THE UNIVERSITY OF ALBERTA

POTENTIAL IMPACT OF SUBSURFACE IRRIGATION RETURN FLOW ON A PORTION OF THE MILK RIVER AND MILK RIVER AQUIFER IN SOUTHERN ALBERTA

by

© Craig Robertson

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4401 University Drive
Lethbridge, Alberta, Canada
T1K 3M4
403-329-2213

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Supervisor

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ABSTRACT

The Milk River Aquifer is the only major artesian aquifer for domestic and municipal water supply in southern Alberta while the Milk River is a major international river. Irrigation has been proposed for a portion of the Milk River basin. This has raised the need to determine the potential impact of subsurface irrigation return flow on the aquifer and the river.

The lower members of the Milk River Formation, which form the main units of the Milk River Aquifer, subcrop over the majority of the area. The Colorado Group underlays the entire area and forms the lower aquitard to the flow system. The water table is contained primarily within the aquifer. Recharge is occurring toward the south with flow downward through the surficial deposits into the aquifer. Flow is then northward with discharge into the Milk River.

Groundwater within the recharge area is high in Total Dissolved Solids (TDS) while the major ions are Calcium and Sulphate. The stable isotopes of ^{18}O and ^{2}H are depleted. Within the discharge area, TDS are low, the major ions are Sodium and Bicarbonate and the stable isotopes are enriched. It would appear that an older, possibly pre-glacial groundwater is being replaced by a younger post glacial recharge water.

Results of irrigation simulation indicate that the water table will reach a quasi-steady state condition after approximately 400 years. Discharge of subsurface irrigation return flow to the river is not expected to have a major impact on the river quality nor will irrigation have a major impact on the Milk River Aquifer to the north.

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CROP[a]	CONSUMPTIVE[a] USE (mm)	THRESHOLD[b] EC (dS/m)	$LR = \frac{ECiw}{ECdw}$ [c] LR(%)	LR(mm)
ALFALFA	648	2.0	9	36
GRASS	599	7.5	2	7
SUGAR BEETS	546	7.0	2	6
POTATOES	505	1.7	9	23
SOFT WHEAT	493	6.0	3	7
HARD WHEAT	462	6.0	2	4
BARLEY	409	8.0	2	3
FLAX	386	1.7	7	10
CANNING CORN	365	1.7	7	10
FIELD CORN	373	1.8	7	9
TOMATOES	366	2.5	5	6
CANNING PEAS	340	2.5	4	4
$\bar{X}$	459	4.0	5	10
S	100	2.6	3	10

a - from Sonmor (1963)
b - from Bresler et al (1982)
c - from USDA (1954)
LR - Leaching requirement
ECiw - EC of irrigation water plus precipitation
ECdw - EC of soil extract at threshold of crop salt tolerance

Table 5. Calculated leaching requirements

LR(mm) of 3 mm. The mean LR(mm) value is 10 mm. It is unlikely that alfalfa or barley would be planted over the entire irrigated area. A more likely case would be an even distribution of all or some of the crops resulting in a LR(mm) value close to the mean (10 mm).

Pump irrigation systems, either centre pivot or wheel move, will be used to irrigate the land in the study area. These systems allow for good control of the water applied. The centre pivot has proven to be popular in most areas in southern Alberta. As farmers are more likely to under irrigate (Pohjakas, 1984) than over irrigate the LR(mm) value of 10 mm will likely represent a maximum recharge value.

Modelling of Subsurface Return Flow

The impact of subsurface irrigation return flow on the aquifer and the river from a portion of the proposed irrigated area (Figure 21) was evaluated with the help of the simulation model. The area was selected because it represented the largest portion of the study area which was not bisected by natural drainage courses and is representative of the areas proposed for irrigation.

The simulation of the irrigation problem involved transient simulations with the groundwater flow model used previously. This smaller study area was discretized with a grid consisting of 17 columns, 12 rows and 3 layers. The grid blocks are squares, 500 m on a side. Layer 1 of the grid coincides with the Deadhorse Coulee Member plus the till, layer 2 with the Vergille Member and layer 3 with the Telegraph Creek Member. The uppermost part of the Colorado Group was considered to be the lower boundary to flow. The grid was oriented approximately north - south. The east and west boundaries of the irrigated area were established parallel to the groundwater flow

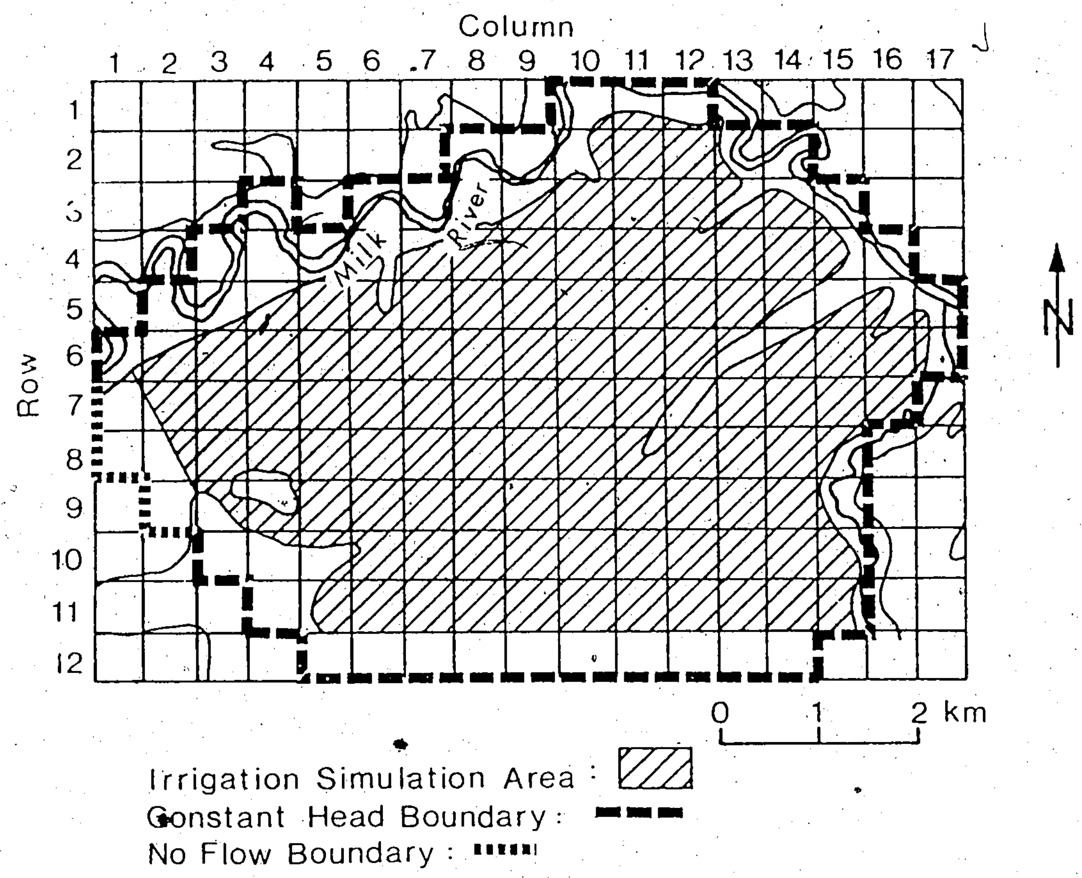


Figure 21. Map showing the area used for the simulation of irrigation and the superimposed grid and boundary conditions used for simulation

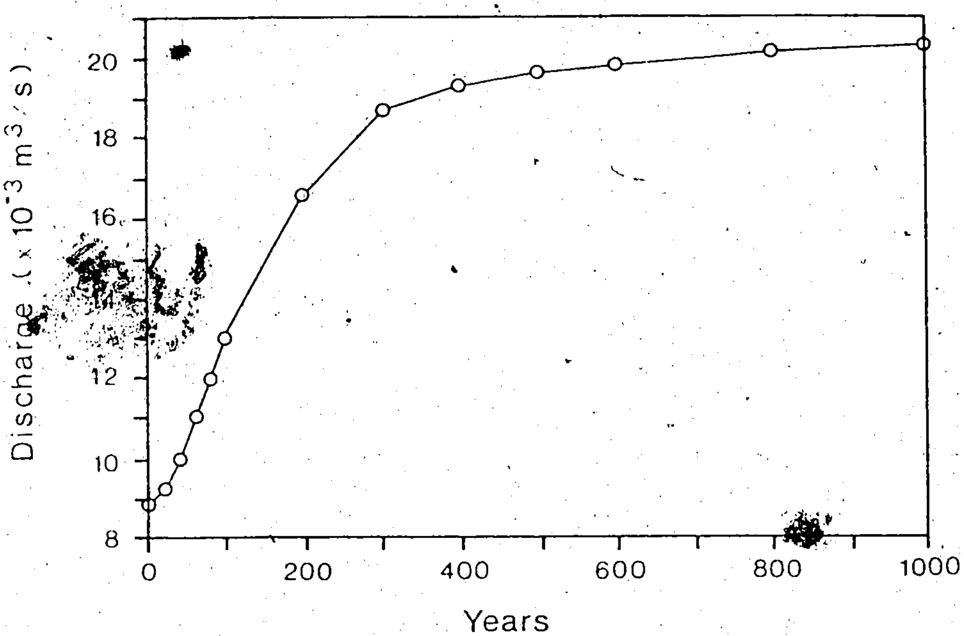
direction. Because no flow lines cross these boundaries under steady state conditions and irrigation will take place on either side, conditions will remain constant and as such these boundaries are set as no flow boundaries. The river, along the north boundary was represented with constant head nodes using the "river package" from the model. The south boundary was established far enough south of the irrigation area as not to be affected by recharge from irrigation and was assigned constant head values from the steady-state simulation. A storativity for the aquifer of 3.5×10^{-4}, which is the mean value for the Milk River aquifer calculated by Meyboom (1960), was used in all runs.

The amount of irrigation recharge applied to each grid was calculated using information from the study by Osborne (1980). Each grid, which contained an area completely classified for irrigation, was given a value of 1. For grids, which contained an area classified as nonirrigable, this number was subsequently reduced by the percentage of land thus classed. These values were then multiplied by LR(mm).

The results from the transient simulations provided data necessary to calculate the increased contribution of groundwater along the entire reach of the Milk River within the study area. Assuming a mixed crop type and a recharge rate from irrigation of 10 mm/yr, the mean rise in the water table after 1000 years would be 9.7 m (s=5.2). Discharge to the river would increase from 9.0×10^{-3} to 2.0×10^{-2} m^3/s. Discharge to the river reaches a quasi steady-state condition after approximately 400 years (Figure 22a).

During the summer months, the flow in the river usually exceeds 16 m^3/s. The increased groundwater discharge during this season is calculated to contribute less that 0.1% of river flow. During the winter

Groundwater Discharge to Milk River



Increase in River Discharge at Minimum Flow

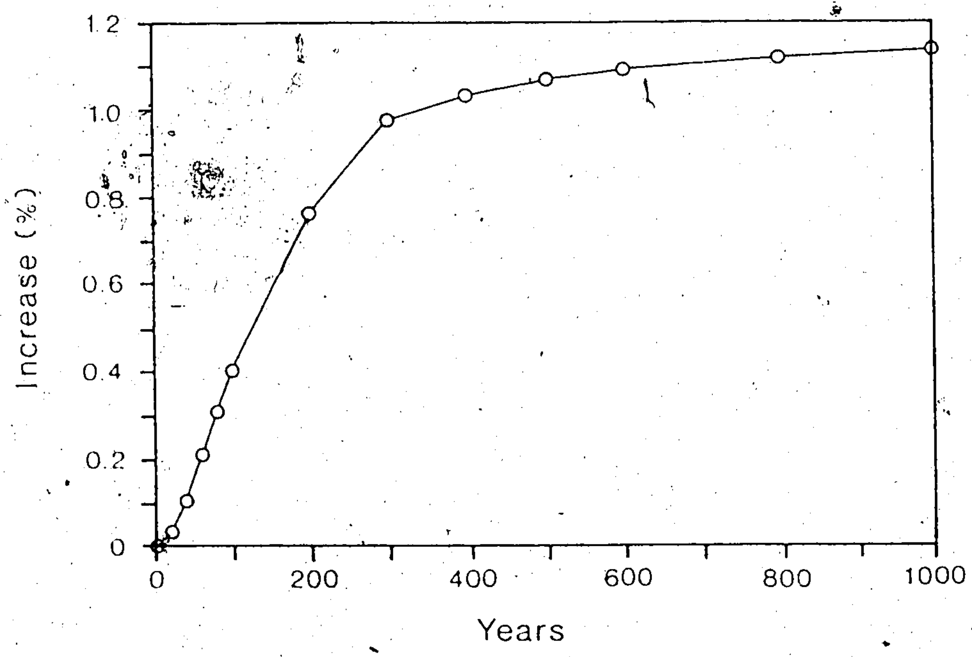


Figure 22. Plots showing the amount of groundwater discharge to the Milk River and the percent increase in river discharge at minimum flow as a result of irrigation return flow with time

months, flow drops to as low as 1 m^3/s with the simulated increased river flow, due to the groundwater contribution, rising to 1.1% (Figure 22b).

Of the 3050 hectares within the irrigated area, waterlogging of the soil could occur on approximately 180 hectares or 6% of the area. The water table is not expected to reach the ground surface during the first 400 years.

Perched water-tables exist in areas where indurated sandstone beds immediately underlay the till. A study of the drill logs indicate that these indurated beds do not underlie the till in the simulation area. Therefore, perched conditions are unlikely to occur due to the proposed irrigation expansion. This is not to say that these conditions may not occur at other sites. If irrigation is to be expanded to the south where perched conditions are known to occur, it would be advisable to study the area in further detail.

Water Quality Impacts

To evaluate the impact of subsurface irrigation return flow on the geochemistry of the Milk River aquifer and any subsequent discharge to the river, it was assumed that any recharge water entering the aquifer would first pass through the till deposits. As a result the water would develop a chemistry similar to that of recharge waters in other parts of the study area that are recharging through the till. These areas can be approximated by the chemistry in the aquifer at sites 345-C and 5075-M. The current chemistry of the groundwater, in the irrigated area, can be represented by that at sites 343-C and 342-C. The process of chemical evolution would proceed from one of mixing of irrigation return flow with formation water to one of eventual replacement by return flow.

The use of equation (3) would allow the travel times from the irrigated areas to the river to be estimated. The value of i (gradient) was adjusted to represent an increase in the water level with time for a recharge rate of 10 mm/yr. In this way the changes to the chemistry of the aquifer and the time frame required could be estimated. Using the centre of the area as the centre of the return flow plume, the travel time from the irrigated area to the river would be greater than 1000 years.

With the current discharge to the river and a chemistry similar to that of 342-C, the total discharge of salts to the river is 1.14×10^4 mg/s. With a recharge rate from irrigation of 10 mm/yr and a change to the chemistry similar to 345-C, after complete flushing of the aquifer the total discharge of salts to the river will be 1.38×10^5 mg/s. During minimum river flow, the increase salt loading will represent an increase in river TDS of approximately 140 mg/l.

River TDS values increase from 100 to 600 mg/l in winter. The increased salt loading as a result of proposed irrigation could result in river TDS values of 740 mg/l for minimum river flow. Because a recharge rate of 10 mm/yr is estimated to represent a worst case scenario it is unlikely that these conditions will be reached even after 1000 years.

CONCLUSIONS

Recharge is occurring at the southern end of the study area. The primary areas of recharge are along the flanks of the valleys where the Deadhorse Coulee member has been eroded and south of the international boundary where a small dendritic valley funnels water into deposits along the floor of Clarinda Creek. Recharge occurs through the till deposits and continues downward into the aquifer. Groundwater flow in the Milk River aquifer is to the north and northwest. Groundwater eventually discharges into the Milk River. Current groundwater discharge from the study area to the river is calculated to be approximately 9.0×10^{-3} m^3/s (1% of minimum river flow).

The water table for the majority of the area is found in the bedrock units. Within the Deadhorse Coulee member and till deposits, water tables are perched. Due to the vadose zone above the water table, the areas of perched water table are not estimated to be contributing a significant quantity of inflow to the Milk River aquifer.

Geochemical and isotopic patterns within the aquifer indicate that there are two separate water bodies. The water at the south end of the study area is the result of recent recharge through the glacial deposits and as such reflects a chemistry that is related to the unique chemical processes operating within these deposits. The total dissolved solids content in water from these units is considerably higher for all ions than the older water to the north. The calculated age of the groundwater at the north end of the study area would indicate that it may have entered the flow system prior to the last glacial advance and as such not recharged through the till.

Assuming a mixed crop distribution throughout the irrigated area and irrigation management practises such that the leaching requirements of the crops grown are met but not exceeded, a maximum recharge rate to the groundwater of 10 mm/yr can be expected. Under these conditions the water table will still be located well below the ground surface for the majority of the area after 1000 years. Discharge to the river will reach a quasi steady state after 400 years and will increase minimum river flow by approximately 1.1%. The maximum increase in TDS to the river at minimum flow should be around 140 mg/l. This increase will not occur however until after about 1000 years. Under these conditions the proposed irrigation is expected to have a minor impact on the Milk River or the irrigated area.

The geochemistry of the groundwater, south of the river, will evolve to that of the aquifer at the south end of the study area. Chemistry will shift from Na,HCO_3 toward Ca+Mg,SO_4 while TDS will increase from about 1000 to >5000 mg/l. Irrigation south of the river will have little if any impact on the Milk River aquifer to the north.

Due to the limited scope of this study it is not possible to extend these results to other areas proposed for irrigation in southern Alberta. The primary area of concern was that subcropped by the Milk River Formation. As the study area covers the majority of the Milk River Formation in Alberta the impact of irrigation over other geologic units is not known.

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INTRODUCTION

Concern has been expressed that irrigation along the Milk River in southern Alberta may have adverse effects on the hydrologic and hydrogeologic environment of the region. The area is part of the recharge zone for the Milk River aquifer, the major source of domestic water for a number of communities, farms and ranches in southern Alberta. The Milk River, which is an international river, flows through the area and is used for irrigation and domestic water supplies downstream in the United States. The quality of these resources may be adversely affected by irrigation. Also, irrigation in the region may impact the agricultural community by causing the waterlogging and salinization of soils.

There has been no major detrimental impact from irrigation return flow in southern Alberta to date. Minor effects have resulted from canal seepage and irrigation. These effects have primarily been in the form of waterlogging and salinization of soils. Studies by Sommerfeld and Chang (1980), Chang and Oosterveld (1981) and others have shown that with canal rehabilitation and proper irrigation management techniques the majority of these problems have been overcome. Although no major impact has occurred to other aquifers or river systems in the area, this is the first time that irrigation has been proposed over the recharge zone of a major aquifer system. Studies in the United States have demonstrated adverse impact on the Colorado and other river systems. With the introduction of irrigation in this area the concern has been raised that irrigation return flow may result in the deterioration of the water quality in the Milk River Aquifer and that the irrigation return flow into the Milk River may reduce the river water quality.

Irrigation expansion in the past has been controlled by the application of classification techniques to determine the suitability of the land for irrigation. This system which is outlined in the Alberta Standards for Irrigated Land Classification (1969) was designed to prevent waterlogging and salinization. This system does not however take into consideration irrigation return flow and its potential impact on the groundwater regime or the discharge of subsequent irrigation return flow into adjacent water courses.

The objectives of this study are to determine the hydrogeologic and geochemical character of groundwater in the area and to determine the impact of subsurface irrigation return flow on the Milk River and Milk River Aquifer. The approach followed here will be to first measure the existing conditions within the groundwater regime and use computer simulation to evaluate the impact of irrigation return flow. In this way the simulated impact can be related back to existing conditions and outline the possible impact of irrigation.

PHYSICAL SETTING

The study site is located in southern Alberta and northern Montana approximately 3 km east of the twin communities of Coutts, Alberta and Sweetgrass, Montana and approximately 105 km southeast of Lethbridge, Alberta (Figure 1). It covers an area of approximately 280 km^2 within the Milk River drainage basin.

Climate

According to the Koeppen classification, the climate of southern Alberta is designated as Bwk (Strahler, 1969), a cool temperate zone with long cool summers.

The mean daily temperature, based on records from the community of Milk River (1951-1980), is 5.2°C. The coldest month is January with a mean daily temperature of -10.8°C and the warmest month is July with a mean daily temperature of 18.9°C (Table 1). During the winter Chinooks often produce significant variability in temperature. Temperatures can increase from well below zero to 10 to 15°C in a short time period. These warm temperatures last from a few hours to several days (Fletcher, 1972). As a result of these temperature increases, water stored in the snow pack is frequently lost during winter through sublimation (McKay, 1964) or by melting and subsequent evaporation (Gray, 1968).

The mean annual precipitation is 316 mm. Of the total, approximately 77 mm falls as snow from November to April. Much of the remainder occurs as rainfall from April to June (Table 1). Fall and summer are typically dry with only 63 mm and 42 mm of precipitation occurring during these periods.

As expected in this arid area, evapotranspiration is significantly in

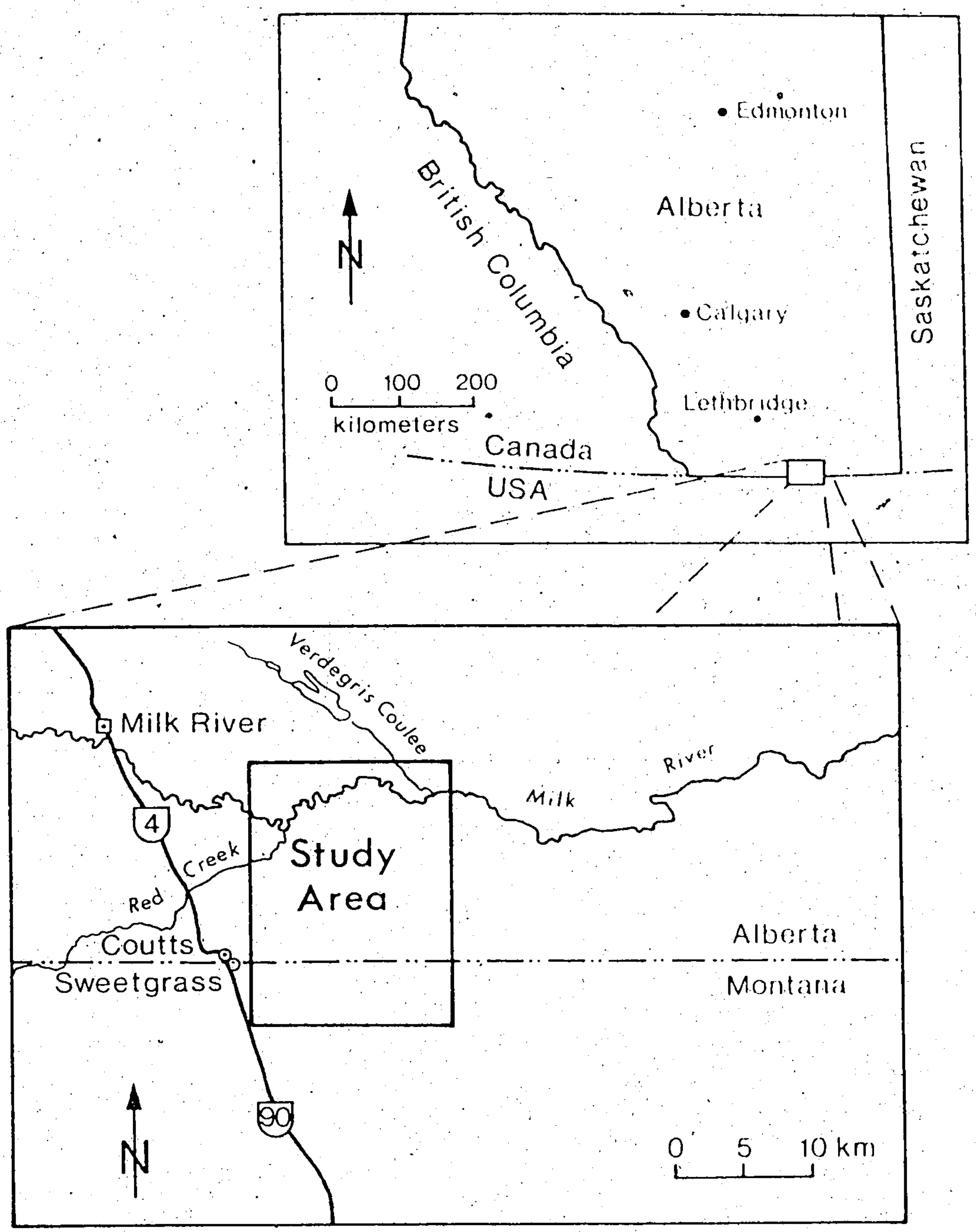


Figure 1. Maps showing the general location of the study area on the Alberta Montana border

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
DAILY MAX TEMP (°C)	-5.5	-0.1	4.1	11.3	17.8	22.1	26.6	25.7	19.9	14.3	4.4	0.9	11.6
DAILY MIN TEMP (°C)	-16.0	-11.0	-7.7	-1.6	4.2	8.7	11.1	10.1	5.0	0.3	-6.6	11.3	1.2
DAILY TEMP (°C)	-10.8	-5.6	-1.8	4.8	11.0	15.4	18.9	17.9	12.5	7.3	-0.9	6.1	5.2
STANDARD DEVEATION, DAILY TEMP (°C)	4.7	4.5	3.2	2.7	1.3	1.8	1.1	2.1	2.8	2.2	3.0	4.1	1.0
EXTREME MAX TEMP (°C)	13.3	18.3	23.3	28.9	31.7	35.6	37.8	41.1	35.6	32.8	22.8	16.1	41.1
EXTREME MIN TEMP (°C)	-37.2	-33.3	-33.3	-20.0	-8.3	0.0	2.2	2.2	-11.1	-18.3	-27.2	-40.6	-40.6
RAINFALL (mm)	0.0	1.0	2.6	18.7	42.6	64.3	28.2	34.7	23.3	8.2	1.6	1.4	226.6
SNOWFALL (mm)	17.8	7.6	9.5	15.8	1.8	0.1	0.0	0.0	1.7	3.6	12.0	14.2	84.1
TOTAL PRECIP (mm)	17.8	8.6	12.2	34.5	44.4	64.5	28.2	34.7	27.6	14.1	13.7	15.4	315.7
STANDARD DEVEATION, TOTAL PRECIP (mm)	15.9	6.6	10.0	24.7	25.6	37.6	24.8	22.6	24.8	8.6	9.5	14.6	123.5

a - from Canada Dept of Environment (1982)

Table 1. Summary of temperature and precipitation data collected at the community of Milk River, Alberta, 1951-1980[a]

excess of precipitation. Shown in Figure 2 is a comparison of the calculated mean monthly potential evaporation with the maximum possible evapotranspiration. The potential evapotranspiration is approximately 560 mm. Looking closely at Figure 2, you will notice that for all months from April to October the potential evapotranspiration is significantly greater than the precipitation.

