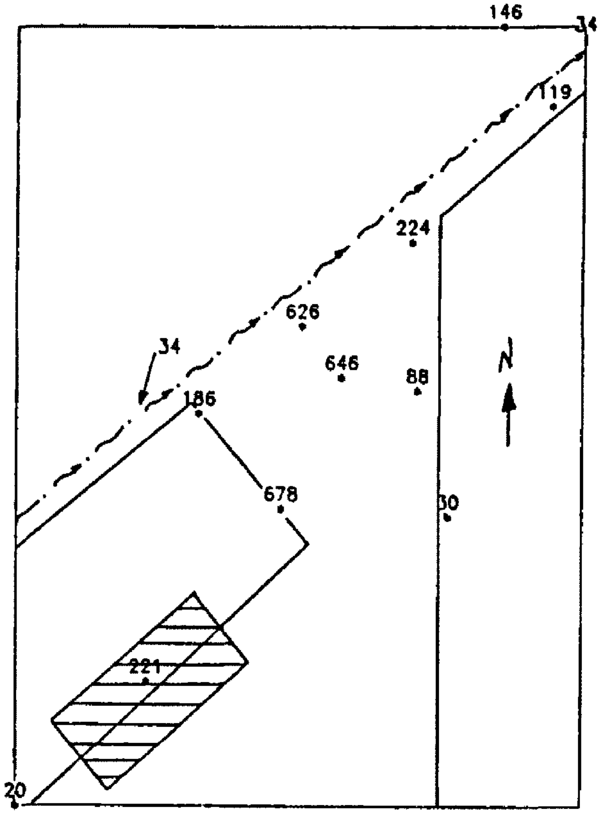
SPECIFIC
CONDUCTANCE umohs/cm: JUNE, 1988
(CORRECTED TO 25°C)



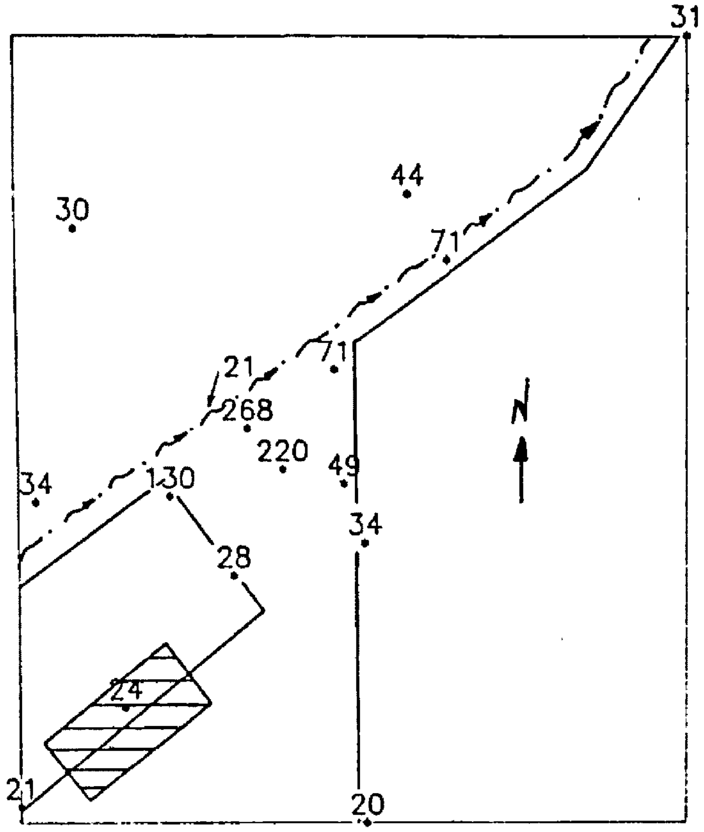
Cl CONCENTRATION mg/l: JULY, 1987



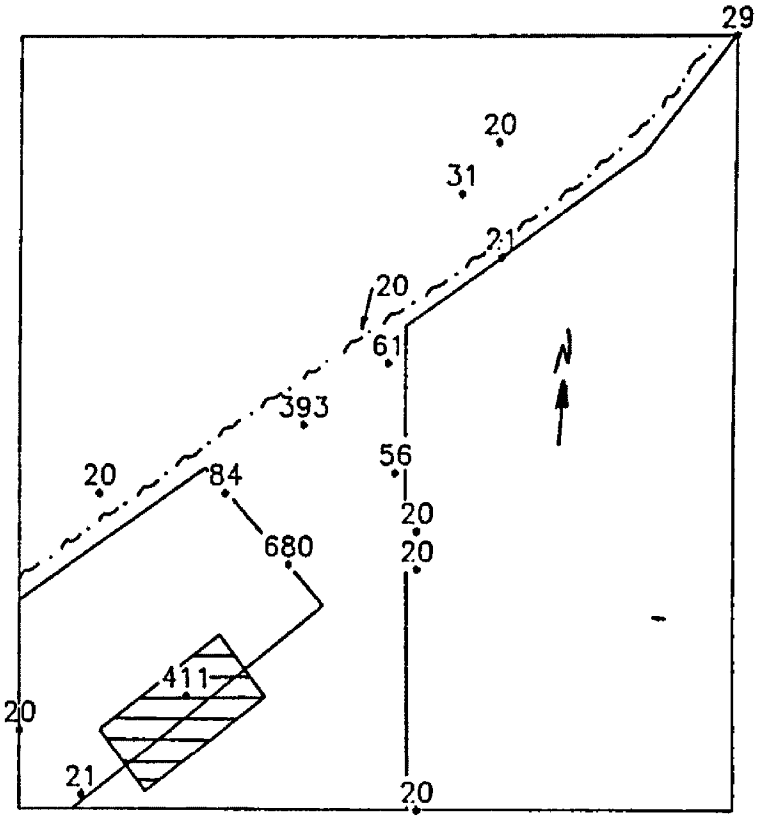
Cl CONCENTRATION mg/l: OCT., 1987



Cl CONCENTRATION mg/l: APRIL, 1988

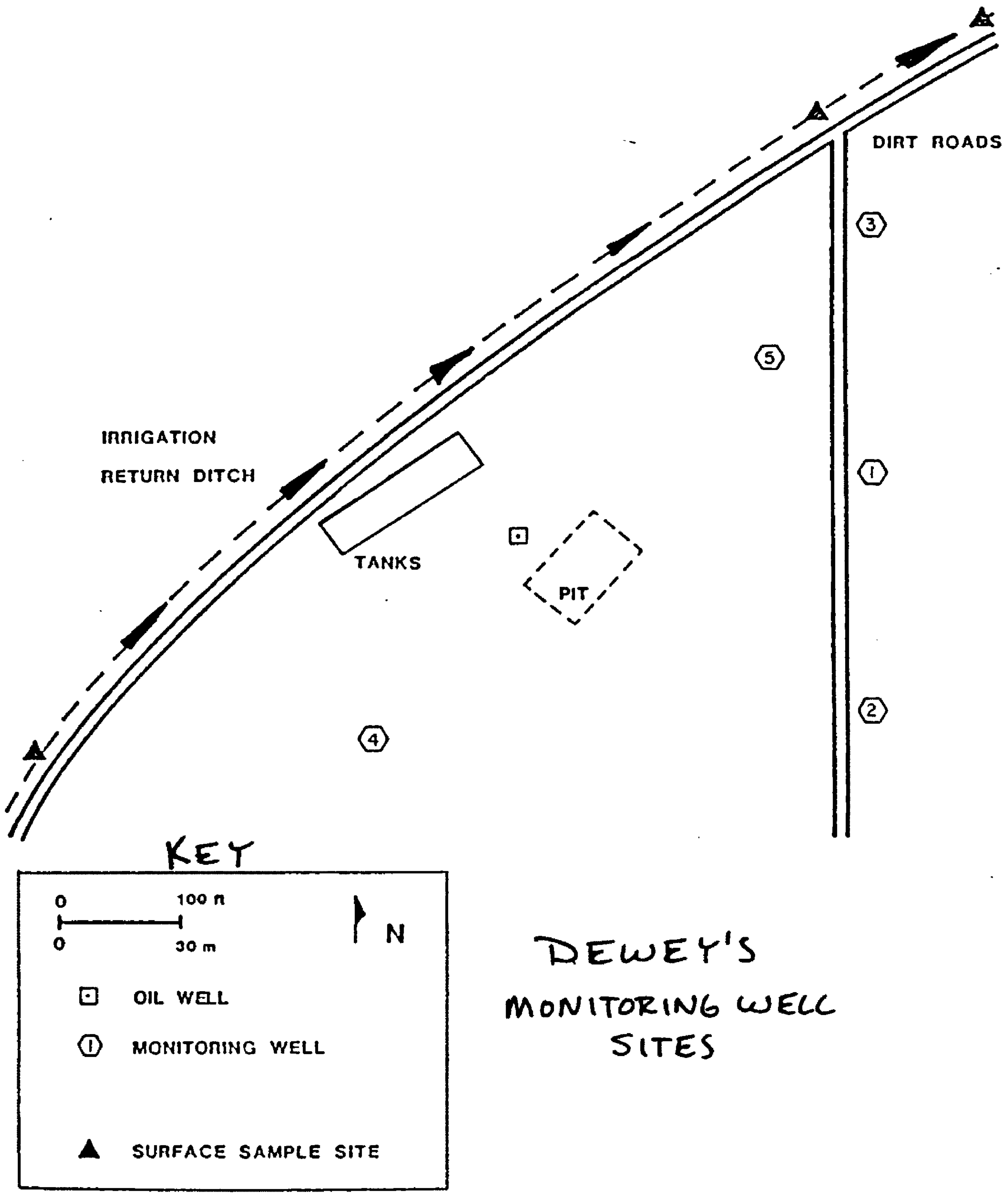


Cl CONCENTRATION mg/l: JUNE, 1988



# APPENDIX O

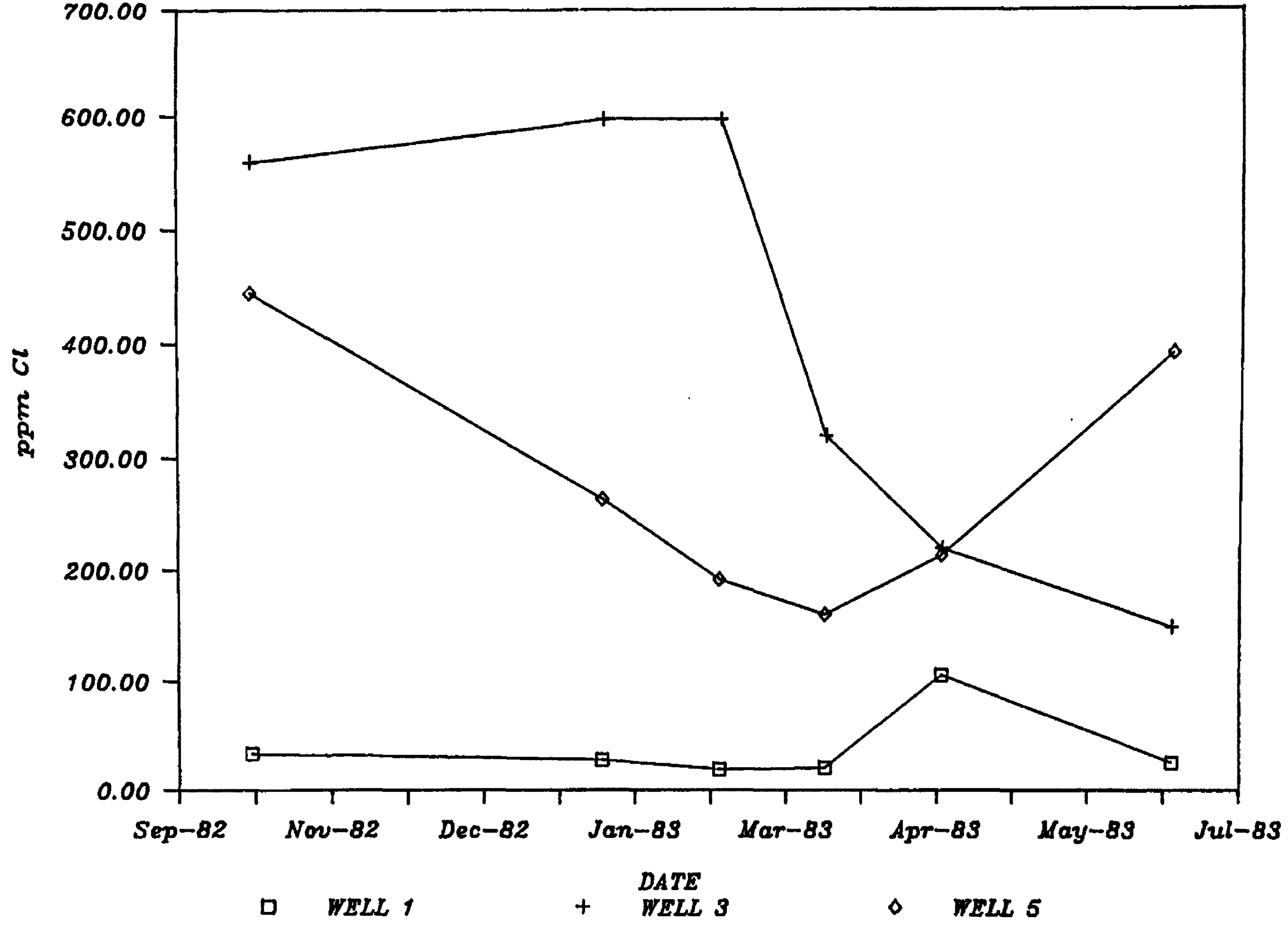
# YELLOWSTONE RIVER CHEMISTRY AND DEWEY'S DATA



DEWEY'S
MONITORING WELL
SITES

# DEWEY'S CHLORIDE CONC. IN ppm

## IVERSON SITE



DATA PRESENTED BY DEWEY CHEMICAL DATA FOR HER WELLS FROM 1982-1983
(NOTE MAP IN THIS APPENDIX FOR WELL LOCATION)

CHLORIDE CONCENTRATION IN ppm

| | 10/15/82 | 01/15/83 | 02/15/83 | 03/15/83 | 04/15/83 | 06/15/83 |
|---|---|---|---|---|---|---|
| WELL 3 | 560 | 600 | 600 | 321 | 220 | 150 |
| WELL 5 | 445 | 264 | 192 | 161 | 214 | 395 |
| WELL 1 | 33.5 | 27.8 | 19.1 | 20.7 | 106 | 25 |

SULFATE CONCENTRATION IN ppm

| | | | | | | |
|---|---|---|---|---|---|---|
| WELL 3 | 265 | 252 | 260 | 259 | 260 | 264 |
| WELL 5 | 234 | 223 | 231 | 240 | 249 | 247 |
| WELL 1 | 217 | 217 | 225 | 225 | 240 | 237 |

SPECIFIC
CONDUCTANCE IN umhos/cm 25 C

| | 08/18/82 | 08/24/82 | 09/01/82 | 09/04/82 | 09/09/82 | 10/28/82 | 01/30/83 |
|---|---|---|---|---|---|---|---|
| WELL 3 | | 2219 | 1790 | 1862 | 1854 | 2675 | 1522 |
| WELL 5 | | | | 2085 | 3382 | 2339 | 2353 |
| WELL 1 | 1125 | 1153 | 987 | 1128 | 1543 | 1231 | 1213 |

(ppm) CHEMICAL PARAMETERS AUGUST, 1982 (DISSOLVED IONS)

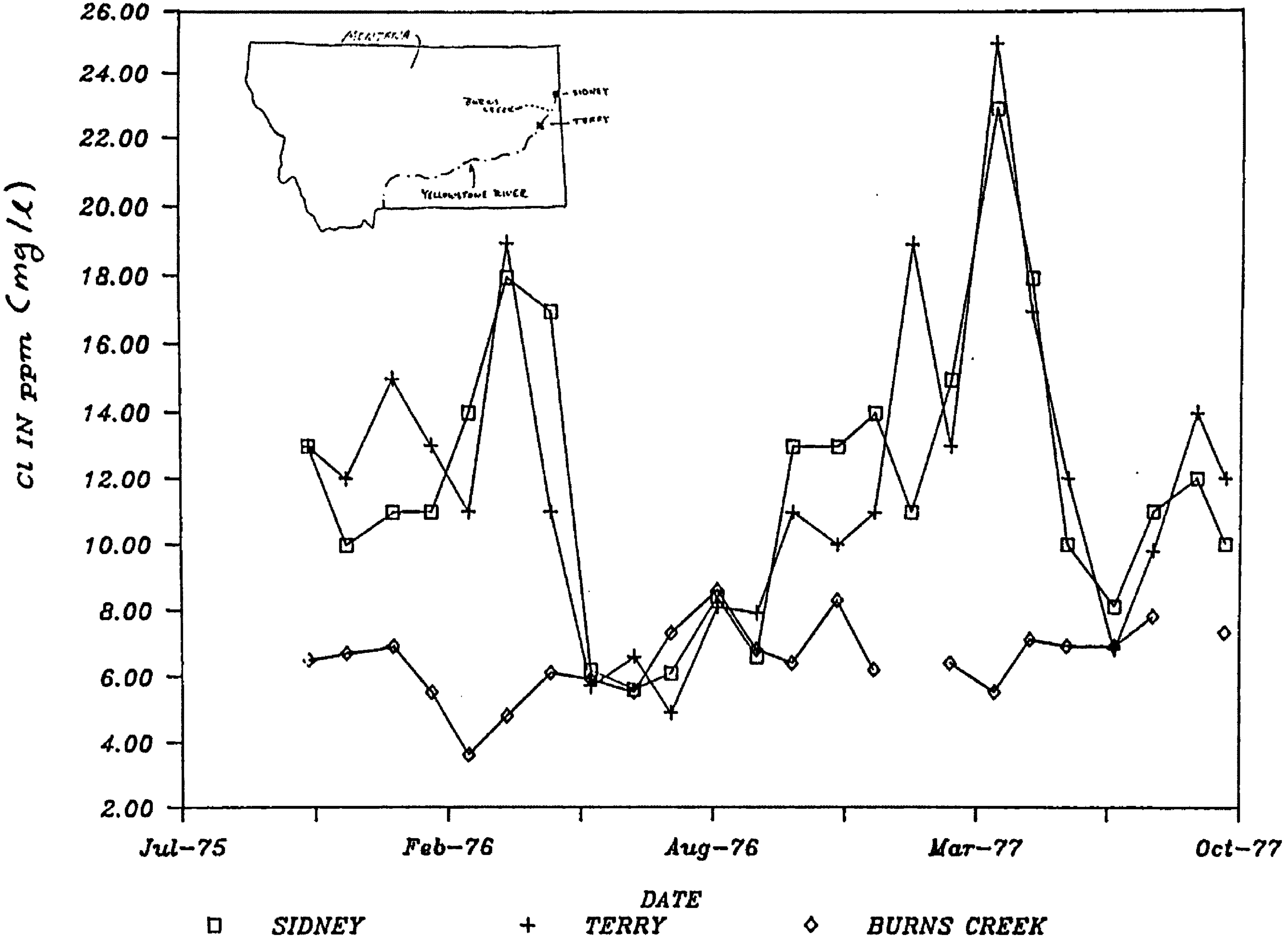
| PARAMETER | WELL 1 | WELL 2 | WELL 3 | DITCH BL |
|---|---|---|---|---|
| Ca | 85.3 | 93.1 | 124.8 | 56.9 |
| Mg | 38.1 | 31.6 | 70 | 35.5 |
| Na | 114 | 102.4 | 285.7 | 84.2 |
| K | 6.8 | 6.4 | 11.4 | 6.1 |
| HCO3 | 436.8 | 424.6 | 510 | 305 |
| CO3 | 0 | 0 | 0 | 0 |
| Cl | 14.5 | 13.5 | 368 | 17.5 |
| SO4 | 230 | 195 | 250 | 190 |
| | | | | |
| pH | 7.77 | 7.69 | 7.78 | 8.21 |
| TDS | 925 | 866.6 | 1619 | 695.2 |
| CONDUCT. | 1139 | 1085 | 2312 | 911 |
| HARDNESS | 370 | 363 | 600 | 288 |
| ALKALIN. | 358 | 348 | 418 | 250 |
| SAR | 2.6 | 2.3 | 5.1 | 2.2 |

(ppm) CHEMICAL PARAMTERS FOR SEPT. 1982 (DISSOLVED IONS)

| PARAMETER | WELL 1 | WELL 2 | WELL 3 | WELL 5 | DITCH BL |
|---|---|---|---|---|---|
| Ca | 89.2 | 67.2 | 89.6 | 156.8 | 58.9 |
| Mg | 35.04 | 40.8 | 49.5 | 60.1 | 29.5 |
| Na | 113.6 | 111.2 | 241.9 | 261 | 81 |
| K | 7.4 | 8 | 10.1 | 13.4 | 5.8 |
| HCO3 | 392.8 | 395.3 | 475.8 | 283.1 | 293 |
| CO3 | 0 | 0 | 0 | 0 | 0 |
| Cl | 29 | 14.8 | 200 | 450 | 17.5 |
| SO4 | 225 | 235 | 250 | 225 | 195 |
| | | | | | |
| pH | 7.81 | 7.95 | 8.04 | 7.78 | 8.06 |
| TDS | 892.4 | 872.3 | 1316.9 | 1549.4 | 670.7 |
| CONDUCT. | 1190 | 1136 | 1825 | 2357 | 882 |
| HARDNESS | 368 | 336 | 428 | 639 | 269 |
| ALKALIN. | 322 | 324 | 390 | 314 | 232 |
| SAR | 2.6 | 2.6 | 5.1 | 4.5 | 2.2 |

# CHLORIDE IN ppm IN SURFACE WATER

## AT VARIOUS LOCATIONS IN E. MT.



## REGIONAL WATER QUALITY (USGS)

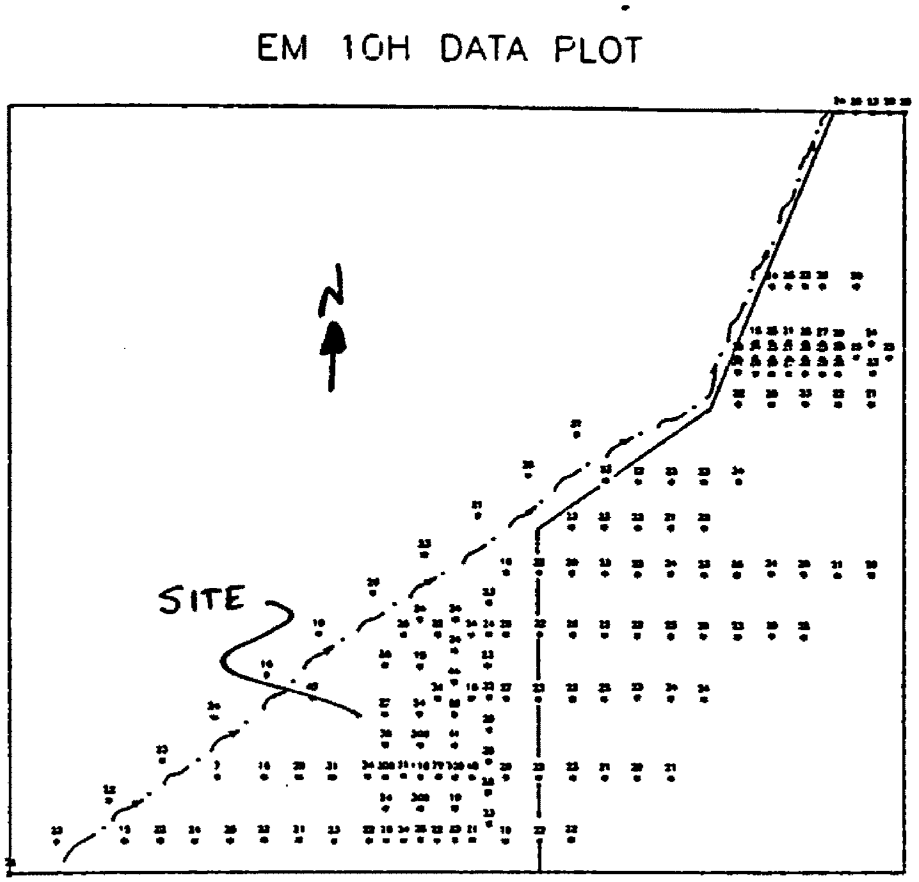
CHLORIDE (ppm)
DATE

| LOCATION | Oct-75 | Nov-75 | Dec-75 | Jan-76 | Feb-76 | Mar-76 | Apr-76 | May-76 | Jun-76 | Jul-76 | Aug-76 | Sep-76 | Oct-76 | Nov-76 | Dec-76 | Jan-77 | Feb-77 | Mar-77 | Apr-77 | May-77 | Jun-77 | Jul-77 | Aug-77 | Sep-77 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YS/SIDNEY | 13 | 10 | 11 | 11 | 14 | 18 | 17 | 6.2 | 5.6 | 6.1 | 8.4 | 6.6 | 13 | 13 | 14 | 11 | 15 | 23 | 18 | 10 | 8.1 | 11 | 12 | 10 |
| YS/TERRY | 13 | 12 | 15 | 13 | 11 | 19 | 11 | 5.7 | 6.6 | 4.9 | 8.1 | 7.9 | 11 | 10 | 11 | 19 | 13 | 25 | 17 | 12 | 6.8 | 9.8 | 14 | 12 |
| BURNS CK | 6.5 | 6.7 | 6.9 | 5.5 | 3.6 | 4.6 | 6.1 | 5.9 | 5.5 | 7.3 | 8.6 | 6.8 | 6.4 | 8.3 | 6.2 |  | 6.4 | 5.5 | 7.1 | 6.9 | 6.9 | 7.8 |  | 7.3 |
| SODIUM (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 66 | 63 | 69 | 62 | 72 | 90 | 89 | 25 | 31 | 32 | 51 | 49 | 65 | 73 | 73 | 67 | 70 | 90 | 77 | 60 | 42 | 77 | 91 | 74 |
| YS/TERRY | 70 | 62 | 75 | 68 | 63 | 83 | 67 | 29 | 38 | 25 | 44 | 46 | 59 | 63 | 63 | 79 | 69 | 87 | 81 | 57 | 35 | 72 | 69 | 66 |
| BURNS CK | 200 | 200 | 190 | 200 | 55 | 120 | 210 | 230 | 200 | 230 | 220 | 220 | 200 | 270 | 190 |  | 190 | 160 | 260 | 240 | 260 | 280 |  | 230 |
| SULFATE (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 190 | 200 | 210 | 190 | 220 | 230 | 240 | 83 | 140 | 97 | 140 | 130 | 220 | 260 | 230 | 200 | 230 | 360 | 250 | 210 | 120 | 220 | 250 | 210 |
| YS/TERRY | 190 | 200 | 240 | 210 | 220 | 260 | 220 | 95 | 96 | 74 | 130 | 150 | 210 | 230 | 210 | 260 | 210 | 280 | 280 | 190 | 110 | 200 | 240 | 220 |
| BURNS CK | 440 | 460 | 430 | 460 | 140 | 390 | 540 | 530 | 450 | 460 | 490 | 430 | 400 | 530 | 390 |  | 350 | 340 | 640 | 520 | 510 | 560 |  | 490 |
| CALCIUM (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 57 | 59 | 69 | 60 | 59 | 63 | 66 | 36 | 38 | 34 | 49 | 48 | 61 | 71 | 66 | 70 | 65 | 62 | 65 | 53 | 42 | 57 | 58 | 58 |
| YS/TERRY | 55 | 63 | 75 | 61 | 60 | 66 | 59 | 36 | 32 | 30 | 47 | 47 | 57 | 59 | 63 | 76 | 60 | 69 | 64 | 53 | 38 | 52 | 55 | 61 |
| BURNS CK | 63 | 70 | 71 | 76 | 31 | 52 | 79 | 68 | 58 | 44 | 49 | 52 | 66 | 90 | 70 |  | 57 | 52 | 77 | 54 | 51 | 54 |  | 56 |
| POTASSIUM (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 3.9 | 3.5 | 3.4 | 3.6 | 3.6 | 3.9 | 3.9 | 2.1 | 2.3 | 2.6 | 3.5 | 3.7 | 3.9 | 3.9 | 3.7 | 3.7 | 3.6 | 4.7 | 4.4 | 3.6 | 2.9 | 4.4 | 5 | 4.2 |
| YS/TERRY | 3.7 | 3.4 | 3.8 | 3.6 | 3.5 | 4.4 | 3.7 | 2.4 | 2.3 | 2.3 | 3.2 | 3.2 | 3.5 | 3.7 | 3.5 | 3.9 | 3.6 | 4 | 4.3 | 3.2 | 2.5 | 3.9 | 4.4 | 4 |
| BURNS CK | 8.3 | 7.5 | 6.1 | 7.8 | 6.2 | 7.9 | 9.1 | 8.3 | 8.5 | 9.8 | 9.6 | 9.5 | 7.7 | 9 | 6.6 |  | 6.8 | 5.6 | 8.6 | 8.4 | 8.9 | 11 |  | 8.5 |
| MAGNESIUM (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 22 | 22 | 24 | 22 | 23 | 26 | 27 | 11 | 13 | 12 | 18 | 21 | 27 | 28 | 28 | 25 | 24 | 49 | 29 | 20 | 15 | 26 | 32 | 24 |
| YS/TERRY | 21 | 22 | 27 | 23 | 24 | 27 | 24 | 13 | 11 | 10 | 17 | 19 | 22 | 25 | 23 | 28 | 23 | 28 | 31 | 20 | 14 | 23 | 29 | 27 |
| BURNS CK | 82 | 77 | 77 | 79 | 29 | 53 | 94 | 93 | 82 | 79 | 77 | 79 | 75 | 100 | 76 |  | 61 | 59 | 94 | 91 | 83 | 82 |  | 77 |
| SOLIDS (ppm) |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 476 | 468 | 506 | 476 | 523 | 574 | 575 | 227 | 274 | 251 | 358 | 352 | 517 | 579 | 538 | 544 | 506 | 794 | 580 | 462 | 317 | 513 | 578 | 511 |
| YS/TERRY |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| BURNS CK |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| STREAM FLOW IN CFS |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| YS/SIDNEY | 11100 | 8600 | 12600 | 10800 | 11000 | 13200 | 12100 | 37600 | 33300 | 13800 | 6440 | 9300 | 9590 | 7600 | 7600 | 9800 | 7400 | 6700 | 6300 | 12200 | 10500 | 3630 | 4000 | 5170 |
| YS/TERRY | 9770 | 10600 | 6700 | 9730 | 10800 | 10600 | 15700 | 32500 | 42100 | 20500 | 9590 | 9150 | 10000 | 9360 | 8200 | 3930 | 8230 | 5960 | 6710 | 11100 | 15800 | 5350 | 4100 | 5920 |
| BURNS CK | 1.7 | 2.3 | 3 | 2.1 | 63 | 17 | 6.3 | 6.9 | 4.6 | 0.77 | 0.78 | 0.89 | 18 | 1 | 1.3 |  | 1.9 | 3.5 | 2.1 | 1.1 | 0.64 | 0.32 |  | 0.69 |

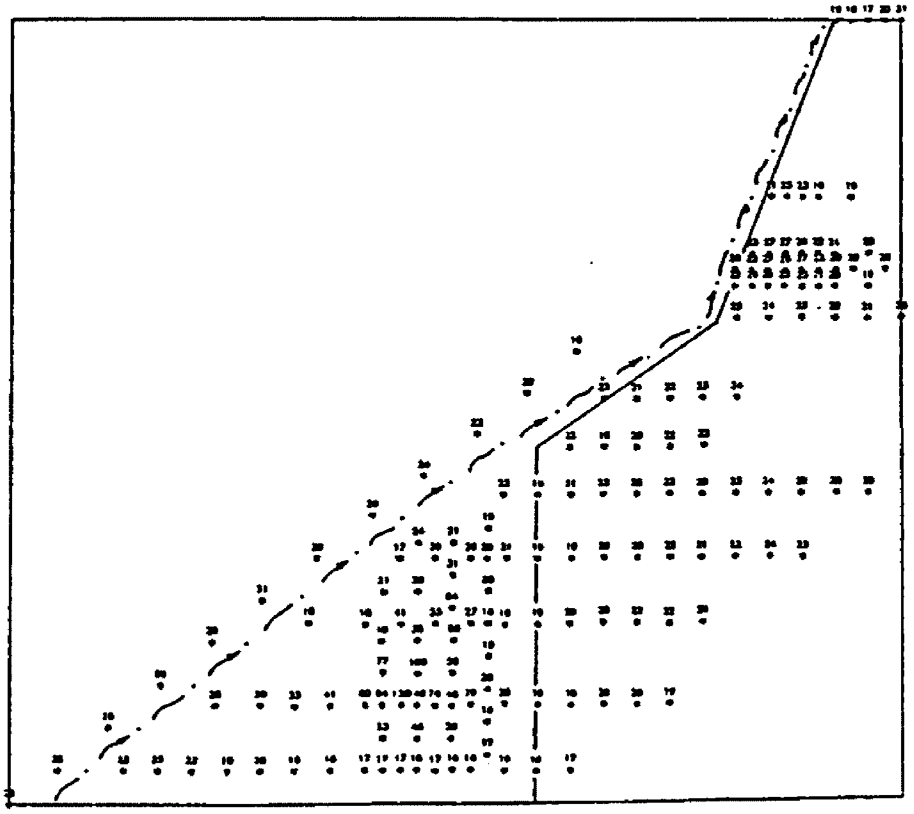
# APPENDIX P

# EM 10,20, AND 40 m DATA/PLOTS

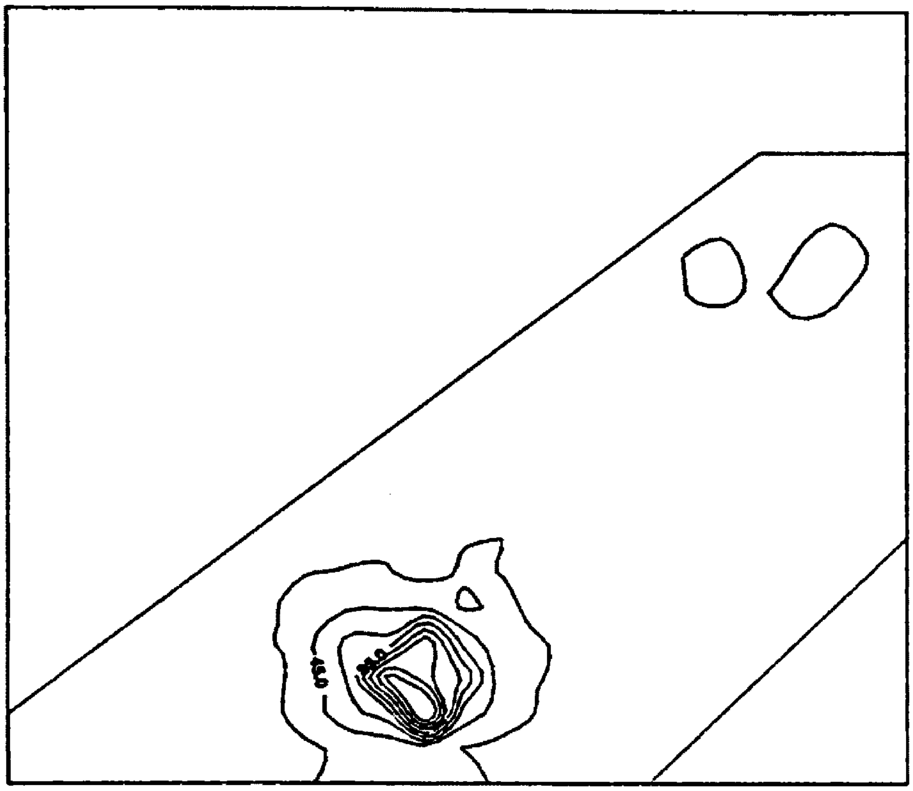
## EM 10H DATA PLOT



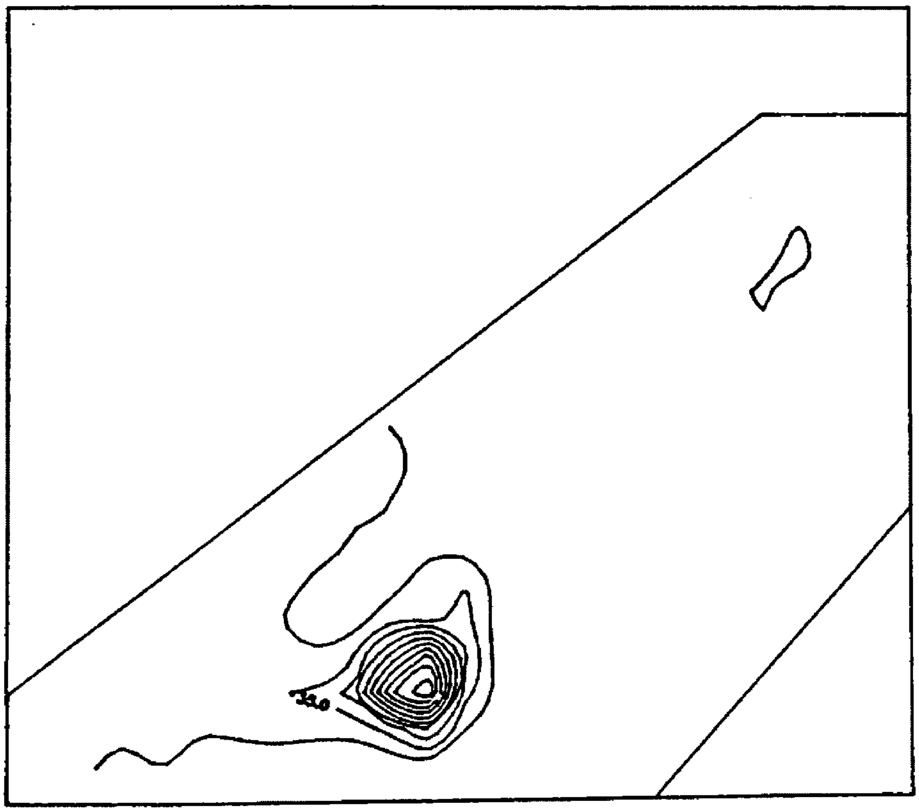
## EM 10V DATA PLOT



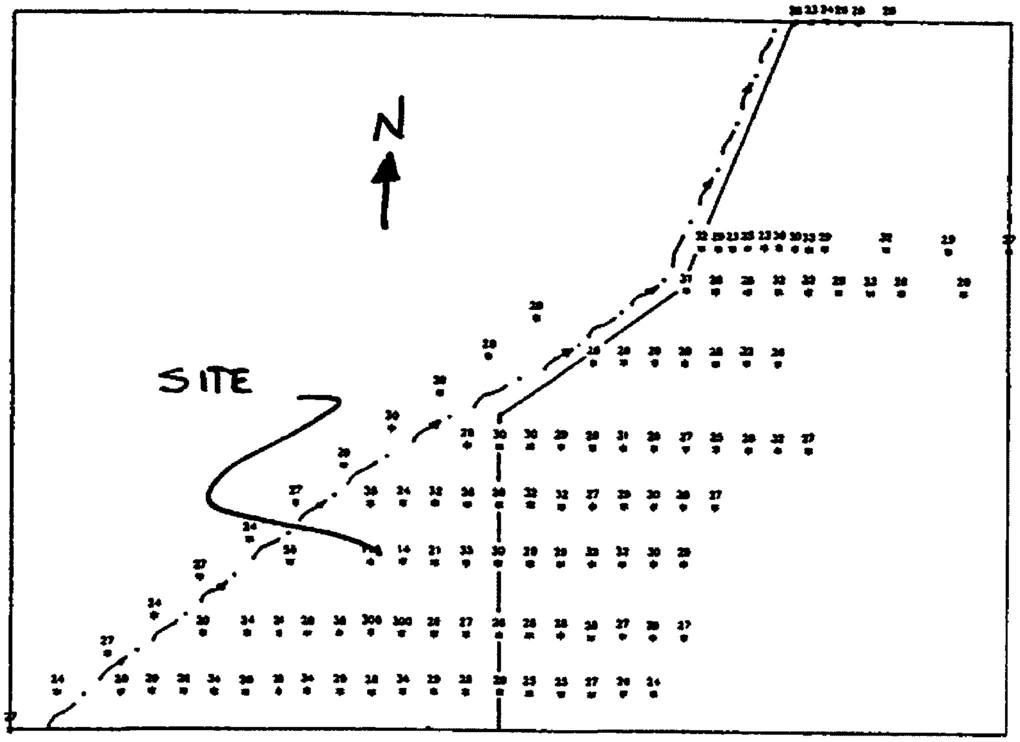
10 METRE EM – HORIZONTIAL COIL, CI=20 mmhos/m



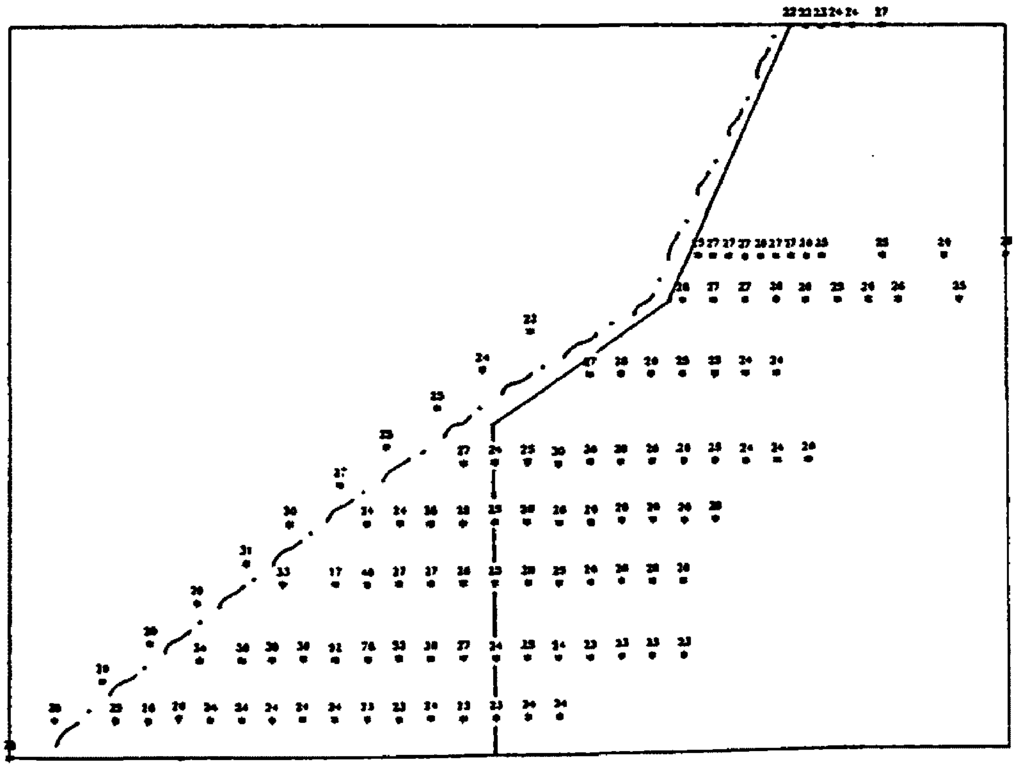
10 METRE EM – VERTICAL COIL, CI=10 mmhos/m



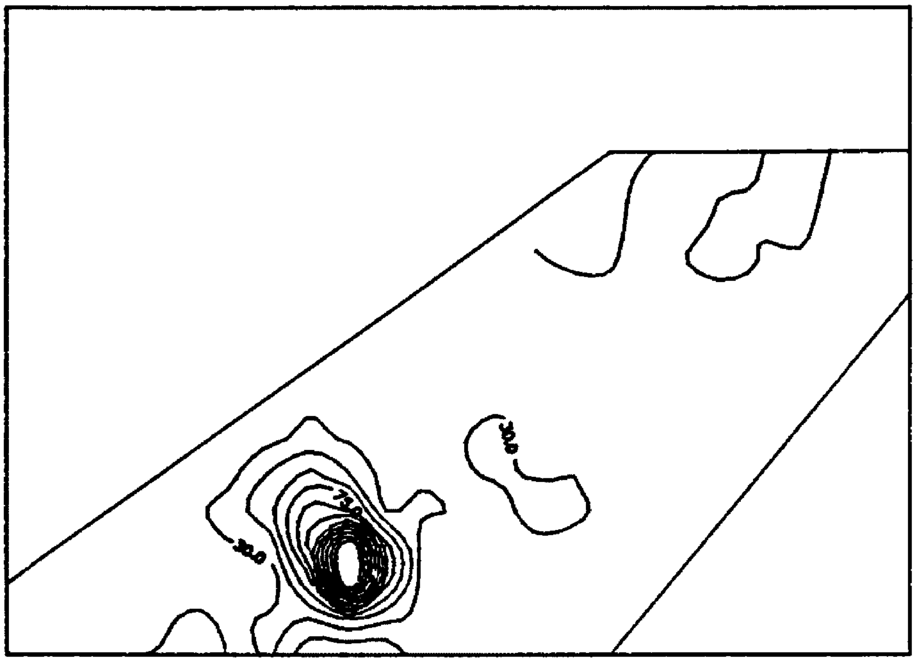
## EM 20H DATA PLOT



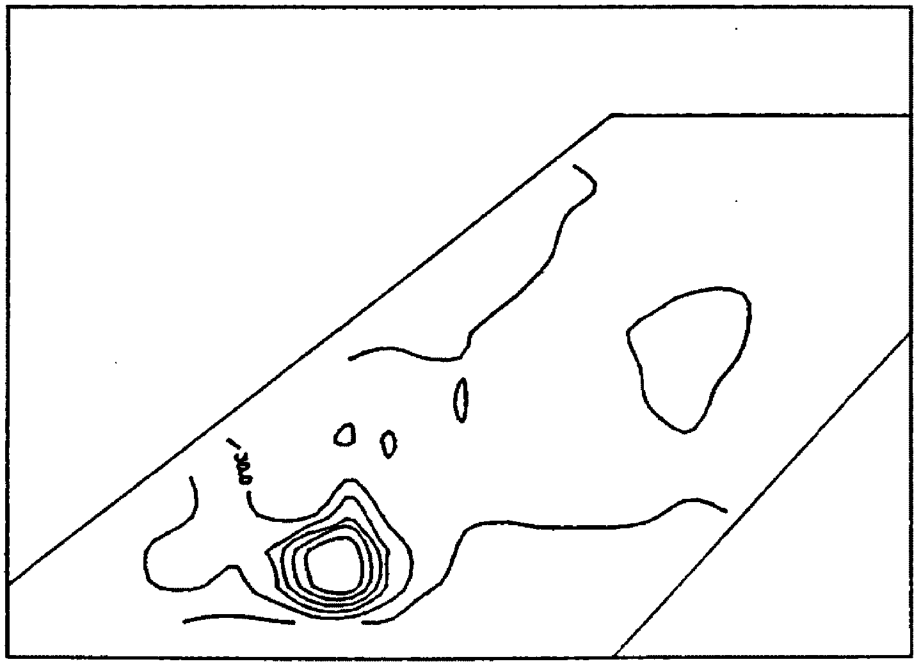
## EM 20V DATA PLOT



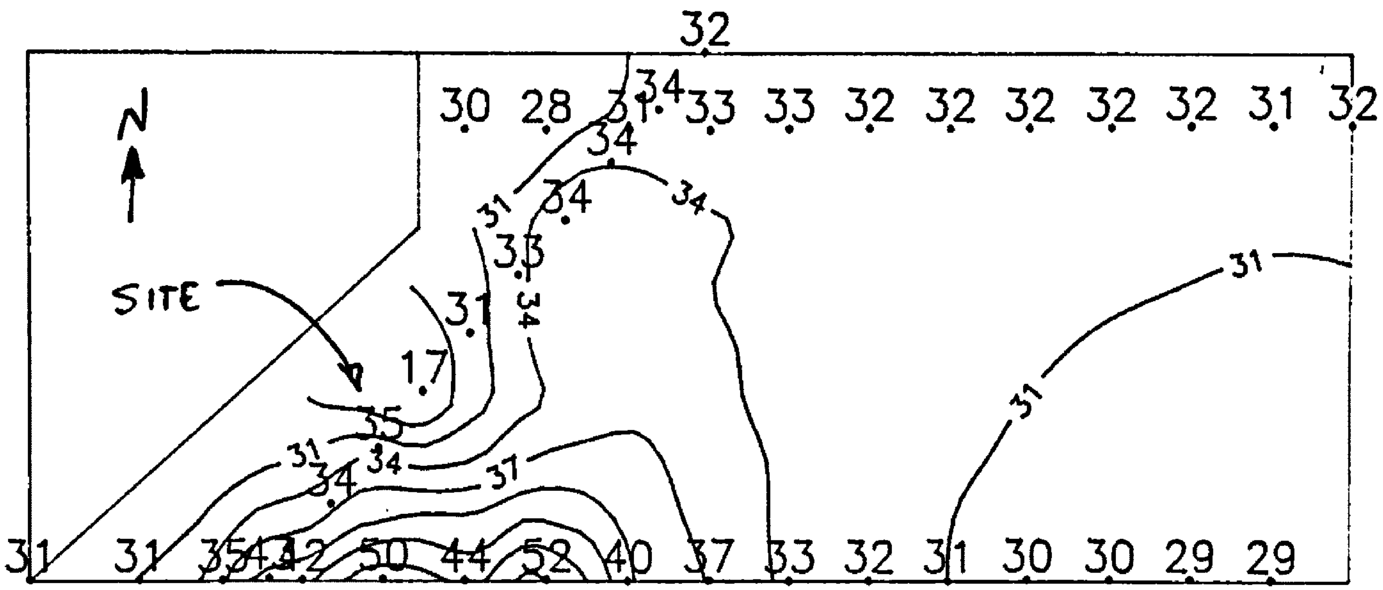
20 METRE EM – HORIZONTIAL COIL, CI=15 mmhos/m



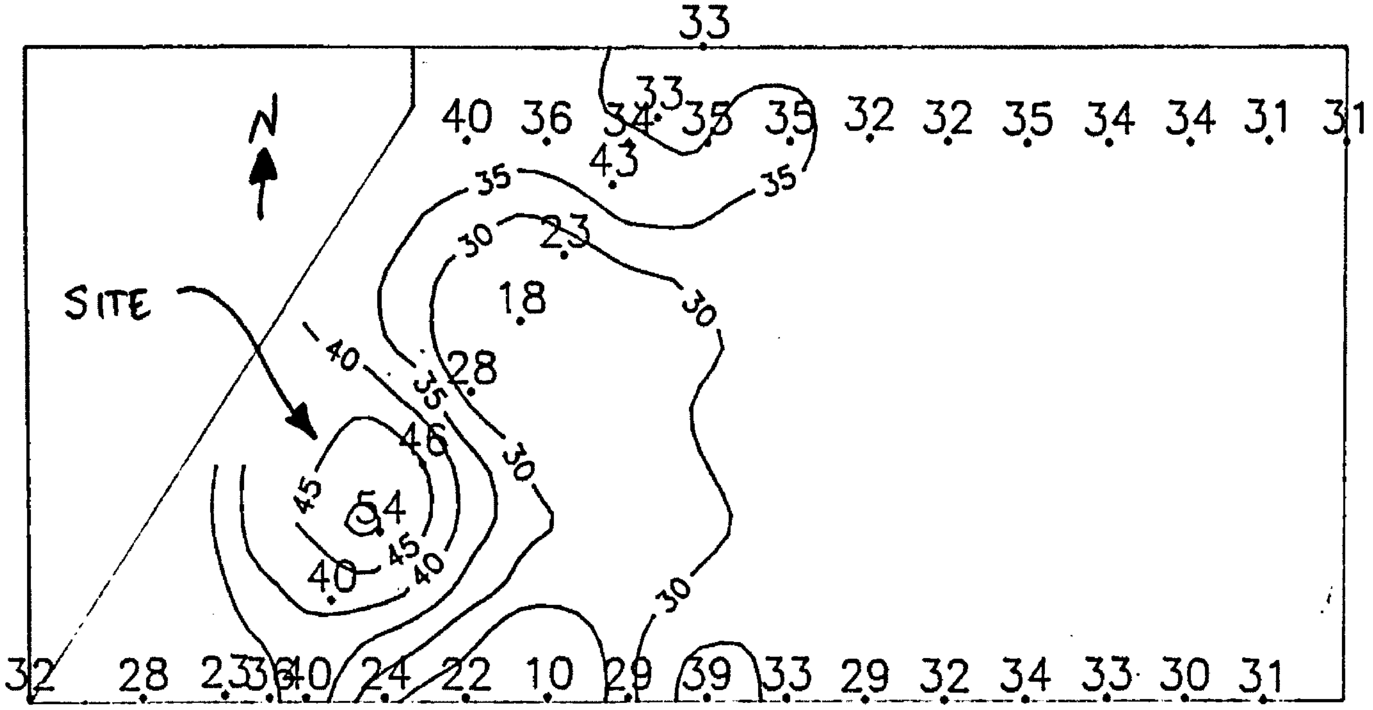
20 METRE EM – VERTICAL COIL, CI=5 mmhos/m



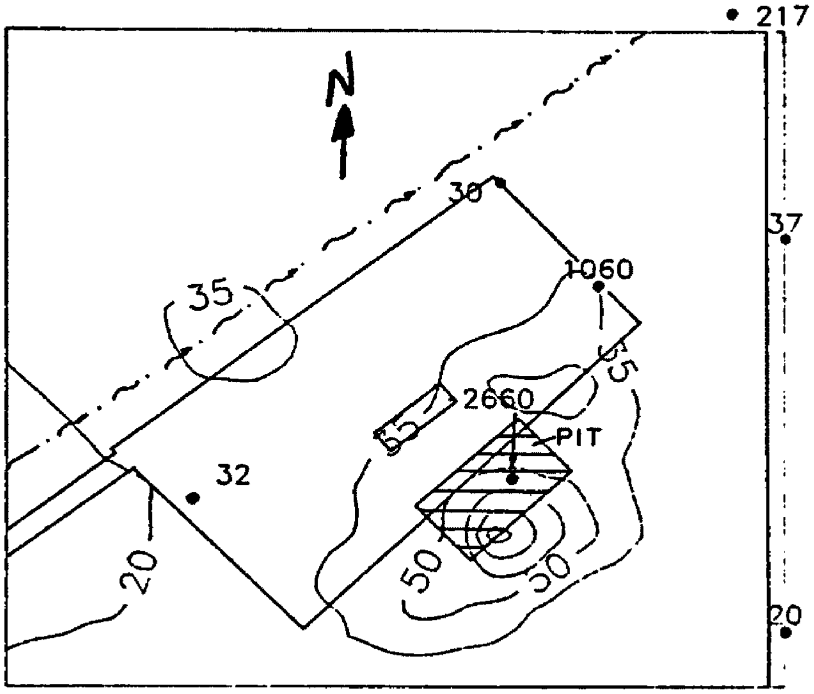
40m EM-VERT. COIL, CI=5 mmohs/m



40m EM-HORZ. COIL, CI=5 mmohs/m

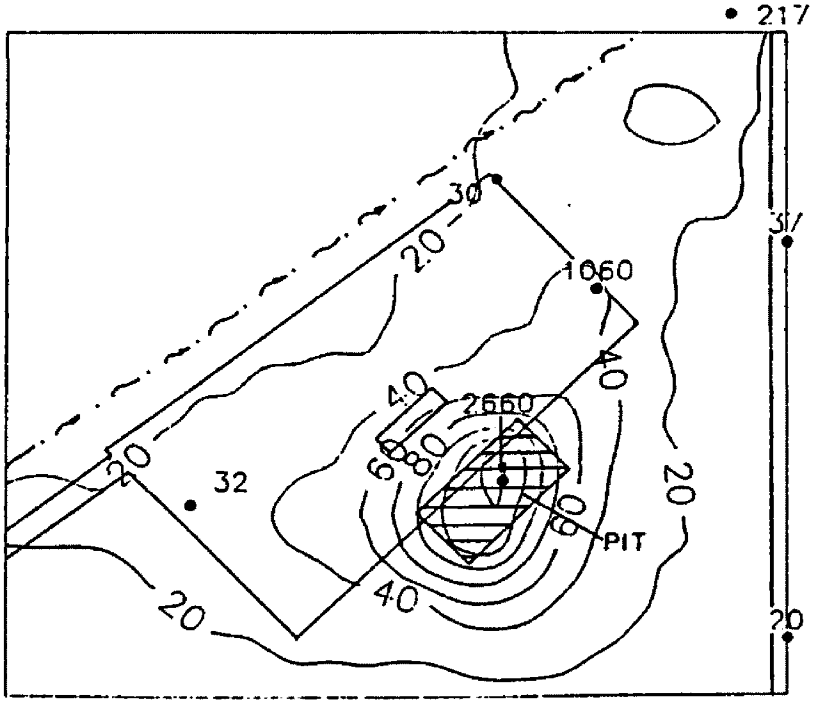


10m EM-HORZ. (mmhos/m) PLOTTED with ppm Cl

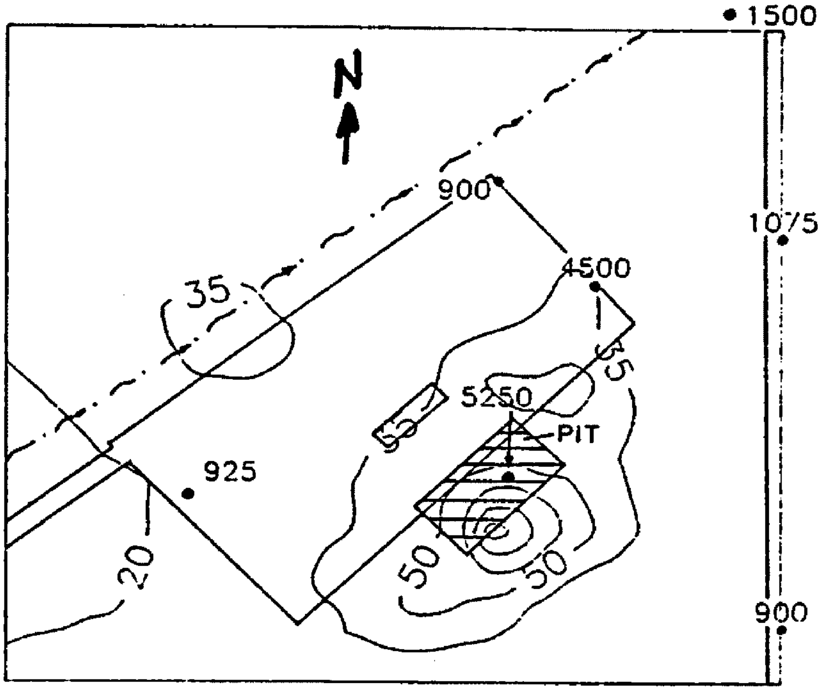


(SMALL #'S ARE Cl)