Topography

The Milk River flows through the northern part of the study area within a narrow, steep sided, valley more than 50 m deep (Figure 3). In the northeast corner of the area, Verdigris Coulee joins the river. This broad, flat-bottomed meltwater channel is about 800 m wide and forms the valley of the Milk River east of the junction.

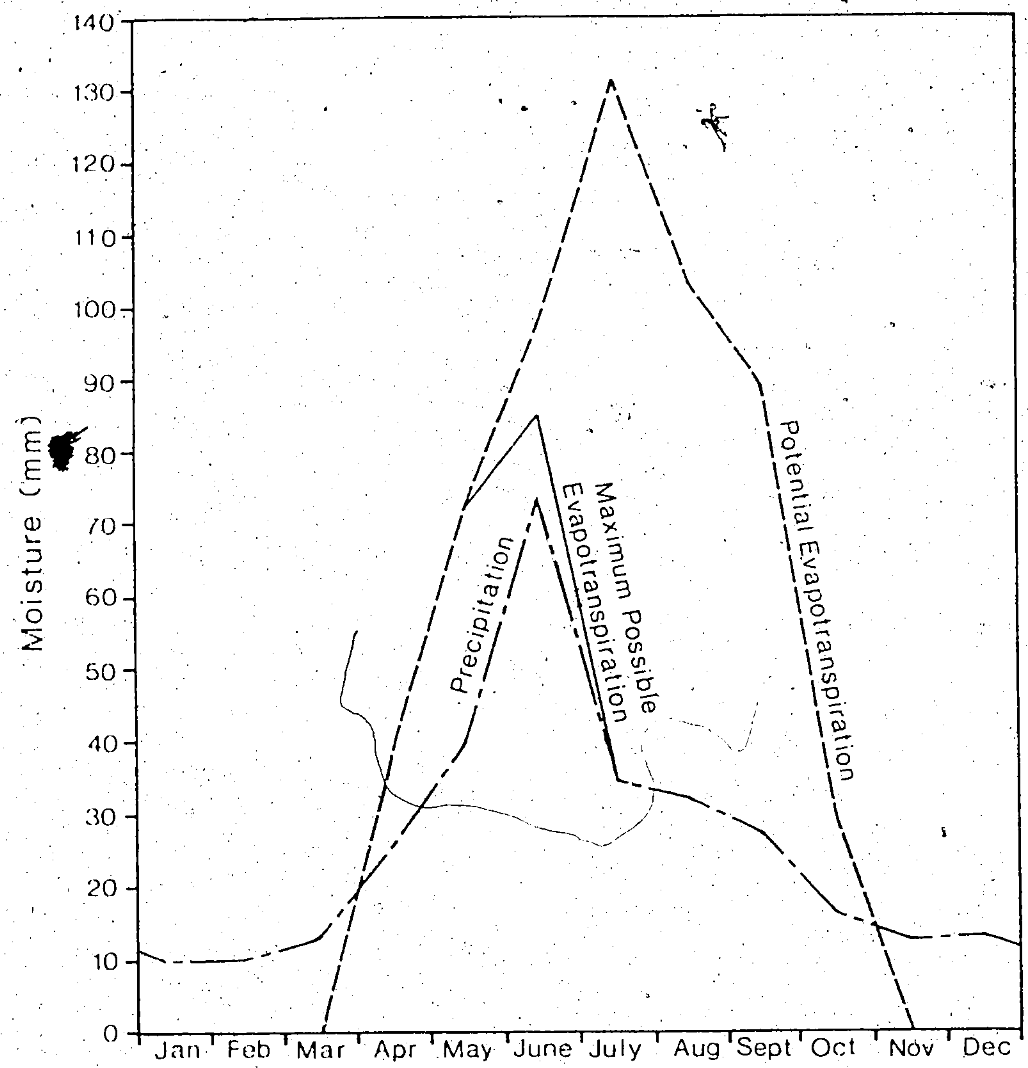
South of the Milk River, the study area contains portions of three drainage basins (Figure 3). Clarinda Creek rises in the southwest corner of the study area in an area of gently rolling topography. It then flows north-northeast and occupies a broad flat valley 2 km wide. The drainage divides parallel the valley and they rise from 20 to 40 m above the valley floor.

West of Clarinda Creek is the Red Creek basin. This basin has gentler slopes than the Clarinda Creek basin. Red Creek has cut a deep steep sided canyon where it flows into the Milk River.

The remaining drainage basin, found in the southeast corner of the area, is part of the Van Cleeve drainage basin that drains into Van Cleeve Coulee to the northeast and eventually into the Milk River.

Soils

The major soil type in the study area is a Brown Chernozem (Kjearsgaard et al., 1984). In the upland areas, the soils have a heavy



(from Fletcher, 1972)

Figure 2. Comparison of potential and maximum possible evapotranspiration calculated from Class A Pan evaporation with the mean monthly precipitation for Lethbridge, Alberta

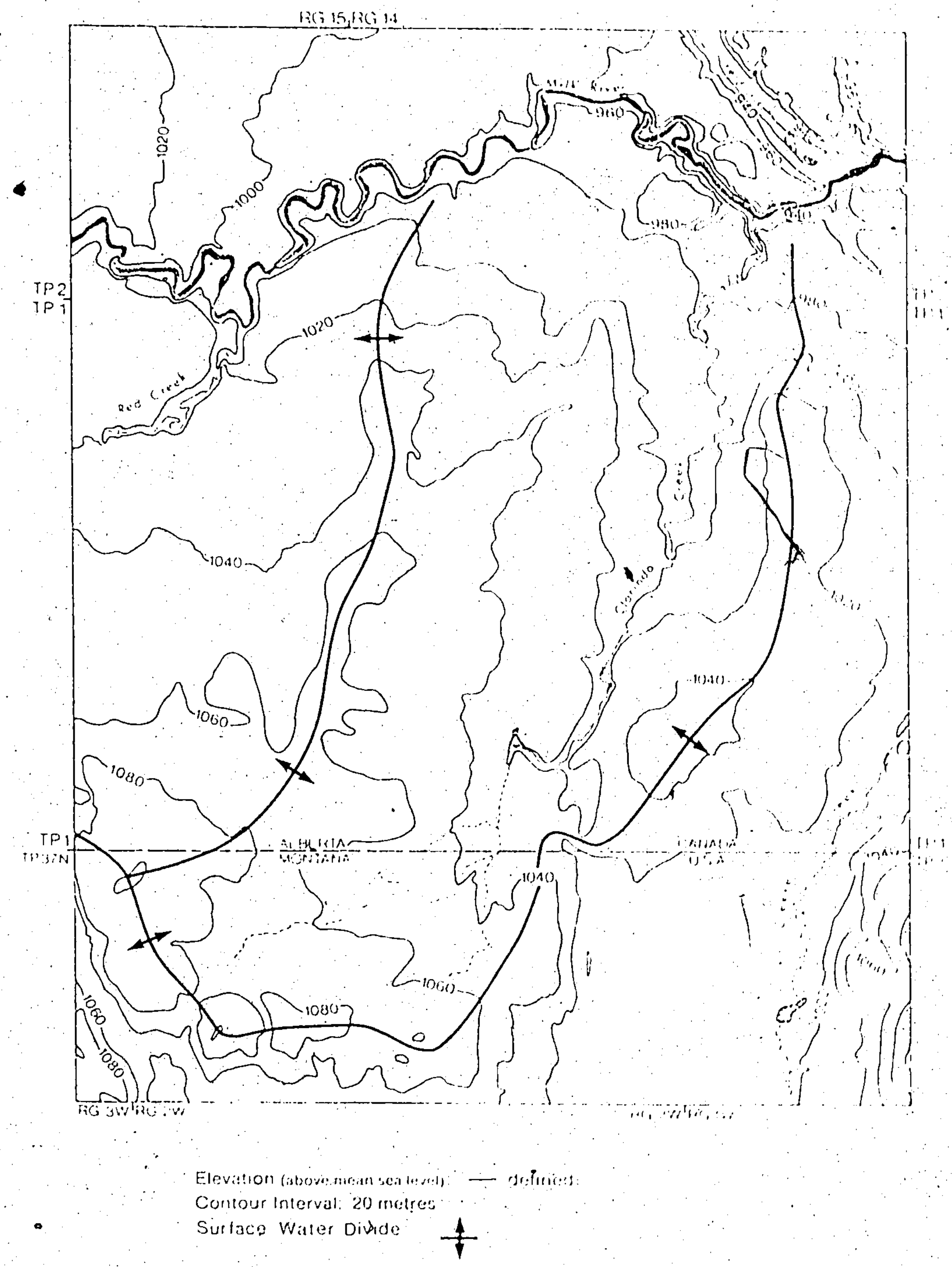


Figure 3. Map showing the surface topography and the location of major surface divides

loam texture and are developed mainly on glacial sediments or resorted glacial sediments. Along the coulees and valleys, the soils are developed mainly on alluvium. The occurrence of a Dark Brown Chernozem in the extreme southeast corner of the site is associated with the foothills of the Sweetgrass hills.

Land Use and Natural Vegetation

The study area lies within the boundaries of the short grass prairie and under natural conditions supports a semiarid prairie flora (Wyatt et al., 1941). The dominant land use is dryland farming with about 80% of the area under cultivation. The primary crops are cereal grains such as wheat, barley and oats. The remaining land is used as pasture for livestock.

Proposed Irrigation

Two studies have been undertaken to determine the irrigation potential of the region. The first was a soil irrigability study by Osborne (1980), and included the portion of the study area in townships 1 and 2, ranges 14 and 15 (Figure 4). Of the approximately 10,000 hectares included in the study, about 7,000 were classified as irrigable. The primary limitation to the irrigability of these areas is steep topography, located along the Milk River valley, Clarinda Creek, Red Creek and Verdigris Coulee. A second soil irrigability study (Karkanis et al., 1983) was less detailed and encompassed the entire study site. This study concurred with Osborne's findings and classified the remainder of the area, with the exception of the land along the bottom of Clarinda and Red Creeks, as irrigable.

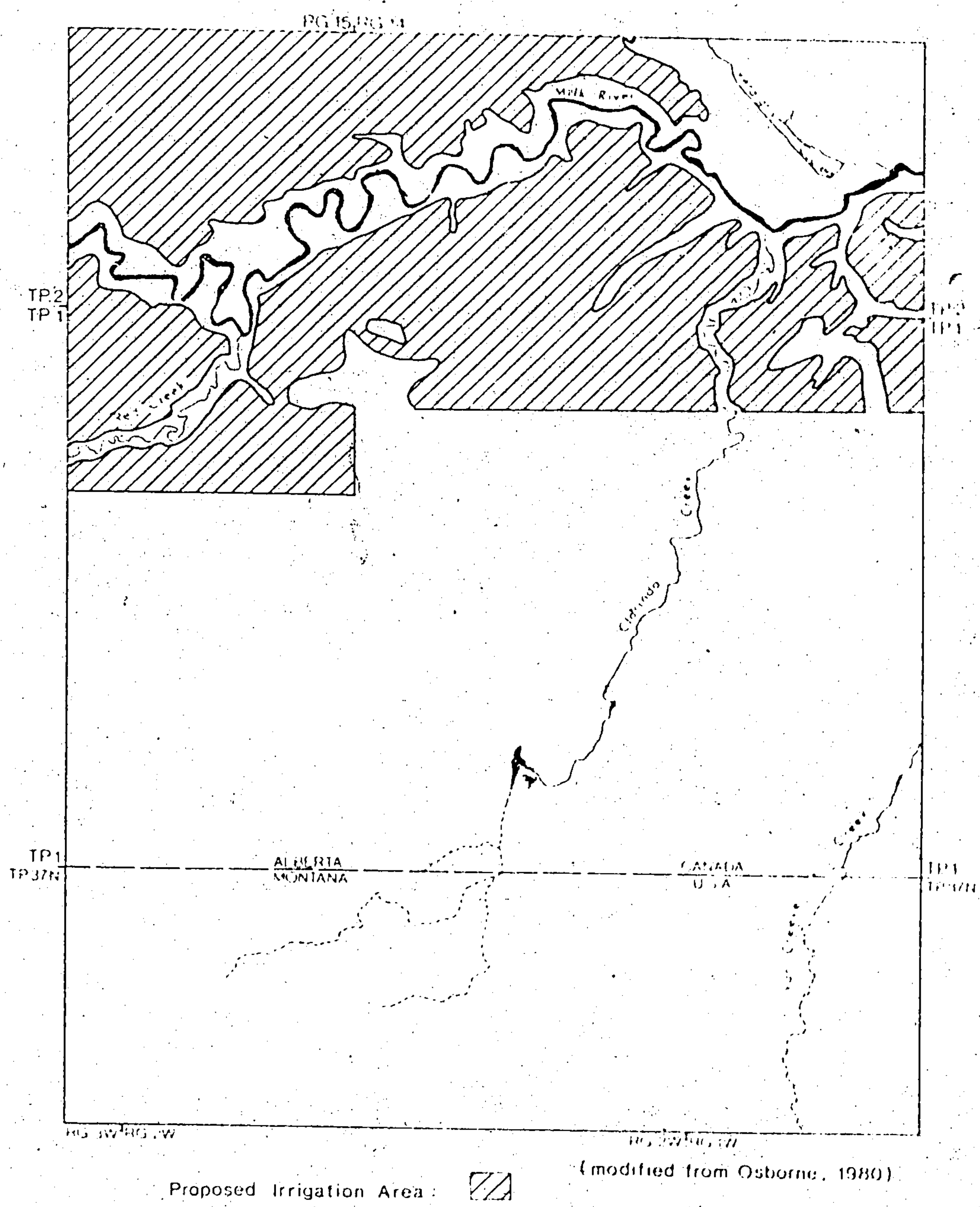


Figure 4. Map showing the area proposed for irrigation

GEOLOGY

The interpretation of geologic conditions is based on published information for the study area and field and laboratory investigations carried out as part of this study. Test holes, ranging in depth from less than 10 to more than 91 m, were drilled and litho-logged at 63 sites (Figure 5). Results of litho-logging are presented in Appendix A. Resistivity and Spontaneous Potential logs were completed at eight test holes to compliment the litho-logging. These results are presented in Appendix B.

Surficial Geology

Almost the entire study area is mantled by till (Figure 6) varying in thickness from 1 to 20 m. The till ranges in colour from yellowish brown to dark greyish brown, and as elsewhere in southern Alberta is indicative of oxic conditions. In a few locations tills are non weathered and grey to dark grey (5117-M) in colour. Texturally the till varies from sandy clay loam to clay loam. Discontinuous lenses of silt and sand occur locally. However, these units are not continuous over the study area. As described by Westgate (1968), the till was deposited during the Wildhorse glacial advance.

The other surficial deposit of significance is a post glacial sand that ranges in texture from sandy clay loam to sand. This deposit is found at the south end of the study area as indicated on Figure 6. Westgate (1968) indicates these materials may be eolian in origin. Colour is usually yellowish to dark brown.

Locally, interglacial sands and gravels underlie the tills. They have a maximum thickness of from 15 to 23 m. These materials were deposited near the end of the earlier Elkwater glacial advance

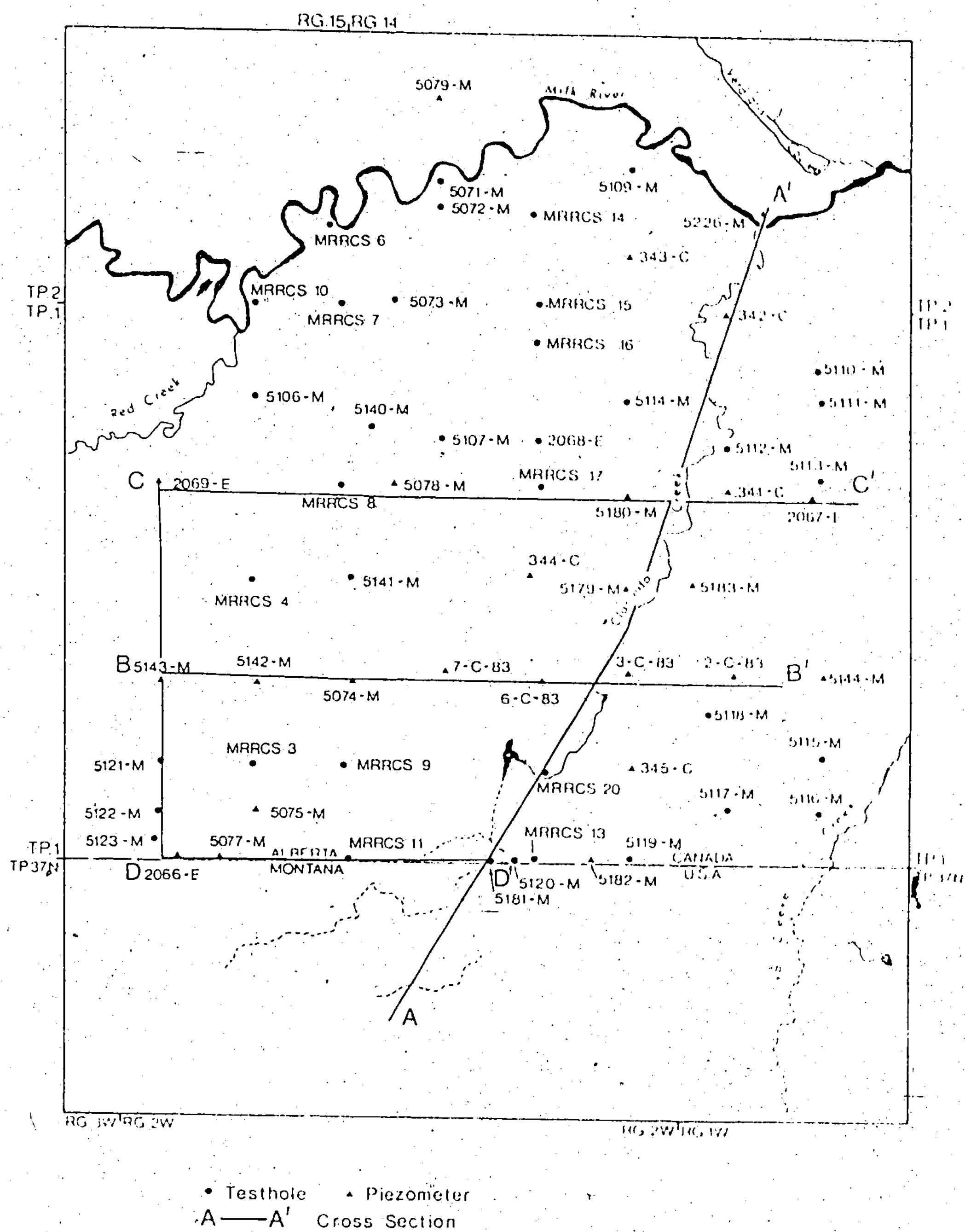
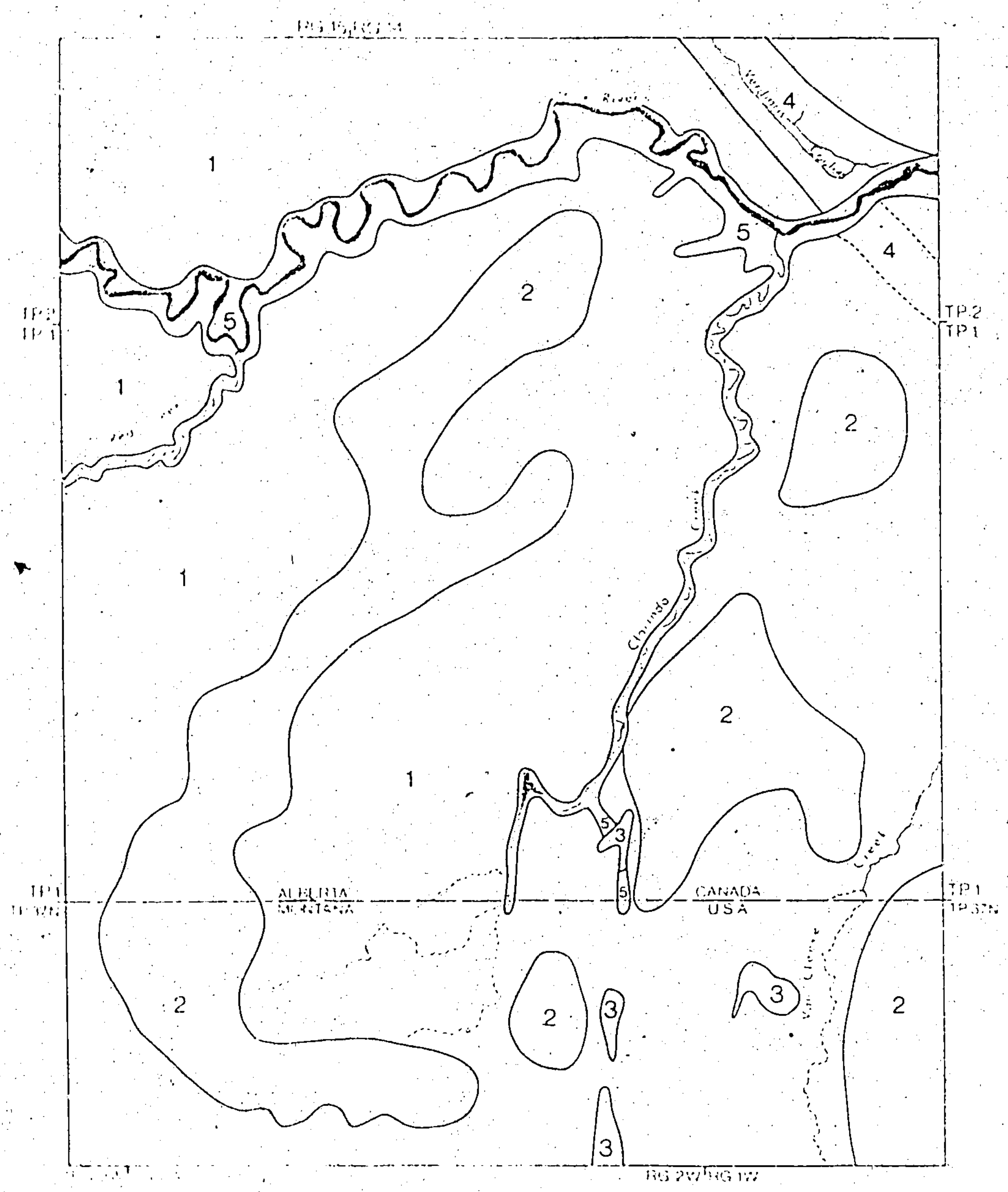


Figure 5. Map showing the location of test holes, piezometers and cross sections used for fence diagrams



(modified from Westgate, 1968)

Geologic Boundary: —— defined ----- assumed

1 Ground Moraine
2 Shallow Ground Moraine (<5m thick)
3 Lacustrine Deposits (recent)
4 Meltwater Channel Deposits
5 Alluvial Deposits (recent)

Figure 6. Map showing surficial geology

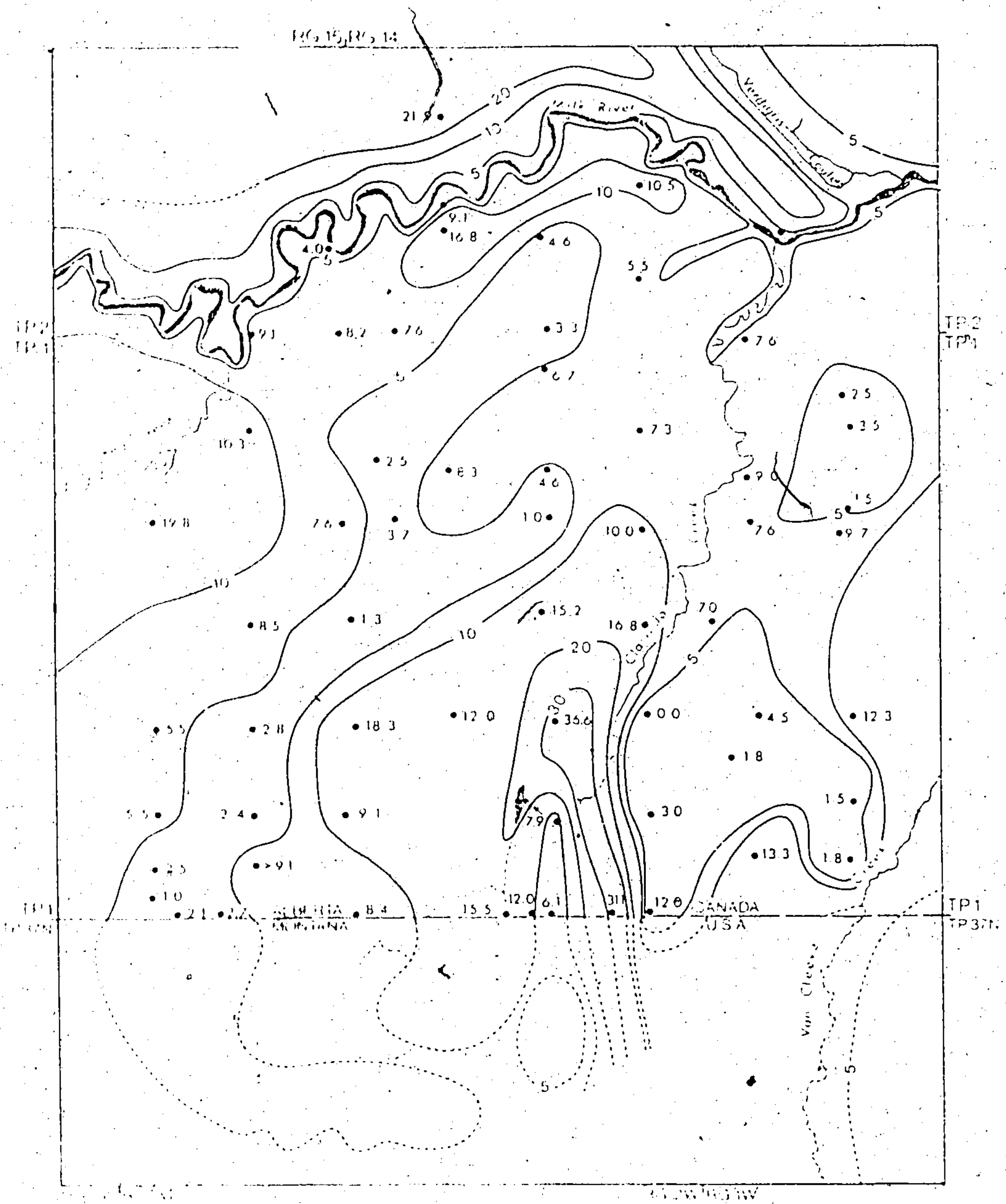
(Westgate, 1968). Gravel deposits were detected at the extreme northern end of the study area and are believed to represent the preglacial deposits in the Whiskey River valley. Modern sands and gravels are found along the valley of the Milk River.