10m EM-VERT.(mmhos/m) PLOTTED with ppm Cl

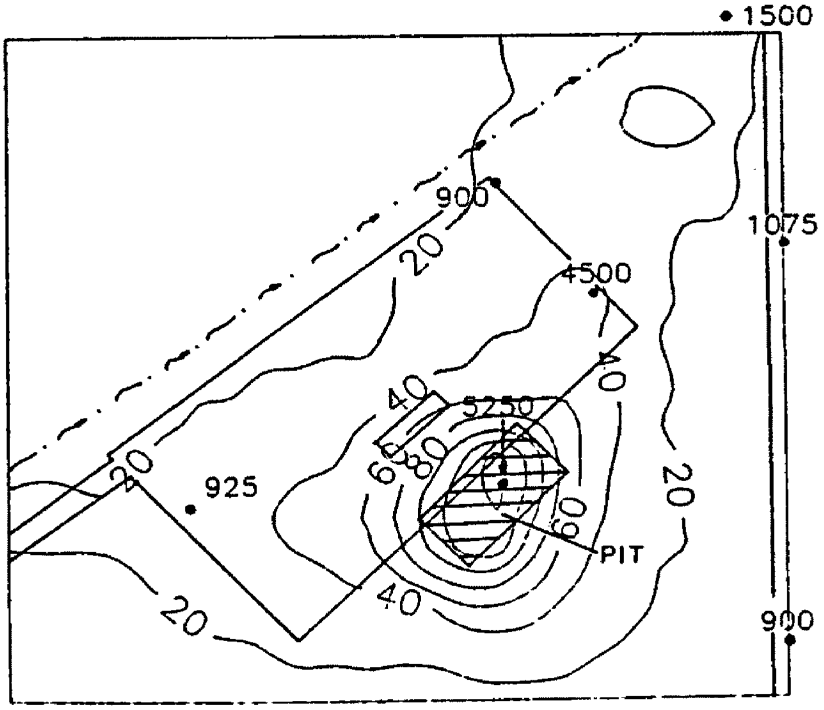


10m EM-HORZ.(mmhos/m) PLOTTED with SC (umhos/cm)



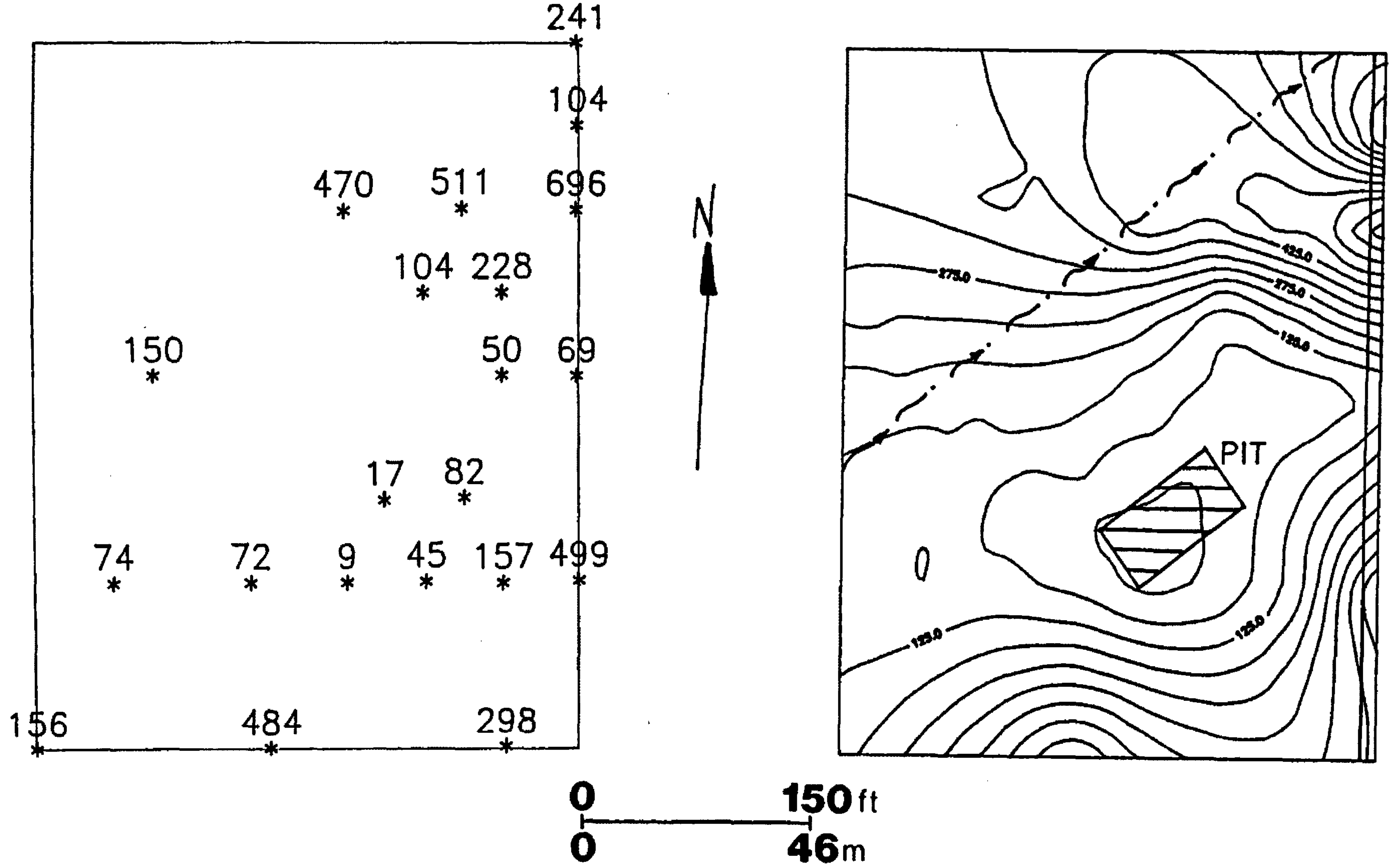
(SMALL #'s ARE SC)

10m EM–VERT.(mmhos/m) PLOTTED with SC (mmhos/cm)



# APPENDIX Q

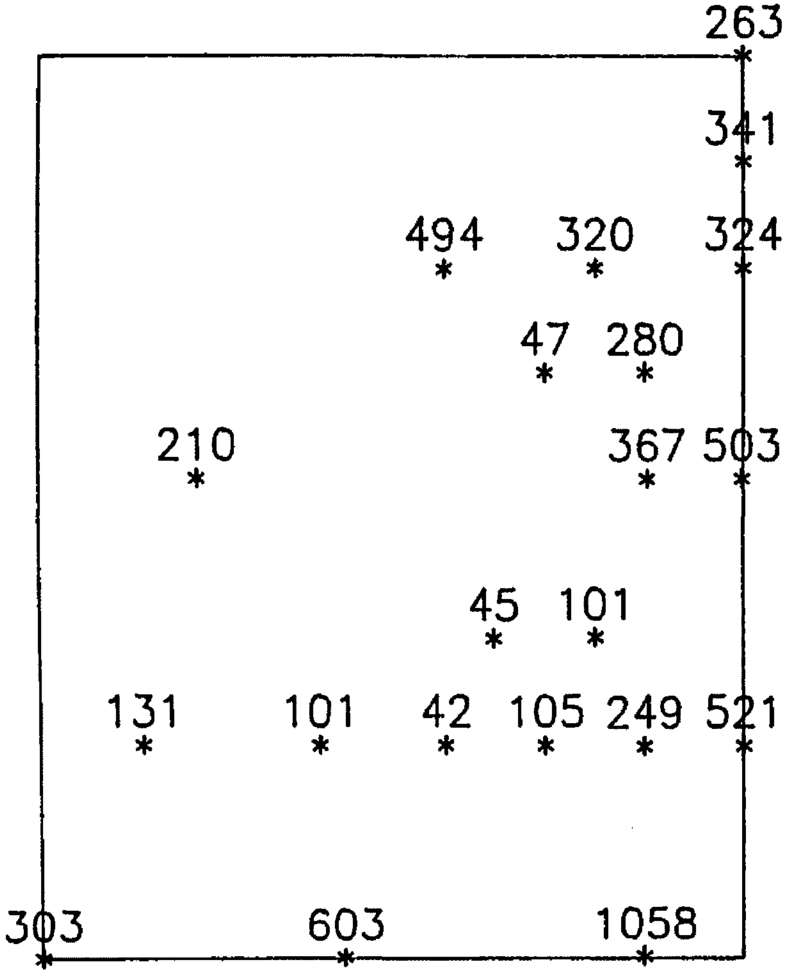
# RESISTIVITY DATA/PLOTS



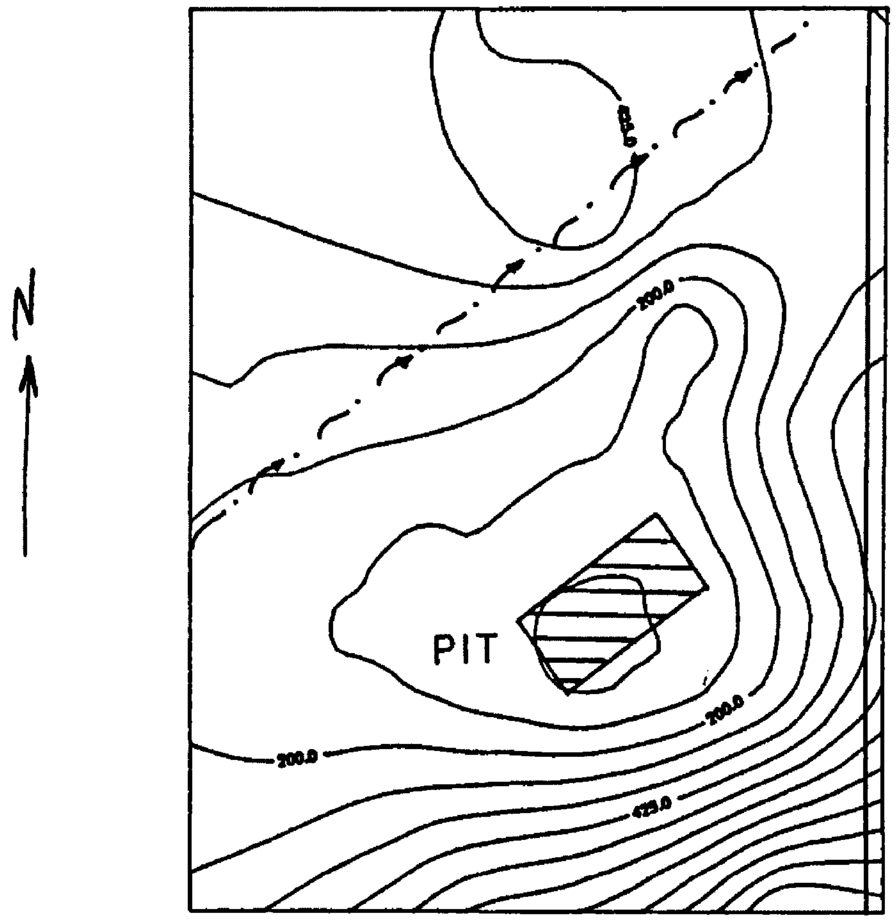
10 ft. a–SPACING ISORESISTIVITY DATA IN OHM–ft

10 ft. a–SPACING ISORESISTIVITY, CI=50 OHM–ft

20 ft. a–SPACING ISORESISTIVITY DATA IN OHM–ft

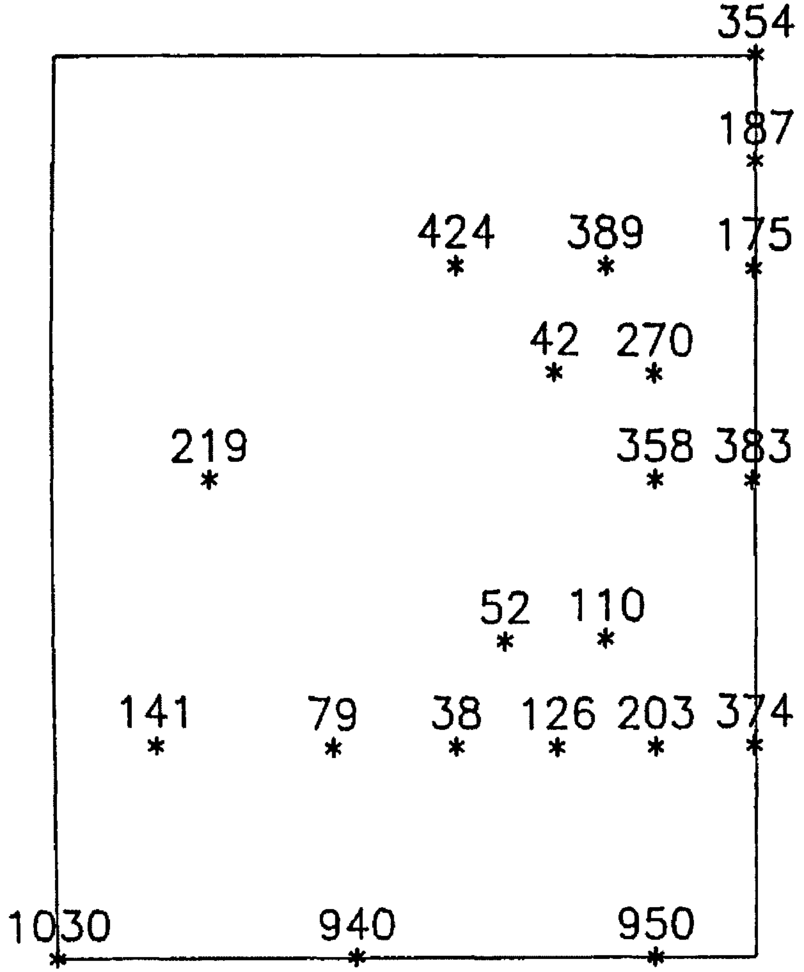


20 ft. a–SPACING ISORESISTIVITY, CI=75 OHM–ft

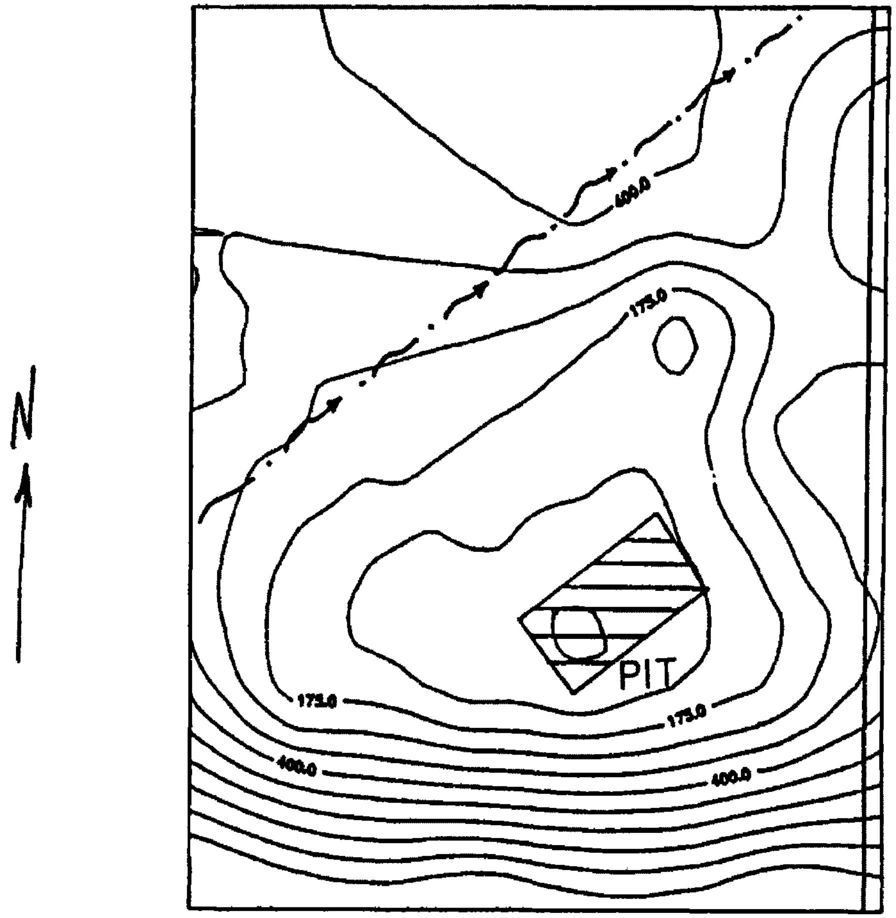


SAME SCALE AS 10 ft. DATA

30 ft. a–SPACING ISORESISTIVITY DATA IN OHM–ft



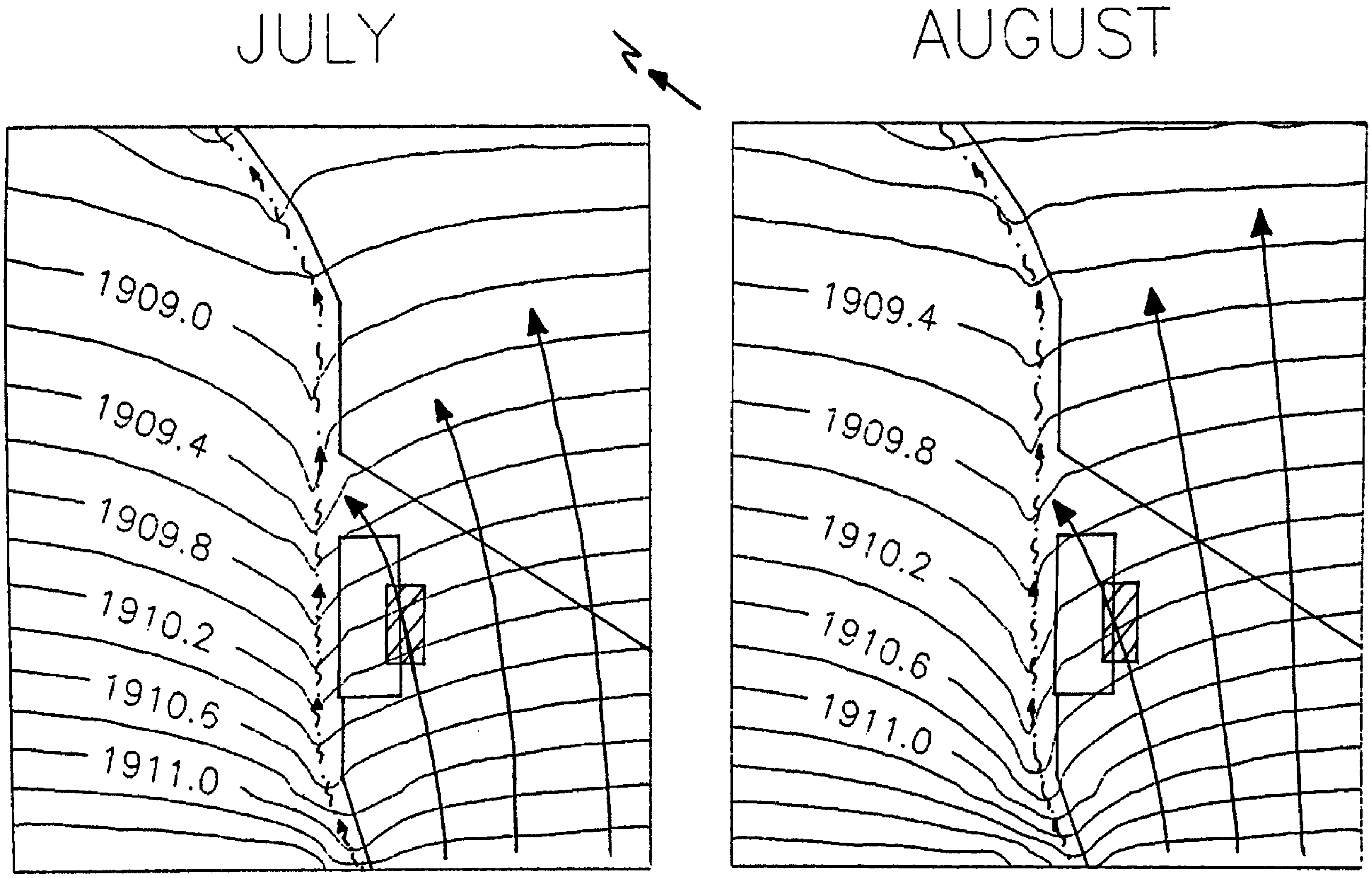
30 ft. a–SPACING ISORESISTIVITY, CI=75 OHM–ft