To illustrate the distribution and thickness of the surficial deposits in detail, an isopach map (Figure 7) and fence diagram (Figure 8) have been constructed. From Figure 7, it is apparent that drift is thickest in the south-central part of the area blanketing the Clarinda Channel. Along the drainage divides and in the Milk River valley, the drift is typically less than 5 m thick. From Figure 8, it is apparent that the alluvium is primarily found in the valleys while till blankets the remaining areas.

Bedrock Geology

Three near-surface bedrock units of Cretaceous age are of interest in this study. The youngest is the Pakowki Formation (Kpa), which subcrops in the extreme northwest corner of the area (Figure 9). It consists mainly of interbedded grey and dark grey marine shales with minor sandstone units in the middle of the sequence (Tovell, 1958). The Pakowki Formation is underlain by the Milk River Formation (Kmr) which is divided into the Deadhorse Coulee (Kdc), Vergille (Kv) and Telegraph Creek (Ktc) Members (Meijer-Drees and Myhr, 1981).

The Deadhorse Coulee Member consists of light brownish grey to dark grey silty shale, shale, claystone and sandstone. It contains variously coloured bands of carbonaceous and calcareous material, which are indurated at some locations. This unit has a continental origin, having formed along the shore of the Colorado sea as deltaic and lagoonal deposits. Thicknesses of up to 28 m were encountered during



Isopach —— defined ----- assumed
Contour Interval: 10 metres (5 m isopach included for clarity)
Measured Thickness: • 36.6 (m)

Figure 7. Isopach map of surficial deposits

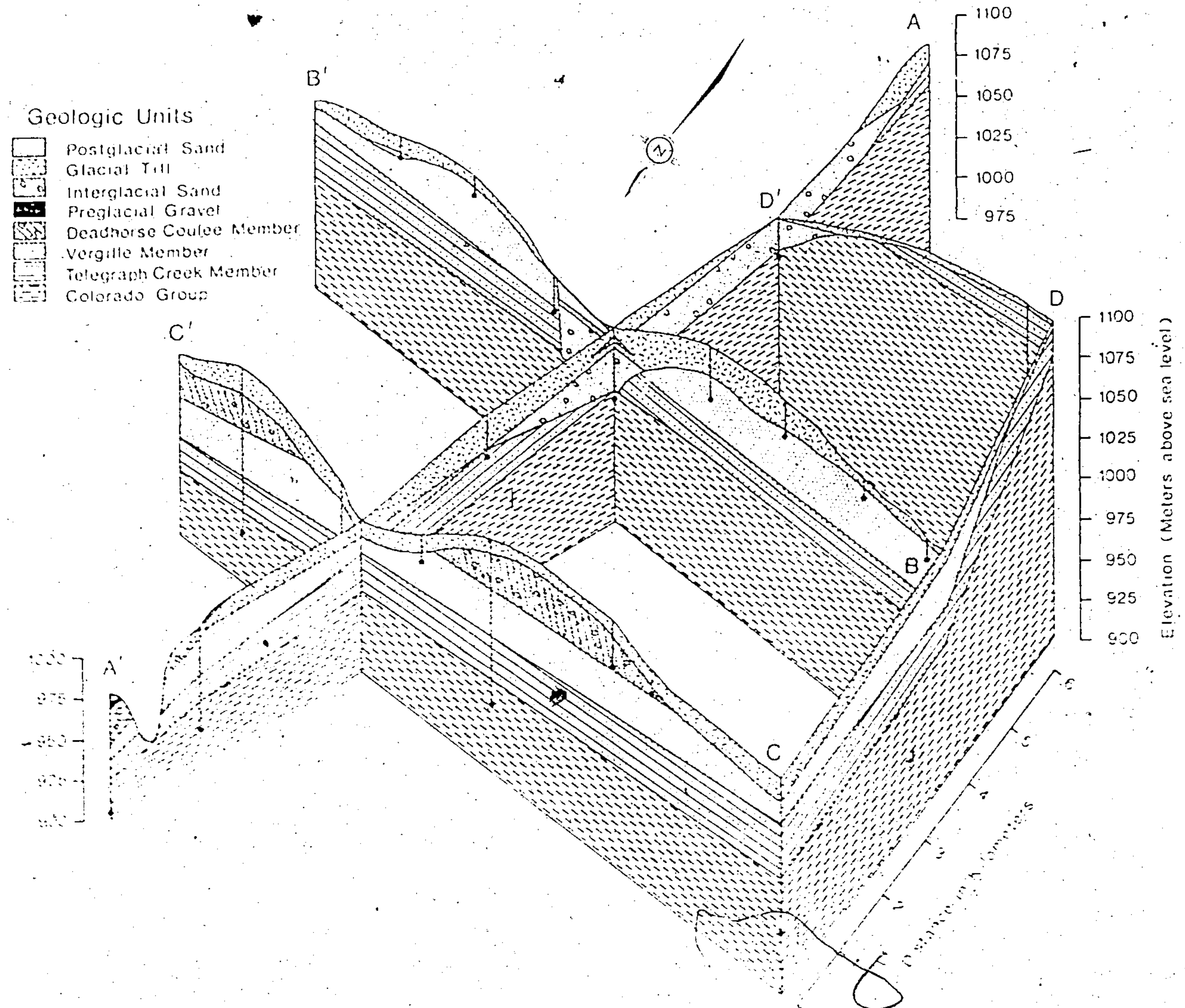
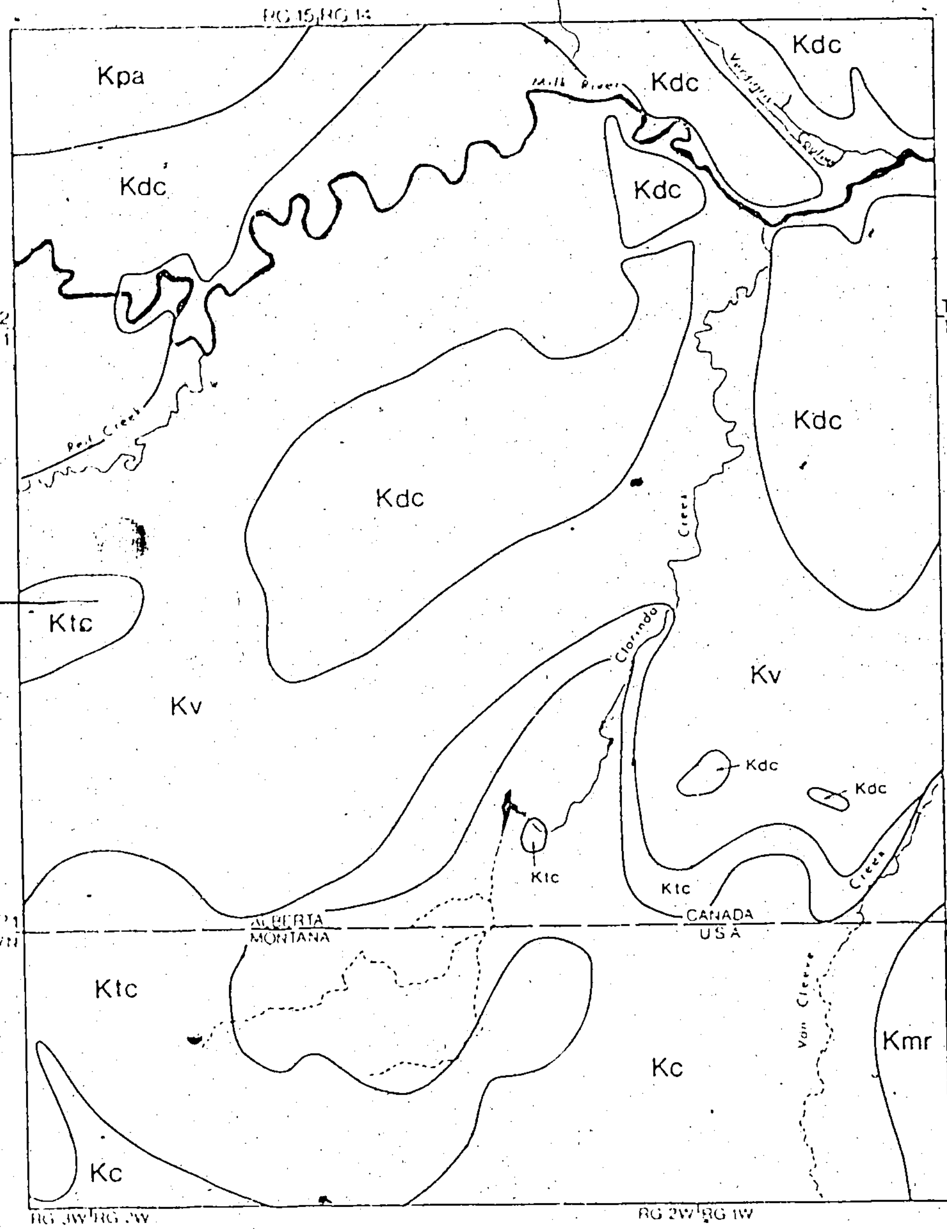


Figure 5. Fence diagram showing the distribution of major drift and bedrock units



(modified from Irish, 1967)

Unit boundary : —— defined

Kpa Pakowki Formation

Kmr Milk River Formation

Kdc Deadhorse Coulee Member

Kv Vergille Member

Ktc Telegraph Creek Member

Kc Colorado Formation

Figure 9. Map of bedrock geology

drilling. The base of this member is usually marked by the last occurrence of a carbonaceous shale layer.

The Vergille Member is mainly a sandstone varying in thickness from 13 to 35 m. It is usually capped by an indurated cross-bedded sandstone layer approximately 1.5 m in thickness. The massive sandstone occurring beneath this bed is soft and yellowish brown. Reddish brown ironstone concretions are common in some locations.

The Vergille Member becomes more argillaceous with depth. The bottom of this unit is marked by an increase in clay content or the occurrence of claystone beds. Changes in lithology can be detected on the electric-logs as a decrease in both resistivity and spontaneous potential (Appendix B). The Vergille Member subcrops over most of the area (Figure 9). Toward the extreme southern part of the area it has been eroded. This member is of shallow marine origin and represents the seaward margin of a littoral environment (Meyboom, 1960).

The Telegraph Creek Member consists mainly of argillacious sandstone with minor claystone and shale beds. It varies from 13 to 26 m in thickness and is mainly grey to dark grey in colour. The contact with the overlying Vergille member is often indistinct and is usually taken as the first occurrence of a claystone or shale bed. Where the claystone or shale bed is absent, the contact is taken where there is a definite decrease in spontaneous potential and resistivity on the electric-logs. The bottom of the member is marked by the occurrence of the continuous shale of the Colorado Group. This member underlies the majority of the area and subcrops in a small area in the south central portion (Figure 9).

The oldest subcropping beds are the upper units of the Colorado Group (Kc). They underlie the entire study area and subcrop in a small area at the south end of the study area. They consist of over 500 m of dark grey shale and mudstone. Minor sandstone lenses, which are lenticular in nature, were observed during drilling. The Colorado Group is interpreted to be of marine origin and deposited in deep water.

Structurally the study area lies on the east flank of Red Coulee anticline, and west of the Skiff syncline. Bedrock beds within the study area strike at 290° to 295° and dip to the north east at 0.5° or 9m/km. Clarinda Creek flows roughly parallel to the direction of the dip.

GROUNDWATER FLOW

An essential part of this study involves characterizing the hydrogeology more specifically the patterns of flow, hydraulic parameters and groundwater geochemistry. Seventy-three piezometers and 25 water-table wells were emplaced at 26 of the test drilling sites. Each nest consists of from one to six piezometers completed at different depths. Most nests also contained a water-table well. This arrangement allowed for the measurement of the hydraulic heads in the various geologic units, the collection of water samples for chemical and isotopic analysis and the in situ measurement of hydraulic conductivity.

Each piezometer was placed in a separate borehole and constructed from 50 mm I.D. PVC pipe. The intakes were 0.5 m long and made of 48 mm I.D. plastic wound well screen. The piezometers are completed with a sand pack around the screen and bentonite seal typically 2 m long. Above the seal, the holes were backfilled with drill cuttings.

Water-table wells are constructed of 50 mm I.D. PVC pipe, perforated with 3 mm holes at 50 mm intervals. Once the water-table wells were placed in the bore holes, the holes were backfilled with drill cuttings. Completion details of the groundwater instrumentation are contained in Appendix C.

Hydraulic Conductivity

Single well response tests were performed on 40 piezometers to determine the in situ horizontal hydraulic conductivity (K_x) of the various geologic units. The procedure used in these tests is outlined by Hvorslev (1951). It involves bailing a known volume of water from a piezometer in which water levels are stabilized and measuring the rate at which the water level returns to equilibrium. These observed responses of the water levels in the piezometers provide the basic data necessary to calculate the K_x of the geologic material surrounding the piezometer intake. For four piezometers installed in the shale of the Colorado Group and one for the Deadhorse Coulee Member, which did not completely return to static equilibrium after testing, the plotted curve of the response was projected to an assumed equilibrium level.

The piezometers selected for testing were chosen to provide a representative set of values for units in the study area. The results of the hydraulic conductivity tests are presented in Appendix D.

Figure 10 presents the distribution of the calculated hydraulic conductivities. Values of K_x range from 3.4×10^{-6} to 5.6×10^{-10} m/s. The geologic unit with the highest geometric mean K_x is the post glacial sands at 1.8×10^{-7} m/s. The unit with the lowest geometric mean K_x is the Colorado Group at 3.8×10^{-9} m/s.

The Vergille and Telegraph Creek Members contain massive sandstone, indurated sandstone and shale beds all of which are close to isotropic. However the pattern of layering will create anisotropy on the scale of the individual members with the $K_x >> K_z$. Because the individual beds are relatively thick, it is difficult to develop a reasonable estimate of K_z for these members. Another problem is that piezometers were typically not emplaced in the low permeability beds.

For example five of the six tests conducted in the Vergille Member were with piezometers installed within the massive sandstone unit. Only one test was performed on a piezometer installed within one of the indurated sandstone beds. The sandstone unit has a geometric mean K_x of 2.3×10^{-7} m/s whereas the indurated bed has a K_x of 1.9×10^{-9} m/s. It is possible to estimate an effective value of K_z for each

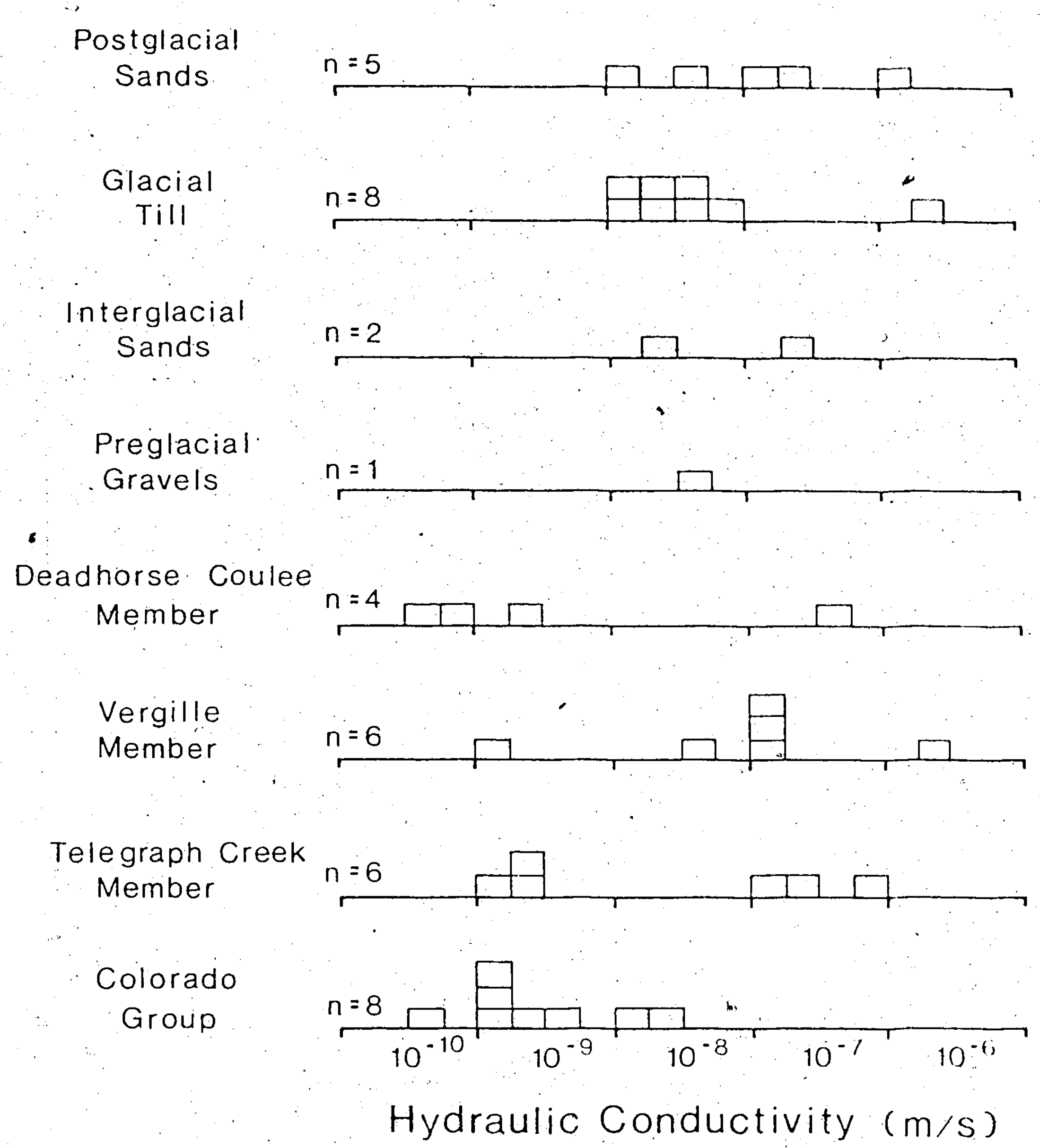


Figure 10. Histogram showing the distribution of calculated hydraulic conductivities

member assuming that the units are layered, and that the mean values apply to all of the massive and indurated sandstones in the section. The governing equation is:

$$K_z = \frac{d}{\sum_{i=1}^{n} d_i / K_i} \qquad (1)$$

where d = total thickness of unit, d_i = thickness of layers and K_i = hydraulic conductivity of layers (Freeze and Cherry, 1979). By using lithologic logs for drill holes which fully penetrated the Vergille member (5226-M, 343-C and 2068-M) (Appendix A) mean values for d and d_i were calculated. In these three cases, the calculations were based on an estimated 5 to 10 separate units. In general, the range of values were all quite similar. The mean value of K_z is 8.7×10^{-9} m/s and shows the importance of the low permeability beds in controlling vertical flow.

Where flow occurs parallel to bedding, the mean value of hydraulic conductivity is calculated with a different form of the averaging equation as follows:

$$K_x = \sum_{i=1}^{n} \frac{K_i d_i}{d} \qquad (2)$$

The mean hydraulic conductivity in the x-direction for the Vergille Member is 1.8×10^{-7} m/s.

Within the Telegraph Creek Member, much the same condition of layering exists. In this case however, its origin is due to interbedded mudstone and shale beds. The sandstone beds within the

Telegraph Creek have a geometric mean hydraulic conductivity of 3.3×10^{-7} m/s while the clay layers have a mean of 3.1×10^{-9} m/s. Assuming anisotropy in the clay layers to be 10:1 and using the same calculation as before, K_z is estimated to be 2.4×10^{-9} m/s using equation (1). Similarly K_x is estimated with (2) to be 2.9×10^{-7} m/s. Estimated hydraulic conductivities are presented on Table 2.

Hydraulic Heads

Monitoring of the water levels in the piezometers and water-table wells was carried out from December 1981 or from the time that the instrumentation was installed until September, 1985. A battery operated Spore™ tape, which has an accuracy of ±10 mm, was used for measurements. Water-level elevations for the wells and piezometers are presented in Appendix E and in hydrograph form in Appendix F. In all cases elevations were measured with sea level as datum.

The highest elevations of the water table were measured in the southwest, west of Clarinda Creek, and in the southeast between Clarinda and Van Cleeve Creeks (Figure 11). From these areas the gradient of the water table is about 9 m/km to the northeast, parallel to Clarinda creek. There is also a gradient (12 m/km), between these areas, toward the centre of the Clarinda channel. At the south end of the Clarinda channel, along the international boundary, the water-table gradient is toward the south and Van Cleeve Creek. A groundwater divide occurs between this area and the remainder of the Clarinda basin. The divide extends to the east and southwest and separates groundwater flow between the north and south. North of the Milk River the water-table gradient is south toward the Milk River and east toward Verdigris Coulee (Figure 11).

GEOLOGIC UNIT	HYDRAULIC CONDUCTIVITY HORIZONTAL	VERTICAL
Postglacial Sand	1.79×10^{-7}	1.79×10^{-7}
Till	7.00×10^{-8}	7.00×10^{-8}
Interglacial Sand	8.28×10^{-8}	8.28×10^{-8}
Preglacial Gravel	6.78×10^{-8}	6.78×10^{-8}
Deadhorse Coulee	6.19×10^{-9}	6.19×10^{-10} [a]
Vergille	1.81×10^{-7}	8.74×10^{-9}
Telegraph Creek	2.85×10^{-7}	2.44×10^{-9}
Colorado	3.76×10^{-9}	$10^{-10}-10^{-11}$ [b]

[a] Assuming anisotropy of 10:1
[b] From Hendry et al (1988)

Table 2. Estimated hydraulic conductivity (m/s)

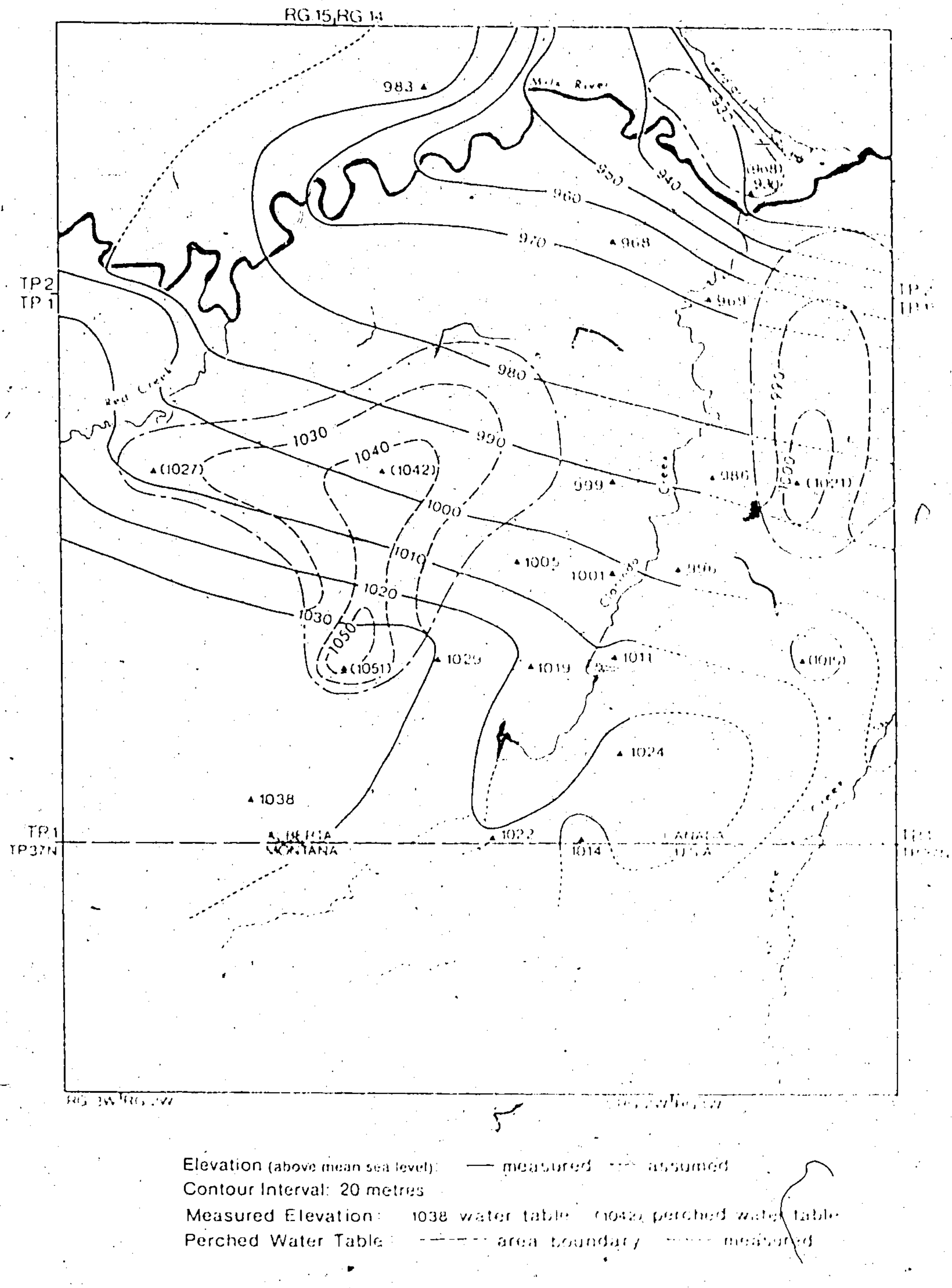


Figure 11. Map showing the elevation of the water table and the distribution and elevation of perched water-table areas

Throughout the majority of the study area the water table occurs within bedrock. Occasionally however the water table can be found in surficial materials such as along the thalwag of the Clarinda channel and north of the Milk River. The situation in the Clarinda channel has the water table located in the thick post glacial and interglacial sands and till deposits at the south end of the valley. North of the Milk River the water table is located in the preglacial Whiskey Valley deposits.

A perched water table is observed in the central portion of the study area (Figure 11). In general a perched water table is located in the till or Deadhorse Coulee Member while the permanent water table is found in the underlying Vergille Member.

The water levels in five piezometers did not reach equilibrium during the study period. With one exception, the piezometers are all completed in the Colorado Group. The exception is located in the Deadhorse Coulee Member. Forty five piezometers and water-table wells, ranging in depth from 2.1 to 41.4 m, remained dry. These wells and piezometers are completed predominantly in the till and Vergille units and reflect the tendency for the shallowest deposits to be unsaturated.

Excluding an initial period during which the wells and piezometers were developed and water levels re-equilibrated, three types of water-level fluctuations were measured during the monitoring period. Relatively small fluctuations of less that 0.3 m were measured in 29 piezometers, the majority of which are completed in the Vergille and Telegraph Creek Members at the north end of the study area.

Much larger fluctuations with a seasonal nature were observed in 18 piezometers and water-table wells. The general pattern of response is for water levels to rise abruptly during the spring snowmelt, and late spring rains and fall gradually through summer, fall and winter. These seasonal fluctuations can be observed in all units, with the exception of the Colorado. Wells and piezometers exhibiting this kind of behavior are located, predominantly, at the south end of the study area.

The third type of water level fluctuation is a general decline of between 0.3 to 5.0 m over the 38 month period of monitoring. This response was observed in 19 wells and piezometers. They are emplaced at or near the water table at the south end of the study area. This general decline is attributed to drought conditions, which have been occurring in southern Alberta during the first half of this decade (Grace and Hobbs, 1986).

Vertical hydraulic gradients were calculated at 14 of the 26 piezometer nests. Their distribution is presented in Figure 12. With the exception of small areas at the south end of the Clarinda valley, near the international boundary and near the mouth of Verdigris Coulee, the vertical gradients in the south portion of the study area and north of the Milk River are either downward or apparently zero. These downward gradients are continuous from the water table, through the Milk River Aquifer, into the Colorado Group. Sites with no apparent vertical gradients occur along the floor of Clarinda Creek.

The northern portion of the study area south of the Milk River, the small area at the south end of Clarinda Creek, and the area near the mouth of Verdigris Coulee have upward hydraulic gradients from

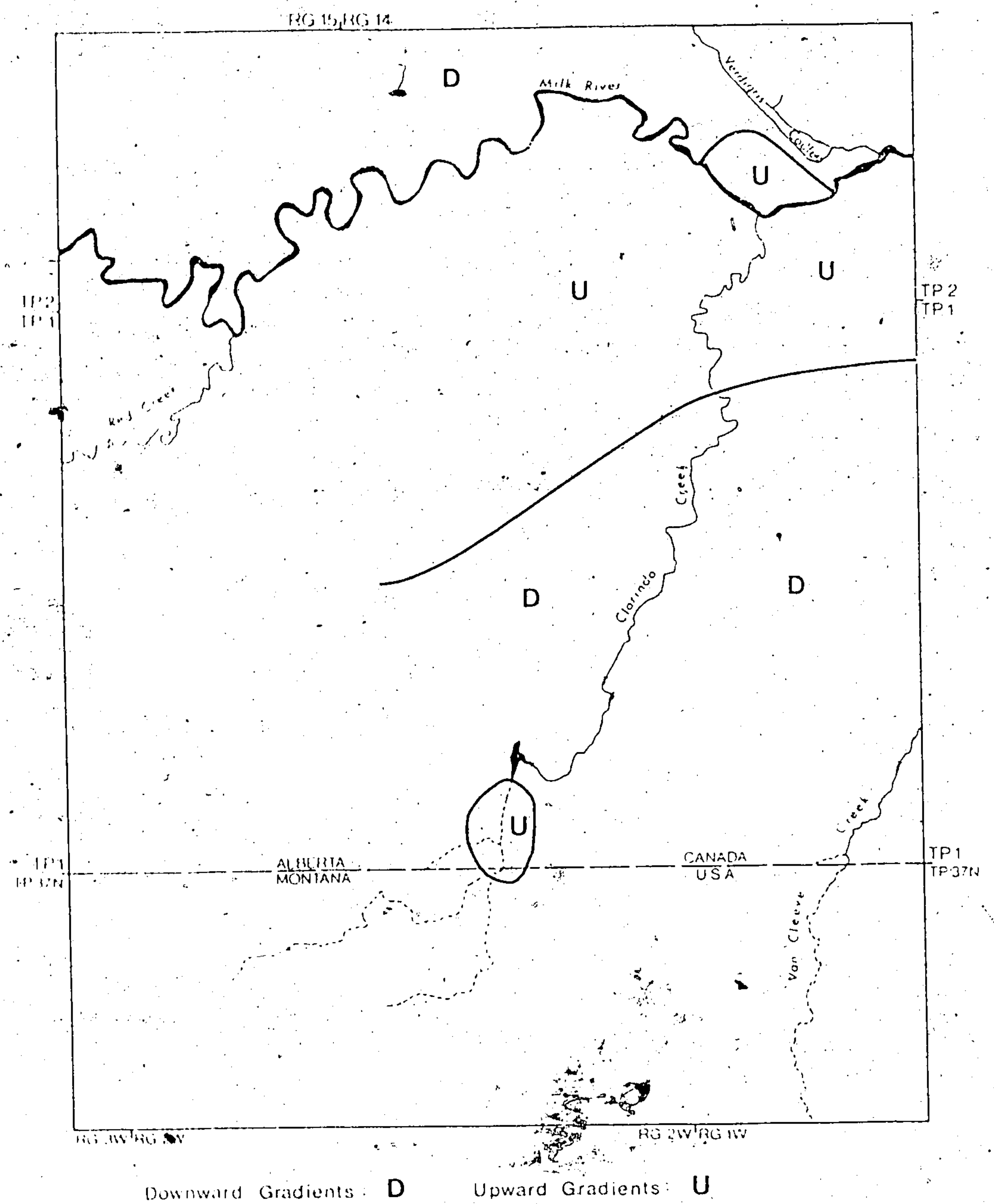


Figure 12. Map showing the distribution of vertical hydraulic gradients

the Colorado Group toward the water table.

The pattern of hydraulic gradients when coupled with the water-table gradient indicate that recharge to the flow system takes place at the southern end of the study area. This area corresponds well with that showing seasonal fluctuation of the water table. Along the heights of land between the valleys, recharge enters the system through the unsaturated tills. Where these tills overly an indurated sandstone bed or the Deadhorse Coulee Member is the subcropping unit, a perched water table is likely to be found. It is assumed that recharge to the remaining flow system from the perched areas is taking place at a very slow rate.

The water table is generally found in the bedrock where there is a downward component of flow through the Vergille and Telegraph Creek Members to the Colorado Group. The low hydraulic conductivity of the shales in the upper Colorado Group would indicate that this unit is a lower boundary to flow. The horizontal component of flow is toward the north and east and west into the valleys.

Along the valley floors recharge is occurring to the postglacial sands and till.. Flow is downward through the interglacial sands to the Colorado Group and northward into the Telegraph Creek and Vergille Members.

At the north end of the study area, south of the river, flow is upward from the Colorado Group toward the water table and toward the north. Discharge is occurring from the aquifer into the Milk River.

North of the river and west of Verdigris Coulee there is recharge to the water table with flow downward into the aquifer and southward to the river.

Along the international boundary within the Clarinda valley is located a small area of groundwater discharge. Because the Colorado Group is the subcropping unit at this site it is assumed that the upward flow is the result of the thinning of the surface deposits from the south. Upward gradients and perched conditions near the mouth of Verdigris Coulee would suggest the possibility of recharge from the Milk River to the Milk River Aquifer to the north.

GROUNDWATER FLOW MODELING

The groundwater flow modeling was designed to assist in interpreting the hydrogeology of the study area, and provide a way of predictively evaluating the potential impact of irrigation. Simulations were carried out using the modular three-dimensional, finite-difference, groundwater flow model (MODFLOW) developed by McDonald et al. (1984). This model was selected because of (1) its proven history of reliability in many different studies, (2) its capability in simulating complex 3-D systems of the type present here, and (3) its user-friendly design based on a modular format and comprehensive user's guide. This code in addition is particularly flexible in simulating relatively complex patterns of recharge and discharge to the aquifer and river. This latter feature is particularly important because the model is to use the recharge from the proposed irrigation.

The site was divided into 8 columns and 9 rows on a grid 1600 m square that was oriented approximately north south. This orientation was chosen because it best fit the entire study area and allowed for the least number of cells. Geologic layering was represented by four model layers. The three members of the Milk River Formation were assigned to the first three layers (Figure 13). Where these members have been eroded, the surficial deposits were used to produce three complete layers. The fourth and lowermost layer of the model represents the lenticular sandstone layers in the upper 10 m of the Colorado Group. The shale in the remainder of the Colorado Group has such a low permeability that it can be treated effectively as a no-flow boundary.

Fluctuations of the water table represent a small percentage of the overall head distribution and would appear to be cyclic rather than

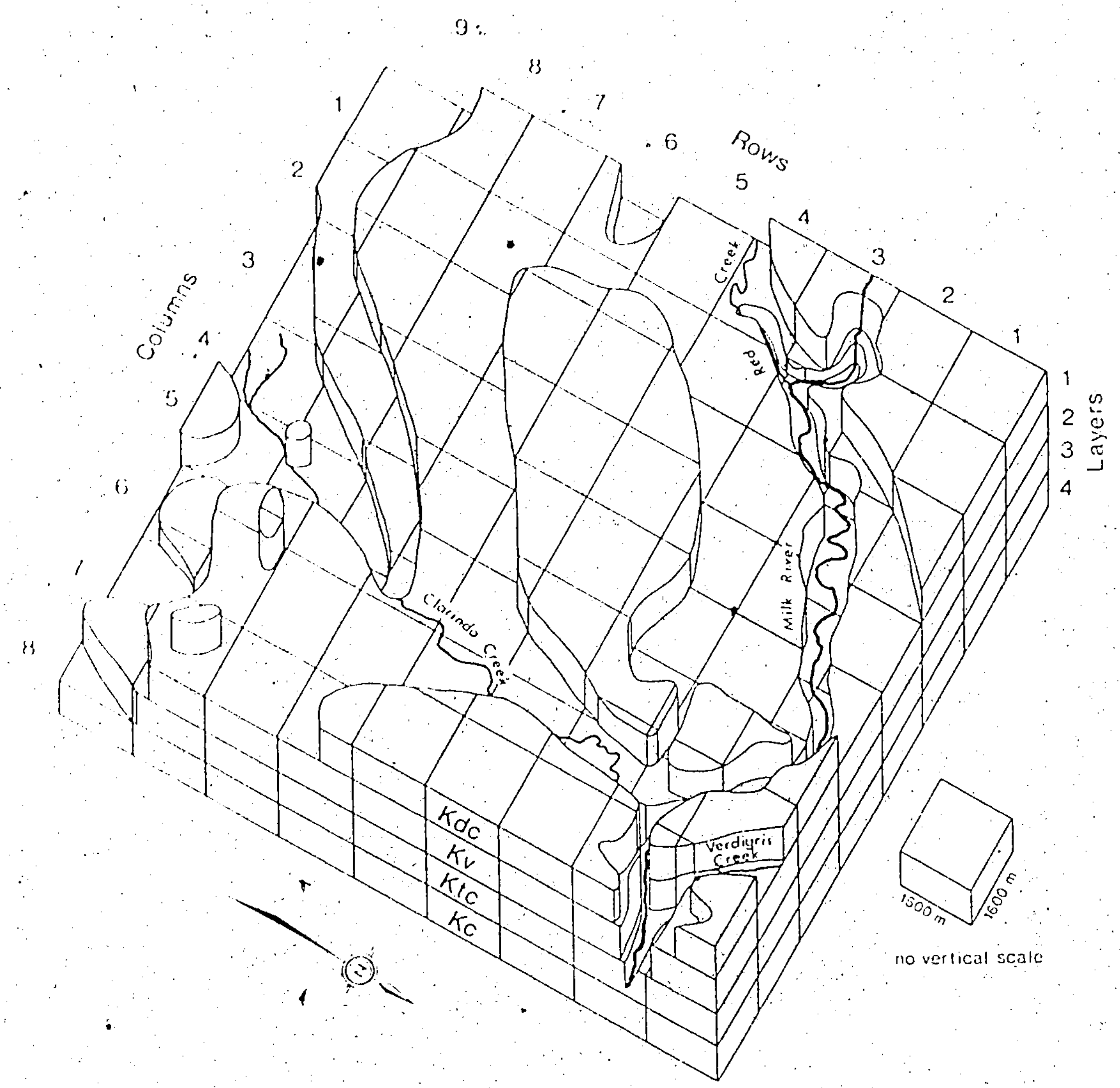


Figure 13. Schematic map showing distribution of bedrock units within the three dimensional computer grid

linear. It can therefore be assumed that the groundwater flow within the geologic units is at steady-state.

For the purpose of steady-state simulations, values were required for layer thickness, K_x and K_z. Thickness of units was calculated from measured values from drill logs while the estimated mean K_x and K_z values were used (Table 2). To account for discharge into the Milk River, the River Package of the model was implemented (McDonald et al. 1984). Constant head values were assigned for each river stage in nodes through which it traversed. Because Red Creek is a perennial stream, constant head values were also assigned for the portion of its course within the study area.

A no flow boundary was assigned to the southern boundary of the study area while a constant flux boundary was assigned to the north boundary. Because the direction of groundwater flow only approximately paralleled that of the grid it was also necessary to set constant flux boundaries along the east and west boundaries. Flux was set using the General Head Boundary package of the computer model. The General Head Boundary package consists of a source of water outside the modeled area which supplies water to a cell in the modeled area at a rate proportional to the head difference between the source and the cell (McDonald et al., 1984).

Recharge was applied to the model by implementing the Model Recharge package (McDonald et al., 1984). Recharge was initially applied at a rate representing 5% of annual precipitation (Rehm et al., 1982) to the areas where seasonal fluctuations to the water table and downward hydraulic gradients are occurring.

The model was calibrated by adjusting the model parameters in a trial and error method until the results of the simulation were in general agreement (± 3 m) with the observed field results. A total of 43 runs were required to bring the simulation within agreement of observed values. A comparison of the simulated and observed values is presented in Table 3. The simulated equipotenial distribution and flow lines within the various layers is presented in Figure 14. It is noted that although the measured and simulated head values match closely, the results of this simulation do not represent a unique solution. Also the simulation of perched conditions was not achieved using this model.

To verify the simulation a sensitivity analysis was conducted to determine the effect on head values of changes in the mean hydraulic conductivity of the geologic units, in the conductivity of the river bed, and in recharge rates. In this analysis the value of all of these variables was fixed but one. The value of each variable of interest was adjusted upward and downward by up to one order of magnitude in a series of model trials. The most sensitive parameter was K_x. For example a change in K_x of one order of magnitude in each of the units produced head changes of from 14 to 81 m. Recharge rates proved to be a less sensitive variable with an order of magnitude change producing a 2 to 4 m change in head. Changes in K_z of one order of magnitude only produced head changes of from 0.8 to 4 m. Conductivity to the river bed proved to be the least sensitive parameter.

Recharge rates varied from 0.0 to 2.3 mm/yr. Values in this range are less than one percent of the total annual precipitation. These estimated values are also lower than those found in other studies

CO-ORDINATES			HYDRAULIC HEAD (m)	
LAYER	COLUMN	ROW	SIMULATED	MEASURED
1	1	5	1027.90	1027.30
	8	5	1008.40	1009.10
	6	6	1004.20	1001.00
2	4	1	960.43	957.88
	7	3	965.64	963.87
	7	5	985.43	988.59
	5	6	1007.00	1004.60
	5	7	1920.50	1019.10
	6	9	1017.80	1014.60
3	4	1	960.37	957.87
	7	2	931.80	929.77
	6	3	966.78	968.62
	7	3	968.39	969.01
	7	5	985.44	986.41
	6	6	1000.10	999.82
	5	7	1015.50	1017.80
	6	7	1013.30	1011.40
	2	8	1036.70	1038.10
	6	8	1021.60	1023.90
	4	9	1020.40	1022.40
	6	9	1010.80	1012.60
4	4	1	967.37	967.10
	7	2	951.80	954.44
	6	3	956.78	956.55
	7	3	973.39	970.21
	7	5	985.44	986.42
	5	6	1006.90	1003.90
	6	8	1015.60	1014.70
	4	9	1025.40	1026.10

Table 3. Comparison of the measured and simulated hydraulic head data

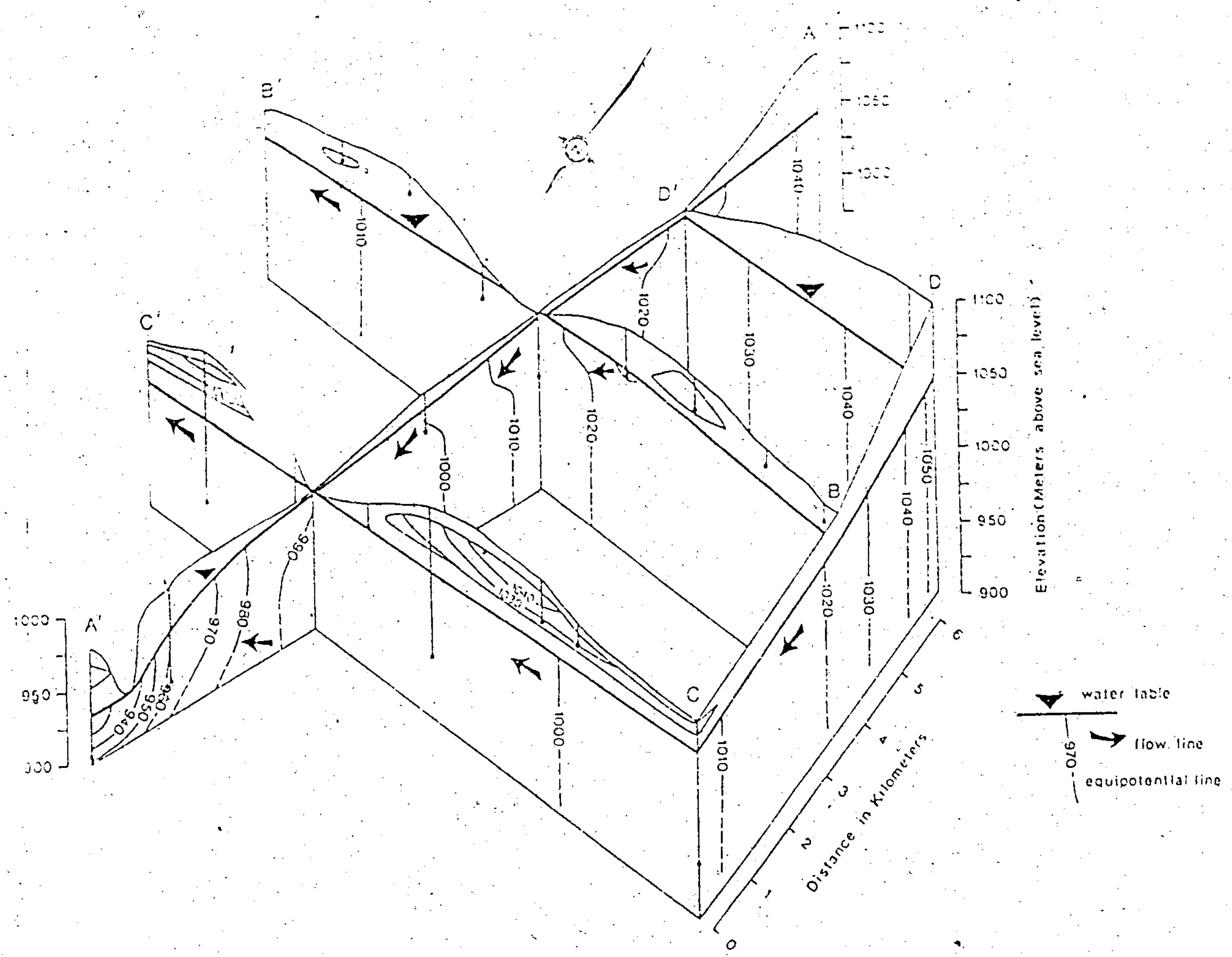


Figure 14. Fence diagram showing the distribution of equipotential and flow lines derived from the computer simulation

on the prairies of North America (2 to 9% of annual precipitation)(Rehm et al., 1982). Rehm et al. (1982) determined that a significant amount of recharge occurs from major permanent depressions and from ephemeral standing water bodies resulting from snow melt. The extremely high evapotranspiration and loss of snow cover due to chinook conditions eliminates most recharge from these sources and may therefore account for the lower values. Another important factor that may control recharge rates is the relatively low hydraulic conductivity of the near-surface units. Under normal hydraulic gradients it is very difficult to move significant quantities of water through these materials.

Calculated discharge of groundwater to the river is approximately 9.0×10^{-3} m^3/s. Recharge from the river to the Vergille Member, north of the river, is approximately 4.5×10^{-5} m^3/s. Thus, there is an overall net gain of groundwater by the Milk River as is flows through the study area.

Swanick (1982) calculated that groundwater flowing from the international boundary to the river, within the study area, should take from 30,000 to 40,000 years. To compare Swanick's results with those of this study, the results of the simulation were used to calculate travel times for the same distance. Actual estimates are based on the following simple form of the Darcy Equation:

$$t = dn/Ki \qquad (3)$$

This calculation assumes a porosity of 10 - 15% based on data presented by Meyboom (1960); a mean hydraulic conductivity of 2.3×10^{-7} m/s; and gradient and distance measured for this study. A travel time of between 28,000 and 41,000 years was calculated from the international boundary to the river. These travel times coincide well with those calculated by Swanick (1982) and help to verify the accuracy of the model.

GEOCHEMISTRY

A significant part of this study involves the detailed characterization of the groundwater chemistry. The water quality aspects of the irrigation return flow to the Milk River are an important factor in assessing the suitability of irrigation.

Geochemical Sampling

Water samples were collected from all piezometers on at least two occasions using either a bailer or compressed nitrogen (Ulmer, 1988). Samples were analysed for pH, electrical conductivity (EC), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, CO_3^{2-}, SO_4^{2-}, and Cl^{-}. Methods used for sampling and the ion determinations are detailed in Appendix G. Results of water analyses are presented in Appendix H. With minor exceptions, little change in ionic composition was apparent over the two sampling periods.

Water samples for chemical analysis were not collected from the Milk River during this study. A comprehensive study by Noton (1980) and supplemented by Alberta Environment (1986) has adequately characterized the chemistry of the Milk River.

Twenty-seven water samples were collected for stable isotope analysis in January 1984 with a repeat sampling involving 45 samples in September 1985. Oxygen-18 (^{18}O) and Deuterium (^{2}H) ratios of groundwater samples were determined by the Isotope Laboratory, Department of Earth Sciences, University of Waterloo. Isotope ratios are expressed in delta units (δ) as per mille (parts per thousand or ‰) differences relative to standard mean ocean water (SMOW):

$$\delta ‰ = [(R - R_{standard}) / R_{standard}] \times 1000 \qquad (4)$$

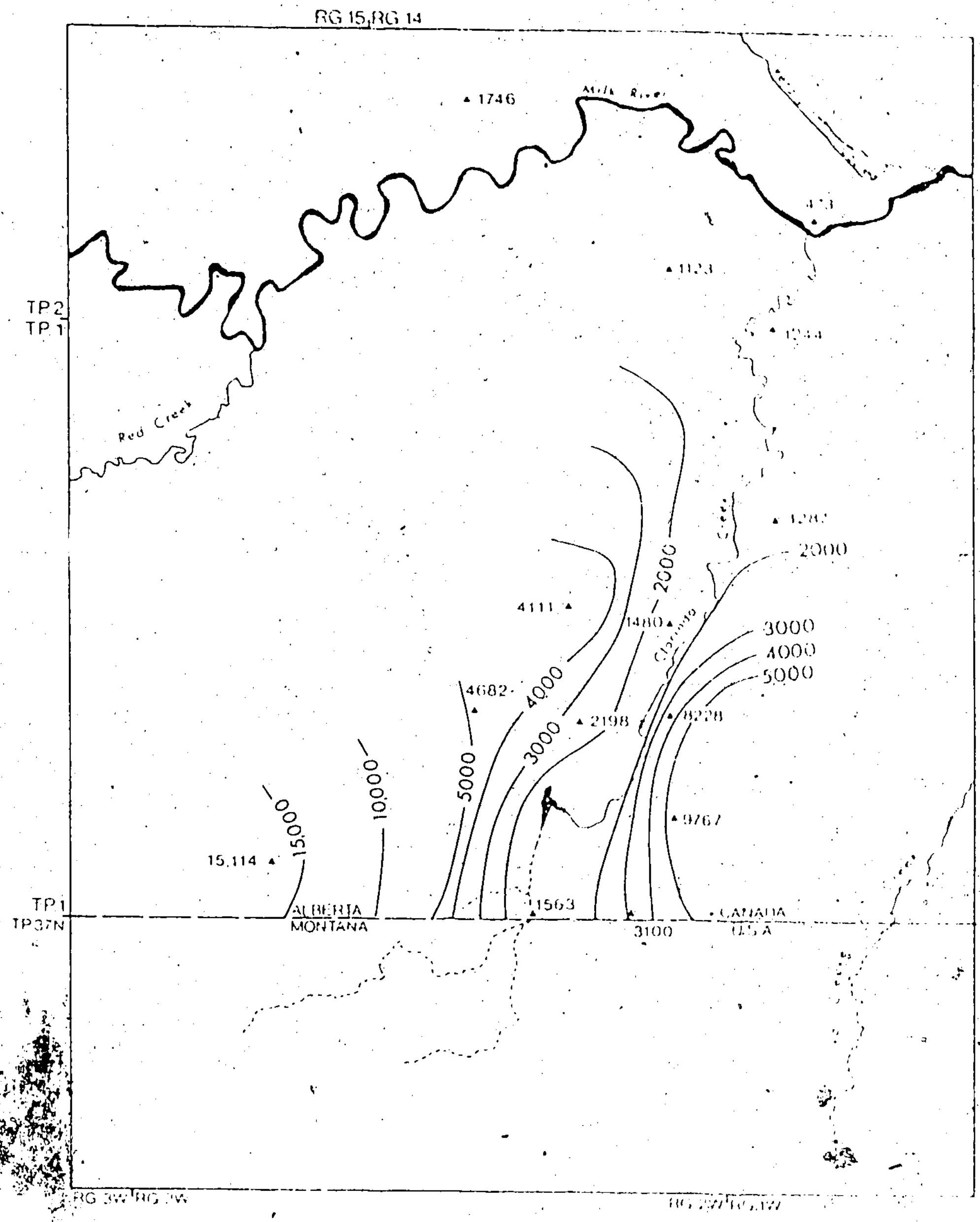
where R and $R_{standard}$ are the isotope ratios, $^2H/^1H$ or $^{18}O/^{16}O$, of the sample and the standard, respectively (Freeze and Cherry, 1979). The accuracy of measurement is better than ± 0.2 and ±2‰ for $\delta^{18}O$ and δ^2H, respectively. The analysis results are contained in Appendix I.