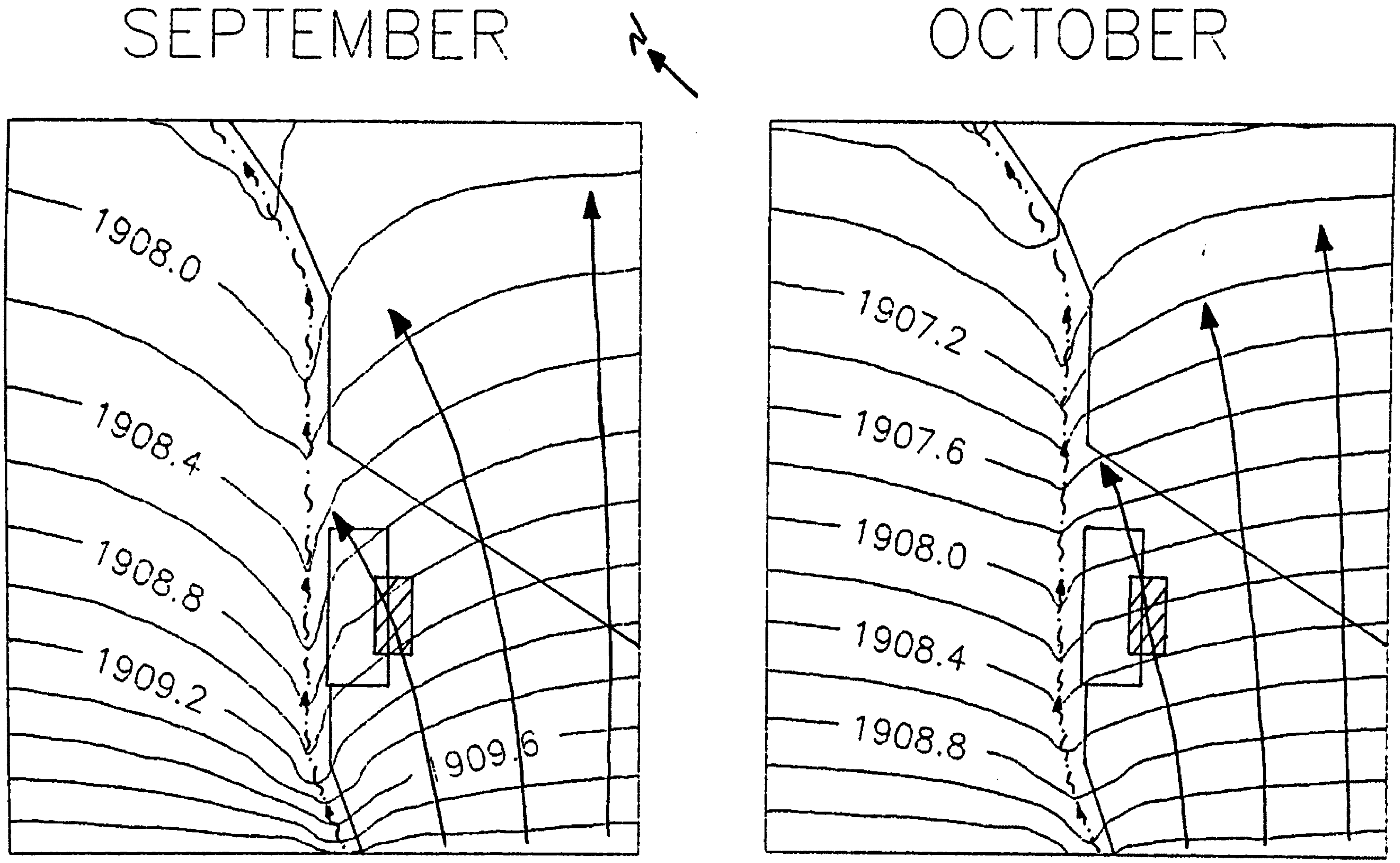


SAME SCALE AS 10 ft DATA

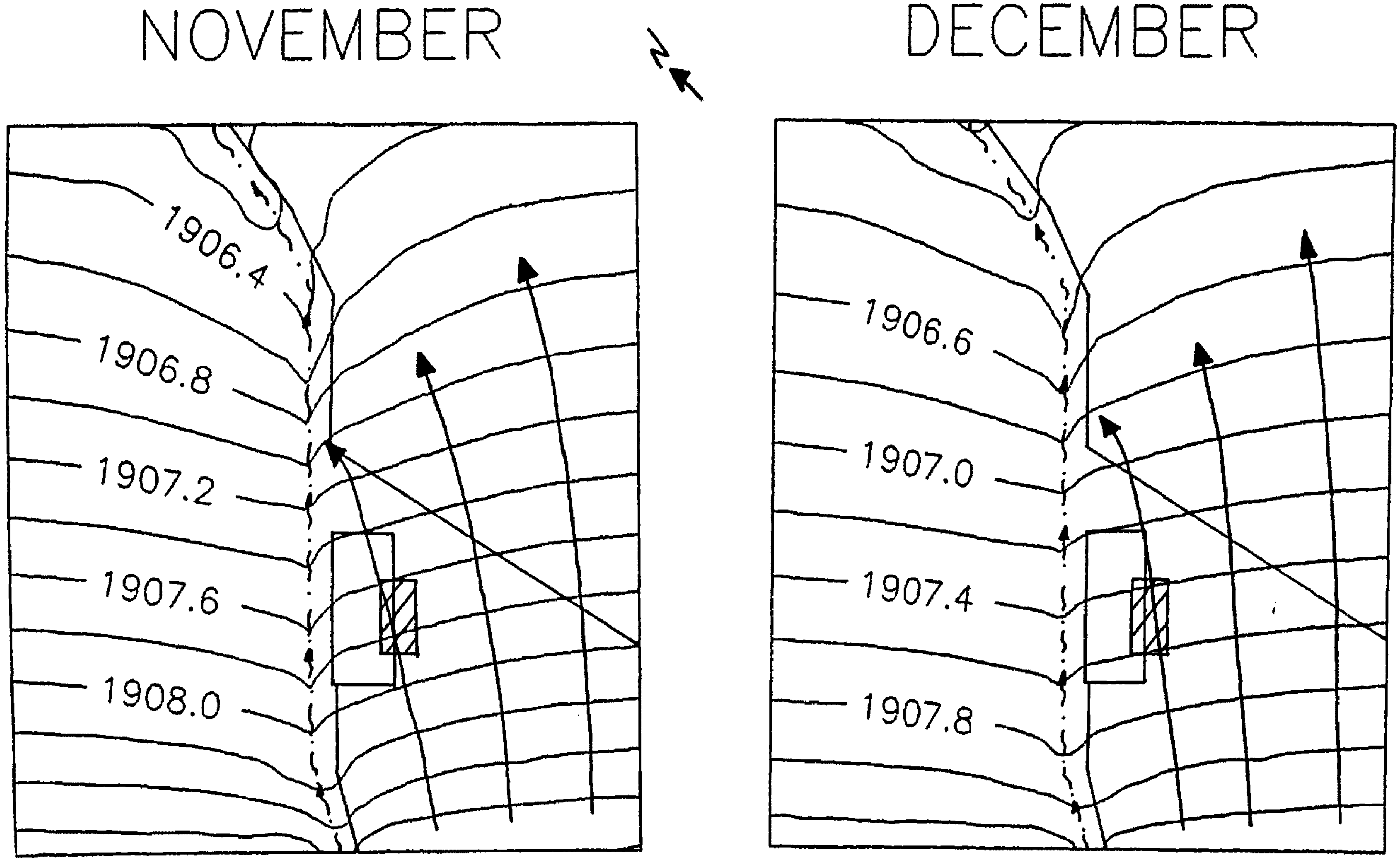
# APPENDIX R

# JULY, 87 TO JUNE, 88 SIMULATED FLOW FIELDS

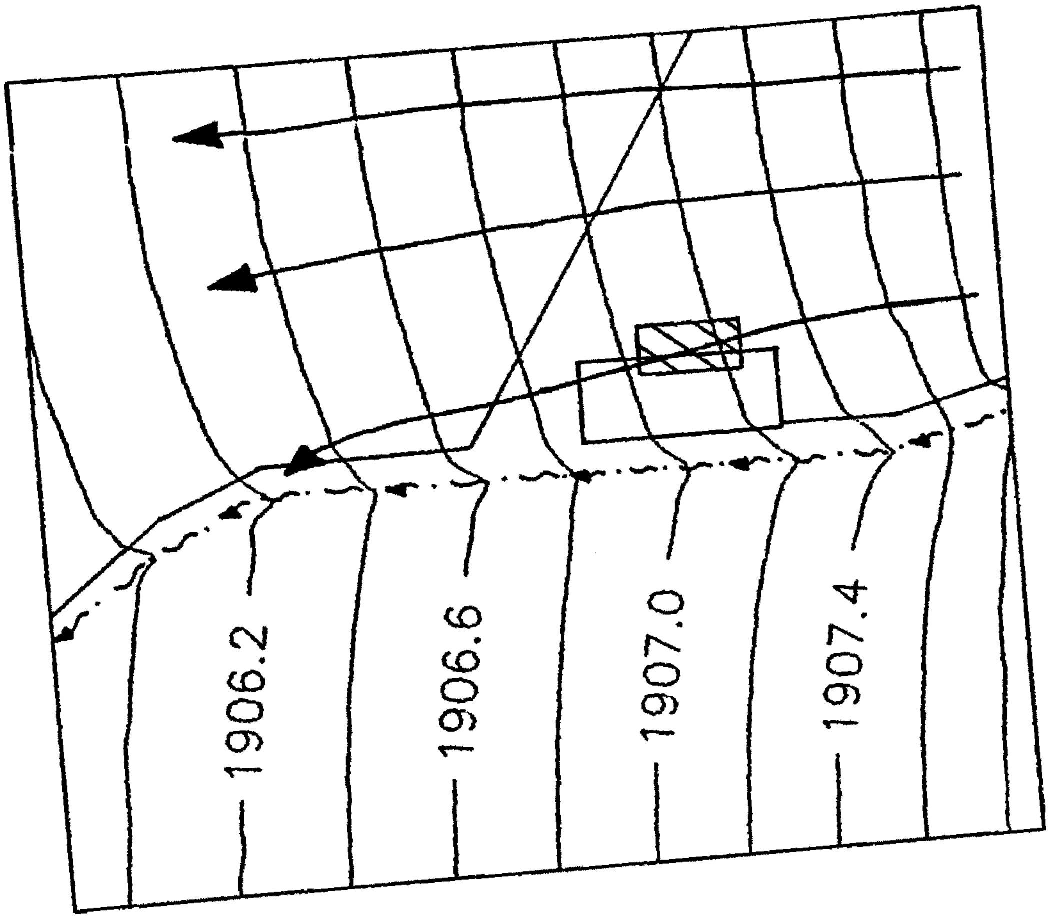

JULY
AUGUST
N
1909.0
1909.4
1909.8
1910.2
1910.6
1911.0
1909.4
1909.8
1910.2
1910.6
1911.0


SEPTEMBER

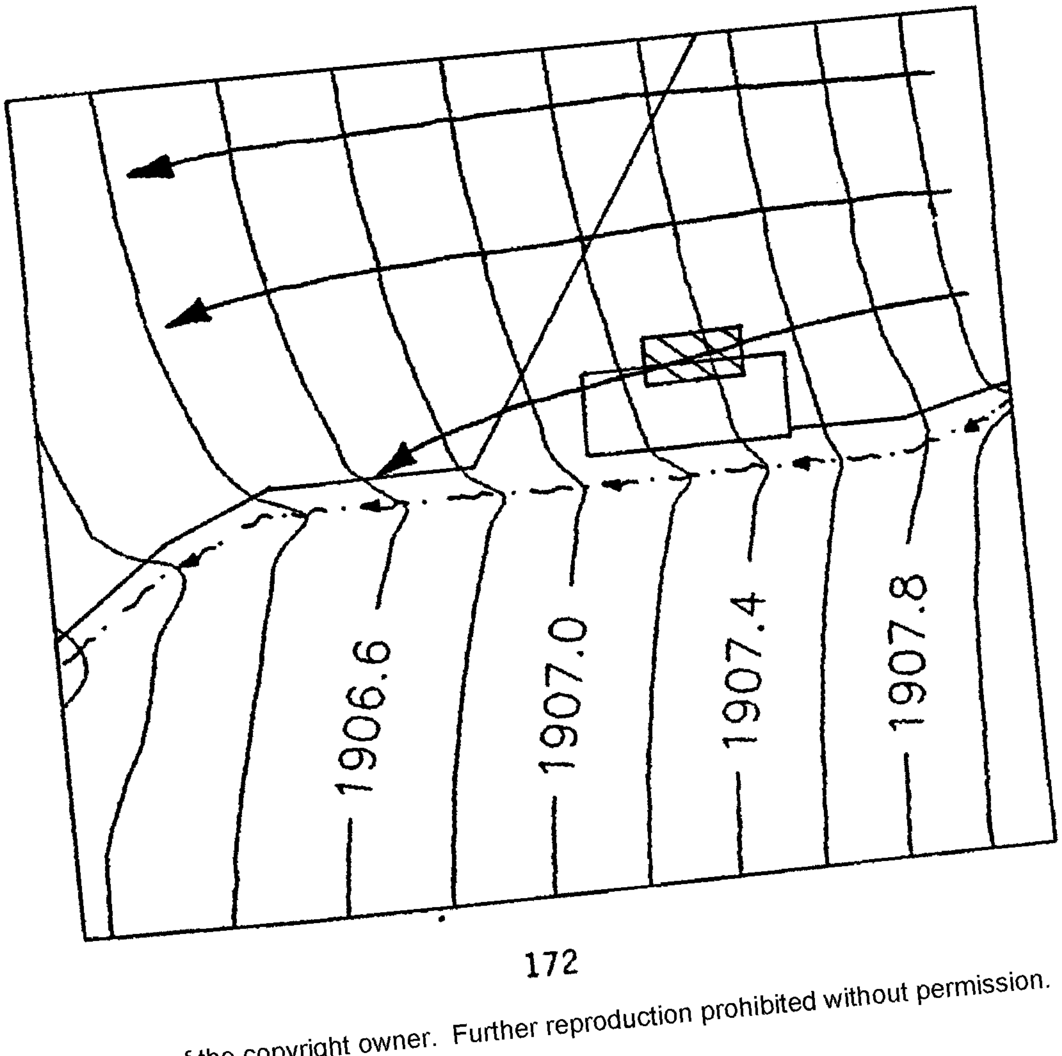
OCTOBER

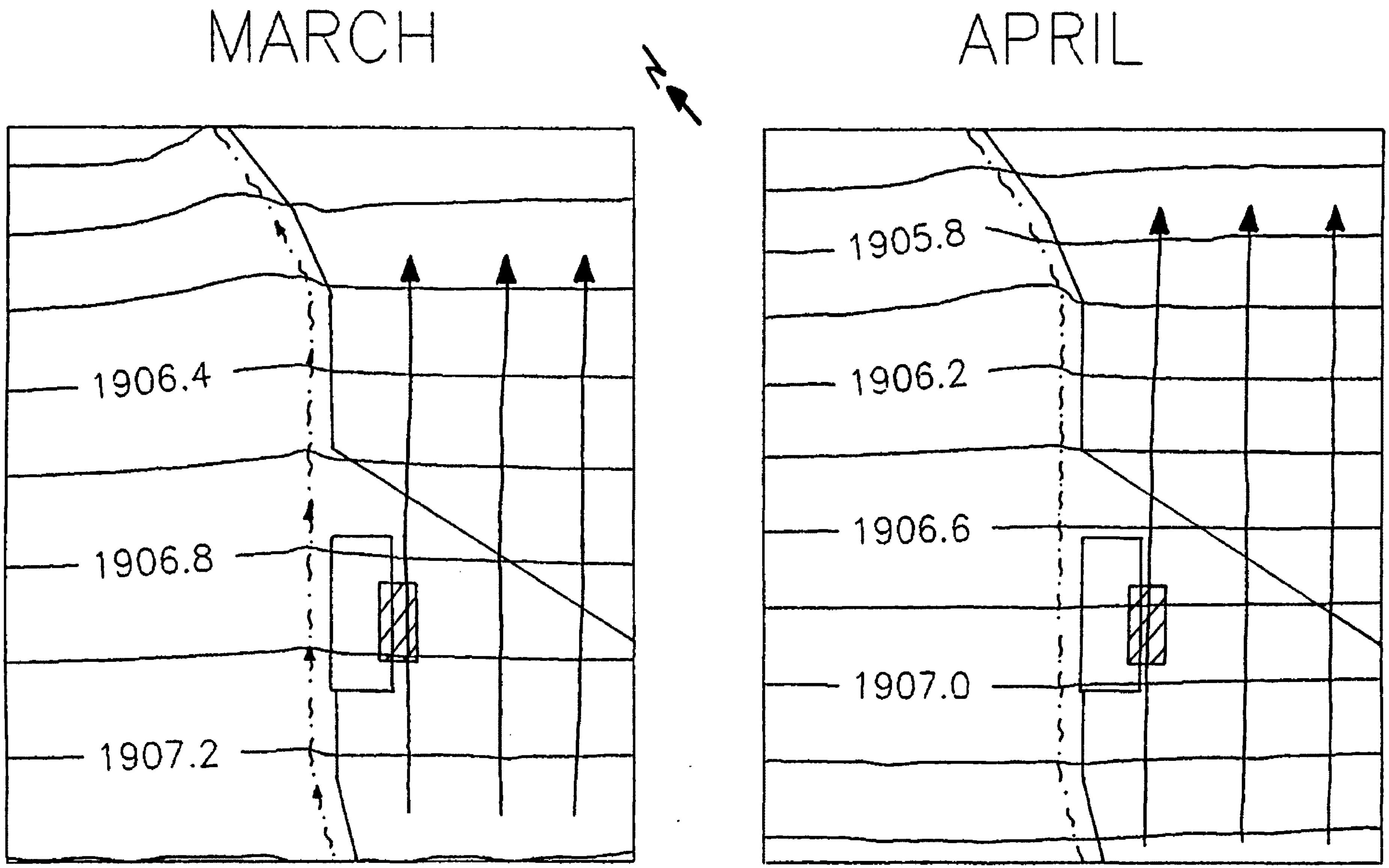

NOVEMBER
DECEMBER
N
1906.4
1906.8
1907.2
1907.6
1908.0
1906.6
1907.0
1907.4
1907.8

FEBUARY

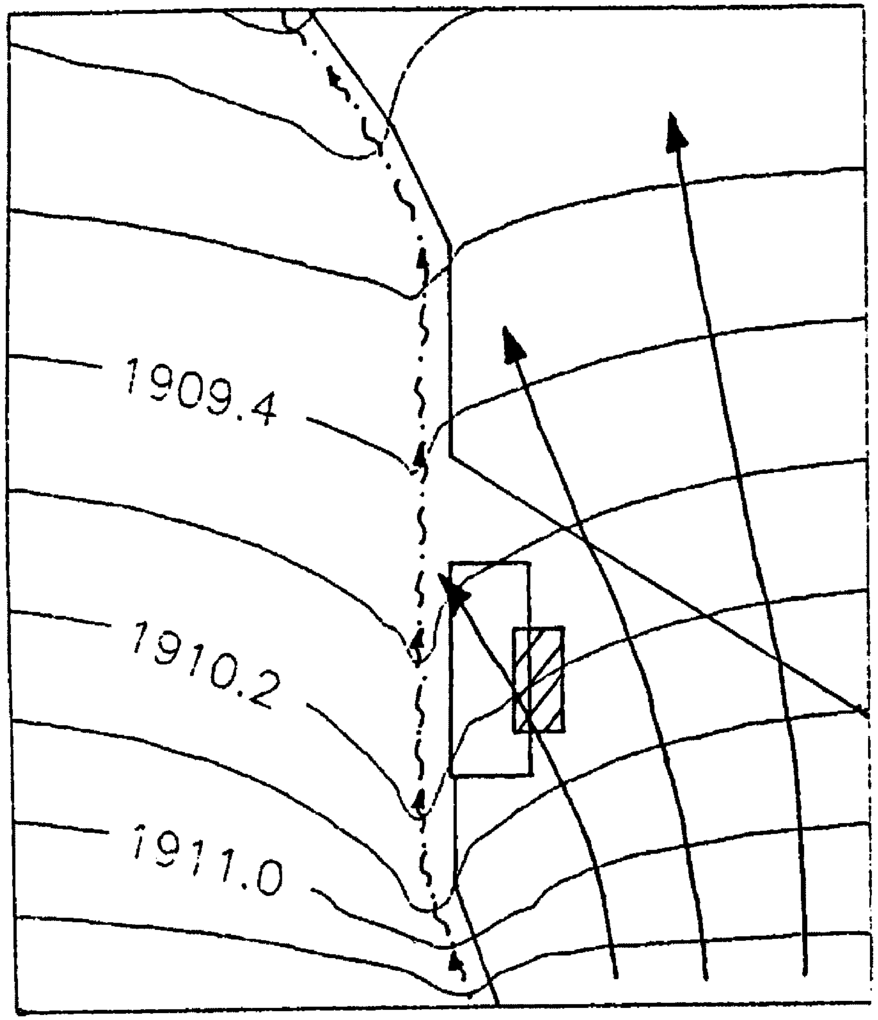


JANUARY

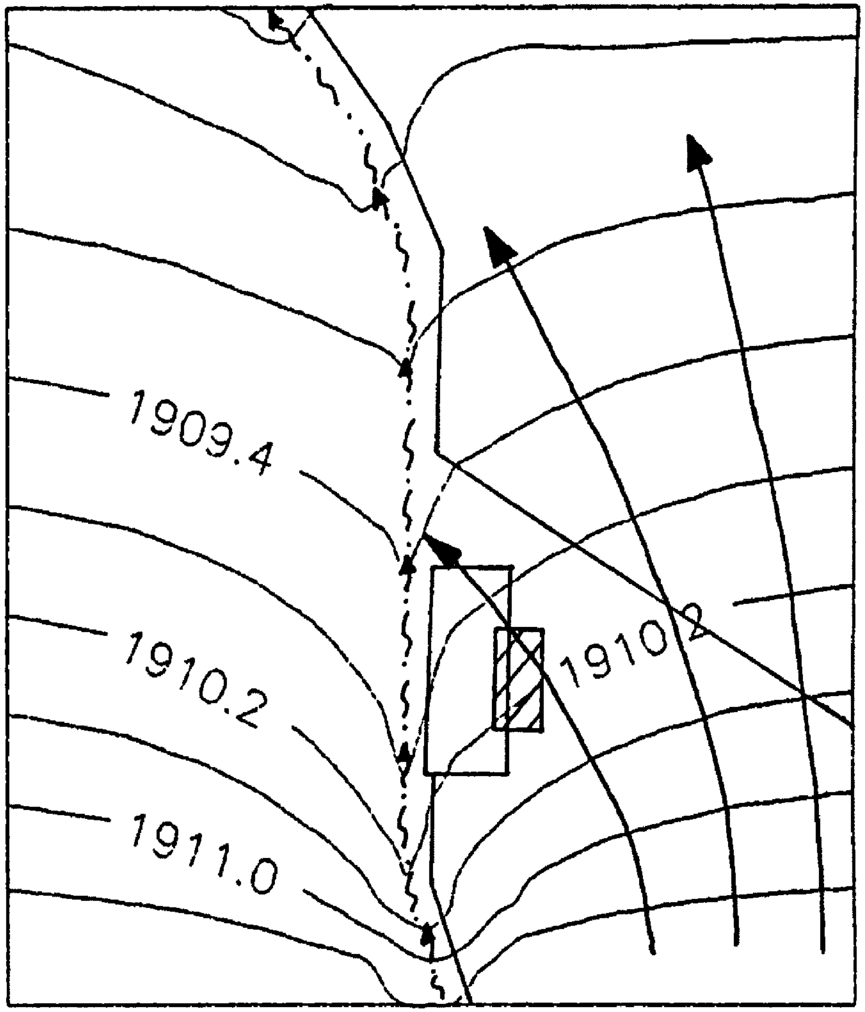



MARCH
APRIL
N
1906.4
1906.8
1907.2
1905.8
1906.2
1906.6
1907.0

MAY



JUNE



# APPENDIX S

# CONSTANT HEAD DATA FOR MODELING

MONTHLY CONSTANT HEAD INPUT FOR FLOW MODEL

| MONTH | i | j | K HEAD | MONTH | i | j | K HEAD | MONTH | i | j | K HEAD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 1 | 1 | 1908.65 | 8 | 1 | 1 | 1908.93 | 9 | 1 | 1 | 1907.9 |
| 7 | 2 | 1 | 1908.6 | 8 | 2 | 1 | 1908.88 | 9 | 2 | 1 | 1907.85 |
| 7 | 3 | 1 | 1908.44 | 8 | 3 | 1 | 1908.75 | 9 | 3 | 1 | 1907.8 |
| 7 | 4 | 1 | 1908.3 | 8 | 4 | 1 | 1908.65 | 9 | 4 | 1 | 1907.7 |
| 7 | 5 | 1 | 1908.49 | 8 | 5 | 1 | 1908.75 | 9 | 5 | 1 | 1907.79 |
| 7 | 6 | 1 | 1908.5 | 8 | 6 | 1 | 1908.76 | 9 | 6 | 1 | 1907.79 |
| 7 | 7 | 1 | 1908.51 | 8 | 7 | 1 | 1908.76 | 9 | 7 | 1 | 1907.79 |
| 7 | 8 | 1 | 1908.51 | 8 | 8 | 1 | 1908.76 | 9 | 8 | 1 | 1907.82 |
| 7 | 9 | 1 | 1908.51 | 8 | 9 | 1 | 1908.76 | 9 | 9 | 1 | 1907.84 |
| 7 | 10 | 1 | 1908.52 | 8 | 10 | 1 | 1908.77 | 9 | 10 | 1 | 1907.85 |
| 7 | 11 | 1 | 1908.52 | 8 | 11 | 1 | 1908.77 | 9 | 11 | 1 | 1907.86 |
| 7 | 12 | 1 | 1908.52 | 8 | 12 | 1 | 1908.77 | 9 | 12 | 1 | 1907.87 |
| 7 | 13 | 1 | 1908.52 | 8 | 13 | 1 | 1908.77 | 9 | 13 | 1 | 1907.88 |
| 7 | 14 | 1 | 1908.53 | 8 | 14 | 1 | 1908.78 | 9 | 14 | 1 | 1907.89 |
| 7 | 15 | 1 | 1908.53 | 8 | 15 | 1 | 1908.78 | 9 | 15 | 1 | 1907.89 |
| 7 | 16 | 1 | 1908.53 | 8 | 16 | 1 | 1908.78 | 9 | 16 | 1 | 1907.9 |
| 7 | 17 | 1 | 1908.53 | 8 | 17 | 1 | 1908.78 | 9 | 17 | 1 | 1907.9 |
| 7 | 18 | 1 | 1908.54 | 8 | 18 | 1 | 1908.79 | 9 | 18 | 1 | 1907.9 |
| 7 | 1 | 24 | 1911.65 | 8 | 1 | 24 | 1911.95 | 9 | 1 | 24 | 1910.15 |
| 7 | 2 | 24 | 1911.64 | 8 | 2 | 24 | 1911.94 | 9 | 2 | 24 | 1910.14 |
| 7 | 3 | 24 | 1911.64 | 8 | 3 | 24 | 1911.94 | 9 | 3 | 24 | 1910.14 |
| 7 | 4 | 24 | 1911.63 | 8 | 4 | 24 | 1911.93 | 9 | 4 | 24 | 1910.13 |
| 7 | 5 | 24 | 1911.63 | 8 | 5 | 24 | 1911.93 | 9 | 5 | 24 | 1910.13 |
| 7 | 6 | 24 | 1911.63 | 8 | 6 | 24 | 1911.93 | 9 | 6 | 24 | 1910.13 |
| 7 | 7 | 24 | 1911.63 | 8 | 7 | 24 | 1911.93 | 9 | 7 | 24 | 1910.13 |
| 7 | 8 | 24 | 1911.63 | 8 | 8 | 24 | 1911.93 | 9 | 8 | 24 | 1910.13 |
| 7 | 9 | 24 | 1911.5 | 8 | 9 | 24 | 1911.8 | 9 | 9 | 24 | 1910.08 |
| 7 | 10 | 24 | 1911.2 | 8 | 10 | 24 | 1911.4 | 9 | 10 | 24 | 1910.06 |
| 7 | 11 | 24 | 1911 | 8 | 11 | 24 | 1911.1 | 9 | 11 | 24 | 1909.15 |
| 7 | 12 | 24 | 1911.05 | 8 | 12 | 24 | 1911.32 | 9 | 12 | 24 | 1909.95 |
| 7 | 13 | 24 | 1911.2 | 8 | 13 | 24 | 1911.6 | 9 | 13 | 24 | 1910.08 |
| 7 | 14 | 24 | 1911.33 | 8 | 14 | 24 | 1911.73 | 9 | 14 | 24 | 1910.08 |
| 7 | 15 | 24 | 1911.34 | 8 | 15 | 24 | 1911.74 | 9 | 15 | 24 | 1910.09 |
| 7 | 16 | 24 | 1911.35 | 8 | 16 | 24 | 1911.75 | 9 | 16 | 24 | 1910.1 |
| 7 | 17 | 24 | 1911.36 | 8 | 17 | 24 | 1911.76 | 9 | 17 | 24 | 1910.11 |
| 7 | 18 | 24 | 1911.39 | 8 | 18 | 24 | 1911.78 | 9 | 18 | 24 | 1910.13 |
| 7 | 4 | 1 | 1908.3 | 8 | 4 | 1 | 1908.65 | 9 | 4 | 1 | 1907.7 |
| 7 | 6 | 2 | 1908.55 | 8 | 6 | 2 | 1909 | 9 | 6 | 2 | 1907.75 |
| 7 | 9 | 3 | 1908.75 | 8 | 9 | 3 | 1909.2 | 9 | 9 | 3 | 1907.8 |
| 7 | 9 | 4 | 1908.82 | 8 | 9 | 4 | 1909.28 | 9 | 9 | 4 | 1907.83 |
| 7 | 9 | 5 | 1908.87 | 8 | 9 | 5 | 1909.36 | 9 | 9 | 5 | 1907.86 |
| 7 | 9 | 6 | 1908.9 | 8 | 9 | 6 | 1909.4 | 9 | 9 | 6 | 1907.9 |
| 7 | 9 | 7 | 1908.93 | 8 | 9 | 7 | 1909.44 | 9 | 9 | 7 | 1907.93 |
| 7 | 9 | 8 | 1908.96 | 8 | 9 | 8 | 1909.48 | 9 | 9 | 8 | 1907.97 |
| 7 | 9 | 9 | 1908.99 | 8 | 9 | 9 | 1909.52 | 9 | 9 | 9 | 1908 |
| 7 | 9 | 10 | 1909.02 | 8 | 9 | 10 | 1909.58 | 9 | 9 | 10 | 1908.04 |
| 7 | 9 | 11 | 1909.07 | 8 | 9 | 11 | 1909.63 | 9 | 9 | 11 | 1908.09 |
| 7 | 9 | 12 | 1909.13 | 8 | 9 | 12 | 1909.69 | 9 | 9 | 12 | 1908.13 |
| 7 | 9 | 13 | 1909.26 | 8 | 9 | 13 | 1909.75 | 9 | 9 | 13 | 1908.18 |
| 7 | 9 | 14 | 1909.39 | 8 | 9 | 14 | 1909.79 | 9 | 9 | 14 | 1908.21 |
| 7 | 9 | 15 | 1909.5 | 8 | 9 | 15 | 1909.82 | 9 | 9 | 15 | 1908.24 |
| 7 | 9 | 16 | 1909.6 | 8 | 9 | 16 | 1909.86 | 9 | 9 | 16 | 1908.27 |
| 7 | 9 | 17 | 1909.7 | 8 | 9 | 17 | 1909.9 | 9 | 9 | 17 | 1908.34 |
| 7 | 9 | 18 | 1909.8 | 8 | 9 | 18 | 1909.95 | 9 | 9 | 18 | 1908.4 |
| 7 | 9 | 19 | 1909.9 | 8 | 9 | 19 | 1909.99 | 9 | 9 | 19 | 1908.45 |
| 7 | 9 | 20 | 1910 | 8 | 9 | 20 | 1910.02 | 9 | 9 | 20 | 1908.5 |
| 7 | 9 | 21 | 1910.1 | 8 | 9 | 21 | 1910.06 | 9 | 9 | 21 | 1908.55 |
| 7 | 9 | 22 | 1910.22 | 8 | 9 | 22 | 1910.11 | 9 | 9 | 22 | 1908.63 |
| 7 | 9 | 23 | 1910.4 | 8 | 9 | 23 | 1910.16 | 9 | 9 | 23 | 1908.8 |
| 7 | 11 | 24 | 1911 | 8 | 11 | 24 | 1911.1 | 9 | 11 | 24 | 1909.15 |