Ion Geochemistry

There are major variations in water chemistry from the recharge area along the flow system. As was mentioned previously, groundwater recharge is occurring primarily in two areas. The first is a' " q the surface divides between the Clarinda basin and the adjoining Red and Van Cleeve basins. Recharge is moving vertically downward through the overlying till and then northward into the Telegraph Creek and Vergille Members. At the northern end of the study area, south of the river, discharge is occurring to the water table and subsequently into the Milk River.

The second area of recharge is along the floor of Clarinda Creek. Recharge moves downward through post glacial sands and till and into the underlying interglacial deposits. Flow is then northward until the interglacial deposits pinch out and water enters the Telegraph Creek and Vergille Members. From this point the flow combines with that from the other recharge areas.

Total Dissolved Solids (TDS) in the recharge area varies from 1480 to 15,114 mg/l. The lower value is associated with the valley deposits where a mean TDS of 1872 mg/l occurs. The higher values are associated with the surface divides. Down the flow system in the Milk River aquifer TDS steadily decreases until at the discharge area TDS ranges from 1123 to 1287 mg/l. TDS distribution within the aquifer is presented on Figure 15.



Total Dissolved Solids : —— measured
Measured Values : ▲ 9767 (mg/l)

Figure 15. Map showing the distribution of total dissolved solid values in the Milk River aquifer

The major cations in groundwater from the recharge area along the valley floor are Ca^{2+} and Mg^{2+}. For the remainder of the recharge area the major species is Na^{+}. The major anion is SO_4^{2-}. For the discharge area the major ions are Na^{+} and HCO_3^{-}.

A statistical summary of the ion data by lithologic unit is presented on Table 4. Inspection of this table indicates that there is a significant difference in the chemistry of water from the tills and the Colorado Group. Water from the Deadhorse Coulee Member has a chemistry similar to that of the Colorado Group. The other units however do not demonstrate any significant patterns.

Figures 16 and 17 present the areal distribution of the individual ion species. As can be seen from Figure 16 all of the cations decrease in concentration from the recharge areas, along the flow system to the discharge area. The recharge area along the valley floor has lower concentrations than the area along the intervening ridges. Areas where the water table is perched have the highest concentration in all cations for the tills and in Na^{+} for the Deadhorse Coulee Member. Groundwater from the Colorado Group is highest in Na^{+} especially within the discharge area. The recharge area north of the river is low in all cation species.

A close examination of Figure 17 shows that SO_4^{2-} concentrations follow the same type of distribution as the cations. SO_4^{2-} values are highest in the recharge area and decline toward the discharge area. HCO_3^{-} also declines from the ridges along the south end of the study area toward the north. There is however a slight increase in HCO_3^{-} from the valley floor at the south end toward the discharge area. There is an over all decline in the mean values from the recharge to

GEOLOGIC UNIT	SAMPLE n	pH	Ca	Mg	Na+K	CO3+HCO3	SO4	Cl	TDS
			IONIC SPECIES (mg/l)						
TILL	9	7.79b	342.46a	191.91a	657.17a	509.54b	2285.19a	136.96a	4122.23a
		(0.35)	(169.22)	(123.02)	(469.52)	(171.33)	(1422.34)	(104.54)	(2187.70)
ALLUVIUM	9	7.93b	169.49b	79.99b	162.8b	399.73b	707.12b	35.45b	1554.58bc
		(0.21)	(107.61)	(71.39)	(111.77)	(125.21)	(597.60)	(33.94)	(739.32)
DEADHORSE COULEE	4	8.37a	74.55bc	22.98bc	3688.07ab	955.43a	6604.82ab	108.46ab	11454.31abc
		(0.17)	(113.08)	(31.92)	(4747.13)	(327.00)	(9662.15)	(154.76)	(14484.10)
VERGILLE	6	7.97b	155.61abc	179.92abc	688.95a	792.27a	1835.65ab	39.94b	3641.84abc
		(0.13)	(166.57)	(238.56)	(443.75)	(229.69)	(1780.14)	(45.72)	(2641.32)
TELEGRAPH CREEK	7	7.93b	112.79bc	118.37ab	1045.38ab	760.58ab	2448.20ab	28.31b	4539.34ac
		(0.14)	(104.09)	(119.52)	(1517.71)	(476.96)	(3508.10)	(24.74)	(5655.85)
COLORADO	10	8.32a	33.59c	20.28c	473.05a	750.92ab	452.70b	60.51ab	1790.84b
		(0.38)	(19.81)	(11.42)	(329.08)	(507.20)	(476.32)	(64.78)	(1002.27)

Values are means (standard deviations). Means within columns not followed by the same letter are significantly different ($P_{\alpha} = 0.05$) as determined by LSD.

Table 4. Statistical summary of ion data

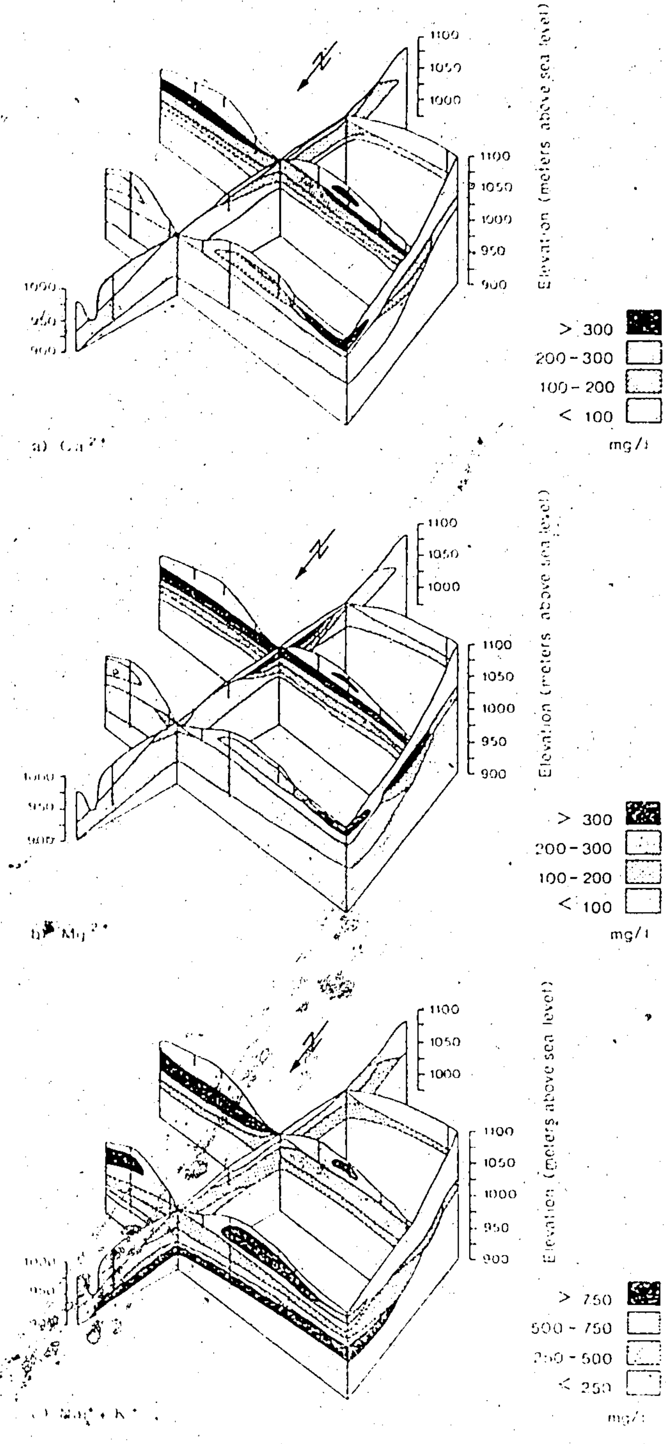


Figure 16. Fence diagram showing the distribution of the major cations

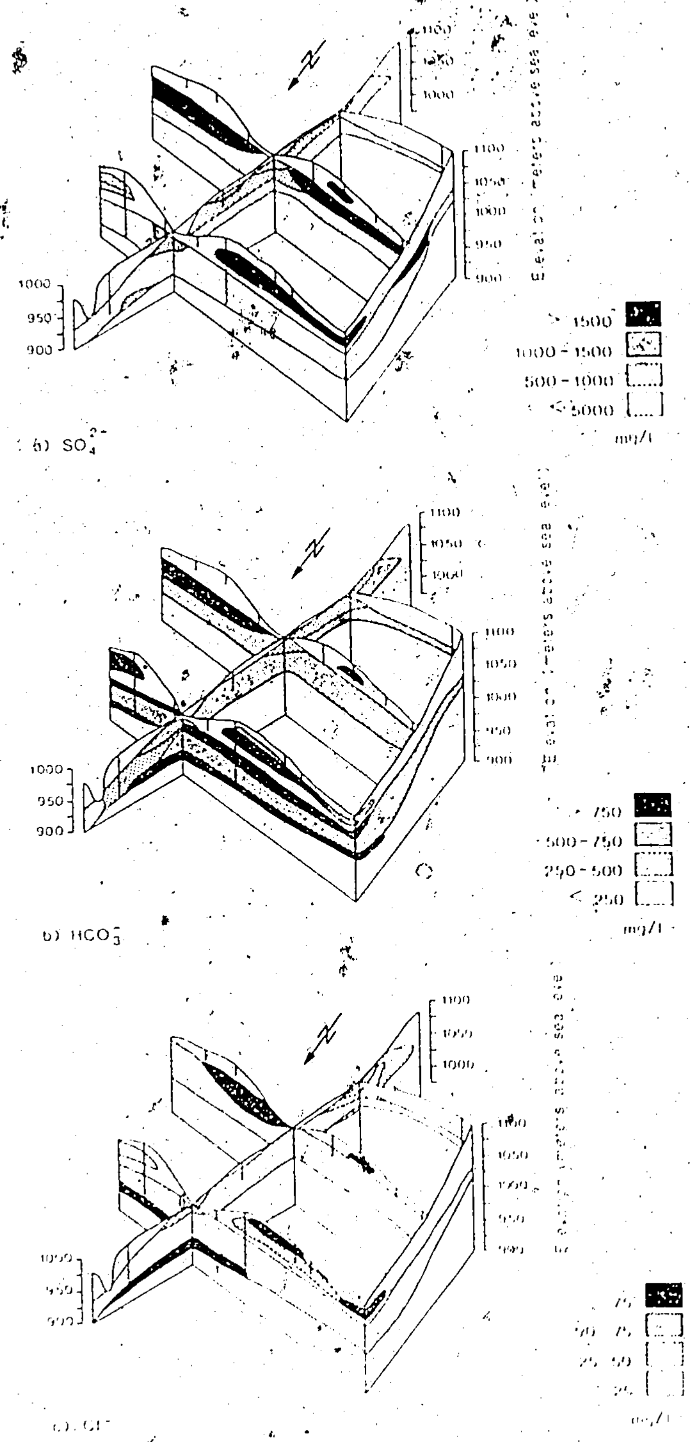


Figure 17. Fence diagram showing the distribution of the major anions

discharge areas indicating that HCO_3^- becomes the dominant anion in the discharge area due to a decline in SO_4^{2-} rather than an increase in HCO_3^-. Cl^- generally declines in concentration, however, there appears to be minor reversals along the flow paths. Within the perched areas, both SO_4^{2-} and HCO^-_3 are abundant while water from the Colorado Group mainly contains HCO_3^- especially in the recharge area.

The PHREEQE computer program, developed by Parkhurst et al. (1980) was used to calculate the saturation indicies (SI) of calcite, dolomite and gypsum and the partial pressure of carbon dioxide (P_{CO2}). The calculations are carried out using the concentrations of major and minor constituents and pH. The resulting calculations are presented in Appendix J with histograms of the distribution of SI values and P_{CO2} presented on Figures 18 and 19. The value of the calcium:magnesium ratio for each sample was also calculated and is presented in Figure 19.

Within the entire recharge area both calcite and dolomite are super saturated while gypsum is undersaturated. As can be seen from Figure 18 these conditions persist in the discharge area however there is an apparent decline in the SI values of dolomite and gypsum. P_{CO2} exhibits no apparent pattern of distribution along the flow path. However, the P_{CO2} appears to be higher for the bedrock units than for the surficial deposits in the recharge area. The $Ca^{2+}:Mg^{2+}$ ratio for the bedrock units in the recharge area are below unity while for the surficial deposits it is greater than unity. For the discharge area the ratio is greater than unity (Figure 19).

In general, the processes involved in the chemical evolution of groundwater along a flow system can be explained by a series of chemical and biological reactions. The most common chemical processes

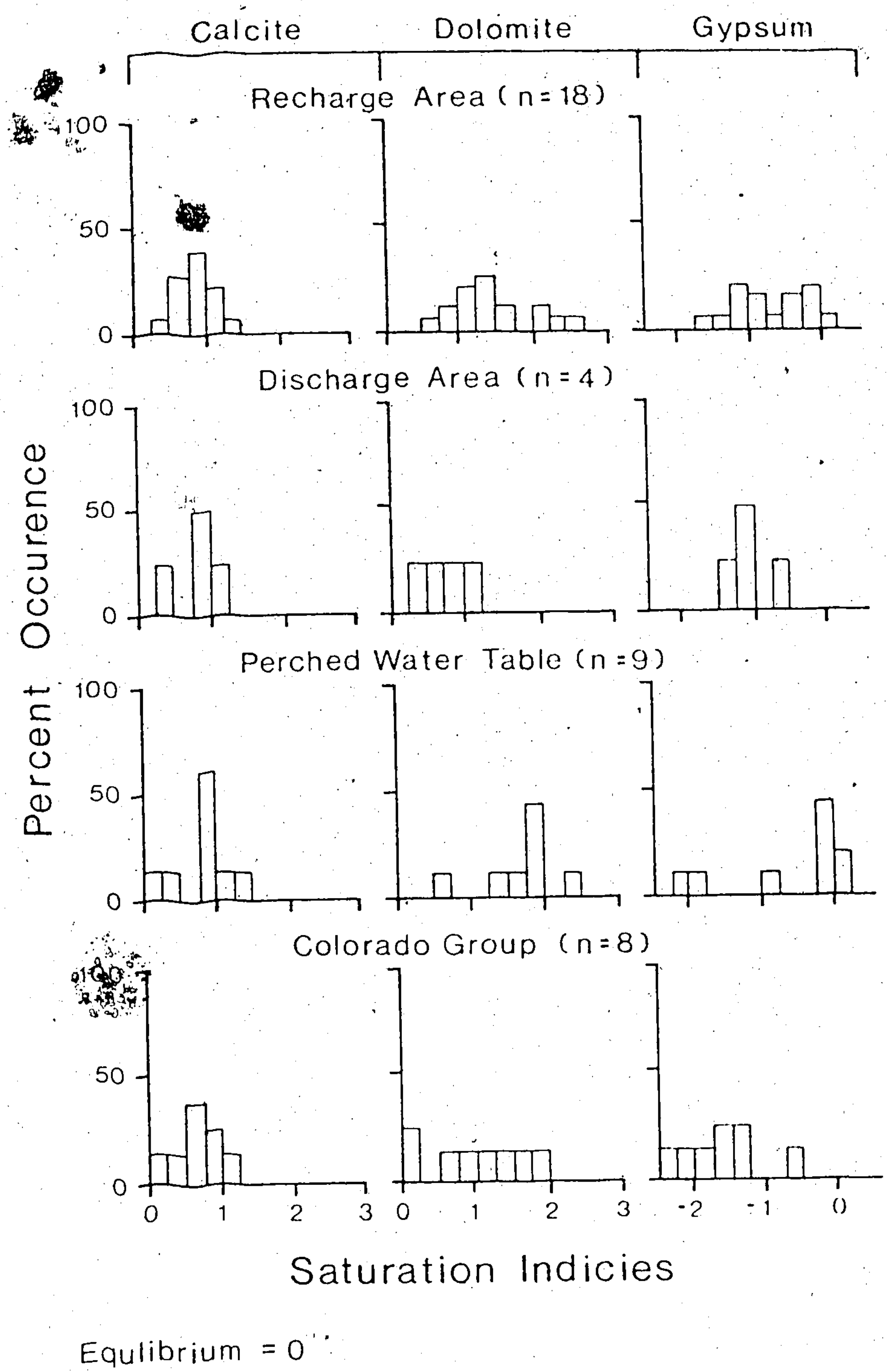


Figure 18. Histogram showing the distribution of saturation indicies with aerial distribution

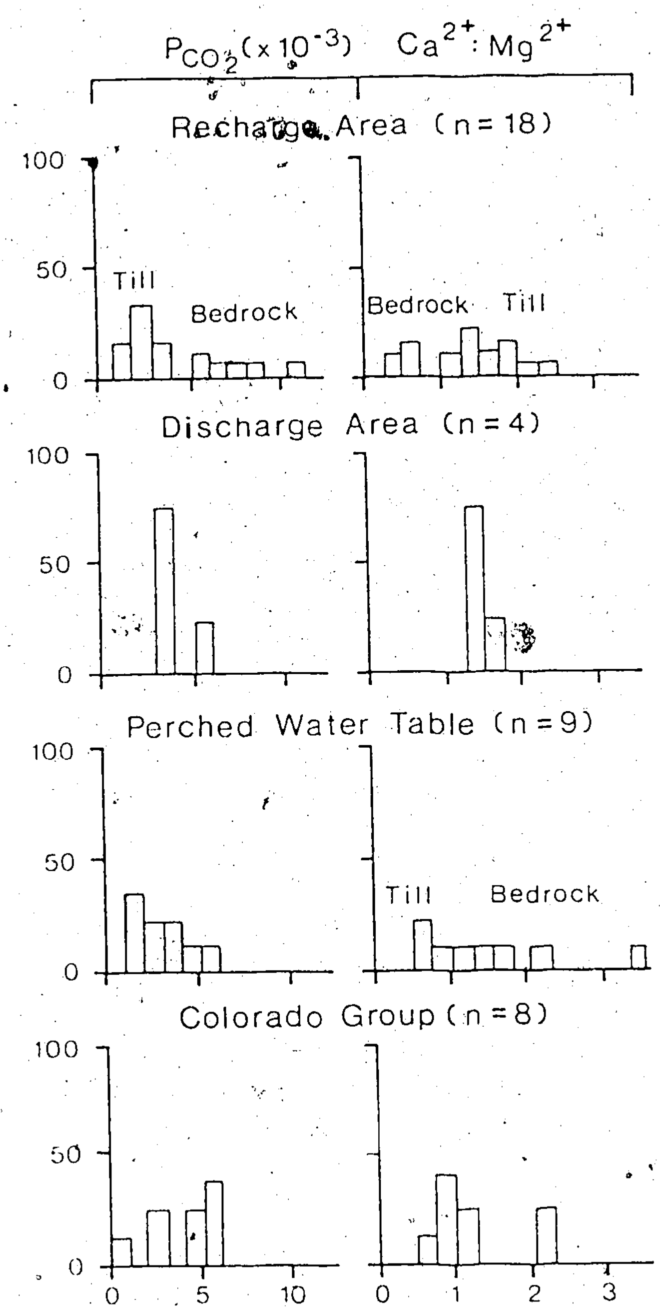


Figure 19. Histogram showing the distribution of P_{CO_2} and calcium:magnesium ratio values with areal distribution

within shallow aquifers include the dissolution of the porous medium, precipitation of mineral phases, ion exchange between the pore fluid and the porous medium and osmosis or reverse osmosis (Schwartz, 1974). Biological processes that add or remove CO_2 and reduce SO_4^{2-} are also important in controlling water chemistry.

Water infiltrating into the CO_2 rich soils will rapidly acquire relatively high concentrations of Ca^{2+}, Mg^{2+}, HCO_3^- and SO_4^{2-} from the dissolution of calcite, dolomite and gypsum. Because all samples, even those near the water table were saturated with calcite and dolomite and near saturation with respect to gypsum these reactions would appear to be important in this area.

The dissolution reactions, particularly those involving the high concentrations of gypsum in the till would explain the high Ca^{2+}, SO_4^{2-} within the recharge area. The high Na^+ content of some of the water in the recharge area, especially in the areas of perched water table, and within the Colorado Group in the discharge area, can be explained by cation exchange of Ca^{2+} and Mg^{2+} for Na^+. This process requires a high proportion of clay minerals to supply the exchange sites for the ions. Nearly all the drift and bedrock units contain a proportionally high percentage of clay minerals with Na^+ available for exchange.

Following along the flow paths there is a decline in SO_4^{2-}. The biological process of sulfate reduction could account for this decrease. A by-product of sulfate reduction, however is H_2S which was not detected during this study. This situation implies that perhaps other processes could be controlling SO_4^{2-} concentrations. Along with SO_4^{2-}, there is a general decline in all ion species in the direction of flow. The precipitation of calcite would account for the decline in Ca^{2+} and

HCO_3^- however it cannot account for the decline in Mg^{2+}, Na^+, SO_4^{2-} and especially Cl^-. The loss of Ca^{2+} and SO_4^{2-} to the precipitation of gypsum is not likely because in most cases gypsum is undersaturated. In fact, no combination of chemical processes could realistically bring about the changes that are observed in this system.

Schwartz (1974) discussed the possibility of membrane filtration in the reduction of ion species within a shallow aquifer system. Phillips et al. (1986) discussed the possibility of this mechanism for concentrating Cl^- in the Milk River aquifer north of the study site. However, the pattern of decline in the direction of flow is opposite to what might be expected from a membrane-type system of the type envisioned by Phillips et al. (1986). Further, the system is so shallow that it is difficult to believe that the units above the Milk River aquifer would operate as a membrane.

Another mechanism for reduction of ion species could be the mixing of two waters or the replacement of one water type with another. There is no apparent source of groundwater other than that which recharges at the south end of the study area. Conductivities in the Colorado Group are too low to account for a second source of water from below. Therefore, if this process is ocurring, the older water at the north end is being replaced by younger water from the south. To account for the changes in chemistry there must have been a change in the recharge conditions at some time in the past.

Travel times from the north end of the recharge area to the river, using (3), are calculated using hydraulic arguments to be between 18,000 and 27,000 years. This time coincides with the estimated advance and retreat of the last glacial advance into the area (Westgate, 1968). If the water in the discharge area entered the flow system as recharge prior to the last glacial advance it is likely that it did not recharge through till and as such would have a different chemical signature. This hypothesis is favoured in this study. The combination of a changing climate with the addition of reactive materials near the surface could explain this tendency for younger waters to be more saline.

Oxygen-18 and Deuterium

The environmental isotopes ^{18}O and ^{2}H have also proved useful in explaining chemical patterns within the study area. The standard plot of $\delta^{18}O$ verses $\delta^{2}H$ (Figure 20) indicates that the analysis results fall along the straight line $\delta^{2}H = 6.31\delta^{18}O - 32.71‰$ ($r^2 = 0.97$). The plotted line falls below the meteoric water line as described by Craig (1961) with an intercept at $\delta^{18}O = -24.8$ and $\delta^{2}H = -188.7$. In general there is a progressive enrichment in both ^{18}O and ^{2}H in the direction of flow. On Figure 20 samples from the recharge areas generally fall close to the meteoric water line, while those farther along the flow system are isotopically heavier and deviate from the Craig (1961) line. With the exception of one area, all of the enriched samples were collected at the northern end of the flow system. The exception is located along the international boundary where a small area of artesian pressure is found along the valley floor. This latter area is one with a shallow water table and seasonal ponding. The likelihood of enrichment by evaporation is probably responsible for this anomalous result. For the remainder of the area however the flow is at depth and evaporation is an unlikely cause for enrichment.

When combined with the flow and geochemical data, the isotope

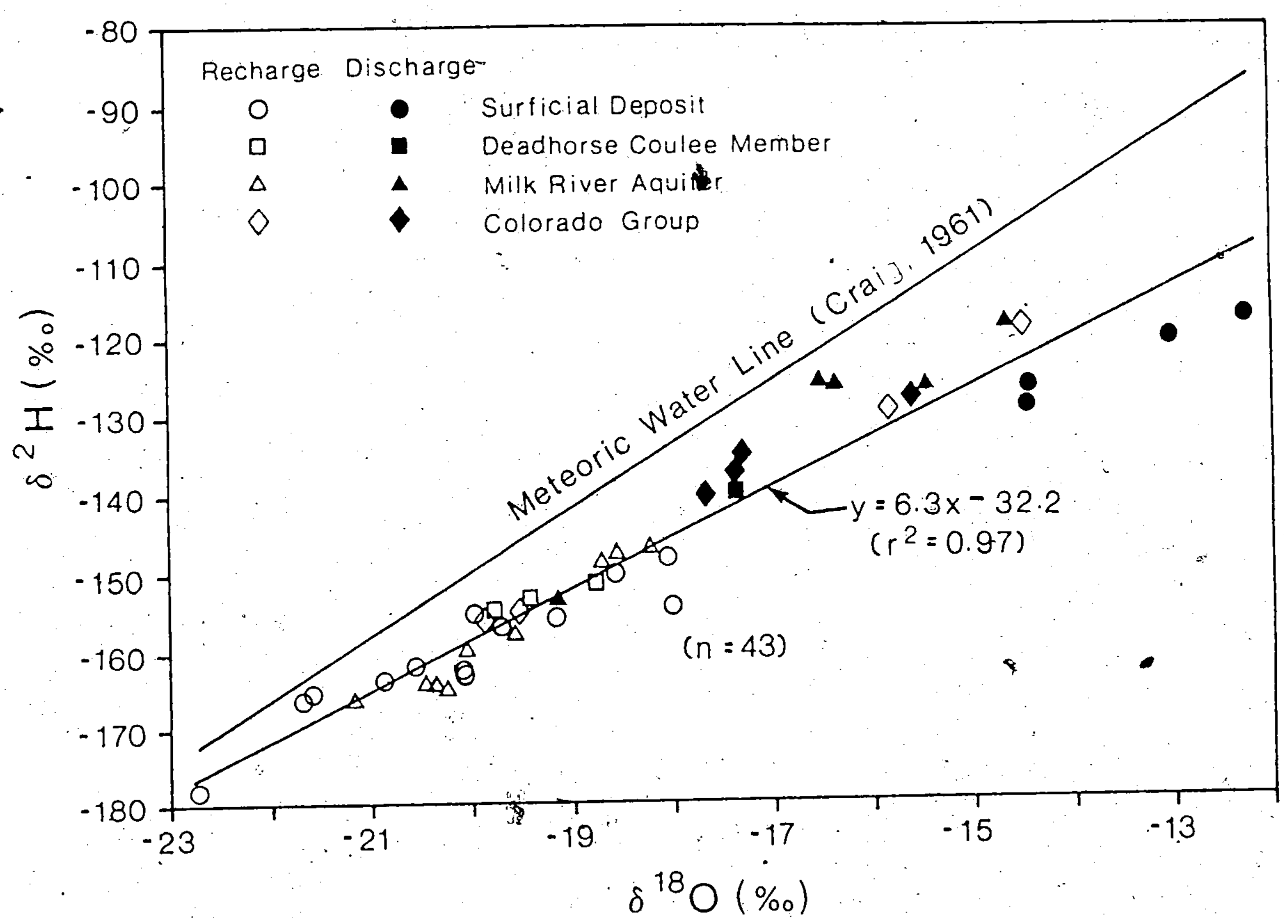


Figure 20. Plot showing measured oxygen-18 and deuterium data in relation to the Craig (1961) meteoric water line

data corroborates the findings that there are two separate waters. Recent recharge water is depleted in $\delta^{18}O$ and $\delta^{2}H$ while the older water is more enriched. The reasons why the older groundwater is enriched with respect to ^{18}O and ^{2}H is a subject requiring further investigation and beyond the scope of this study.

SUBSURFACE IRRIGATION RETURN FLOW

Potential Recharge

To prevent salt accumulation within the root zone of the soil profile as a result of irrigation, it is necessary to apply sufficient water to leach these salts through the profile. The calculated fraction of applied water that must be passed through the plant root zone to maintain the EC at or below a specified value is defined as the Leaching Requirement (LR(%)) (Bresler et al., 1982). Water that passes through the root zone can effectively be considered as incorporated into the groundwater. Assuming that the LR(%) is not exceeded, it can therefore be equated as the maximum recharge rate to the groundwater from irrigation.

The USDA (1954), Rhoades (1974), Hoffman (1983), Smith and Hancock (1986) and others have described methods to calculate LR(%). Considerable debate has been generated as to which method is the most accurate (Hoffman, 1983). The USDA (1954) calculations produce the largest LR(%) values. Because this method would represent a worst case scenario of maximum recharge to the groundwater regime this method was used to calculate recharge rates to the aquifer.

LR(%) was calculated using the equation:

$$LR(\%) = EC_{iw}/EC_{dw} \qquad (4)$$

where EC_{iw} is the electrical conductivity of the irrigation water and EC_{dw} is the electrical conductivity of the drainage water. Luthin (1973) indicated that EC_{iw} should be a weighted average of the conductivity of the rain water EC_{rw} (0.05 mS/cm) and irrigation water

EC_{iw} and is calculated using the formula:

$$EC_{(rw+iw)} = D_{rw}EC_{rw}+D_{iw}EC_{iw}/D_{rw}+D_{iw} \quad (5)$$

where D_{rw} and D_{iw} are the depths of precipitation and irrigation water that enter the soil. EC_{dw} is the EC of the soil extract at the threshold of crop salt tolerance.

Salt tolerance varies with the crop type and a variety of crops are grown in southern Alberta. To calculate the LR(%) values for each crop type EC_{dw} values are taken from Bresler et al (1982). Because the Milk River is the likely source of the irrigation water the value of EC_{iw} was calculated from the mean concentration of the Milk River during the growing season (i.e., 100 mg/l)(Noton, 1980) using the formula:

$$TDS = 765.1\ EC^{1.087} \quad (6)$$

from Chang et al (1983).

To calculate the LR (depth of water) the formula:

$$LR(mm) = W_{iw} \times LR(\%) \quad (7)$$

was used where W_{iw} is the consumptive use of the crop minus the mean growing season precipitation (248 mm). Values for consumptive use are from Sonmor (1963).

As can be seen from Table 5, the maximum calculated LR(mm) value is for alfalfa (36 mm). The minimum value is for barley with an

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APPENDIX A

LITHOLOGIC LOGS FOR TEST HOLES

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5071-M (SE 7-2-14-4)					
0 - 1.5	Alluvium (SCL)		D		
1.5- 9.1	Alluvium (GS)		D		
Hole Number 5072-M (NE 6-2-14-4)					
0 - 3.0	Alluvium (GSCL)				
3.0- 7.6	Till (C)				
7.6-12.2	Outwash (S)				
12.2-16.8	Till (GSL)				
16.8-21.3	Sandstone				Shell Fragments
21.3-29.0	Sandstone				
Hole Number 5073-M (SE 6-2-14-4)					
0 - 7.6	Till (CL)				
7.6- 9.1	Silty Shale		M		
9.1-1[illegible].8	Sandstone		SM		Bentonitic
12[illegible]	[illegible]tone			Strong	
1[illegible]	[illegible]tone				Shell Fragments
15.2-16.[illegible]	[illegible]tone				Carbonaceous
16.8-18.3	Silty Shale				
18.3-19.8	Silty Sandstone				Carbonaceous
19.8-23.5	Silty Sandstone				
23.5-27.4	Siltstone				
27.4-29.0	Silty Shale				
Hole Number 5074-M (NW 7-1-14-4)					
0 - 3.0	Till (CL)		SM		
3.0- 9.1	Till (CL)	Light Olive Brown	SM		
9.1-10.7	Till (CL-C)	Light Olive Brown	M		
10.7-16.8	Till (C)	Light Brownish Gray	M		
16.8-18.3	Till (C)	Olive Brown	M		
18.3-20.4	Sandstone	Light Olive Brown			
20.4-22.2	Shale	Light Olive Brown		Strong	
22.2-22.8	Sandstone	Light Gray		Moderate	Very Hard
Hole Number 5075-M (NW 1-1-15-4)					
0 - 1.5	Till (CL)	Brown			
1.5- 3.0	Till (L)	Yellowish Brown			
3.0- 7.6	Till (L)	Olive Brown			
7.6- 9.1	Till (CL)	Light Olive Brown			
9.1-10.7	Sandstone	Light Olive Brown		Moderate	
10.7-13.7	Sandstone	Olive		Moderate	
13.7-15.2	Sandstone	Olive		Weak	
15.2-16.8	Sandstone	Brownish Yellow			
16.8-18.3	Silty Shale	Dark Gray			Carbonaceous
18.3-21.3	Sandstone	Light Olive Brown		Weak	
21.3-24.4	Sandstone	Olive		Moderate	
24.4-29.6	Sandstone	Dark Gray		Weak	

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5077 M (SW 2-1-15-4)					
0 2.7	Till (CL)	Brown	SM		
2.7 4.3	Sandstone	Light Yellowish Brown	SM	Strong	
4.3 6.4	Sandstone	Dark Yellowish Brown	SM	Moderate	
6.4 7.6	Sandstone	Dark Yellowish Brown	SM	Weak	
7.6 9.1	Sandstone	Light Yellowish Brown	M	Weak	
9.1 14.3	Sandstone	Light Olive Brown	M	Weak	
14.3 14.6	Sandstone	Light Gray	D	Strong	

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5078-M (SW 30-1-14-4)					
0 0.3	Top Soil (L)	Brown	SM		
0.3 1.5	Till (FSCL)	Light Gray	D	Strong	
1.5 3.7	Till (SCL)	Light Olive Brown	SM	Weak	
3.7 4.9	Silty Shale	Light Brownish Gray	D		Very Hard
4.9 5.5	Silty Shale	Olive Brown	SAT		Very Hard
5.5 7.9	Silty Shale	Olive Brown	VM		Carbonaceous Chips
7.9 9.1	Claystone	Dark Brown	SM		
9.1-12.2	Claystone	Light Olive Brown	SM		
12.2-13.4	Sandstone	Dark Yellowish Brown	VM	Moderate	
13.4 14.9	Sandstone	Olive Brown	VM		
14.9 16.7	Shale	Gray	M		Carbonaceous
16.7 18.3	Shale	Dark Gray	M		Carbonaceous
18.3-19.8	Shale	Gray	SM		Carbonaceous
19.8-27.4	Shale	Dark Gray	SM		
27.4-29.0	Shale	Gray	SM		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5079-M (SE 18-2-14-4)					
0 - 0.3	Top Soil (CL)		D		
0.3- 0.6	Alluvium (SL)	Brown	D	Moderate	
0.6- 1.2	Alluvium (SL)	Yellowish Brown	D	Moderate	
1.2- 1.5	Alluvium (S)	Light Olive Brown	D	Moderate	
1.5- 3.0	Alluvium (SL)	Dark Yellowish Brown	SM	Moderate	
3.0 4.6	Till (SCL)	Olive Brown	M	Moderate	Mottled
4.6- 5.2	Till (SCL)	Olive Brown	VM		Mottled
5.2- 5.8	Till (SCL)	Yellowish Brown	SAT	Weak	
5.8 6.4	Till (SCL)	Gray	SAT	Strong	
6.4 7.3	Till (SCL)	Light Olive Brown	VM	Moderate	
7.3 7.8	Till (C)	Gray	VM		
7.8 9.1	Till (C)	Dark Grayish Brown	M		
9.1 18.2	Till (CL)	Very Dark Gray	M		
18.2 19.8	Alluvium (G)	Black			
19.8-21.9	Alluvium (G)	Dark Grayish Brown			
21.9-24.4	Sandstone	Light Brownish Gray			
24.4-25.9	Sandstone	Gray			
25.9-27.4	Sandstone	Gray		Ledge	
27.4-29.3	Sandstone	Gray			
29.3 30.5	Sandstone	Gray		Ledge	
30.5 48.8	Sandstone	Gray			
48.8-53.3	Sandy Mudstone	Gray			
53.3 59.[illegible]	Mudstone	Gray			

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5106-M (SW 36-1-15-4)					
0 - 0.25	Top Soil (L)	Dark Yellowish Brown	M		
0.25- 0.50	Top Soil (L)	Yellowish Brown	D		
0.50- 1.75	Till (CL)	Yellowish Brown	D		Salt Streaks
1.75- 2.25	Till (CL)	Dark Brown	SM		Salt Streaks
2.25- 4.25	Till (CL)	Dark Brown	M		
4.25- 6.00	Till (CL)	Very Dark Brown	M		
6.00- 7.75	Till (CL)	Dark Grayish Brown	M		
7.75-10.25	Till (CL-C)	Dark Grayish Brown	M		Dense
10.25-10.50	Sandstone	Gray	D		Argillaceous
Hole Number 5107-M (NE 30-1-14-4)					
0 - 0.25	Top Soil (CL)	Grayish Brown	SM		
0.25- 1.50	Till (CL)	Dark Brown	M		
1.50- 4.25	Till (CL)	Dark Grayish Brown	M		
4.25- 4.50	Till (CL)	Dark Grayish B[illegible]	VM		
4.50- 7.50	Till (C)	Dark Grayish [illegible]	M		
7.50- 8.25	Till [illegible]	Very Dark Gra[illegible]wn	M		
8.25- 8.50	Shale	Very Dark Gra[illegible]	SM		
8.50- 9.00	Shale	Gray	SM		
Hole Number 5108-M (SW 4-2-[illegible]4)					
0 - 0.25	Top Soil (L)	Brown	D		
0.25- 0.75	Drift (FSL)	Very Pale Brown	D		
0.75- 1.00	Till (CL)	Brown	SM		
1.00- 3.25	Till (CL)	Dark Grayish Brown	M		
3.25- 3.50	Sandstone	Very Pale Brown	M		
3.50- 3.75	Sandstone	Yellow	M		
3.75- 4.75	Sandstone	White	M		
4.75- 6.25	Sandstone	Yellow	M		
6.25- 7.25	Sandstone	Brown	M		
7.25- 7.75	Sandstone	Light Gray	M		
7.75- 8.50	Sandstone	Olive Yellow	M		
8.50- 9.25	Sandstone	Yellow	M		
9.25-10.50	Sandstone	Brownish Yellow	M		
10.50-10.75	Sandstone	Light Yellowish Brown	M		
10.75-11.00	Sandstone	Olive Yellow	M		Laminated Light Gray
11.00-11.50	Sandstone	Brownish Yellow	M		
11.50-13.50	Sandstone	Yellow	M		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5109-M (NE 9-2-14-4)					
0 - 0.50	Top Soil (SiL)	Yellowish Brown	D		
0.50 1.25	Till (CL)	Grayish Brown	D		
1.25 1.75	Till (CL)	Dark Grayish Brown	SM		
1.75 3.00	Till (CL-C)	Dark Grayish Brown	M		Salts
3.00 4.25	Till (SL)	Dark Grayish Brown	SM		
4.25 4.50	Till (SL)	Dark Brown	SM		
4.50 6.00	Outwash (LFS)	Dark Brown	M		
6.00 6.50	Outwash (G)		M		
6.50 7.50	Outwash (LFS)	Olive Brown	VM		
7.50 8.50	Till (CL)	Very Dark Grayish Brown	M		
8.50 9.50	Outwash (LFS)	Light Olive Brown	VM		
9.50 10.50	Till (CL)	Dark Grayish Brown	M		
10.50 11.50	Shale	Gray	M		
11.50 12.25	Shale	Gray	SM		
Hole Number 5110-M (SE 35-1-14-4)					
0 0.50	Top Soil (L)	Brown	D		
0.50 1.75	Till (SiCL)	Dark Grayish Brown	M		
1.75 2.50	Till (CL)	Very Dark Grayish Brown	M		
2.50 2.75	Shale	Gray	SM		Weathered
2.75 3.00	Shale	Gray	D		
Hole Number 5111-M (SW 36-1-14-4)					
0 0.50	Top Soil (L)	Brown	D		
0.50 1.25	Till (SiCL)	Light Brownish Gray	D		
1.25 1.50	Till (CL)	Dark Grayish Brown	SM		Salt Streaks
1.50 3.50	Till (CL)	Dark Grayish Brown	M		
3.50 4.00	Shale	Olive Gray	SM		Salt Crystals, Layered (10YR 5/6)
Hole Number 5112-M (NE27-1-14-4)					
0 - 0.25	Top Soil (L)	Light Brownish Gray	D		
0.25 2.00	Till (SiCL)	Light Brownish Gray	D		
2.00 2.50	Till (CL)	Dark Brownish Gray	SM		
2.50 3.00	Outwash (LFS)	Pale Brown	M		
3.00 6.00	Till (CL)	Dark Grayish Brown	SM		
6.00 9.00	Till (CL)	Dark Grayish Brown	D		
9.00 9.25	Sandstone	Dark Grayish Brown	D		
Hole Number 5113-M (SE 26-1-14-4)					
0 0.50	Top Soil (L)	Light Yellowish Brown	D		
0.50 1.25	Till (CL)	Yellowish Brown	D		
1.25 1.50	Shale	Light Gray	D		
Hole Number 5114-M (SE 33-1-14-4)					
0 0.25	Top Soil (L)	Light Brownish Gray	D		
0.25 3.00	Till (CL)	Dark Brown	M		
3.00 3.25	Till (C)	Brown	M		Saturated Fine Sand Lenses
3.25 3.50	Shale	Olive Gray	SM		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5115-M (SW 12-1-14-4)					
0 - 0.25	Top Soil (L)	Light Gray	D		
0.25- 1.50	Till (CL)	Light Gray	D		
1.50- 1.75	Shale	Olive Gray	D		
Hole Number 5116-M (NE 2-1-14-4)					
0 - 0.50	Top Soil (L)	Grayish Brown	D		
0.50- 1.75	Till (CL)	Grayish Brown	D		
1.75- 2.25	Sandstone	Pinkish White	D		
Hole Number 5117-M (NE 3-1-14-4)					
0 - 0.25	Top Soil (L)	Dark Brown	D		
0.25- 1.75	Till (SiCL)	Dark Brown	M		
1.75- 2.50	Till (FSL)	Dark Brown	VM		
2.50- 3.00	Till (SCL)	Dark Brown	M		
3.00- 3.75	Outwash (LFS)	Dark Brown	VM		
3.75- 4.00	Till (C)	Brown	M		
4.00- 4.50	Till (CL)	Dark Brown	M		
4.50- 5.00	Outwash (SL)	Dark Brown	M		
5.00- 5.50	Outwash (G)	Dark Brown	VM		
5.50- 7.50	Till (CL)	Dark Brown	M		
7.50-12.75	Till (C)	Dark Gray	M		Reduced
12.75-13.00	Till (CL)	Gray	M		Reduced
13.00-13.25	Outwash (VFSL)	Gray	SAT		Reduced
Hole Number 5118-M (SE 10-1-14-4)					
0 - 0.25	Top Soil (L)	Light Yellowish Brown	D		
0.25- 1.00	Till (CL)	Very Dark Grayish Brown	SM		Oxidized
1.00- [illegible]5	Till (CL)	Dark Grayish Brown	M		Oxidized
1.75- 2.00	Shale	Dark Gray	SM		
2.00- 2.25	Sandstone	Brownish Yellow	SM		
Hole Number 5119-M (SE 4-1-14-4)					
0 - 0.25	Top Soil (L)	Light Gray	D		
0.25- 1.75	Till (CL)	Light Gray	D		
1.25-1.50	Outwash (FSL)	Yellowish Brown	SM		
1.50-2.00	Till (SiCL)	Olive	M		
2.00- 3.25	Till (CL)	Dark Grayish Brown	M		
3.25- 3.75	Till (SCL)	Dark Grayish Brown	M		Sandy
3.75-11.50	Till (CL)	Dark Grayish Brown	M		
11.50-12.00	Till (CL)	Dark Brown	M		
12.00-12.50	Shale	Dark Gray	SM		[illegible]
12.50-13.00	Sandy Shale	Reddish Yellow	SM		
13.00-13.75	Silty Shale	Yellow	SM		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5120 M (SE 5-1-14-4)					
0 - 0.25	Top Soil (L)	Dark Grayish Brown	SM		
0.25 - 1.75	Till (CL)	Dark Grayish Brown	SM		
1.75 - 3.00	Till (SCL)	Dark Grayish Brown	M		Sandy
3.00 - 4.75	Till (SCL)	Dark Grayish Brown	M		
4.75 - 5.75	Outwash (LFS)	Dark Grayish Brown	SAT		
5.75 - 8.50	Till (SCL)	Dark Grayish Brown	VM		Sandy
8.50 - 10.50	Outwash (FSL)	Dark Grayish Brown	SAT		
10.50 - 12.00	Till (SCL)	Yellowish Brown	M		Sandy
12.00 - 12.25	Shale	Yellowish Brown	D		
Hole Number 5124 M (SW 11-1-15-4)					
0 - 1.00	Till (CL)	Yellowish Brown	D		
1.00 - 5.50	Till (CL)	Dark Grayish Brown	M		
5.50 - 10.50	Sandstone	Brown	SM		Very Fine Argillaceous
10.50 - 10.75	Silty Shale	Light Yellowish Brown	SM		
10.75 - 12.25	Sandstone	White	D	Strong	Ledge
12.25 - 15.50	Sandstone	Light Yellowish Brown	M	Weak	
15.50 - 16.25	Sandstone	White	D	Strong	Ledge
16.25 - 18.25	Sandstone	Light Yellowish Brown	SM		Laminated Sandstone/ Shale (Gray)
18.25 - 18.50	Shale	Gray	D	Strong	
18.50 - 18.75	Sandstone	Gray	D	Strong	Ledge
18.75 - 21.25	Sandstone	Gray	SM	Strong	Laminated Shale
21.25 - 24.50	Sandstone	Gray	M	Strong	
24.50 - 25.75	Sandstone	Gray	M	Strong	Laminated Shale
25.75 - 29.00	Shale	Gray	SM	Strong	Laminated Sandstone
29.00 - 33.00	Shale	Gray	SM	Strong	
33.00 - 33.50	Shale	Gray	D	Strong	Hard
33.50 - 35.50	Shale	Gray	D	Strong	
35.50 - 36.25	Shale	Gray	D	Strong	Hard
36.25 - 38.50	Shale	Gray	D	Strong	

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5122-M (SW 2-1-15-4)					
0 - 1.25	Till (SL)	Brown	SM		Sandy
1.25- 2.50	Till (SCL)	Brown	M		Sandy
2.50- 2.75	Sandstone	Light Brownish Gray	SM		
2.75- 3.25	Sandstone	Light Gray	D	Strong	Ledge
3.25- 3.50	Sandstone	Light Gray	D	Strong	
3.50- 3.75	Sandstone	Light Gray	D	Strong	Ledge
3.75- 5.25	Sandstone	Pale Brown	D		
5.25- 5.50	Sandstone	Light Gray	D		Ledge Carbonaceous
5.50- 7.00	Sandstone	Light Gray	D		
7.00- 7.25	Sandstone	Light Gray	D		Ledge Carbonaceous
7.25- 9.00	Sandstone	Light Gray	D		
9.00-12.00	Sandstone	Light Gray	D		Laminated $CaCO_3$
12.00-13.50	Sandstone	Very Pale Brown	D	Weak	
13.50-17.50	Sandstone	Light Yellowish Brown	D		
17.50-18.00	Sandstone	Light Gray	D	Strong	Ledge
18.00-24.50	Sandstone	Light Yellowish Brown	SM	Moderate	
24.50-26.75	Sandstone	Light Yellowish Brown	SM		
26.75-27.25	Sandstone	Light Gray	M	Moderate	
27.25-27.75	Sandstone	Gray	SM	Strong	
27.75-28.00	Sandstone	Gray	D	Strong	Ledge
28.00-29.25	Sandstone	Gray	D	Strong	Laminated Shale
29.25-30.75	Sandstone	Light Gray	D	Strong	Ledge
30.75-31.25	Shale	Dark Gray	D	Strong	
31.25-32.50	Sandstone	Gray	SM	Strong	
32.50-33.50	Sandstone	Gray	M	Strong	Argillaceous
33.50-34.25	Sandstone	Gray	SM	Strong	Ledge
34.25-34.75	Sandstone	Gray	D	Strong	Ledge
34.75-38.50	Mudstone	Gray	M	Strong	Arenaceous
38.50-38.75	Sandstone	Gray	D	Strong	Ledge
38.75-39.50	Sandstone	Gray	M	Strong	Argillaceous
39.50-42.00	Shale	Dark Gray	D	Strong	Laminated Shale
42.00-43.50	Shale	Gray	D	Strong	
43.50-44.25	Shale	Gray	M	Strong	

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5123-M (SE 3-1-15-4)					
0 - 1.00	Till (CL)	Brown	SM		
1.00 2.00	Sandstone	Light Gray	D	Moderate	Ledge
2.00 2.50	Sandstone	Light Gray	D	Moderate	Ledge, Very Hard
2.50 3.25	Sandstone	Olive Gray	D		
3.25 4.50	Sandstone	Light Gray	D	Strong	Ledge
4.50 7.00	Sandstone	Light Yellowish Brown	D	Moderate	
7.00 7.50	Sandstone	Light Gray	D	Strong	Ledge
7.50 8.25	Sandstone	Light Yellowish Brown	D	Moderate	
8.25 - 9.00	Sandstone	Light Gray	D	Strong	Ledge
9.00 11.25	Sandstone	Light Yellowish Brown	D	Moderate	Argillaceous
11.25-18.00	Sandstone	Light Yellowish Brown	D		Argillaceous
18.00 18.75	Sandstone	Yellowish Brown	M		Argillaceous
18.75-19.25	Sandstone	Gray	M	Strong	Argillaceous
19.25-21.25	Sandstone	Brown	M	Strong	Argillaceous
21.25-22.75	Sandstone	Gray	M		Argillaceous
22.75 23.75	Sandstone	Light Gray	D	Strong	Ledge
23.75-25.25	Sandstone	Light Yellowish Brown	SM	Moderate	
25.25 26.50	Sandstone	Brown	SM		
26.50-28.00	Sandstone	Light Gray	SM		
28.00-28.50	Sandstone	Brown	SM		Interbedded (Light Gr.
28.50 29.00	Sandstone	Light Gray	D	Strong	Ledge
29.00-29.75	Sandstone	Brown	SM		Interbedded (Light Gr.
29.75-30.00	Sandstone	Gray	D	Strong	Ledge
30.00-31.00	Sandstone	Gray	SM	Strong	Argillaceous
31.00-31.50	Sandstone	Gray	SM		Interbedded Shale
31.50-32.25	Shale	Dark Gray	D	Moderate	
32.25-33.00	Sandstone	Gray	SM	Strong	Argillaceous
33.00-33.50	Sandstone	Light Gray	D	Strong	Ledge
33.50-34.25	Sandstone	Gray	SM	Strong	Argillaceous
34.25-36.75	Sandstone	Gray	SM	Strong	Argillaceous
36.75-37.00	Shale	Dark Gray	D	Strong	Interbedded Shale
37.00-37.50	Sandstone	Light Gray	D	Strong	Ledge
37.50-38.50	Shale	Gray	M		Arinaceous

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5140-M (NW 30-1-14-4)					
0 0.25	Top Soil (L)	Olive Gray	F		
0.25-0.50	Till (CL)	Olive Gray	SM		
0.50 1.00	Till (SCL)	Olive Gray	M		
1.00 2.00	Till (CL)	Olive Gray	M		
2.00-2.25	Sand	Dark Yellowish Brown	SM		
2.25-2.50	Sand	Light Olive Brown	M		
2.50 3.00	Sandstone	Dark Brown	M		Carbonaceous and Siltstone Layers
3.00-3.50	Siltstone	Olive Gray	M		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number [illegible]					
[illegible]	[illegible]	Dark Grayish Brown	M		
[illegible]	[illegible]	Dark Yellowish Brown	M		
[illegible]	[illegible]	Light Olive Brown	M		
[illegible]	[illegible]	Dark Brown	SM		Carbonaceous Layer