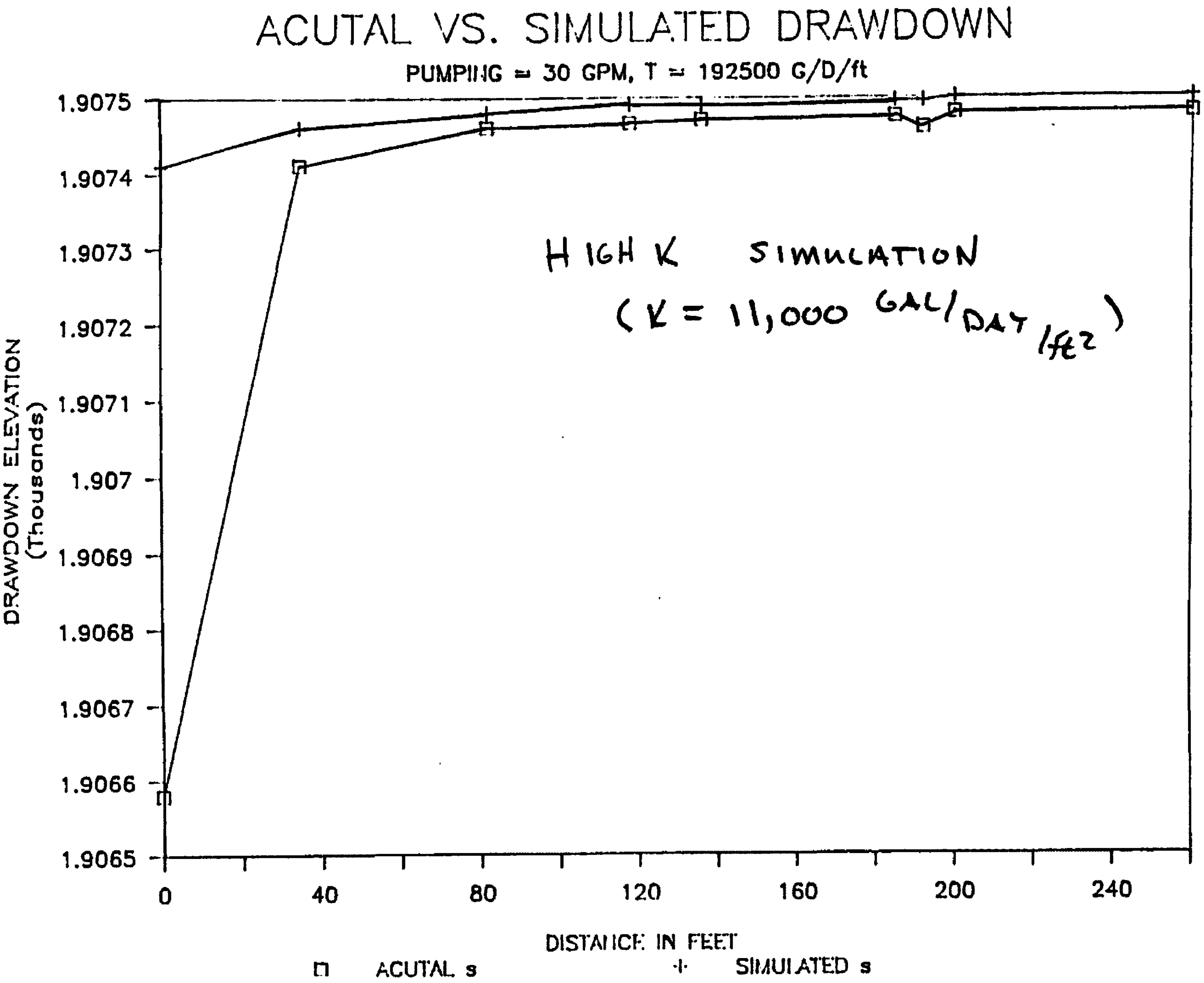
| MONTH | i | j | K HEAD | MONTH | i | j | K HEAD | MONTH | i | j | K HEAD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1 | 1 | 1906.78 | 11 | 1 | 1 | 1906.3 | 12 | 1 | 1 | 1906.23 |
| 10 | 2 | 1 | 1906.75 | 11 | 2 | 1 | 1906.29 | 12 | 2 | 1 | 1906.22 |
| 10 | 3 | 1 | 1906.73 | 11 | 3 | 1 | 1906.28 | 12 | 3 | 1 | 1906.08 |
| 10 | 4 | 1 | 1906.53 | 11 | 4 | 1 | 1905.88 | 12 | 4 | 1 | 1905.94 |
| 10 | 5 | 1 | 1906.73 | 11 | 5 | 1 | 1906.29 | 12 | 5 | 1 | 1906.08 |
| 10 | 6 | 1 | 1906.74 | 11 | 6 | 1 | 1906.29 | 12 | 6 | 1 | 1906.2 |
| 10 | 7 | 1 | 1906.75 | 11 | 7 | 1 | 1906.29 | 12 | 7 | 1 | 1906.2 |
| 10 | 8 | 1 | 1906.75 | 11 | 8 | 1 | 1906.29 | 12 | 8 | 1 | 1906.2 |
| 10 | 9 | 1 | 1906.75 | 11 | 9 | 1 | 1906.29 | 12 | 9 | 1 | 1906.21 |
| 10 | 10 | 1 | 1906.75 | 11 | 10 | 1 | 1906.3 | 12 | 10 | 1 | 1906.21 |
| 10 | 11 | 1 | 1906.76 | 11 | 11 | 1 | 1906.31 | 12 | 11 | 1 | 1906.22 |
| 10 | 12 | 1 | 1906.76 | 11 | 12 | 1 | 1906.33 | 12 | 12 | 1 | 1906.22 |
| 10 | 13 | 1 | 1906.76 | 11 | 13 | 1 | 1906.35 | 12 | 13 | 1 | 1906.23 |
| 10 | 14 | 1 | 1906.77 | 11 | 14 | 1 | 1906.37 | 12 | 14 | 1 | 1906.25 |
| 10 | 15 | 1 | 1906.77 | 11 | 15 | 1 | 1906.39 | 12 | 15 | 1 | 1906.27 |
| 10 | 16 | 1 | 1906.78 | 11 | 16 | 1 | 1906.41 | 12 | 16 | 1 | 1906.29 |
| 10 | 17 | 1 | 1906.79 | 11 | 17 | 1 | 1906.43 | 12 | 17 | 1 | 1906.31 |
| 10 | 18 | 1 | 1906.8 | 11 | 18 | 1 | 1906.45 | 12 | 18 | 1 | 1906.33 |
| 10 | 1 | 24 | 1909.37 | 11 | 1 | 24 | 1908.7 | 12 | 1 | 24 | 1908.3 |
| 10 | 2 | 24 | 1909.36 | 11 | 2 | 24 | 1908.69 | 12 | 2 | 24 | 1908.29 |
| 10 | 3 | 24 | 1909.36 | 11 | 3 | 24 | 1908.69 | 12 | 3 | 24 | 1908.29 |
| 10 | 4 | 24 | 1909.35 | 11 | 4 | 24 | 1908.68 | 12 | 4 | 24 | 1908.29 |
| 10 | 5 | 24 | 1909.35 | 11 | 5 | 24 | 1908.69 | 12 | 5 | 24 | 1908.29 |
| 10 | 6 | 24 | 1909.35 | 11 | 6 | 24 | 1908.68 | 12 | 6 | 24 | 1908.28 |
| 10 | 7 | 24 | 1909.35 | 11 | 7 | 24 | 1908.69 | 12 | 7 | 24 | 1908.28 |
| 10 | 8 | 24 | 1909.35 | 11 | 8 | 24 | 1908.68 | 12 | 8 | 24 | 1908.28 |
| 10 | 9 | 24 | 1909.3 | 11 | 9 | 24 | 1908.63 | 12 | 9 | 24 | 1908.26 |
| 10 | 10 | 24 | 1909.2 | 11 | 10 | 24 | 1908.53 | 12 | 10 | 24 | 1908.24 |
| 10 | 11 | 24 | 1908.66 | 11 | 11 | 24 | 1908.19 | 12 | 11 | 24 | 1907.84 |
| 10 | 12 | 24 | 1909.23 | 11 | 12 | 24 | 1908.7 | 12 | 12 | 24 | 1908.26 |
| 10 | 13 | 24 | 1909.25 | 11 | 13 | 24 | 1908.72 | 12 | 13 | 24 | 1908.27 |
| 10 | 14 | 24 | 1909.25 | 11 | 14 | 24 | 1908.74 | 12 | 14 | 24 | 1908.28 |
| 10 | 15 | 24 | 1909.26 | 11 | 15 | 24 | 1908.76 | 12 | 15 | 24 | 1908.3 |
| 10 | 16 | 24 | 1909.27 | 11 | 16 | 24 | 1908.78 | 12 | 16 | 24 | 1908.32 |
| 10 | 17 | 24 | 1909.28 | 11 | 17 | 24 | 1908.8 | 12 | 17 | 24 | 1908.34 |
| 10 | 18 | 24 | 1909.3 | 11 | 18 | 24 | 1908.82 | 12 | 18 | 24 | 1908.36 |
| 10 | 4 | 1 | 1906.53 | 11 | 4 | 1 | 1905.88 | 12 | 4 | 1 | 1905.94 |
| 10 | 6 | 2 | 1906.61 | 11 | 6 | 2 | 1906.06 | 12 | 6 | 2 | 1906.14 |
| 10 | 9 | 3 | 1906.69 | 11 | 9 | 3 | 1906.22 | 12 | 9 | 3 | 1906.24 |
| 10 | 9 | 4 | 1906.77 | 11 | 9 | 4 | 1906.3 | 12 | 9 | 4 | 1906.31 |
| 10 | 9 | 5 | 1906.85 | 11 | 9 | 5 | 1906.38 | 12 | 9 | 5 | 1906.4 |
| 10 | 9 | 6 | 1906.97 | 11 | 9 | 6 | 1906.5 | 12 | 9 | 6 | 1906.46 |
| 10 | 9 | 7 | 1907.09 | 11 | 9 | 7 | 1906.62 | 12 | 9 | 7 | 1906.56 |
| 10 | 9 | 8 | 1907.21 | 11 | 9 | 8 | 1906.74 | 12 | 9 | 8 | 1906.64 |
| 10 | 9 | 9 | 1907.33 | 11 | 9 | 9 | 1906.86 | 12 | 9 | 9 | 1906.78 |
| 10 | 9 | 10 | 1907.45 | 11 | 9 | 10 | 1906.98 | 12 | 9 | 10 | 1906.87 |
| 10 | 9 | 11 | 1907.57 | 11 | 9 | 11 | 1907.1 | 12 | 9 | 11 | 1906.95 |
| 10 | 9 | 12 | 1907.69 | 11 | 9 | 12 | 1907.19 | 12 | 9 | 12 | 1907.03 |
| 10 | 9 | 13 | 1907.78 | 11 | 9 | 13 | 1907.26 | 12 | 9 | 13 | 1907.1 |
| 10 | 9 | 14 | 1907.84 | 11 | 9 | 14 | 1907.34 | 12 | 9 | 14 | 1907.17 |
| 10 | 9 | 15 | 1907.87 | 11 | 9 | 15 | 1907.4 | 12 | 9 | 15 | 1907.24 |
| 10 | 9 | 16 | 1907.9 | 11 | 9 | 16 | 1907.43 | 12 | 9 | 16 | 1907.31 |
| 10 | 9 | 17 | 1907.97 | 11 | 9 | 17 | 1907.5 | 12 | 9 | 17 | 1907.37 |
| 10 | 9 | 18 | 1908.05 | 11 | 9 | 18 | 1907.6 | 12 | 9 | 18 | 1907.44 |
| 10 | 9 | 19 | 1908.13 | 11 | 9 | 19 | 1907.66 | 12 | 9 | 19 | 1907.5 |
| 10 | 9 | 20 | 1908.22 | 11 | 9 | 20 | 1907.73 | 12 | 9 | 20 | 1907.55 |
| 10 | 9 | 21 | 1908.32 | 11 | 9 | 21 | 1907.75 | 12 | 9 | 21 | 1907.61 |
| 10 | 9 | 22 | 1908.43 | 11 | 9 | 22 | 1907.96 | 12 | 9 | 22 | 1907.66 |
| 10 | 9 | 23 | 1908.55 | 11 | 9 | 23 | 1907.98 | 12 | 9 | 23 | 1907.75 |
| 10 | 11 | 24 | 1908.66 | 11 | 11 | 24 | 1908.19 | 12 | 11 | 24 | 1907.84 |

| MONTH | i | j | K HEAD | MONTH | i | j | K HEAD | MONTH | i | j | K HEAD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1906.16 | 2 | 1 | 1 | 1905.91 | 3 | 1 | 1 | 1905.69 |
| 1 | 2 | 1 | 1906.15 | 2 | 2 | 1 | 1905.89 | 3 | 2 | 1 | 1905.69 |
| 1 | 3 | 1 | 1906.03 | 2 | 3 | 1 | 1905.88 | 3 | 3 | 1 | 1905.69 |
| 1 | 4 | 1 | 1905.9 | 2 | 4 | 1 | 1905.76 | 3 | 4 | 1 | 1905.82 |
| 1 | 5 | 1 | 1906.03 | 2 | 5 | 1 | 1905.92 | 3 | 5 | 1 | 1905.79 |
| 1 | 6 | 1 | 1906.15 | 2 | 6 | 1 | 1905.93 | 3 | 6 | 1 | 1905.79 |
| 1 | 7 | 1 | 1906.15 | 2 | 7 | 1 | 1905.94 | 3 | 7 | 1 | 1905.79 |
| 1 | 8 | 1 | 1906.15 | 2 | 8 | 1 | 1905.94 | 3 | 8 | 1 | 1905.9 |
| 1 | 9 | 1 | 1906.16 | 2 | 9 | 1 | 1905.95 | 3 | 9 | 1 | 1905.8 |
| 1 | 10 | 1 | 1906.16 | 2 | 10 | 1 | 1905.95 | 3 | 10 | 1 | 1905.81 |
| 1 | 11 | 1 | 1906.17 | 2 | 11 | 1 | 1905.96 | 3 | 11 | 1 | 1905.81 |
| 1 | 12 | 1 | 1906.18 | 2 | 12 | 1 | 1905.96 | 3 | 12 | 1 | 1905.81 |
| 1 | 13 | 1 | 1906.19 | 2 | 13 | 1 | 1905.97 | 3 | 13 | 1 | 1905.92 |
| 1 | 14 | 1 | 1906.2 | 2 | 14 | 1 | 1905.98 | 3 | 14 | 1 | 1905.82 |
| 1 | 15 | 1 | 1906.22 | 2 | 15 | 1 | 1905.99 | 3 | 15 | 1 | 1905.83 |
| 1 | 16 | 1 | 1906.24 | 2 | 16 | 1 | 1906 | 3 | 16 | 1 | 1905.83 |
| 1 | 17 | 1 | 1906.26 | 2 | 17 | 1 | 1906.01 | 3 | 17 | 1 | 1905.84 |
| 1 | 18 | 1 | 1906.28 | 2 | 18 | 1 | 1906.02 | 3 | 18 | 1 | 1905.84 |
| 1 | 1 | 24 | 1908.15 | 2 | 1 | 24 | 1907.88 | 3 | 1 | 24 | 1907.41 |
| 1 | 2 | 24 | 1908.14 | 2 | 2 | 24 | 1907.87 | 3 | 2 | 24 | 1907.41 |
| 1 | 3 | 24 | 1908.14 | 2 | 3 | 24 | 1907.86 | 3 | 3 | 24 | 1907.41 |
| 1 | 4 | 24 | 1908.13 | 2 | 4 | 24 | 1907.85 | 3 | 4 | 24 | 1907.41 |
| 1 | 5 | 24 | 1908.13 | 2 | 5 | 24 | 1907.84 | 3 | 5 | 24 | 1907.41 |
| 1 | 6 | 24 | 1908.13 | 2 | 6 | 24 | 1907.83 | 3 | 6 | 24 | 1907.41 |
| 1 | 7 | 24 | 1908.13 | 2 | 7 | 24 | 1907.82 | 3 | 7 | 24 | 1907.41 |
| 1 | 8 | 24 | 1908.12 | 2 | 8 | 24 | 1907.81 | 3 | 8 | 24 | 1907.4 |
| 1 | 9 | 24 | 1908.1 | 2 | 9 | 24 | 1907.8 | 3 | 9 | 24 | 1907.4 |
| 1 | 10 | 24 | 1908.05 | 2 | 10 | 24 | 1907.8 | 3 | 10 | 24 | 1907.4 |
| 1 | 11 | 24 | 1907.91 | 2 | 11 | 24 | 1907.7 | 3 | 11 | 24 | 1907.44 |
| 1 | 12 | 24 | 1908.07 | 2 | 12 | 24 | 1907.87 | 3 | 12 | 24 | 1907.4 |
| 1 | 13 | 24 | 1908.08 | 2 | 13 | 24 | 1907.88 | 3 | 13 | 24 | 1907.4 |
| 1 | 14 | 24 | 1908.1 | 2 | 14 | 24 | 1907.89 | 3 | 14 | 24 | 1907.4 |
| 1 | 15 | 24 | 1908.12 | 2 | 15 | 24 | 1907.9 | 3 | 15 | 24 | 1907.41 |
| 1 | 16 | 24 | 1908.14 | 2 | 16 | 24 | 1907.91 | 3 | 16 | 24 | 1907.41 |
| 1 | 17 | 24 | 1908.16 | 2 | 17 | 24 | 1907.92 | 3 | 17 | 24 | 1907.41 |
| 1 | 18 | 24 | 1908.18 | 2 | 18 | 24 | 1907.93 | 3 | 18 | 24 | 1907.42 |
| 1 | 4 | 1 | 1905.9 | 2 | 4 | 1 | 1905.76 | 3 | 4 | 1 | 1905.82 |
| 1 | 6 | 2 | 1906.13 | 2 | 6 | 2 | 1905.98 | 3 | 6 | 2 | 1906.03 |
| 1 | 9 | 3 | 1906.27 | 2 | 9 | 3 | 1906.13 | 3 | 9 | 3 | 1906.24 |
| 1 | 9 | 4 | 1906.39 | 2 | 9 | 4 | 1906.23 | 3 | 9 | 4 | 1906.33 |
| 1 | 9 | 5 | 1906.43 | 2 | 9 | 5 | 1906.35 | 3 | 9 | 5 | 1906.39 |
| 1 | 9 | 6 | 1906.51 | 2 | 9 | 6 | 1906.4 | 3 | 9 | 6 | 1906.45 |
| 1 | 9 | 7 | 1906.6 | 2 | 9 | 7 | 1906.45 | 3 | 9 | 7 | 1906.51 |
| 1 | 9 | 8 | 1906.65 | 2 | 9 | 8 | 1906.5 | 3 | 9 | 8 | 1906.56 |
| 1 | 9 | 9 | 1906.7 | 2 | 9 | 9 | 1906.55 | 3 | 9 | 9 | 1906.61 |
| 1 | 9 | 10 | 1906.76 | 2 | 9 | 10 | 1906.6 | 3 | 9 | 10 | 1906.66 |
| 1 | 9 | 11 | 1906.84 | 2 | 9 | 11 | 1906.68 | 3 | 9 | 11 | 1906.69 |
| 1 | 9 | 12 | 1906.92 | 2 | 9 | 12 | 1906.75 | 3 | 9 | 12 | 1906.75 |
| 1 | 9 | 13 | 1906.98 | 2 | 9 | 13 | 1906.8 | 3 | 9 | 13 | 1906.79 |
| 1 | 9 | 14 | 1907.04 | 2 | 9 | 14 | 1906.84 | 3 | 9 | 14 | 1906.84 |
| 1 | 9 | 15 | 1907.09 | 2 | 9 | 15 | 1906.89 | 3 | 9 | 15 | 1906.88 |
| 1 | 9 | 16 | 1907.12 | 2 | 9 | 16 | 1906.95 | 3 | 9 | 16 | 1906.92 |
| 1 | 9 | 17 | 1907.19 | 2 | 9 | 17 | 1907 | 3 | 9 | 17 | 1906.96 |
| 1 | 9 | 18 | 1907.29 | 2 | 9 | 18 | 1907.03 | 3 | 9 | 18 | 1907 |
| 1 | 9 | 19 | 1907.35 | 2 | 9 | 19 | 1907.06 | 3 | 9 | 19 | 1907.04 |
| 1 | 9 | 20 | 1907.41 | 2 | 9 | 20 | 1907.13 | 3 | 9 | 20 | 1907.08 |
| 1 | 9 | 21 | 1907.51 | 2 | 9 | 21 | 1907.2 | 3 | 9 | 21 | 1907.12 |
| 1 | 9 | 22 | 1907.59 | 2 | 9 | 22 | 1907.25 | 3 | 9 | 22 | 1907.17 |
| 1 | 9 | 23 | 1907.71 | 2 | 9 | 23 | 1907.34 | 3 | 9 | 23 | 1907.26 |
| 1 | 11 | 24 | 1907.91 | 2 | 11 | 24 | 1907.7 | 3 | 11 | 24 | 1907.42 |

| MONTH | i | j | K HEAD | MONTH | i | j | K HEAD | MONTH | i | j | K HEAD |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | 1 | 1906 | 5 | 1 | 1 | 1908.54 | 6 | 1 | 1 | 1908.54 |
| 4 | 2 | 1 | 1906 | 5 | 2 | 1 | 1908.45 | 6 | 2 | 1 | 1908.45 |
| 4 | 3 | 1 | 1906 | 5 | 3 | 1 | 1908.4 | 6 | 3 | 1 | 1908.25 |
| 4 | 4 | 1 | 1906 | 5 | 4 | 1 | 1907.98 | 6 | 4 | 1 | 1907.89 |
| 4 | 5 | 1 | 1906 | 5 | 5 | 1 | 1908.52 | 6 | 5 | 1 | 1908.45 |
| 4 | 6 | 1 | 1906 | 5 | 6 | 1 | 1908.53 | 6 | 6 | 1 | 1908.46 |
| 4 | 7 | 1 | 1906 | 5 | 7 | 1 | 1908.54 | 6 | 7 | 1 | 1908.47 |
| 4 | 8 | 1 | 1906 | 5 | 8 | 1 | 1908.55 | 6 | 8 | 1 | 1908.48 |
| 4 | 9 | 1 | 1906 | 5 | 9 | 1 | 1908.57 | 6 | 9 | 1 | 1908.5 |
| 4 | 10 | 1 | 1906 | 5 | 10 | 1 | 1908.6 | 6 | 10 | 1 | 1908.53 |
| 4 | 11 | 1 | 1906 | 5 | 11 | 1 | 1908.62 | 6 | 11 | 1 | 1908.55 |
| 4 | 12 | 1 | 1906 | 5 | 12 | 1 | 1908.62 | 6 | 12 | 1 | 1908.55 |
| 4 | 13 | 1 | 1906 | 5 | 13 | 1 | 1908.62 | 6 | 13 | 1 | 1908.55 |
| 4 | 14 | 1 | 1906 | 5 | 14 | 1 | 1908.61 | 6 | 14 | 1 | 1908.54 |
| 4 | 15 | 1 | 1906 | 5 | 15 | 1 | 1908.59 | 6 | 15 | 1 | 1908.52 |
| 4 | 16 | 1 | 1906 | 5 | 16 | 1 | 1908.57 | 6 | 16 | 1 | 1908.5 |
| 4 | 17 | 1 | 1906 | 5 | 17 | 1 | 1908.57 | 6 | 17 | 1 | 1908.5 |
| 4 | 18 | 1 | 1906 | 5 | 18 | 1 | 1908.55 | 6 | 18 | 1 | 1908.48 |
| 4 | 1 | 24 | 1908 | 5 | 1 | 24 | 1911.82 | 6 | 1 | 24 | 1911.97 |
| 4 | 2 | 24 | 1908 | 5 | 2 | 24 | 1911.79 | 6 | 2 | 24 | 1911.94 |
| 4 | 3 | 24 | 1908 | 5 | 3 | 24 | 1911.79 | 6 | 3 | 24 | 1911.94 |
| 4 | 4 | 24 | 1908 | 5 | 4 | 24 | 1911.77 | 6 | 4 | 24 | 1911.92 |
| 4 | 5 | 24 | 1908 | 5 | 5 | 24 | 1911.77 | 6 | 5 | 24 | 1911.92 |
| 4 | 6 | 24 | 1908 | 5 | 6 | 24 | 1911.76 | 6 | 6 | 24 | 1911.91 |
| 4 | 7 | 24 | 1908 | 5 | 7 | 24 | 1911.76 | 6 | 7 | 24 | 1911.91 |
| 4 | 8 | 24 | 1908 | 5 | 8 | 24 | 1911.76 | 6 | 8 | 24 | 1911.91 |
| 4 | 9 | 24 | 1908 | 5 | 9 | 24 | 1911.7 | 6 | 9 | 24 | 1911.85 |
| 4 | 10 | 24 | 1908 | 5 | 10 | 24 | 1911.6 | 6 | 10 | 24 | 1911.75 |
| 4 | 11 | 24 | 1909 | 5 | 11 | 24 | 1910.85 | 6 | 11 | 24 | 1909.54 |
| 4 | 12 | 24 | 1908 | 5 | 12 | 24 | 1911.66 | 6 | 12 | 24 | 1911.91 |
| 4 | 13 | 24 | 1908 | 5 | 13 | 24 | 1911.68 | 6 | 13 | 24 | 1911.93 |
| 4 | 14 | 24 | 1908 | 5 | 14 | 24 | 1911.7 | 6 | 14 | 24 | 1911.95 |
| 4 | 15 | 24 | 1908 | 5 | 15 | 24 | 1911.7 | 6 | 15 | 24 | 1911.95 |
| 4 | 16 | 24 | 1908 | 5 | 16 | 24 | 1911.66 | 6 | 16 | 24 | 1911.91 |
| 4 | 17 | 24 | 1908 | 5 | 17 | 24 | 1911.65 | 6 | 17 | 24 | 1911.9 |
| 4 | 18 | 24 | 1908 | 5 | 18 | 24 | 1911.65 | 6 | 18 | 24 | 1911.9 |
| 4 | 4 | 1 | 1906 | 5 | 4 | 1 | 1907.98 | 6 | 4 | 1 | 1907.98 |
| 4 | 6 | 2 | 1906.24 | 5 | 6 | 2 | 1908.4 | 6 | 6 | 2 | 1908.28 |
| 4 | 9 | 3 | 1906.4 | 5 | 9 | 3 | 1908.72 | 6 | 9 | 3 | 1908.58 |
| 4 | 9 | 4 | 1906.48 | 5 | 9 | 4 | 1908.98 | 6 | 9 | 4 | 1908.78 |
| 4 | 9 | 5 | 1906.57 | 5 | 9 | 5 | 1909.12 | 6 | 9 | 5 | 1908.92 |
| 4 | 9 | 6 | 1906.68 | 5 | 9 | 6 | 1909.16 | 6 | 9 | 6 | 1908.96 |
| 4 | 9 | 7 | 1906.8 | 5 | 9 | 7 | 1909.19 | 6 | 9 | 7 | 1908.99 |
| 4 | 9 | 8 | 1906.92 | 5 | 9 | 8 | 1909.22 | 6 | 9 | 8 | 1909.02 |
| 4 | 9 | 9 | 1907.04 | 5 | 9 | 9 | 1909.31 | 6 | 9 | 9 | 1909.06 |
| 4 | 9 | 10 | 1906.16 | 5 | 9 | 10 | 1909.36 | 6 | 9 | 10 | 1909.11 |
| 4 | 9 | 11 | 1907.28 | 5 | 9 | 11 | 1909.4 | 6 | 9 | 11 | 1909.15 |
| 4 | 9 | 12 | 1907.4 | 5 | 9 | 12 | 1909.44 | 6 | 9 | 12 | 1909.19 |
| 4 | 9 | 13 | 1907.49 | 5 | 9 | 13 | 1909.47 | 6 | 9 | 13 | 1909.22 |
| 4 | 9 | 14 | 1907.56 | 5 | 9 | 14 | 1909.5 | 6 | 9 | 14 | 1909.25 |
| 4 | 9 | 15 | 1907.58 | 5 | 9 | 15 | 1909.53 | 6 | 9 | 15 | 1909.28 |
| 4 | 9 | 16 | 1907.61 | 5 | 9 | 16 | 1909.58 | 6 | 9 | 16 | 1909.33 |
| 4 | 9 | 17 | 1907.68 | 5 | 9 | 17 | 1909.63 | 6 | 9 | 17 | 1909.38 |
| 4 | 9 | 18 | 1907.78 | 5 | 9 | 18 | 1909.66 | 6 | 9 | 18 | 1909.41 |
| 4 | 9 | 19 | 1907.84 | 5 | 9 | 19 | 1909.7 | 6 | 9 | 19 | 1909.45 |
| 4 | 9 | 20 | 1907.93 | 5 | 9 | 20 | 1909.73 | 6 | 9 | 20 | 1909.48 |
| 4 | 9 | 21 | 1908.03 | 5 | 9 | 21 | 1909.76 | 6 | 9 | 21 | 1909.51 |
| 4 | 9 | 22 | 1908.14 | 5 | 9 | 22 | 1909.95 | 6 | 9 | 22 | 1909.55 |
| 4 | 9 | 23 | 1908.28 | 5 | 9 | 23 | 1910.1 | 6 | 9 | 23 | 1909.58 |
| 4 | 11 | 24 | 1908.37 | 5 | 11 | 24 | 1910.85 | 6 | 11 | 24 | 1909.64 |