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5142-M (NW 12-1-15-4)					
0 - 0.25	Top Soil (CL)	Very Dark Grayish Brown	M		
0.25- 1.50	Till (CL)	Light Yellowish Brown	SM		
1.50- 2.75	Fluvial (SiL)	Brown	M		
2.75- 6.20	Sandstone	Light Yellowish Brown	D		
Hole Number 5143-M (NW 11-1-15-4)					
0 - 0.25	Top Soil (CL)	Very Dark Grayish Brown	M		
0.25- 1.25	Till (CL)	Light Yellowish Brown	D		
1.25- 1.50	Till (HC)	Olive Gray	SM		
1.50- 2.00	Till (HC)	Dark Olive Gray	M		
2.00- 2.25	Till (SCL)	Light Yellowish Brown	D		
2.25- 2.50	Outwash (LFS)	Light Yellowish Brown	D		
2.50- 5.50	Till (C)	Light Yellowish Brown	D		
5.50- 5.75	Shale	Brown	D		
5.75- 9.00	Sandstone	Light Gray	D		
9.00- 9.50	Sandstone	Light Gray	D		Ledge
Hole Number 5144-M (SW 13-1-14-4)					
0 - 0.25	Top Soil (L)	Very Dark Brown	M		
0.25- 0.50	Till (CL)	Very Dark Brown	M		
0.50- 1.25	Till (CL)	Light Gray	D		
1.25- 1.75	Till (CL)	Olive	SM		Salts
1.75- 4.00	Till (C)	Yellowish Brown	SM		Salts
4.00- 4.50	Till (SC)	Light Yellowish Brown	D		
4.50- 5.50	Till (SC)	Light Yellowish Brown	SM		
5.50- 6.50	Till (SC)	Yellowish Brown	SM		
6.50- 6.75	Till (C)	Brown	SM		Gravelly
6.75- 7.00	Till (C)	Brown	SM		
7.00- 7.50	Till (C)	Dark Grayish Brown	M		
7.50-12.25	Alluvium (G)	Yellowish Brown	M		
12.25-14.00	Sandstone	Light Yellowish Brown	D		
Hole Number 5179-M (NE 16-1-14-4)					
0 - 3.00	Till (CL)	Very Dark Grayish Brown	M		
3.00- 7.60	Till (SCL)	Olive Brown	M		
7.60-10.70	Till (SCL)	Dark Grayish Brown	M		
10.70-16.80	Till (SCL)	Dark Gray	M		
16.80-18.30	Sandstone	Dark Gray	M		
18.30-19.80	Sandstone	Light Olive Brown	M		
19.80-21.30	Sandstone	Light Olive Brown	SM		Interbedded Ledges
21.30-22.90	Sandstone	Gray	M		
Hole Number 5180-M (NE 21-1-14-4)					
0 - 1.50	Till (CL)		SM		
1.50-10.00	Till (CL)	Dark Grayish Brown	M		
10.00-12.50	Sandstone	Light Olive Brown	SM		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 5181-M (SE 5-1-14-4)					
0 - 1.00	Alluvium (FSCL)	Dark Brown	M		
1.00 11.20	Alluvium (SCL)	Dark Grayish Brown	SAT		
11.20 15.50	Alluvium	Dark Gray	VM		
15.50 18.20	Shale	Dark Gray	M		
Hole Number 5182-M (SE 4-1-14-4)					
0 1.50	Alluvium (SCL)	Olive Brown	M		
1.50 10.00	Alluvium (LS)	Dark Grayish Brown	VM		
10.00 10.70	Alluvium (CL)	Light Olive Brown	M		
10.70 12.20	Till (CL)	Light Olive Brown	M		
12.20 31.10	Till (CL)	Dark Gray	M		Gravel Layers
31.10 32.30	Sandstone	Very Dark Gray	D		Ledge
Hole Number 5183-M (SE 22-1-14-4)					
0 1.50	Till (CL)	Dark Brown	SM		
1.50 7.00	Till (CL)	Olive Brown	M		
7.00 9.10	Sandstone	Yellowish Brown	SM	Moderage	
Hole Number 5226-M (SE 11-2-14-4)					
0 - 5.80	Outwash (LFS)	Olive	D	Moderate	Poorly Saturated
5.80 7.60	Outwash (LFS)	Olive	D		
7.60-10.70	Till (SiL)	Olive Gray	D		
10.70-10.90	Alluvium (Gr)				
10.90-13.10	Sandstone	Light Gray	SM		
13.10 15.20	Siltstone	Dark Gray	M		
15.20-19.80	Silty Claystone	Dark Gray	M		
19.80-20.40	Silty Claystone	Dark Gray	M		SS Lamina
20.40 23.80	Silty Claystone	Dark Gray	M		
23.80-26.80	Mudstone	Gray	M-VM		VF Sands
26.80 27.40	Mudstone	Gray	M-VM		High & Sand
27.40 30.10	Sandy Mudstone	Gray	M-VM		
30.10 30.80	Sandstone	Gray	SM-D		Ledge
30.80 36.60	Silty Sandstone	Gray	SM	Moderate	VF Sand
36.60 37.20	Sandstone	Gray	SM	Strong	Ledge
37.20 38.70	Sandstone	Gray	SM	Moderate	
38.70 39.90	Sandstone	Gray	SM		Ledge
39.90 40.50	Sandstone	Gray	SM		
40.50 42.70	Silty Sandstone	Gray	SM		
42.70 44.20	Siltstone	Gray	SM-M		
44.20 45.70	Silty Sandstone	Gray	M		
45.70 48.80	Silty Sandstone	Gray	M		Shale Layers
48.80-50.30	Sandy Siltstone	Gray	M		
50.30 62.50	Mudstone	Gray	M		
62.50 64.00	Claystone	Dark Gray	M		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 2066-E (SW 2-1-15-4)					
0 - 0.50	Top Soil (CL)		D		
0.50- 2.10	Till (CL-C)		SM		
2.10- 3.00	Sandstone		D		Ledge, Very Hard
3.00- 9.70	Sandstone		SM		Argillaceous
9.70-20.10	Sandstone		SM		Argillaceous
20.10-21.60	Sandstone		D		Ledge
21.60-38.10	Silty Shale		SM		
38.10-91.40	Shale		SM		Sandstone Layers
Hole Number 2067-E (NE 23-1-14-4)					
0 - 9.70	Till (CL-C)		SM		
9.70-16.60	Silty Shale		SM		Sandstone Layers
16.60-33.50	Shale		SM		
33.50-38.10	Silty Shale		SM		
38.10-59.10	Silty Sandstone		D		
59.10-61.00	Sandstone		D		Ledge
61.00-86.90	Silty Sandstone		SM		Argillaceous
86.90-91.40	Shale		D		
Hole Number 2068-E (SW 28-1-14-4)					
0 - 4.60	Till (CL-C)		M		
4.60-10.70	Silty Shale	Light Gray	SM		
10.70-16.80	Silty Shale	Light Gray	SM		
16.80-18.30	Shale	Gray	SM		
18.90-19.80	Shale	Gray	SM		Sandstone Layers
19.80-21.30	Shale	Gray	SM		
21.30-22.90	Sandy Shale	Gray	SM		
22.90-23.20	Shale	Gray	SM		
23.20-36.60	Sandstone	Gray	SM		Argillaceous
36.60-45.70	Silty Sandstone	Gray	SM		
45.70-47.20	Sandstone	Light Gray	SM		Ledge
47.20-56.40	Sandstone	Light Gray	SM		
56.40-62.50	Sandstone	Light Gray	SM		
62.50-64.00	Silty Sandstone	Light Gray	D		
64.00-64.90	Silty Shale	Light Gray	D		
64.90-65.50	Sandstone	Light Gray	D		Ledge
65.50-67.10	Silty Shale	Gray	SM		
67.10-67.30	Sandstone	Light Gray	D		Ledge
67.30-79.20	Silty Shale	Gray	SM		
79.20-91.40	Shale	Dark Gray	SM		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 2069-E (SW 26-1-15-4)					
0 - 3.00	Till (CL-C)		M		Fine Sand Lenses
3.00- 3.30	Outwash (G)		M		Cobbles
3.30-13.40	Till (CL-C)		M		Fine Sand Lenses
13.40-16.80	Till (CL-C)		M		Gypsum Streaks
16.80-19.20	Till (C)		M		Oxidation Stains
19.20-19.50	Sandstone	Reddish Yellow	M		
19.50-19.80	Till		M		
19.80-23.20	Sandstone	Reddish Yellow	M		
23.20-23.50	Sandstone	Very Dark Gray	SM		Ledge
23.50-25.90	Sandstone	Reddish Yellow	SM		
25.90-29.90	Sandstone	Light Gray	SM		
29.90-30.50	Silty Sandstone	Light Gray	D		Ledge
30.50-33.50	Shale	Very Dark Gray	M		
33.50-39.60	Shale	Very Dark Gray	M		
39.60-42.70	Shale	Very Dark Gray	M		
42.70-48.80	Silty Sandstone	Gray	M		
48.80-50.30	Silty Sandstone	Gray	M		
50.30-55.50	Silty Shale	Gray	M		
55.50-56.10	Sandstone	Yellow	SM		Ledge
56.10-64.00	Silty Shale	Dark Reddish Brown	M		
64.00-91.40	Shale	Very Dark Gray	SM		
Hole Number 341-C (SW 26-1-14-4)					
0 - 7.60	Till (C)				
7.60-10.70	Sandstone				
10.70-16.80	Sandstone				Oxidized, Iron Stained
16.80-24.40	Sandstone				Argillaceous, Bentonite
24.40-29.00	Sandstone				Ledge
29.00-39.60	Sandstone				
29.60-42.00	Sandstone				Ledge
42.00-51.80	Sandstone				Thin Hard Ledge
51.80-56.40	Claystone	Very Dark Gray			
Hole Number 342-C (NW 35-1-14-4)					
0 - 7.60	Till (C)				
7.60- 9.10	Sandstone				
9.10-10.70	Sandstone				Ledge
10.70-16.80	Sandstone				
16.80-18.30	Sandstone				Ledge
18.30-21.30	Sandstone				
21.30-29.00	Sandstone	Yellowish Brown			
29.00-37.50	Sandstone	Gray			
37.50-40.80	Claystone				
40.80-51.80	Sandstone				Argillaceous
51.80-59.40	Shale	Dark Gray			

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 343 C (NW 3-2-14-4)					
0 5.50	Till (C)				
5.50 6.10	Claystone				
6.10 7.00	Sandstone				Ledge
7.00 7.30	Coal		D		
7.30 8.20	Sandstone				Ledge
8.20 12.20	Claystone				Carbonaceous
12.20 15.20	Sandstone				Argillaceous
15.20 25.60	Sandstone				Ledge
25.60 29.00	Sandstone				
29.00 47.20	Sandstone				Argillaceous, Bentoniti
47.20 48.80	Shale				
48.80 54.20	Siltstone				
54.20 57.00	Sandstone				Ledge
57.00 65.50	Sandstone				
65.50 70.10	Shale				
Hole Number 344 C (SE 20-1-14-4)					
0 12.20	Till (CL)				Oxidized
12.20 15.20	Till (C)				Reduced
15.20 16.80	Sandstone	Buff			Oxidized
16.80 18.30	Sandstone				Ledge
18.30 21.30	Sandstone				Iron Stained
21.30 26.80	Sandstone	Gray			Argillaceous
26.80 29.90	Sandstone				Ledge
29.90 33.50	Siltstone				
33.50 42.70	Sandstone				
42.70 47.20	Shale	Dark Gray			
47.20 56.40	Claystone				
Hole Number 345-C (SW 10-1-14-4)					
0 3.00	Till (C)				
3.00 4.60	Silty Sandstone				Ledge
4.60 10.70	Sandstone	Yellowish Brown			
10.70 16.80	Clayey Sandstone	Gray			
16.80 18.30	Sandstone				Ledge
18.30 29.00	Silty Sandstone				Interbedded Carbonaceous Shale
29.00 42.70	Sandy Mudstone				
42.70 51.80	Clayey Mudstone	Dark Gray			White Specks
51.80 56.50	Clayey Mudstone				
Hole Number 2 C-83 (SW 14-1-4-4)					
0 1.50	Till (CL)		D		
1.50 4.50	Till (CL)	Olive Brown	M		
4.50 5.00	Claystone		SM		
5.00 6.20	Sandstone	Pinkish Gray	D		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number 3-C-83 (SE 16-1-14-4)					
0 - 2.00	Sandstone	Light Olive Brown	D		Weathered
2.00- 3.00	Sandstone	Light Olive Brown	D		Weathered
3.00- 6.50	Sandstone		SM		
6.50-11.00	Sandstone	Light Gray	SM		
11.00-15.00	Sandstone	Yellowish Brown	SM		
15.00-18.00	Sandstone	Dark Yellowish Brown	M		
18.00-20.00	Sandstone	Olive Gray	SAT		
Hole Number 6-C-83 (NW 9-1-14-4)					
0 - 1.50	Till (CL)	Olive Brown	M		
1.50- 3.00	Till (CL)		M		Gypsum Salts
3.00- 3.60	Till (CL)		M		
3.60- 5.70	Fluvial (S-G)		SAT		
5.70- 6.50	Till (C)	Light Olive Brown	M		
6.50-13.50	Till (CL)	Very Dark Grayish Brown	M		
13.50-36.60	Fluvial (S-G)		SAT		Sand and Coarse Gravel
36.60-39.60	Sandy Shale	Dark Gray			
Hole Number 7-C-83 (SW 17-1-14-4)					
0 - 1.50	Till (CL)		D		
1.50- 3.00	Till (CL)	Dark Brown	D		
3.00- 4.50	Till (CL)	Light Olive Brown	SM		Sandy
4.50- 6.00	Till (CL)	Light Olive Brown	SM		
6.00- 7.20	Till (SCL)	Dark Yellowish Brown	SM		Stoney
7.20-12.00	Till (CL)	Brown	SM		
12.00-12.50	Sandstone	Yellowish Brown	D		
12.50-13.00	Sandstone	Pale Brown	D		Ledge
13.00-21.00	Sandstone	Yellowish Brown	D		
21.00-30.00	Sandstone	Yellowish Brown	D		
Hole Number MRRCS-3 (NW 1-1-15-4)					
0 - 0.60	(CL)	Yellowish Brown	D		
0.60- 1.20	Till (CL)	Pale Brown	D		
1.20- 2.10	Till (SCL)	Brown	SM		
2.10- 2.40	(SCL)	Light Yellowish Brown	SM		
2.40- 2.70	Silt Stone	Light Olive Brown	SM		
2.70- 3.00	Sandstone	Light Olive Brown	SM		
Hole Number MRRCS-4 (SE 23-1-15-4)					
0 - 1.00	(SCL-CL)	Dark Yellowish Brown	SM		
1.00- 1.30	(CL)	Brown	SM		
1.30- 1.80	(CL)	Olive Brown	SM		
1.80- 2.10	(CL)	Olive Brown	M		
2.10- 6.10	Till (CL)	Olive Brown	M		
6.10- 8.50	Till (CL)	Dark Grayish Brown	M		
8.50- 9.10	Sandstone				

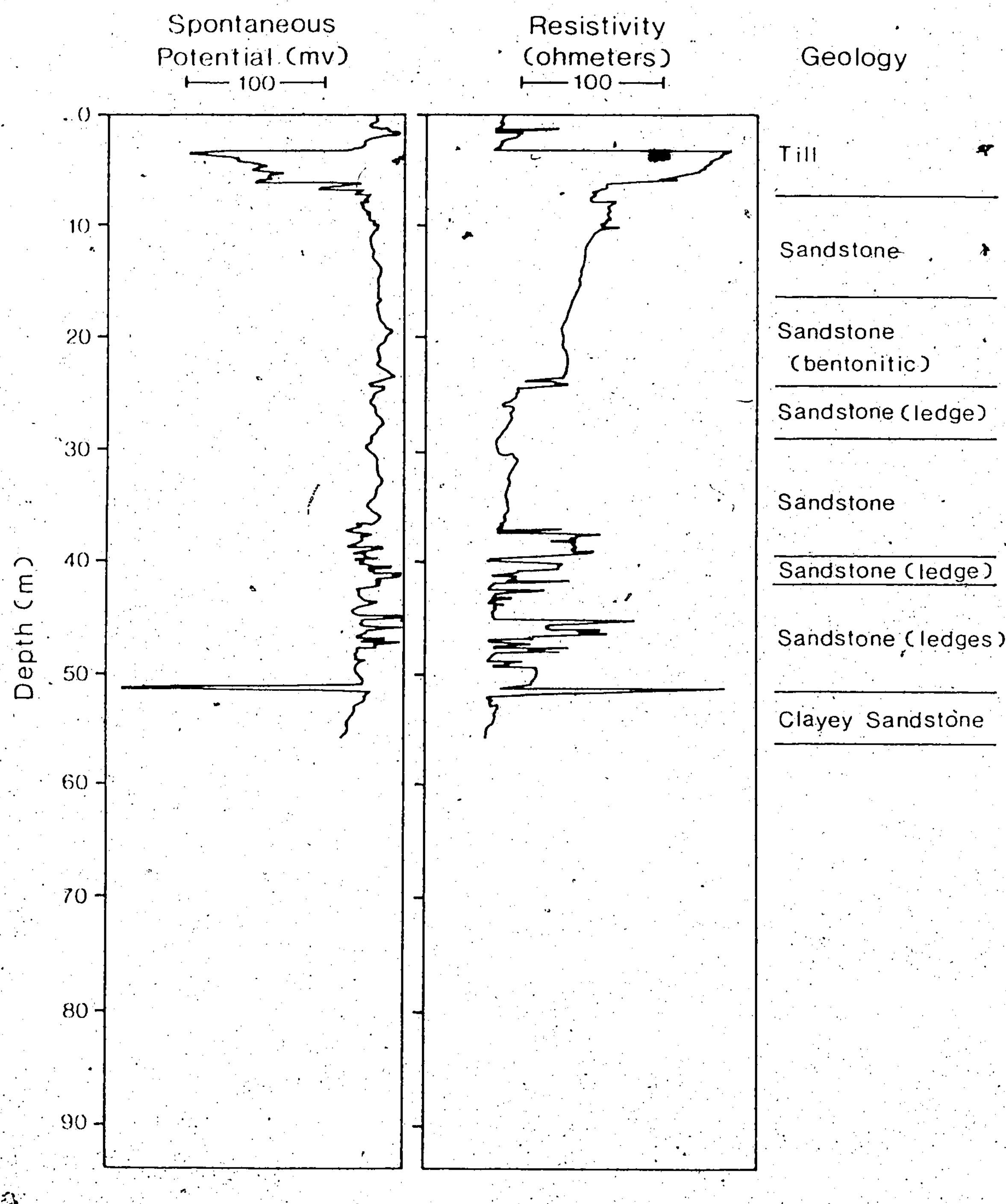
Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number MRRCS-6 (NE 3-2-15-4)					
0 - 0.30	Alluvium (SCL)	Dark Brown	SM		
0.30 - 0.60	Alluvium (GSCL)	Brown	SM		
0.60 - 0.90	Alluvium (GSL)	Yellowish Brown	D		
0.90 - 1.20	Alluvium (GLS)	Yellowish Brown	D		
1.20 - 2.70	Alluvium (G)	Dark Yellowish Brown	D		
2.70 - 3.00	Alluvium (GSL)	Dark Brown	M		
3.00 - 3.30	Alluvium (SL)	Olive Brown	VM		
3.30 - 4.60	Alluvium (LS)	Olive Brown	SAT		
Hole Number MRRCS-7 (SE 1-2-15-4)					
0 - 0.30	(CL)	Olive Brown	M		
0.30 - 0.60	Glaciofluvial (CL)	Pale Olive	SM		
0.60 - 2.40	Glaciofluvial (SiCL)	Dark Brown	M		
2.40 - 5.50	Till (CL-C)	Dark Brown	M		
5.50 - 8.20	Till (CL-C)	Olive Brown	M-SM		
Hole Number MRRCS-8 (NE 24-1-15-4)					
0 - 0.30	(CL)	Dark Brown	SM		
0.30 - 0.60	(CL)	Brown	SM		
0.60 - 0.90	(CL)	Yellowish Brown	D		
0.90 - 1.50	(SCL)	Light Yellowish Brown	D		
1.50 - 7.60	Till (CL)	Yellowish Brown	M		
7.60 - 9.10	Sandstone				
Hole Number MRRCS-9 (NW 6-1-14-4)					
0 - 0.80	(CL)	Brown	SM		
0.80 - 1.50	(CL)	Yellowish Brown	SM		
1.50 - 2.30	Till (SCL)	Olive	M		
2.30 - 5.30	Till (CL-C)	Olive Brown	M		
5.30 - 9.10	Till (C)	Dark Brown	M		
Hole Number MRRCS-10 (SW 1-2-15-4)					
0 - 0.60	(CL)	Yellowish Brown	D		
0.60 - 1.50	(CL)	Pale Brown	D		
1.50 - 2.20	Till (CL)	Olive Brown	SM		
2.20 - 3.00	Till (C)	Olive Brown	M		
3.00 - 3.80	Till (C)	Dark Grayish Brown	M		
3.80 - 4.60	(SL)	Dark Grayish Brown	VM		
4.60 - 6.10	Till (C)	Dark Gray	M		
6.10 - 9.10	Till (SCL)	Pale Brown	M		

Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number MRRCS-11 (SW 6-1-14-4)					
0 - 0.20	(CL)	Pale Brown	D		
0.20- 1.50	Till (CL)	Light Gray	SM		
1.50- 3.00	Till (CL)	Dark Grayish Brown	M		
3.00- 4.60	Till (CL)	Olive Brown	M		
4.60- 5.10	Till (SL)	Olive Brown	M		
5.10- 6.40	Till (C)	Dark Brown	M		
8.40- 9.10	Claystone	Light Brownish Gray	SM		
Hole Number MRRCS-13 (SE 5-1-14-4)					
0 - 0.30	(CL)	Brown	VM		
0.30- 0.60	(CL)	Light Olive Brown	VM-SAT		
0.60- 1.50	Till (CL-C)	Light Olive Brown	VM		
1.50- 3.00	Till (CL)	Olive Brown	VM-SAT		
3.00- 6.10	Till (CL)	Grayish Brown	SAT		
6.10- 9.10	Claystone	Gray	M-SM		
Hole Number MRRCS-14 (SE 8-2-14-4)					
0 - 1.00	(CL)	Brown	SM-M		
1.00- 1.50	(CL)	Pale Brown	M		
1.50- 2.40	Till (CL)	Light Olive Brown	M		
2.40- 3.00	Till (CL)	Olive Brown	M		
3.00- 3.70	Till (CL)	Dark Grayish Brown	M		
3.70- 4.60	Till (SCL)	Light Yellowish Brown	M		
4.60- 5.50	Sandstone	White	SM	Strong	
Hole Number MRRCS-16 (NW 33-1-14-4)					
0 - 0.30	Top Soil (CL)	Light Brownish Gray	F		
0.30- 0.60	Till (CL)	Light Gray	D		
0.60- 1.00	Till (CL)	Light Olive Brown	D		
1.00- 1.50	Till (CL)	Light Olive Brown	SM		
1.50- 6.70	Till (CL)	Olive Brown	SM-M		
6.70- 7.60	Claystone	Dark Grayish Brown	M		
Hole Number MRRCS-17 (SW 28-1-14-4)					
0 - 0.30	Top Soil (CL)	Yellowish Brown	F		
0.30- 1.00	(CL)	Light Yellowish Brown	D		
1.00- 1.20	Shale	Grayish Brown	D		Carbonaceous
1.20- 1.50	Shale	Dark Grayish Brown	SM		
1.50- 1.80	Shale	Grayish Brown	SM		
1.80- 2.40	Shale	Very Pale Brown	SM		
2.40- 2.70	Shale	Light Yellowish Brown	SM		
2.70- 3.00	Shale	Pale Brown	SM		
3.00- 4.60	Shale	Gray	SM		

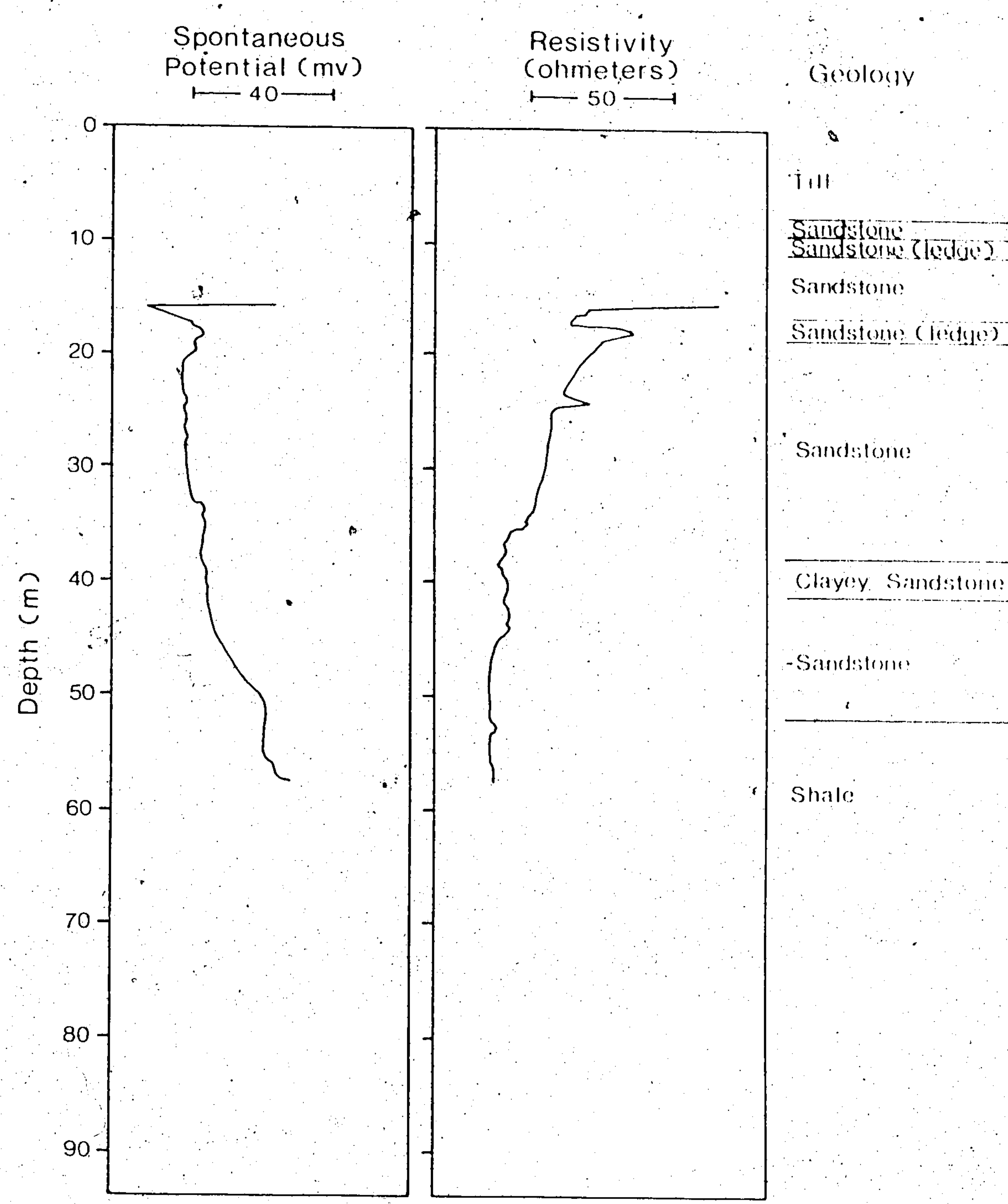
Depth (m)	Lithology	Colour	Moisture	$CaCO_3$	Other
Hole Number MRPC9-20 (SE 8-1-14-4)					
0 - 0.30	Topsoil (CL)	Brown	F		
0.30 - 1.80	Till (C)	Light Olive Brown	M		
1.80 - 3.00	Till (CL)	Olive Brown	M		
3.00 - 3.70	Till (SCL)	Olive Brown	VM-SAT		
3.70 - 6.70	Till (CL-C)	Dark Grayish Brown	M		
6.70 - 7.30	(SCL-SL)	Dark Grayish Brown	VM-SAT		
7.30 - 7.90	(SL)	Dark Gray	SAT		
7.90 - 9.10	Sandstone	Dark Gray	VM		