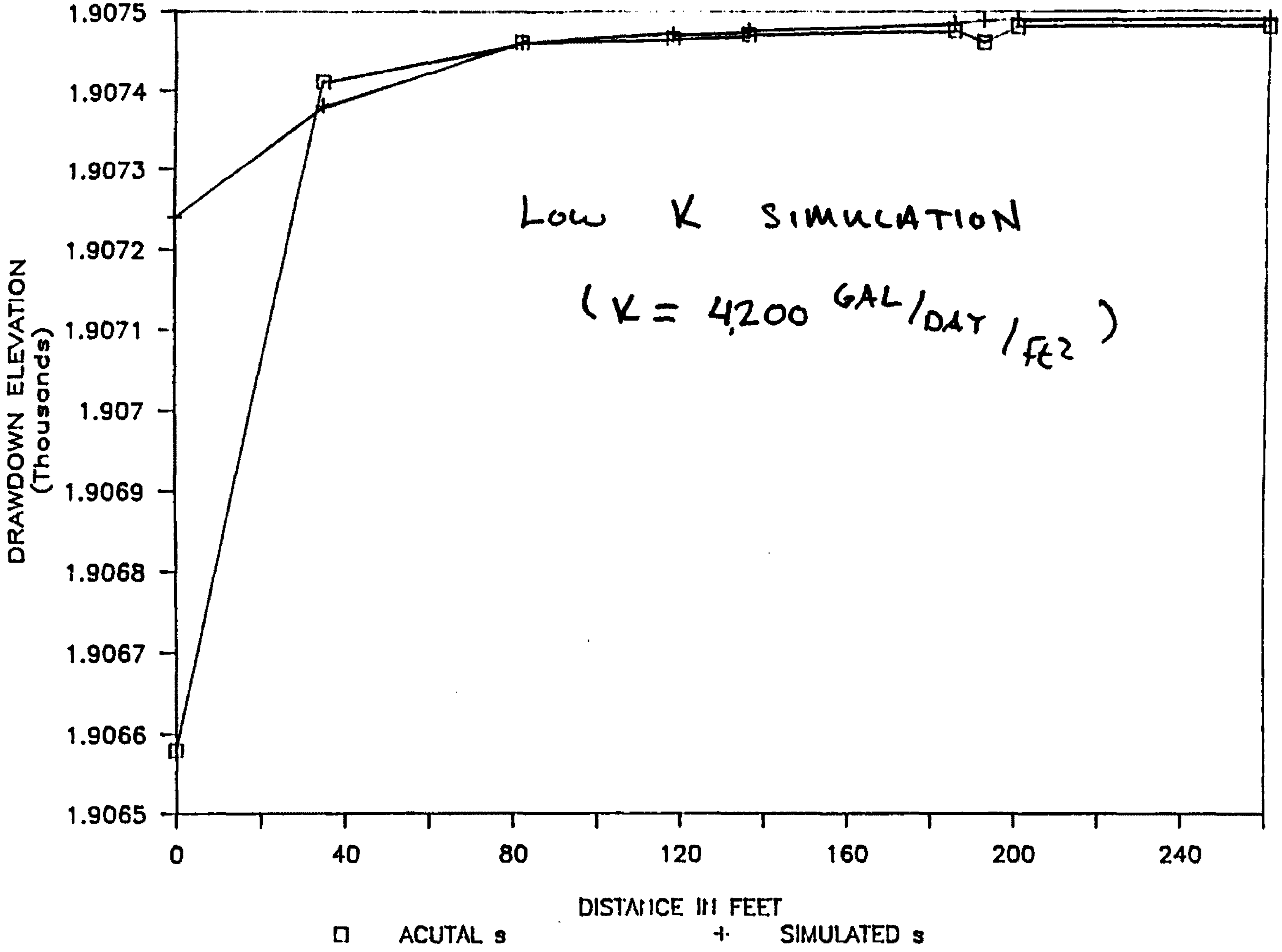
# APPENDIX T

# FLOW MODELING STATISTICS


ACUTAL VS. SIMULATED DRAWDOWN
PUMPING = 30 GPM, T = 192500 G/D/ft
HIGH K SIMULATION
(K = 11,000 GAL/DAY/ft²)
DRAWDOWN ELEVATION
(Thousands)
1.9075
1.9074
1.9073
1.9072
1.9071
1.907
1.9069
1.9068
1.9067
1.9066
1.9065
0
40
80
120
160
200
240
DISTANCE IN FEET
□ ACUTAL s
+ SIMULATED s

ACUTAL VS. SIMULATED DRAWDOWN

PUMPING = 30 GPM, T = 77000 G/D/ft



Low K SIMULATION

(K = 4,200 GAL/DAY/ft²)

### COMPARISON OF DRAWDOWN OF ACT. VS. SIM. AT TWO DIFFERENT PUMPING NODES AND TWO K VALUES

| DISTANCE AWAY | ACTUAL s | PUMP= 14,11 LOW K | PUMP= 13,10 LOW K | PUMP= 13,10 HI K | PUMP= 14.11 HI K |
|---|---|---|---|---|---|
| 0 | 1906.58 | 1907.24 | 1907.28 | 1907.4 | 1907.41 |
| 35 | 1907.41 | 1907.42 | 1907.41 | 1907.46 | 1907.46 |
| 82 | 1907.46 | 1907.44 | 1907.44 | 1907.48 | 1907.48 |
| 118 | 1907.465 | 1907.47 | 1907.46 | 1907.49 | 1907.49 |
| 136 | 1907.47 | 1907.48 | 1907.48 | 1907.495 | 1907.49 |
| 185 | 1907.475 | 1907.48 | 1907.48 | 1907.5 | 1907.495 |
| 192 | 1907.46 | 1907.49 | 1907.48 |  | 1907.495 |
| 200 | 1907.48 | 1907.49 | 1907.48 |  | 1907.5 |
| 260 | 1907.48 | 1907.49 | 1907.47 |  |  |

### DATA FOR MODEL RUN WITH K = 11000 AND T = 192500.

PUMPING NODE 13,10

| DISTANCE | DRAWDOWN | WL ELV. |
|---|---|---|
| 0 | 0.1 | 1907.4 |
| 35 | 0.04 | 1907.46 |
| 82 | 0.02 | 1907.48 |
| 118 | 0.01 | 1907.49 |
| 136 | 0.005 | 1907.495 |
| 185 | 0 | 1907.5 |

PUMPING NODE 14,11

| DISTANCE | DRAWDOWN | WL ELV. |
|---|---|---|
| 0 | 0.09 | 1907.41 |
| 35 | 0.04 | 1907.46 |
| 82 | 0.02 | 1907.48 |
| 118 | 0.01 | 1907.49 |
| 136 | 0.01 | 1907.49 |
| 185 | 0.005 | 1907.495 |
| 192 | 0.005 | 1907.495 |
| 200 | 0 | 1907.5 |

### DATA FOR MODLE RUN WITH K = 4400 AND T = 77000.

PUMPING NODE 13,10

| DISTANCE | DRAWDOWN | WL ELV. |
|---|---|---|
| 0 | 0.22 | 1907.28 |
| 35 | 0.09 | 1907.41 |
| 82 | 0.06 | 1907.44 |
| 118 | 0.04 | 1907.46 |
| 136 | 0.02 | 1907.48 |
| 185 | 0.02 | 1907.48 |
| 192 | 0.02 | 1907.48 |
| 200 | 0.02 | 1907.48 |
| 260 | 0.03 | 1907.47 |

PUMPING NODE 14,11

| DISTANCE | DRAWDOWN | WL ELV. |
|---|---|---|
| 0 | 0.26 | 1907.24 |
| 40 | 0.08 | 1907.42 |
| 80 | 0.06 | 1907.44 |
| 120 | 0.03 | 1907.47 |
| 160 | 0.02 | 1907.48 |
| 200 | 0.02 | 1907.48 |
| 240 | 0.01 | 1907.49 |
| 280 | 0.01 | 1907.49 |
| 320 | 0.01 | 1907.49 |

ACTUAL AQ. TEST DATA

| DISTANCE | DRAWDOWN | WL ELV. |
|---|---|---|
| 0 | 0.92 | 1906.58 |
| 35 | 0.09 | 1907.41 |
| 82 | 0.04 | 1907.46 |
| 118 | 0.035 | 1907.465 |
| 136 | 0.03 | 1907.47 |
| 185 | 0.025 | 1907.475 |
| 192 | 0.04 | 1907.46 |
| 200 | 0.02 | 1907.48 |
| 260 | 0.02 | 1907.48 |

## STEADY-STATE STATISTICS (OCT.)

HEAD

| WELL | ACTUAL | SIMULATED | DIFF. |
|---|---|---|---|
| 2 | 1908.2 | 1908.5 | -0.3 |
| 3 | 1908.1 | 1908.26 | -0.16 |
| 4 | 1907.93 | 1907.91 | 0.02 |
| 5 | 1907.85 | 1907.85 | 0 |
| 6 | 1907.76 | 1907.7 | 0.06 |
| 7 | 1907.6 | 1907.5 | 0.1 |
| 8 | 1906.93 | 1906.81 | 0.12 |
| 11 | 1907.68 | 1907.75 | -0.07 |
| 12 | 1907.92 | 1907.97 | -0.05 |
| 13 | 1907.08 | 1907.05 | 0.03 |
| 14 | 1908.12 | 1908.05 | 0.07 |
| 15 | 1907.76 | 1907.74 | 0.02 |
| 16 | 1907.7 | 1907.7 | 0 |
| 17 | 1907.32 | 1907.24 | 0.08 |
| 18 | 1907.2 | 1907.13 | 0.07 |
| 19 | 1907.68 | 1907.64 | 0.04 |
| 20 | 1907.72 | 1907.7 | 0.02 |
| 21 | 1908.18 | 1908.5 | -0.32 |

## TRANSIENT STATISTICS

HEAD

| | WELL | ACUTAL | SIMULATED | DIFF. |
|---|---|---|---|---|
| JUL | 8 | 1908.56 | 1908.66 | -0.1 |
| | 13 | 1908.74 | 1908.98 | -0.24 |
| | 11 | 1909.38 | 1909.6 | -0.22 |
| | 12 | 1909.68 | 1909.74 | -0.06 |
| | 2 | 1910.11 | 1910.42 | -0.31 |
| | 3 | 1909.94 | 1910.12 | -0.18 |
| | 4 | 1909.9 | 1909.66 | 0.24 |
| | 5 | 1909.65 | 1909.6 | 0.05 |
| | 7 | 1909.35 | 1909.27 | 0.08 |
| | 6 | 1909.55 | 1909.5 | 0.05 |
| | 14 | 1909.96 | 1909.9 | 0.06 |
| AUG | 8 | 1908.79 | 1908.98 | -0.19 |
| | 13 | 1909 | 1909.41 | -0.41 |
| | 11 | 1909.76 | 1909.94 | -0.18 |
| | 12 | 1910.03 | 1910.04 | -0.01 |
| | 2 | 1910.38 | 1910.59 | -0.21 |
| | 3 | 1910.18 | 1910.39 | -0.21 |
| | 4 | 1910.13 | 1910.01 | 0.12 |
| | 5 | 1910.01 | 1909.95 | 0.06 |
| | 7 | 1910.68 | 1910.69 | -0.01 |
| | 6 | 1909.9 | 1909.87 | 0.03 |
| | 14 | 1910.34 | 1910.23 | 0.11 |
| SEP | 13 | 1907.81 | 1907.99 | -0.18 |
| | 11 | 1908.45 | 1908.45 | 0 |
| | 12 | 1908.23 | 1908.46 | -0.23 |
| | 2 | 1909.04 | 1909.07 | -0.03 |
| | 3 | 1908.99 | 1908.93 | 0.06 |
| | 4 | 1908.78 | 1908.56 | 0.22 |
| | 5 | 1908.69 | 1908.48 | 0.21 |
| | 7 | 1908.38 | 1908.27 | 0.11 |
| | 6 | 1908.56 | 1908.47 | 0.09 |
| | 14 | 1908.57 | 1908.8 | -0.23 |
| OCT | 2 | 1908.2 | 1908.5 | -0.3 |
| | 3 | 1908.1 | 1908.26 | -0.16 |
| | 4 | 1907.93 | 1907.91 | 0.02 |
| | 5 | 1907.85 | 1907.85 | 0 |
| | 6 | 1907.76 | 1907.7 | 0.06 |
| | 7 | 1907.6 | 1907.5 | 0.1 |
| | 8 | 1906.93 | 1906.81 | 0.12 |
| | 11 | 1907.68 | 1907.75 | -0.07 |
| | 12 | 1907.92 | 1907.97 | -0.05 |
| | 13 | 1907.08 | 1907.05 | 0.03 |
| | 14 | 1908.12 | 1908.05 | 0.07 |
| | 15 | 1907.76 | 1907.74 | 0.02 |
| | 16 | 1907.7 | 1907.7 | 0 |
| | 17 | 1907.32 | 1907.24 | 0.08 |
| | 18 | 1907.2 | 1907.13 | 0.07 |
| | 19 | 1907.68 | 1907.64 | 0.04 |
| | 20 | 1907.72 | 1907.7 | 0.02 |
| | 21 | 1908.18 | 1908.5 | -0.32 |
| NOV | 8 | 1906.31 | 1906.37 | -0.06 |
| | 13 | 1906.72 | 1906.56 | 0.16 |
| | 18 | 1906.91 | 1906.65 | 0.26 |
| | 11 | 1907.25 | 1907.23 | 0.02 |
| | 12 | 1907.49 | 1907.47 | 0.02 |
| | 2 | 1907.73 | 1908 | -0.27 |
| | 21 | 1907.72 | 1908.02 | -0.3 |
| | 3 | 1907.64 | 1907.77 | -0.13 |
| | 4 | 1907.54 | 1907.41 | 0.13 |
| | 5 | 1907.42 | 1907.37 | 0.05 |
| | 16 | 1907.3 | 1907.21 | 0.09 |
| | 20 | 1907.25 | 1907.23 | 0.02 |
| | 7 | 1907.19 | 1907.04 | 0.15 |
| | 19 | 1907.27 | 1907.18 | 0.09 |
| | 6 | 1907.34 | 1907.24 | 0.1 |
| | 15 | 1907.33 | 1907.28 | 0.05 |
| | 14 | 1907.66 | 1907.58 | 0.08 |
| | 17 | 1906.96 | 1906.79 | 0.17 |
| DEC | 8 | 1906.45 | 1906.3 | 0.15 |
| | 13 | 1906.53 | 1906.51 | 0.02 |
| | 18 | 1906.66 | 1906.59 | 0.07 |
| | 11 | 1907.04 | 1907 | 0.04 |
| | 12 | 1907.26 | 1907.3 | -0.04 |
| | 2 | 1907.48 | 1907.71 | -0.23 |

|  | WELL | ACUTAL | SIMULATED | DIFF. |
|---|---|---|---|---|
|  | 21 | 1907.46 | 1907.71 | -0.25 |
|  | 3 | 1907.39 | 1907.51 | -0.12 |
|  | 4 | 1907.3 | 1907.21 | 0.09 |
|  | 5 | 1907.2 | 1907.19 | 0.01 |
|  | 16 | 1907.08 | 1907.04 | 0.04 |
|  | 20 | 1907.09 | 1907.06 | 0.03 |
|  | 7 | 1907 | 1906.9 | 0.1 |
|  | 19 | 1907.04 | 1907.01 | 0.03 |
|  | 6 | 1907.11 | 1907.06 | 0.05 |
|  | 15 | 1907.12 | 1907.09 | 0.03 |
|  | 14 | 1907.4 | 1907.33 | 0.07 |
|  | 17 | 1906.64 | 1906.68 | -0.04 |
| JAN | 8 | 1906.34 | 1906.27 | 0.07 |
|  | 13 | 1906.44 | 1906.51 | -0.07 |
|  | 18 | 1906.57 | 1906.58 | -0.01 |
|  | 11 | 1906.92 | 1906.98 | -0.06 |
|  | 12 | 1907.09 | 1907.17 | -0.08 |
|  | 2 | 1907.29 | 1907.59 | -0.3 |
|  | 21 | 1907.27 | 1907.58 | -0.31 |
|  | 3 | 1907.2 | 1907.39 | -0.19 |
|  | 4 | 1907.15 | 1907.1 | 0.05 |
|  | 5 | 1907.05 | 1907.08 | -0.03 |
|  | 16 | 1907.83 | 1907.94 | -0.11 |
|  | 20 | 1906.86 | 1906.97 | -0.11 |
|  | 7 | 1906.86 | 1906.83 | 0.03 |
|  | 19 | 1906.89 | 1906.92 | -0.03 |
|  | 6 | 1906.97 | 1906.97 | 0 |
|  | 15 | 1906.96 | 1907 | -0.04 |
|  | 14 | 1907.22 | 1907.22 | 0 |
|  | 17 | 1906.62 | 1906.65 | -0.03 |
| FEB | 8 | 1906.23 | 1906.08 | 0.15 |
|  | 13 | 1906.3 | 1906.35 | -0.05 |
|  | 18 | 1906.46 | 1906.43 | 0.03 |
|  | 11 | 1906.79 | 1906.78 | 0.01 |
|  | 12 | 1906.97 | 1906.96 | 0.01 |
|  | 2 | 1907.17 | 1907.34 | -0.17 |
|  | 3 | 1907.08 | 1907.17 | -0.09 |
|  | 4 | 1907.02 | 1906.9 | 0.12 |
|  | 5 | 1906.9 | 1906.88 | 0.02 |
|  | 16 | 1906.83 | 1906.76 | 0.07 |
|  | 20 | 1906.83 | 1906.77 | 0.06 |
|  | 7 | 1906.75 | 1906.65 | 0.1 |
|  | 19 | 1906.78 | 1906.73 | 0.05 |
|  | 6 | 1906.88 | 1906.77 | 0.11 |
|  | 15 | 1906.81 | 1906.8 | 0.01 |
|  | 17 | 1906.5 | 1906.48 | 0.02 |
| MAR | 8 | 1906.17 | 1905.99 | 0.18 |
|  | 13 | 1906.23 | 1906.38 | -0.15 |
|  | 18 | 1906.39 | 1906.44 | -0.05 |
|  | 11 | 1906.7 | 1906.69 | 0.01 |

|  | WELL | ACUTAL | SIMULATED | DIFF. |
|---|---|---|---|---|
|  | 12 | 1906.88 | 1906.88 | 0 |
|  | 2 | 1906.99 | 1907.11 | -0.12 |
|  | 21 | 1907.04 | 1907.09 | -0.05 |
|  | 4 | 1906.93 | 1906.76 | 0.17 |
|  | 5 | 1906.84 | 1906.78 | 0.06 |
|  | 16 | 1906.73 | 1906.68 | 0.05 |
|  | 20 | 1906.74 | 1906.67 | 0.07 |
|  | 7 | 1906.65 | 1906.66 | -0.01 |
|  | 19 | 1906.7 | 1906.62 | 0.08 |
|  | 6 | 1906.75 | 1906.64 | 0.11 |
|  | 15 | 1906.75 | 1906.66 | 0.09 |
|  | 14 | 1907.02 | 1906.79 | 0.23 |
|  | 17 | 1906.43 | 1906.43 | 0 |
| APR | 8 | 1906.11 | 1905.7 | 0.41 |
|  | 13 | 1906.14 | 1906.17 | -0.03 |
|  | 18 | 1906.29 | 1906.25 | 0.04 |
|  | 11 | 1906.58 | 1906.54 | 0.04 |
|  | 12 | 1906.77 | 1906.76 | 0.01 |
|  | 2 | 1906.95 | 1907.07 | -0.12 |
|  | 21 | 1906.94 | 1907.05 | -0.11 |
|  | 3 | 1906.92 | 1906.88 | 0.04 |
|  | 14 | 1906.89 | 1906.68 | 0.21 |
|  | 5 | 1906.73 | 1906.64 | 0.09 |
|  | 4 | 1906.81 | 1906.63 | 0.18 |
|  | 16 | 1906.62 | 1906.52 | 0.1 |
|  | 19 | 1906.58 | 1906.46 | 0.12 |
|  | 6 | 1906.64 | 1906.49 | 0.15 |
|  | 15 | 1906.63 | 1906.51 | 0.12 |
|  | 7 | 1906.55 | 1906.4 | 0.15 |
|  | 17 | 1906.33 | 1906.23 | 0.1 |
| MAY | 8 | 1908.25 | 1908.7 | -0.45 |
|  | 13 | 1908.52 | 1909.08 | -0.56 |
|  | 18 | 1908.77 | 1909.18 | -0.41 |
|  | 11 | 1909.4 | 1909.68 | -0.28 |
|  | 12 | 1909.96 | 1909.76 | 0.2 |
|  | 2 | 1910.29 | 1910.45 | -0.16 |
|  | 21 | 1910.27 | 1910.53 | -0.26 |
|  | 3 | 1910.16 | 1910.23 | -0.07 |
|  | 14 | 1910.2 | 1910.05 | 0.15 |
|  | 5 | 1909.86 | 1909.74 | 0.12 |
|  | 4 | 1910 | 1909.8 | 0.2 |
|  | 16 | 1909.65 | 1909.59 | 0.06 |
|  | 19 | 1909.6 | 1909.58 | 0.02 |
|  | 6 | 1909.7 | 1909.65 | 0.05 |
|  | 15 | 1909.75 | 1909.69 | 0.06 |
|  | 7 | 1909.46 | 1909.46 | 0 |
|  | 17 | 1909.28 | 1909.02 | 0.26 |
| JUN | 13 | 1908.8 | 1908.92 | -0.12 |
|  | 18 | 1908.79 | 1909.01 | -0.22 |
|  | 11 | 1909.58 | 1909.55 | 0.03 |

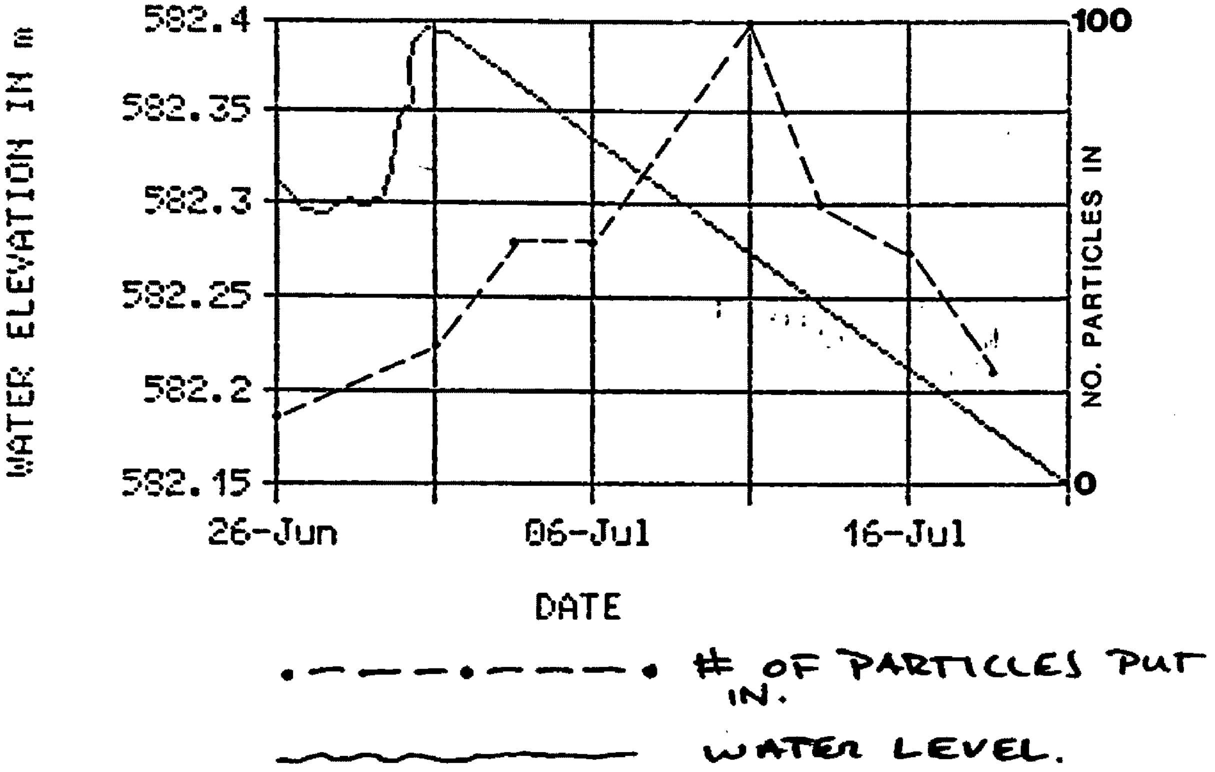
| WELL | ACUTAL | SIMULATED | DIFF. |
|---|---|---|---|
| 12 | 1909.86 | 1909.57 | 0.29 |
| 2 | 1910.41 | 1910.34 | 0.07 |
| 21 | 1910.44 | 1910.49 | -0.05 |
| 3 | 1910.25 | 1910.15 | 0.1 |
| 14 | 1910.34 | 1910.01 | 0.33 |
| 5 | 1909.74 | 1909.57 | 0.17 |
| 4 | 1909.96 | 1909.69 | 0.27 |
| 16 | 1909.51 | 1909.44 | 0.07 |
| 19 | 1909.55 | 1909.47 | 0.08 |
| 6 | 1909.67 | 1909.55 | 0.12 |
| 15 | 1909.73 | 1909.58 | 0.15 |
| 7 | 1909.37 | 1909.31 | 0.06 |
| 17 | 1908.92 | 1909.12 | -0.2 |

```
STEADY-STATE RESULTS
           Regression Output:
Constant                              0
Std Err of Y Est               0.126713
R Squared                      0.926028
No. of Observations                  18
Degrees of Freedom                   17

X Coefficient(s)1.000020
Std Err of Coef.0.000015


TRANSIENT RESULTS
           Regression Output:
Constant                              0
Std Err of Y Est               0.171654
R Squared                      0.983228
No. of Observations                 187
Degrees of Freedom                  186

X Coefficient(s)1.000001
Std Err of Coef.0.000006
```

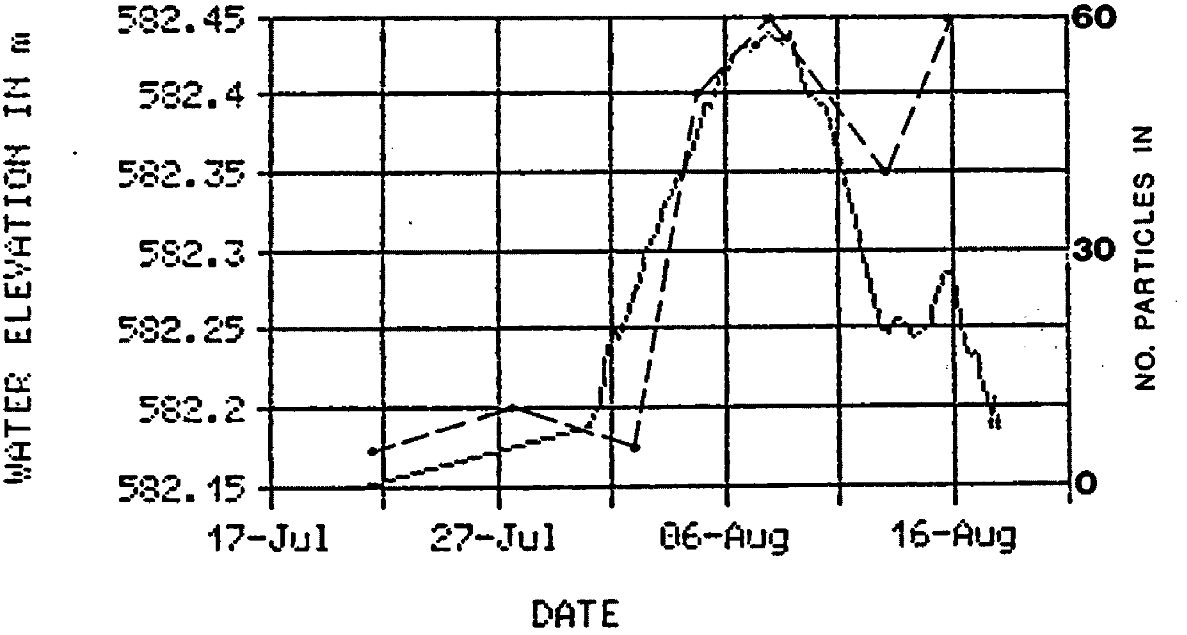
# APPENDIX U

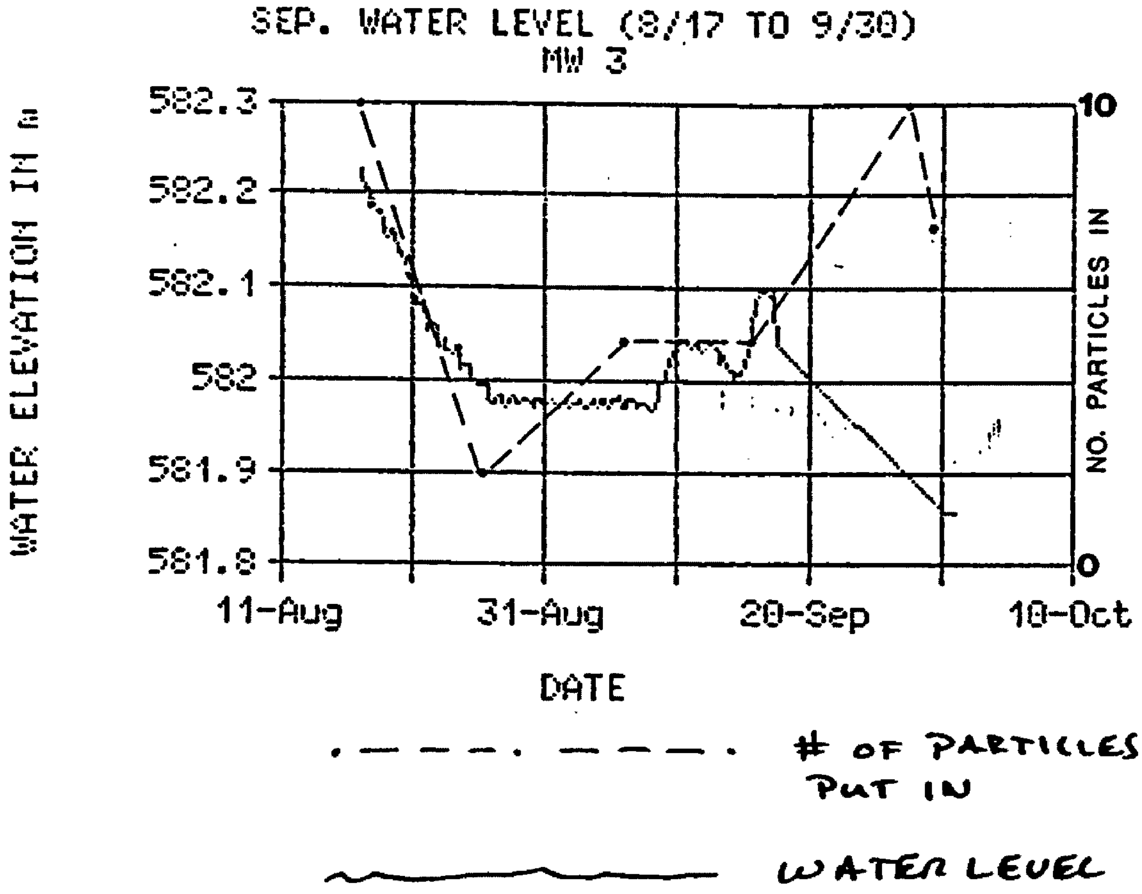
# RANDOM-WALK LOADING

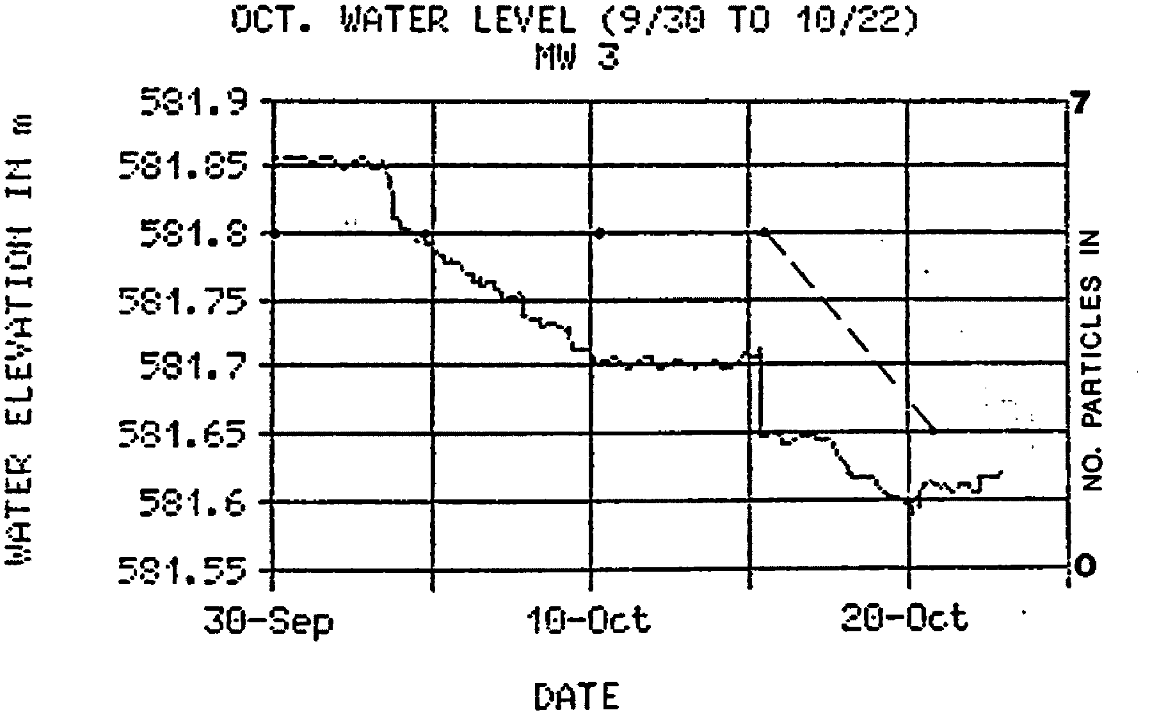
JULY WATER LEVEL (6/26 TO 7/21)
MW 3

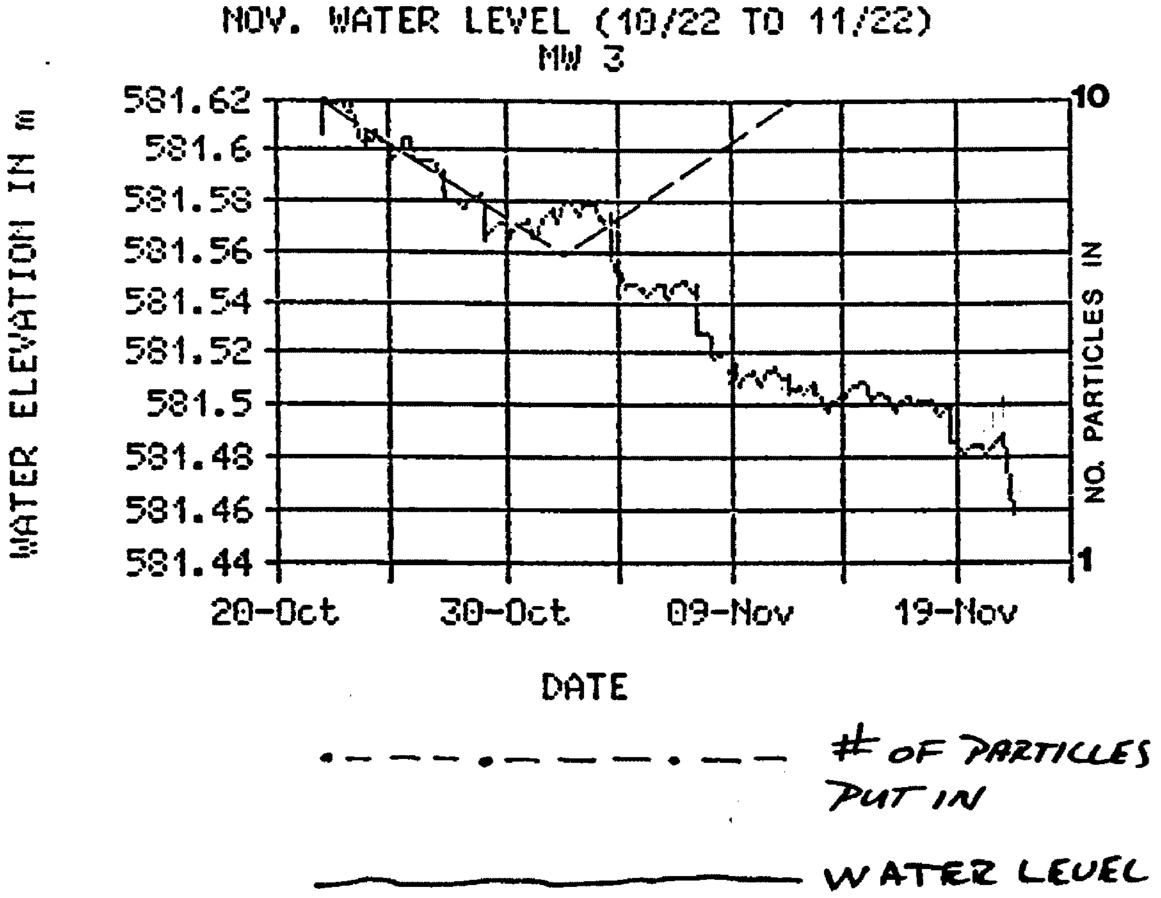


AUG. WATER LEVEL (7/21 TO 8/17)
MW 3

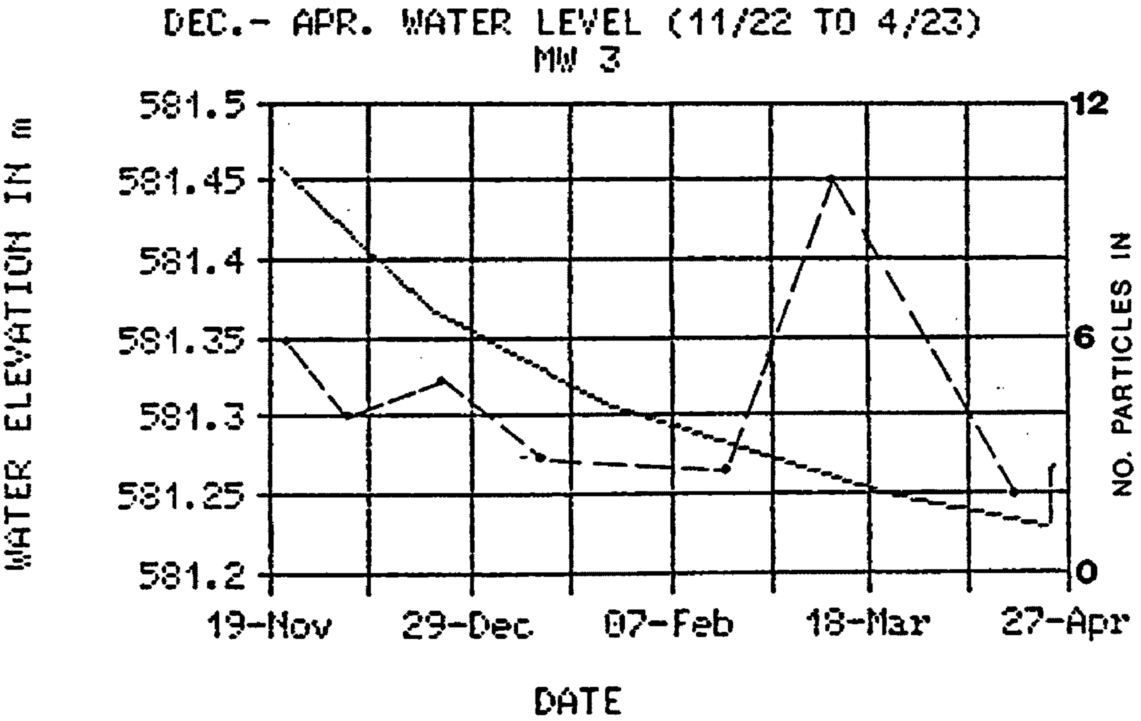



SEP. WATER LEVEL (8/17 TO 9/30)
MW 3
WATER ELEVATION IN m
582.3
582.2
582.1
582
581.9
581.8
10
NO. PARTICLES IN
0
11-Aug
31-Aug
20-Sep
10-Oct
DATE
# OF PARTICLES PUT IN
WATER LEVEL


OCT. WATER LEVEL (9/30 TO 10/22)
MW 3
WATER ELEVATION IN m
581.9
581.85
581.8
581.75
581.7
581.65
581.6
581.55
7
NO. PARTICLES IN
0
30-Sep
10-Oct
20-Oct
DATE

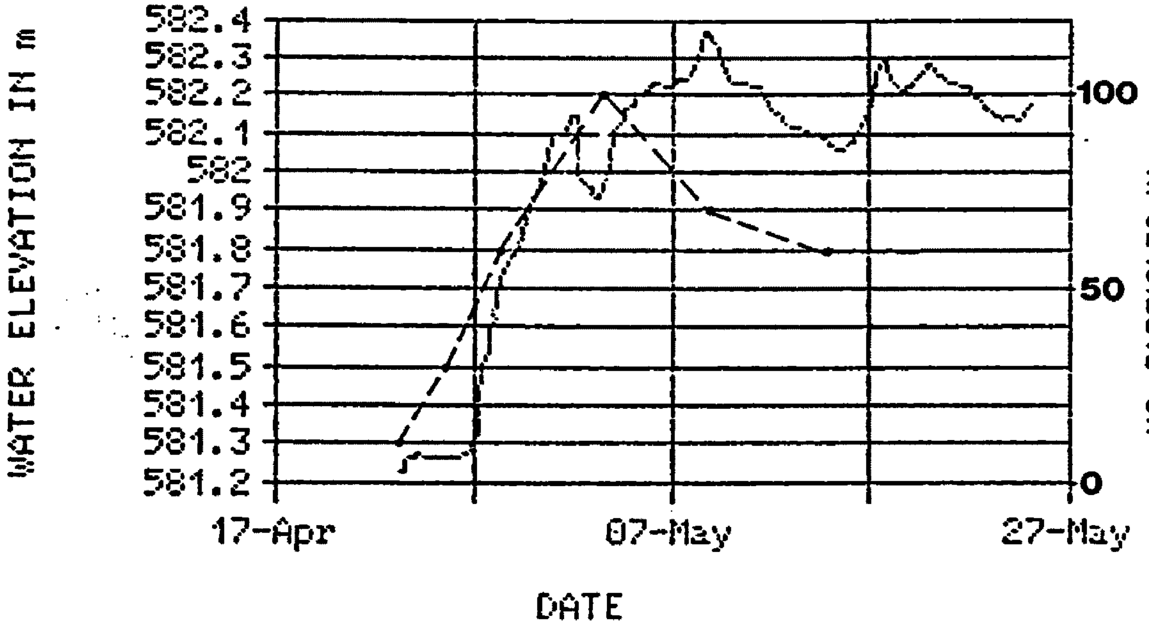


NOV. WATER LEVEL (10/22 TO 11/22)
MW 3



DEC.- APR. WATER LEVEL (11/22 TO 4/23)
MW 3

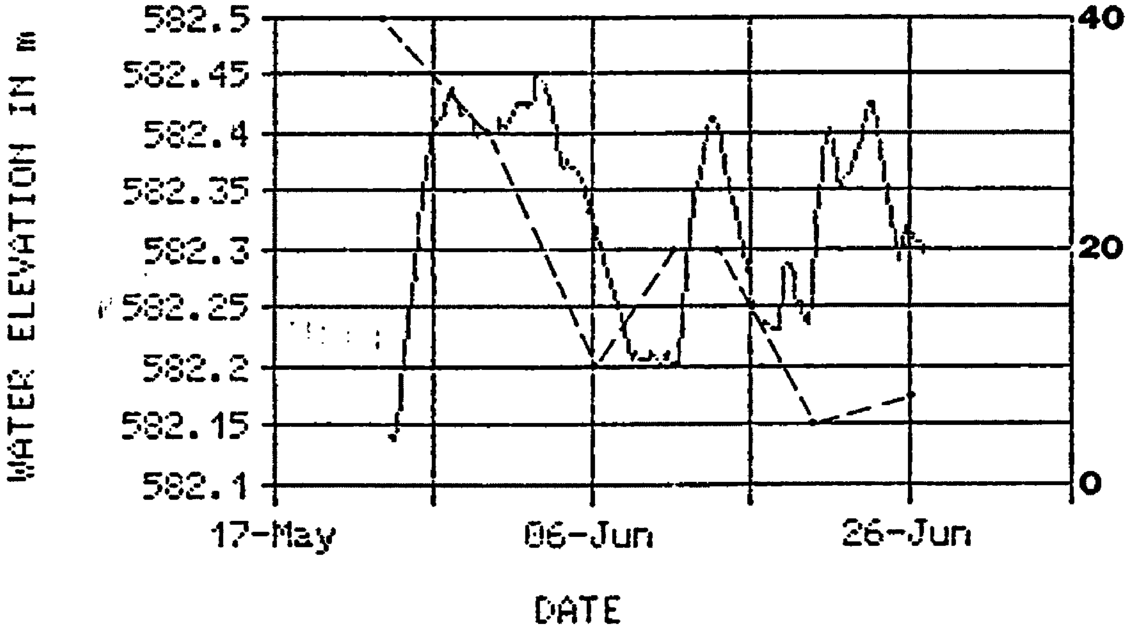
MAY WATER LEVEL (4/23 TO 5/24)
MW 3



•— — —• — — —• # of PARTICLES PUT IN

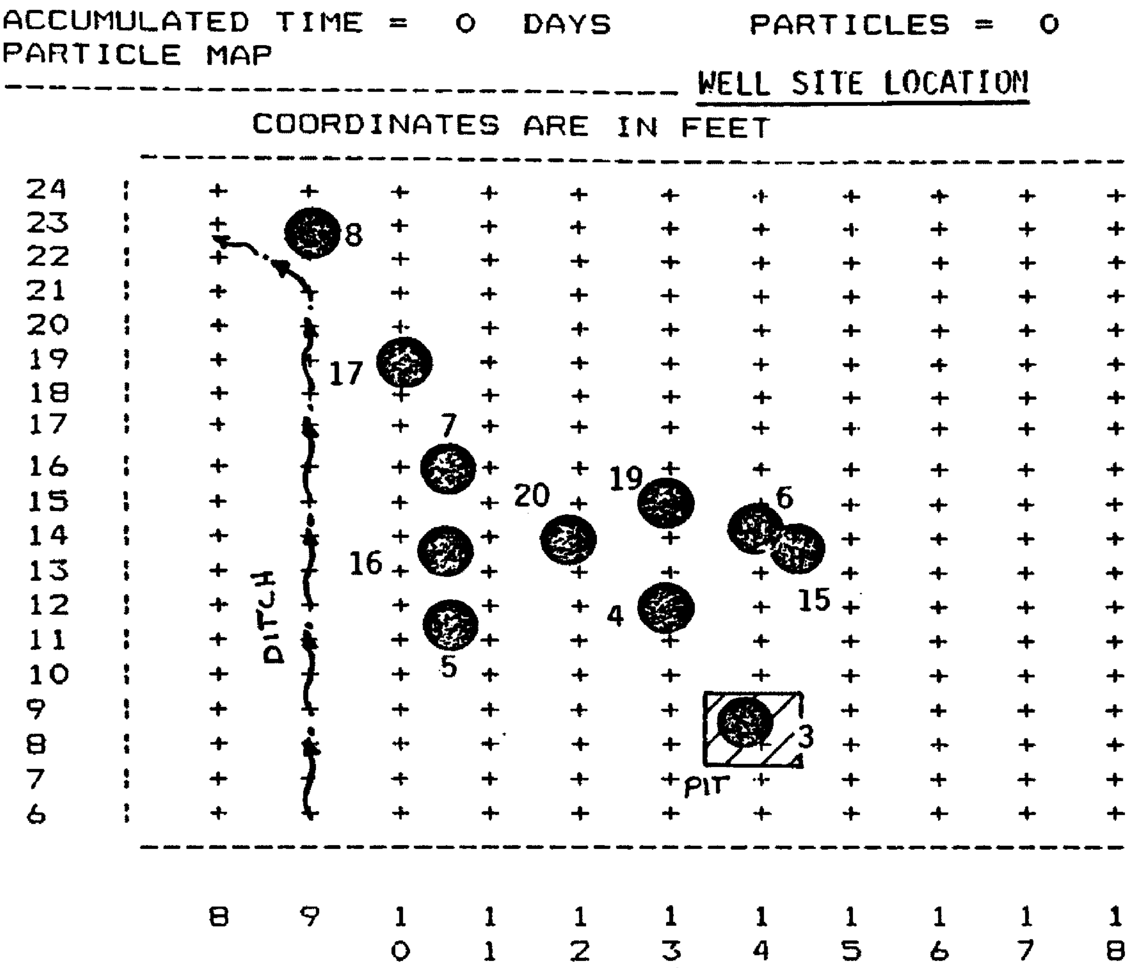
———————— WATER LEVEL

JUNE WATER LEVEL (5/24 TO 6/26)
MW 3



# APPENDIX V

## SIMULATED Cl PLOTS AND ACTUAL VERSES SIMULATED CHLORIDE DATA



```
ACCUMULATED TIME =  0  DAYS       PARTICLES =  0
PARTICLE MAP
------------------------------
                    COORDINATES ARE IN FEET
```

```
ACCUMULATED TIME =  30  DAYS       PARTICLES =  328
CONCENTRATION MAP IN PPM
------------------------------

          COORDINATES ARE IN FEET
      -------------------------------------------
 16 !   +   +   +   +   +   +   +   +   +   +   +
 15 !   +   +   +   +   +   +   +   +   +   +   +
 14 !   +   +   + 127  95   +   +   +   +   +   +
 13 !   +   +   + 295 473 126  42   +   +   +   +
 12 !   +   +   +   + 785 563   +   +   +   +   +
 11 !   +   +   +   + 6251029 247   +   +   +   +
 10 !   +   +   +   +   +1335 743   +   +   +   +
  9 !   +   +   +   +   + 4631129  15   +   +   +
  8 !   +   +   +   +   +  31 654   +   +   +   +
  7 !   +   +   +   +   +   +  41  15   +   +   +
  6 !   +   +   +   +   +   +   +   +   +   +   +
      -------------------------------------------

        8   9   1   1   1   1   1   1   1   1   1
                0   1   2   3   4   5   6   7   8
```

N

```
DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  MAY
```

```
ACCUMULATED TIME =  90  DAYS      PARTICLES =  552
CONCENTRATION MAP IN PPM
------------------------------
           COORDINATES ARE IN FEET
      --------------------------------------------
24  :   +   +   +   +   +   +   +   +   +   +   +
23  :   +   +   +   +   +   +   +   +   +   +   +
22  :   +   +   +   +   +   +   +   +   +   +   +
21  :   +   +   +   +   +   +   +   +   +   +   +
20  :   +   +   +   +   +   +   +   +   +   +   +
19  :   +   +  63   +  32   +   +   +   +   +   +
18  :   +   +  63  42   +   +   +   +   +   +   +
17  :   +   +   +  42 157   +   +   +   +   +   +
16  :   +   + 108 209  94  31   +   +   +   +   +
15  :   +   + 187 749 280  31  21   +   +   +   +
14  :   +   +  62 705 590 155  83   +   +   +   +
13  :   +   +   + 331 836 278  82   +   +   +   +
12  :   +   +   +   + 2781139 184   +   +   +   +
11  :   +   +   +  41 1541779 388   +   +   +   +
10  :   +   +   +   + 3112221220   +   +   +   +
9   :   +   +   +   +   + 3042046   +   +   +   +
8   :   +   +   +   +   +  30 948  15   +   +   +
7   :   +   +   +   +   +   +  60  15   +   +   +
6   :   +   +   +   +   +   +   +  15   +   +   +
      --------------------------------------------

        8   9   1   1   1   1   1   1   1   1   1
                0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  JUL
```

```
ACCUMULATED TIME =  120  DAYS      PARTICLES =  702
CONCENTRATION MAP IN PPM
------------------------------
           COORDINATES ARE IN FEET
      --------------------------------------------
24  :   +   +   +   +   +   +   +   +   +   +   +
23  :   +   +   +   +   +   +   +   +   +   +   +
22  :   +   +   +  31   +   +   +   +   +   +   +
21  :   +   +   +   +   +   +   +   +   +   +   +
20  :   +   +   +   +   +   +   +   +   +   +   +
19  :   +   +  68  45  34   +   +   +   +   +   +
18  :   +   +   +  91 102  34   +   +   +   +   +
17  :   +   + 136 588 169  67   +   +   +   +   +
16  :   +   + 203 811 405  34   +   +   +   +   +
15  :   +   +  681034 673 134   +   +   +   +   +
14  :   +   +   +12111141 368  89   +   +   +   +
13  :   +   +   + 4021605 701  22   +   +   +   +
12  :   +   +   +  45 9001297 265   +   +   +   +
11  :   +   +   +  44 5321459 375   +   +   +   +
10  :   +   +   +   +   +1322 967   +   +   +   +
9   :   +   +   +   +   + 5602561  16   +   +   +
8   :   +   +   +   +   +   +1134   +   +   +   +
7   :   +   +   +   +   +   +  65  32   +   +   +
6   :   +   +   +   +   +   +   +   +   +   +   +
      --------------------------------------------

        8   9   1   1   1   1   1   1   1   1   1
                0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  AUG
```

```
ACCUMULATED TIME =  60  DAYS      PARTICLES =  330
CONCENTRATION MAP IN PPM
------------------------------
           COORDINATES ARE IN FEET
      --------------------------------------------
24  :   +   +   +   +   +   +   +   +   +   +   +
23  :   +   +   +   +   +   +   +   +   +   +   +
22  :   +   +   +   +   +   +   +   +   +   +   +
21  :   +   +   +   +   +   +   +   +   +   +   +
20  :   +   +   +   +   +   +   +   +   +   +   +
19  :   +   +   +   +   +   +   +   +   +   +   +
18  :   +   +   +   +   +   +   +   +   +   +   +
17  :   +   +   +  43   +  32   +   +   +   +   +
16  :   +   + 129 128   +   +   +   +   +   +   +
15  :   +   + 255 298 127   +   +   +   +   +   +
14  :   +   +   + 847 412  32  21   +   +   +   +
13  :   +   + 1271434 726  94  21   +   +   +   +
12  :   +   +  63 9821382 345 104   +   +   +   +
11  :   +   +   + 167 532 718 187   +   +   +   +
10  :   +   +   +   +  93 559 351   +   +   +   +
9   :   +   +   +   +   +  31 411  31   +   +   +
8   :   +   +   +   +   +  62 161  15   +   +   +
7   :   +   +   +   +   +   +  41   +   +   +   +
6   :   +   +   +   +   +   +   +  15   +   +   +
      --------------------------------------------

        8   9   1   1   1   1   1   1   1   1   1
                0   1   2   3   4   5   6   7   9


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  JUN
```

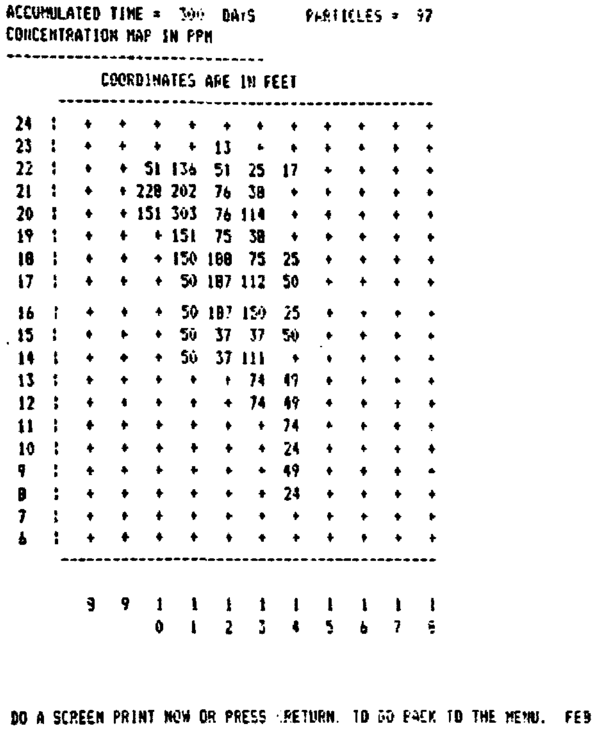
```
ACCUMULATED TIME =  150  DAYS      PARTICLES =  309
CONCENTRATION MAP IN PPM
------------------------------
           COORDINATES ARE IN FEET
      --------------------------------------------
24  :   +   +   +   +   +   +   +   +   +   +   +
23  :   +   +   +   +   +   +   +   +   +   +   +
22  :   +   +   +   +   +   +   +   +   +   +   +
21  :   +   +   +   +   +  34   +   +   +   +   +
20  :   +   +   +  91  34   +   +   +   +   +   +
19  :   +   +  68  91   +   +   +   +   +   +   +
18  :   +   + 204  91  34  34   +   +   +   +   +
17  :   +   +  68 136 169   +   +   +   +   +   +
16  :   +   +  68 541 236  34   +   +   +   +   +
15  :   +   + 1351034 303  34   +   +   +   +   +
14  :   +   + 404 942 738 201   +   +   +   +   +
13  :   +   + 3361341 970 167  22   +   +   +   +
12  :   +   + 134 6241067 865  88   +   +   +   +
11  :   +   +   + 133 532 497 132  33   +   +   +
10  :   +   +   +   +  33 363 132   +   +   +   +
9   :   +   +   +   +  33  99 306  16   +   +   +
8   :   +   +   +   +   +   + 153   +   +   +   +
7   :   +   +   +   +   +   +   +  16   +   +   +
6   :   +   +   +   +   +   +   +   +   +   +   +
      --------------------------------------------

        8   9   1   1   1   1   1   1   1   1   1
                0   1   2   3   4   5   6   7   9


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  SEP
```

```
ACCUMULATED TIME =  180  DAYS       PARTICLES =  290
CONCENTRATION MAP IN PPM
-----------------------------
          COORDINATES ARE IN FEET
      -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +   +   +   +   +   +   +   +   +
22 :   +   +  50   +   +   +   +   +   +   +   +
21 :   +   +  74   +   +   +   +   +   +   +   +
20 :   +   +   + 148  37   +   +   +   +   +   +
19 :   +   + 148 147   +   +   +   +   +   +   +
18 :   +   +  73 391 146  37   +   +   +   +   +
17 :   +   + 146 925 146   +  24   +   +   +   +

16 :   +   + 2911065 217 109   +   +   +   +   +
15 :   +   + 1451301 541 144  24   +   +   +   +
14 :   +   + 216 767 574 323  72  18   +   +   +
13 :   +   +   + 382 500 428  71   +   +   +   +
12 :   +   +   + 190 356 462  47  19   +   +   +
11 :   +   +   +  95  71 105 188   +   +   +   +
10 :   +   +   +   +   + 141 211   +   +   +   +
9  :   +   +   +   +   +   + 233   +   +   +   +
8  :   +   +   +   +   +   +  46   +   +   +   +
7  :   +   +   +   +   +   +   +   +   +   +   +
6  :   +   +   +   +   +   +   +   +   +   +   +
      -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  OCT
```

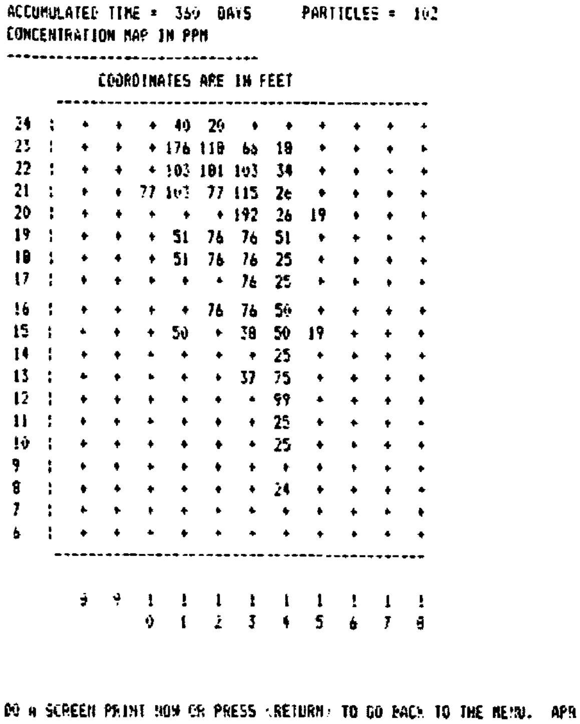
```
ACCUMULATED TIME =  240  DAYS       PARTICLES =  146
CONCENTRATION MAP IN PPM
-----------------------------
          COORDINATES ARE IN FEET
      -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +   +   +   +   +   +   +   +   +
22 :   +   +   +   +   +  25   +   +   +   +   +
21 :   +   +  75 100   +   +   +   +   +   +   +
20 :   +   +   + 149  37   +  25   +   +   +   +
19 :   +   + 149 595 297  37  25   +   +   +   +
18 :   +   + 148 543 195  37   +   +   +   +   +
17 :   +   +   + 148 221  74  49   +   +   +   +

16 :   +   +   + 196 220 110  24   +   +   +   +
15 :   +   +   +  90 256 293  24   +   +   +   +
14 :   +   +   +   + 146  73  73   +   +   +   +
13 :   +   +   +   + 109 291  48   +   +   +   +
12 :   +   +   +   +  72 109  24   +   +   +   +
11 :   +   +   +   +   + 108 144   +   +   +   +
10 :   +   +   +   +   +  36 167   +   +   +   +
9  :   +   +   +   +   +  36  72   +   +   +   +
8  :   +   +   +   +   +   +   +   +   +   +   +
7  :   +   +   +   +   +   +   +   +   +   +   +
6  :   -   +   +   +   +   +   +   +   +   +   +
      -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU. DEC
```

```
ACCUMULATED TIME =  210  DAYS       PARTICLES =  187
CONCENTRATION MAP IN PPM
-----------------------------
          COORDINATES ARE IN FEET
      -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +   +   +   +   +   +   +   +   +
22 :   +   +   +   +   +   +   +   +   +   +   +
21 :   +   +   +  50   +   +   +   +   +   +   +
20 :   +   +   + 298   +   +   +   +   +   +   +
19 :   +   + 149 247 111   +  25   +   +   +   +
18 :   +   +   + 345 184  74   +   +   +   +   +
17 :   +   +  74 343 331   +  24   +   +   +   +

16 :   +   +   + 537 549 183  97   +   +   +   +
15 :   +   +   + 389 291 109  24   +   +   +   +
14 :   +   +   +  97 598 181  40   +   +   +   +
13 :   +   +   +  96 198 253  48   +   +   +   +
12 :   +   +   +   +  72 288  72   +   +   +   +
11 :   +   +   +   +  36 251  72   +   +   +   +
10 :   +   +   +   +   + 143 190   +   +   +   +
9  :   +   +   +   +   +   + 142   +   +   +   +
8  :   +   +   +   +   +   +  71   +   +   +   +
7  :   +   +   +   +   +   +   +   +   +   +   +
6  :   +   +   +   +   +   +   +   +   +   +   +
      -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN  TO GO BACK TO THE MENU.  NOV
```

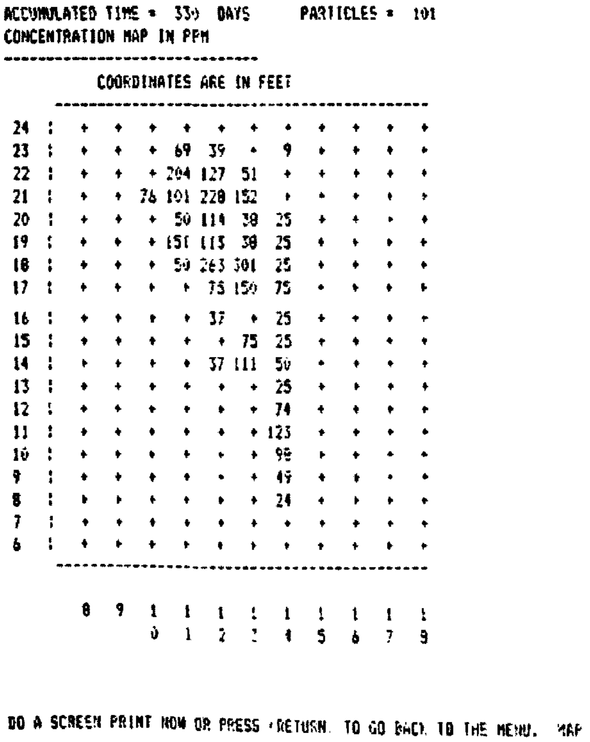
```
ACCUMULATED TIME =  270  DAYS       PARTICLES =  112
CONCENTRATION MAP IN PPM
-----------------------------
          COORDINATES ARE IN FEET
      -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +   +   +   +   +   +   +   +   +
22 :   +   +   +  68   +  25   +   +   +   +   +
21 :   +   +  76 252  76   +  25   +   +   +   +
20 :   +   +   + 151  28  38   +   +   +   +   +
19 :   +   + 150  50  75  75  25   +   +   +   +
18 :   +   +  75 200 299  75  25   +   +   +   +
17 :   +   +  75 147 298 112   +   +   +   +   +

16 :   +   +   +  99 112  74   +   +   +   +   +
15 :   +   +   +  49 111 185  74   +   +   +   +
14 :   +   +   +   +  74 111  74   +   +   +   +
13 :   +   +   +   + 110  37 147   +   +   +   +
12 :   +   +   +   +   +  72  73   +   +   +   +
11 :   +   +   +   +  37  37  73   +   +   +   +
10 :   +   +   +   +   +   + 121   +   +   +   +
9  :   +   +   +   +   +   +  72  18   +   +   +
8  :   +   +   +   +   +   +   +   +   +   +   +
7  :   +   +   +   +   +   +   +   +   +   +   +
6  :   +   +   +   +   +   +   +   +   +   +   +
      -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN  TO GO BACK TO THE MENU. JAN
```



```
ACCUMULATED TIME =  300  DAYS      PARTICLES =  97
CONCENTRATION MAP IN PPM
-----------------------------

            COORDINATES ARE IN FEET
        -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +   +  13   +   +   +   +   +   +
22 :   +   +  51 136  51  25  17   +   +   +   +
21 :   +   + 228 202  76  38   +   +   +   +   +
20 :   +   + 151 303  76 114   +   +   +   +   +
19 :   +   +   + 151  75  38   +   +   +   +   +
18 :   +   +   + 150 188  75  25   +   +   +   +
17 :   +   +   +  50 187 112  50   +   +   +   +

16 :   +   +   +  50 187 150  25   +   +   +   +
15 :   +   +   +  50  37  37  50   +   +   +   +
14 :   +   +   +  50  37 111   +   +   +   +   +
13 :   +   +   +   +   +  74  49   +   +   +   +
12 :   +   +   +   +   +  74  49   +   +   +   +
11 :   +   +   +   +   +   +  74   +   +   +   +
10 :   +   +   +   +   +   +  24   +   +   +   +
 9 :   +   +   +   +   +   +  49   +   +   +   +
 8 :   +   +   +   +   +   +  24   +   +   +   +
 7 :   +   +   +   +   +   +   +   +   +   +   +
 6 :   +   +   +   +   +   +   +   +   +   +   +
        -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  FEB
```



```
ACCUMULATED TIME =  360  DAYS      PARTICLES =  102
CONCENTRATION MAP IN PPM
-----------------------------

            COORDINATES ARE IN FEET
        -------------------------------------------
24 :   +   +   +  40  29   +   +   +   +   +   +
23 :   +   +   + 176 118  66  18   +   +   +   +
22 :   +   +   + 103 101 103  34   +   +   +   +
21 :   +   +  77 103  77 115  26   +   +   +   +
20 :   +   +   +   +   + 192  26  19   +   +   +
19 :   +   +   +  51  76  76  51   +   +   +   +
18 :   +   +   +  51  76  76  25   +   +   +   +
17 :   +   +   +   +   +  76  25   +   +   +   +

16 :   +   +   +   +  76  76  50   +   +   +   +
15 :   +   +   +  50   +  38  50  19   +   +   +
14 :   +   +   +   +   +   +  25   +   +   +   +
13 :   +   +   +   +   +  37  75   +   +   +   +
12 :   +   +   +   +   +   +  99   +   +   +   +
11 :   +   +   +   +   +   +  25   +   +   +   +
10 :   +   +   +   +   +   +  25   +   +   +   +
 9 :   +   +   +   +   +   +   +   +   +   +   +
 8 :   +   +   +   +   +   +  24   +   +   +   +
 7 :   +   +   +   +   +   +   +   +   +   +   +
 6 :   +   +   +   +   +   +   +   +   +   +   +
        -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  APR
```



```
ACCUMULATED TIME =  330  DAYS      PARTICLES =  101
CONCENTRATION MAP IN PPM
-----------------------------

            COORDINATES ARE IN FEET
        -------------------------------------------
24 :   +   +   +   +   +   +   +   +   +   +   +
23 :   +   +   +  69  39   +   9   +   +   +   +
22 :   +   +   + 204 127  51   +   +   +   +   +
21 :   +   +  76 101 228 152   +   +   +   +   +
20 :   +   +   +  50 114  38  25   +   +   +   +
19 :   +   +   + 151 113  38  25   +   +   +   +
18 :   +   +   +  50 263 301  25   +   +   +   +
17 :   +   +   +   +  75 150  75   +   +   +   +

16 :   +   +   +   +  37   +  25   +   +   +   +
15 :   +   +   +   +   +  75  25   +   +   +   +
14 :   +   +   +   +  37 111  50   +   +   +   +
13 :   +   +   +   +   +   +  25   +   +   +   +
12 :   +   +   +   +   +   +  74   +   +   +   +
11 :   +   +   +   +   +   + 123   +   +   +   +
10 :   +   +   +   +   +   +  99   +   +   +   +
 9 :   +   +   +   +   +   +  49   +   +   +   +
 8 :   +   +   +   +   +   +  24   +   +   +   +
 7 :   +   +   +   +   +   +   +   +   +   +   +
 6 :   +   +   +   +   +   +   +   +   +   +   +
        -------------------------------------------

       8   9   1   1   1   1   1   1   1   1   1
               0   1   2   3   4   5   6   7   8


DO A SCREEN PRINT NOW OR PRESS <RETURN> TO GO BACK TO THE MENU.  MAR
```

ACT. VS. SIM. Cl CONC. IN ppm WITH RANDOM-WALK*
(EMPTY COLUMN SPACES REPRESENT NO DATA COLLECTION)

| LOC. | MAY | | JUNE | | JULY | |
|---|---|---|---|---|---|---|
| | ACT. | SIM. | ACT. | SIM. | ACT. | SIM. |
| MW3 | 1144 | 1124 | 391 | 411 | 2640 | 2078 |
| MW4 | 638 | 560 | 660 | 344 | 1040 | 1160 |
| MW5 | 14 | 41 | 64 | 127 | 100** | 150 |
| MW6 | | 0 | <50 | 15 | 17 | 21 |
| MW7 | 0 | 0 | 30 | 128 | 152 | 200 |
| MW8 | <34 | 0 | <50 | 0 | <36 | 0 |
| MW16 | 200 | 126 | 373 | 255 | | 500 |
| MW17 | <34 | 0 | 0 | 0 | | 65 |
| MW19 | 0 | 0 | 27 | 21 | | 32 |
| MW20 | | 94 | | 411 | | 602 |

| LOC. | AUG. | | SEP. | | OCT. | |
|---|---|---|---|---|---|---|
| | ACT. | SIM. | ACT. | SIM. | ACT. | SIM. |
| MW3 | 2764 | 2370 | | 306 | 201 | 227 |
| MW4 | 1254 | 1201 | | 865 | 658 | 449 |
| MW5 | 225** | 410 | | 275 | 166 | 185 |
| MW6 | <36 | 83 | | 16 | | 23 |
| MW7 | 123 | 188 | | 200 | 204 | 283 |
| MW8 | 16 | 0 | | 0 | | 0 |
| MW16 | | 560 | | 700 | 606 | 475 |
| MW17 | | 63 | | 68 | 99 | 144 |
| MW19 | | 124 | | 34 | 68 | 140 |
| MW20 | | 1056 | | 738 | 626 | 559 |

| LOC. | NOV. | | DEC. | | JAN. | |
|---|---|---|---|---|---|---|
| | ACT. | SIM. | ACT. | SIM. | ACT. | SIM. |
| MW3 | 100** | 140 | | 71 | | 72 |
| MW4 | 400** | 284 | 300** | 108 | 200** | 72 |
| MW5 | 150 | 95 | | 36 | | 36 |
| MW6 | <34 | 24 | | 24 | | 73 |
| MW7 | 150 | 250 | 132 | 195 | 41 | 98 |
| MW8 | | 0 | | 0 | | 0 |
| MW16 | 779 | 96 | | 97 | 683 | 109 |
| MW17 | 122 | 148 | 34 | 149 | | 149 |
| MW19 | 61 | 108 | 21 | 125 | | 100 |
| MW20 | 527 | 503 | 405 | 145 | 405 | 109 |

| LOC. | FEB. | | MAR. | | APR. | |
|---|---|---|---|---|---|---|
| | ACT. | SIM. | ACT. | SIM. | ACT. | SIM. |
| MW3 | 14 | 48 | 40 | 49 | 4 | 24 |
| MW4 | 21 | 73 | 29 | 70 | 8.2 | 25 |
| MW5 | 21 | 24 | | 0 | 110 | 0 |
| MW6 | | 49 | | 25 | 14 | 50 |
| MW7 | 81 | 50 | 77 | 37 | 51 | 50 |
| MW8 | 27(?) | 0 | 30 | 20(?) | 11.4 | 30(?) |
| MW16 | 527 | 49 | 398 | 24 | 248 | 37 |
| MW17 | 91 | 150 | 91 | 50 | 51 | 51 |
| MW19 | 34 | 37 | 29 | 75 | 29 | 38 |
| MW20 | 345 | 49 | 257 | 91 | 200 | 37 |

*ALL VALUES USED IN ACT. COLUMNS ARE ESTIMATED BY SUBTRACTING 20 ppm FROM CONC. AS BACKGROUND AND ANY RESIDUAL Cl CONC.

**ESTIMATES OF Cl CONC. IN SHALLOW NESTED WELLS FROM DEEP NESTED WELL CONC.

# APPENDIX W

# Cl LOAD METHODOLOGY AND CONCENTRATIONS

## METHODOLOGY

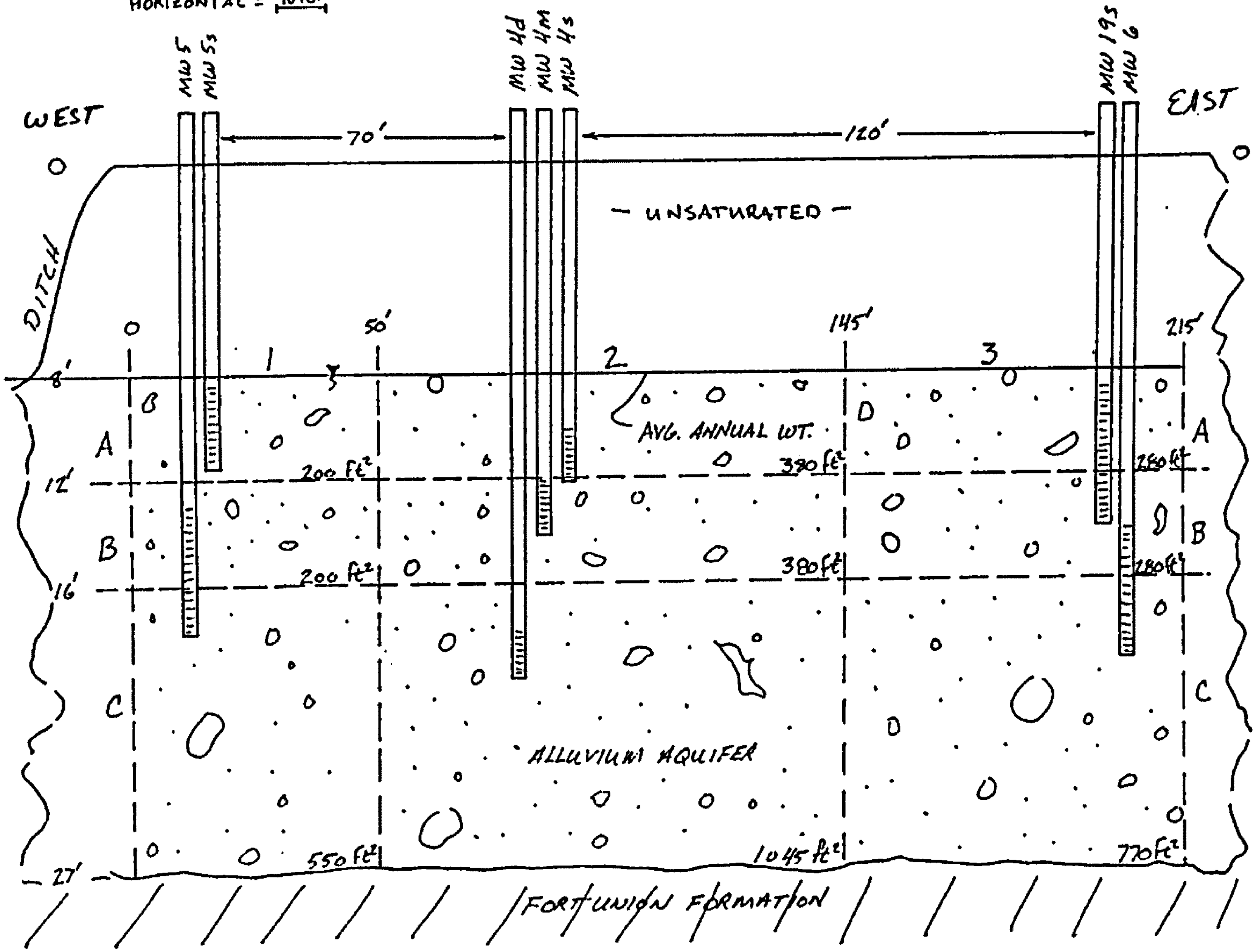
To calculate Cl loading from the reserve pit, I separated each well site with nine discrete blocks of aquifer as shown in Exhibit 12. I used data from well nests MW 4 and MW 5 to stratigraphically separate layering of Cl concentrations. Well MW 6 and MW 19s were assumed to be located at the same place for deep and shallow Cl concentration data.

I calculated loading as follows:

1. (AREA OF EACH ZONE) x (.25 POROSITY) = AREA OF WATER ($ft^2$)
2. (AREA OF WATER) x (MONTHLY VELOCITY) = MONTHLY WATER VOLUME PER ZONE ($ft^3$)
3. CONVERT $ft^3$ INTO LITERS
4. (MONTHLY WATER VOLUME PER ZONE) x (MONTHLY Cl mg/l) = MONTHLY Cl LOAD (mg Cl)
5. (ADD EACH BLOCK OF Cl LOAD PER MONTH) = TOTAL MONTHLY Cl LOAD (mg Cl)
6. (ADD EACH TOTAL MONTHLY Cl LOAD) = TOTAL YEARLY Cl LOAD (mg CL)
7. SUBTRACT BACKGROUND Cl LEVELS OF 20 mg/l FROM TOTAL
8. CONVERT mg OF Cl LOAD PER YEAR INTO kg AND lbs OF Cl

# CHLORIDE LOAD CROSS SECTION

SCALE : VERTICAL = 1 ft.
HORIZONTAL = 10 ft.



CROSS SECTION DATA

| BLOCK SITE | WELL DATA CHEMISTRY | BLOCK AREA ($ft^2$) |
|---|---|---|
| A1 | MW 5s | 200 |
| A2 | MW 4s | 380 |
| A2 | MW 19s | 280 |
| B1 | MW 5 | 200 |
| B2 | MW 4m | 380 |
| B3 | MW 6 | 280 |
| C1 | MW 5/BACKGROUND | 550 |
| C2 | MW 4d | 1045 |
| C3 | MW 6/BACKGROUND | 770 |

GROUND WATER VELOCITY DATA

| MONTH | VELOCITY (ft/day) |
|---|---|
| JUL | 5.6 |
| AUG | 5.3 |
| SEP | 4.7 |
| OCT | 4.5 |
| NOV | 3.2 |
| DEC | 2.9 |
| JAN | 2.9 |
| FEB | 2.8 |
| MAR | 2.6 |
| APR | 2.4 |
| MAY | 5.6 |
| JUN | 5.9 |

Cl CONCENTRATIONS (* = ESTIMATED)

| BLOCK | JUL | AUG | SEP | OCT |
|---|---|---|---|---|
| A1 | 225* | 300* | 250* | 186 |
| A2 | 1060 | 1270 | 1000* | 678 |
| A3 | 120* | 100* | 95* | 88 |
| B1 | 30 | 52 | 45* | 40* |
| B2 | 650 | 895 | 400* | 88 |
| B3 | 37 | 30 | 28* | 24* |
| C1 | 20 | 30 | 28* | 25* |
| C2 | 106 | 36 | 36* | 35* |
| C3 | 30 | 25 | 20* | 20* |

CONT. Cl CONCENTRATIONS

| BLOCK | NOV | DEC | JAN | FEB |
|---|---|---|---|---|
| A1 | 170 | 150* | 140* | 120* |
| A2 | 400* | 300* | 200* | 100* |
| A3 | 81 | 41 | 40* | 54* |
| B1 | 34 | 30* | 35* | 41 |
| B2 | 61 | 47 | 41 | 41 |
| B3 | 22 | 20* | 21* | 21* |
| C1 | 24 | 22 | 20* | 20* |
| C2 | 34 | 30* | 30* | 30* |
| C3 | 20 | 20* | 20* | 20* |

| BLOCK | MAR | APR | MAY | JUN |
|---|---|---|---|---|
| A1 | 100* | 130 | 34 | 84 |
| A2 | 100* | 80* | 658 | 890 |
| A3 | 54 | 50 | 47 | 56 |
| B1 | 50 | 60 | 50* | 45 |
| B2 | 49 | 28 | 30* | 40* |
| B3 | 25* | 34* | 30* | 40* |
| C1 | 22* | 25 | 25* | 30* |
| C2 | 30* | 25 | 25* | 35* |
| C3 | 21* | 22* | 25* | 28* |