APPENDIX B

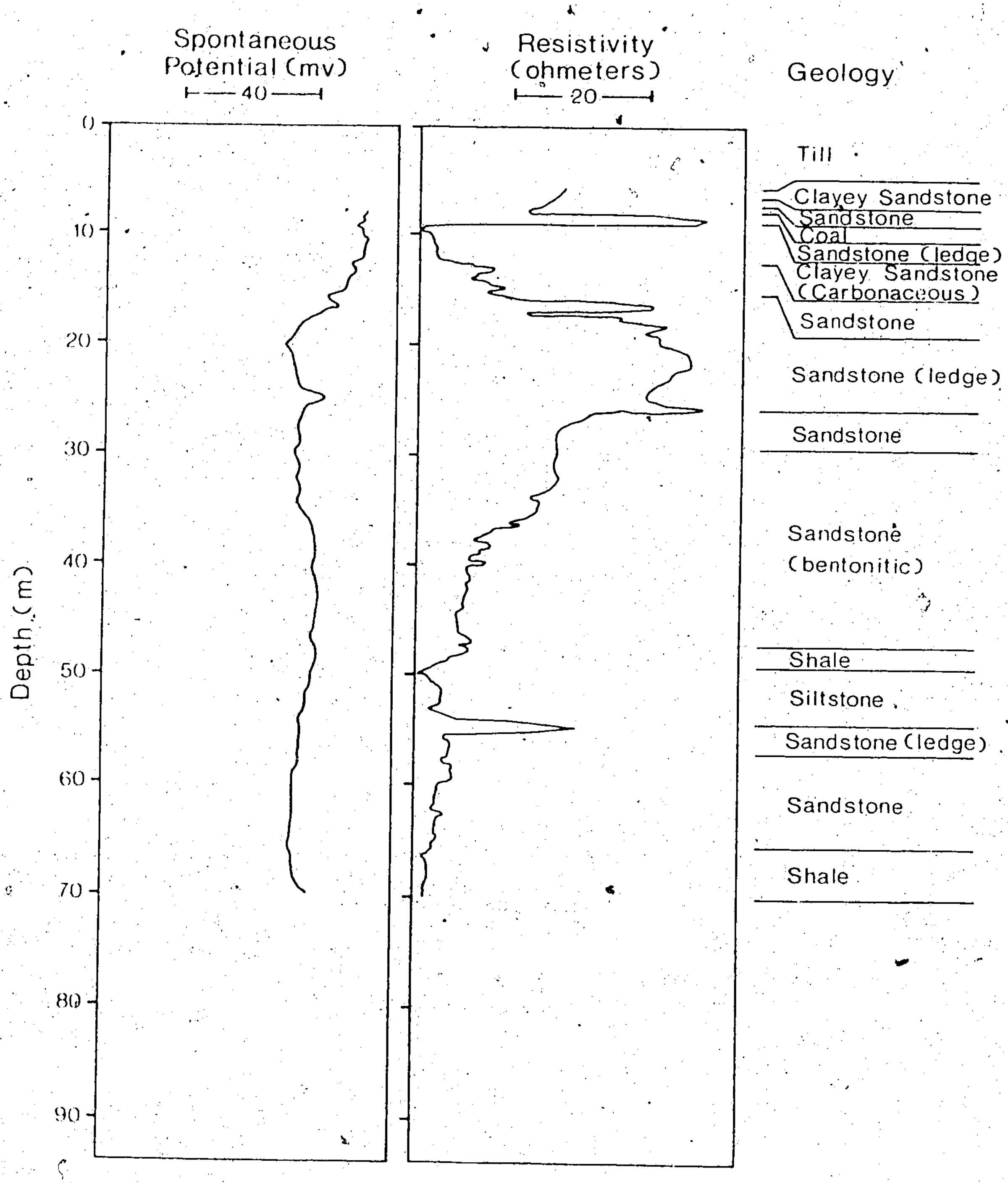
GEOPHYSICAL LOGS


Spontaneous Potential (mv)
100
Resistivity (ohmeters)
100
Geology
Depth (m)
0
10
20
30
40
50
60
70
80
90
Till
Sandstone
Sandstone (bentonitic)
Sandstone (ledge)
Sandstone
Sandstone (ledge)
Sandstone (ledges)
Clayey Sandstone

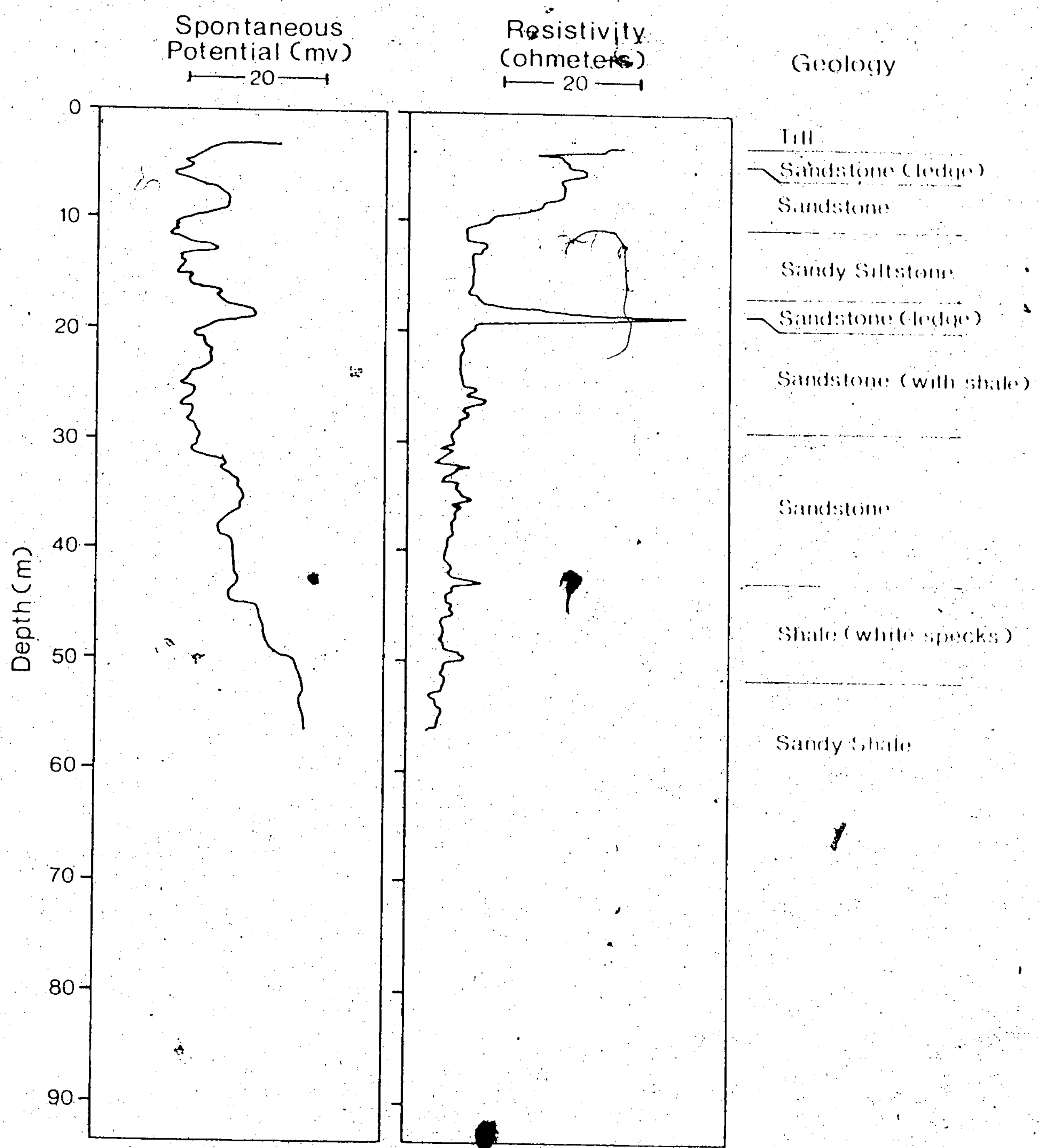
341-C


Spontaneous Potential (mv)
40
Resistivity (ohmeters)
50
Geology
Depth (m)
0
10
20
30
40
50
60
70
80
90
Till
Sandstone
Sandstone (ledge)
Sandstone
Sandstone (ledge)
Sandstone
Clayey Sandstone
Sandstone
Shale

342 - C

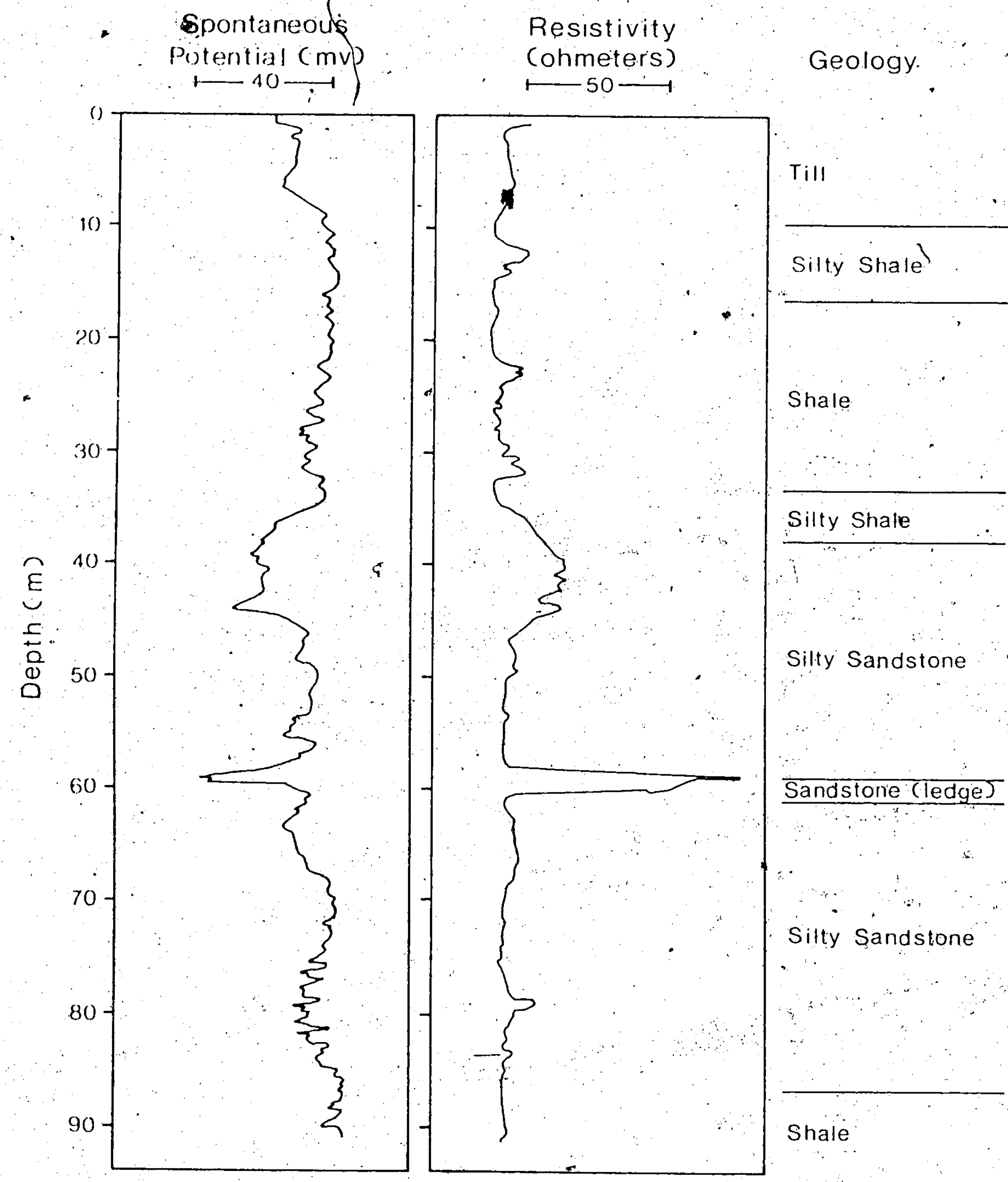

Spontaneous Potential (mv)
40
Resistivity (ohmeters)
20
Geology
Depth (m)
0
10
20
30
40
50
60
70
80
90
Till
Clayey Sandstone
Sandstone
Coal
Sandstone (ledge)
Clayey Sandstone (Carbonaceous)
Sandstone
Sandstone (ledge)
Sandstone
Sandstone (bentonitic)
Shale
Siltstone
Sandstone (ledge)
Sandstone
Shale

343 - C



Spontaneous Potential (mv)
20
Resistivity (ohmeters)
20
Geology
Depth (m)
0
10
20
30
40
50
60
70
80
90
Till
Sandstone (ledge)
Sandstone
Sandy Siltstone
Sandstone (ledge)
Sandstone (with shale)
Sandstone
Shale (white specks)
Sandy Shale

345-C


Spontaneous Potential (mv)
40
Resistivity (ohmeters)
50
Geology
Depth (m)
0
10
20
30
40
50
60
70
80
90
Till
Silty Shale
Shale
Silty Shale
Silty Sandstone
Sandstone (ledge)
Silty Sandstone
Shale

2067 - E

APPENDIX C

COMPLETION DETAILS OF GROUNDWATER INSTRUMENTATION

WATER ANALYSIS RESULTS - Continued

Borehole No. 343-C

Instrumentation No.		1			2		
Date/Property		Dec. 15 1982	Jan. 10 1984	Dec. 12 1984	Dec. 15 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		0.98	1.0	0.98	1.05	1.07	2.09
pH		7.86	8.04	7.76	7.89	7.82	8.43
Bicarbonate (HCO_3)		6.62	6.90	7.65	6.59	7.10	17.2
Carbonate (CO_3)		<0.01	<0.04	<0.01	<0.01	<0.04	0.76
Chlorides (Cl)		0.31	0.28	0.75	0.32	0.29	4.65
Sulfates (SO_4)		4.25	2.79	2.87	5.00	3.22	2.25
Phosphorous as P	- Total						
	- Soluble						
Nitrogen	Total Kjeldahl						
	Free Ammonia		6.4			6.1	
	Nitrite						
	Nitrate	0.01	<0.2	0.004	0.03	<0.2	0.008
Metals	Potassium (K)	0.16	0.14	0.17	0.17	0.15	0.14
	Magnesium (Mg)	2.80	2.58	1.99	3.22	2.58	1.25
	Calcium (Ca)	3.04	2.84	2.99	3.19	2.84	1.06
	Sodium (Na)	4.18	4.44	4.87	5.35	4.35	22.6
	Iron (Fe)		<0.01			<0.01	
	Manganese (Mn)		0.050			0.055	
SAR		2.44	2.69	3.09	2.99	2.64	21.0

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 345-C

Instrumentation No. 3

Date/Property		Dec. 15 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		8.76	8.04	9.12
pH		7.21	7.30	7.86
Bicarbonate (HCO_3)		21.1	18.36	22.3
Carbonate (CO_3)		<0.01	<0.04	<0.01
Chlorides (Cl)		1.62	1.42	2.14
Sulfates (SO_4)		84.2	82.56	115
Phosphorous as P	- Total			
	- Soluble			
Nitrogen	Total Kjeldahl			
	Free Ammonia		4.7	[illegible]
	Nitrite			
	Nitrate	[illegible]	3.2	2.7[illegible]
Metals	Potassium (K)	0.6[illegible]	0.54	0.66
	Magnesium (Mg)	29.3	22.22	28.6
	Calcium (Ca)	13.9	11.13	15.1
	Sodium (Na)	71.5	62.64	92.7
	Iron (Fe)		0.03	
	Manganese (Mn)		2.08	
SAR		15.5	15.34	16.5

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 3-C-83

Instrumentation No. 1

Date/Property		Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		7.73	8.29
pH		7.93	7.4
Bicarbonate (HCO_3)		18.4	17.9
Carbonate (CO_3)		<0.01	<0.01
Chlorides (Cl)		3.67	3.4
Sulfates (SO_4)		97.1	96.1
Phosphorous as P	- Total		
	- Soluble		
Nitrogen]	Total Kjeldahl		
	Free Ammonia		2.84
	Nitrite		
	Nitrate	0.05	<0.05
Metals]	Potassium (K)	0.56	0.49
	Magnesium (Mg)	47.2	44.6
	Calcium (Ca)	23.2	21.2
	Sodium (Na)	54.4	50.0
	Iron (Fe)		<0.02
	Manganese (Mn)		0.16
SAR		9.16	8.72

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 6-C-83

Instrumentation No.		1		2		3	
Date/Property		Jan. 10 1984	Dec. 12 1984	Jan. 10 1984	Dec. 12 1984	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		2.29	1.55	1.83	1.82	2.61	2.32
pH		7.90	8.16	7.54	8.00	7.61	7.98
Bicarbonate (HCO_3)		9.43	8.59	4.20	4.46	4.43	4.34
Carbonate (CO_3)		<0.04	<0.01	<0.04	<0.01	<0.04	<0.01
Chlorides (Cl)		0.54	0.31	0.25	0.27	0.09	0.16
Sulfates (SO_4)		13.76	8.29	18.63	19.8	28.90	27.1
Phosphorus as P	- Total						
	- Soluble						
Nitrogen	Total Kjeldahl						
	Free Ammonia	0.14		<0.10		<0.010	
	Nitrite						
	Nitrate	<0.02	0.13	<0.02	0.02	[illegible]	[illegible]
Metals	Potassium (K)	0.46	0.14	0.26	0.26	0.15	0.16
	Magnesium (Mg)	1.86	1.49	6.57	8.55	17.6	[illegible]
	Calcium (Ca)	1.43	1.53	11.53	12.3	10.93	[illegible]
	Sodium (Na)	19.81	14.5	2.48	3.22	2.48	[illegible]
	Iron (Fe)	<0.01		<0.01		<0.01	
	Manganese (Mn)	0.295		0.333		0.033	
SAR		15.74	11.8	0.82	1.00	0.60	[illegible]

Note: Concentrations ... [illegible] ... for Fe, Mn, and NH_4-N ... [illegible]

WATER ANALYSIS RESULTS - Continued

Borehole No. 7-C-83

Instrumentation No. 1

Date/Property		Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		4.67	5.54
pH		8.11	7.7
Bicarbonate (HCO_3)		9.69	11.7
Carbonate (CO_3)		<0.01	<0.01
Chlorides (Cl)		0.43	0.4
Sulfates (SO_4)		60.4	64.9
Phosphorous as P	- Total		
	- Soluble		
Nitrogen)	Total Kjeldahl		
	Free Ammonia		0.73
	Nitrite		
	Nitrate	0.46	0.12
Metals)	Potassium (K)	0.28	0.26
	Magnesium (Mg)	31.3	41.1
	Calcium (Ca)	11.2	10.7
	Sodium (Na)	23.9	26.1
	Iron (Fe)		<0.02
	Manganese (Mn)		0.05
SAR		5.19	5.[illegible]

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

APPENDIX I

RESULTS OF OXYGEN-18 AND DEUTERIUM ANALYSIS

RESULTS OF OXYGEN-18 AND DEUTERIUM ANALYSES

Borehole Number	Installation No.	Installation Elevation	Oxygen-18 Jan. 10, 1984	Oxygen-18 Sept. 23, 1985	Deuterium Jan. 10, 1984	Deuterium Sept. 23, 1985
5074 M	2	1037.14	- 19.50	- 20.09	- 160.0	- 162.2
	3	1043.65	- 20.00	- 18.56	- 160.0	- 150.4
	4	1044.20	- 18.10	- 18.03	- 157.0	- 148.6
	5	1047.48	- 18.00		- 155.0	
5075 M	1	1031.78	- 19.30	- 19.58	- 162.0	- 155.2
5076 M	1	1018.65	17.50	- 19.47	- 145.0	- 154.3
	2	1035.47	- 17.10	- 17.36	- 145.0	- 140.5
5079 M	1	926.42		- 14.50		- 110.3
	2	951.92		- 19.15		- 155.1
	5	978.38		- 19.95		- 156.1
5179 M	1	986.75	- 19.00	- 20.10	- 152.0	- 162.9
	2	994.70		- 21.69		- 167.1
	3	999.45		- 22.75		- 178.6
5181 M	2	1013.39		- 14.40		- 127.3
	3	1015.81		- 12.99		- 120.6
	4	1017.54		- 14.44		- 129.2
	5	1021.39		- 12.19		- 110.4
5182 M	1	990.60	- [illegible].00	- 19.72	- 152.0	- 157.4
	2	1009.81		- 19.18		- 155.8
	3	1013.59		- 20.60		- 162.9
5226 M	1	912.42		- 17.32		- 136.5
	2	926.77		- 16.39		- 127.3
	4	956.72		- 16.55		- 131.6
341 C	1	950.71	- 18.40	- 17.37	- 149.0	- 138.4
	2	952.05	- 18.50	- 16.49	- 150.0	- 126.2
	3	969.02	- 20.50	- 20.06	- 163.0	- 160.7
342 C	1	924.30	- 18.50	- 15.56	- 151.0	- 128.1
	2	944.07	- 18.50	- 14.64	- 151.0	- 118.8
	3	960.10	- 14.40	- 15.47	- 128.0	- 127.0
[illegible]	1	913.92	- 19.10	- 17.67	- 154.0	- 140.8
	2	929.54	- 19.10	- 18.56	- 154.0	- 148.2
[illegible]	1	968.47	- 19.50		- 155.0	
	2	996.16	- 20.00	- 20.36	- 158.0	- 164.8
345 C	1	985.01	19.80	- 18.70	- 155.0	149.5
	2	999.26	- 20.00	- 19.91	- 156.0	- 156.3
	3	1022.61	- 18.20	- 18.23	- 144.0	- 147.6
3-C 83	1	1001.97		- 21.16		- 166.5
6-C 83	1	958.30	18.90	- 20.90	- 153.0	164.5
	2	1011.29	20.30	- 20.91	- 162.0	- 162.8
	3	1017.42	20.30	21.64	- 151.0	- 166.4
[illegible] 83	1	1035.87		20.28		- 164.7
2066 E	1	1006.06	- 15.40	- 15.82	- 135.0	- 130.0
2067 E	1	1007.22		- 18.72		- 151.3
	2	1016.07	18.80	- 19.83	- 155.0	- 155.6
2068 E	2	1018.82		- 20.48		- 164.4
River				- 19.50		- 153.2
Snow				- 35.20		

APPENDIX J

RESULTS FROM PHREEQE

SITE	SATURATION INDICIES CALCITE	DOLOMITE	GYPSUM	pCO2x10-3	Ca:Mg RATIO
ALLUVIUM n=9					
5097-M-4	0.38	0.19	-1.49	2.34	2.39
5182-M-1	1.06	1.66	-0.98	2.45	1.90
5182-M-3	0.64	1.00	-0.13	1.62	1.25
5181-M-2	1.06	1.55	-0.80	2.88	2.40
5181-M-3	0.95	1.45	-0.52	3.39	1.83
5181-M-4	0.89	1.29	-1.09	2.82	2.07
5181-M-5	0.63	0.95	-1.03	2.82	1.33
6-C-83-1	0.43	0.66	-1.51	2.75	1.02
6-C-83-3	0.68	1.42	-0.43	1.91	0.57
X̄	0.75	1.13	-0.89	2.55	1.64
S	0.26	0.48	0.47	0.54	0.63
TILL n=9					
2069-E-1	1.01	1.87	0.05	4.79	0.97
5182-M-2	0.72	1.11	-0.13	2.04	1.41
5179-M-3	0.87	1.26	-0.82	7.24	1.98
6-C-83-2	0.79	1.24	-0.44	1.95	1.41
5074-M-2	1.49	2.27	0.12	1.86	3.47
5074-M-5	0.87	1.78	-0.10	2.88	0.63
5074-M-3	0.90	1.77	-0.12	3.39	0.70
5074-M-4	0.98	1.91	-0.07	3.72	0.75
5179-M-2	0.80	1.17	-1.15	5.25	1.74
X̄	0.94	1.60	-0.30	3.68	1.45
S	0.23	0.41	0.43	1.81	0.89
Kdc n=4					
5078-M-1	0.48	0.57	-0.97	1.23	1.70
5078-M-2	0.96	1.47	-0.04	5.89	2.13
2067-E-1	0.08	-0.12	-1.99	2.09	1.26
2067-E-2	0.88	1.51	-2.11	1.02	1.16
X̄	0.60	0.86	-1.28	2.56	1.56
S	0.41	0.78	0.97	2.27	0.45
Kv n=6					
5079-M-2	0.31	0.36	-1.62	6.61	1.21
344-C-2	0.81	1.33	-1.30	3.63	1.23
7-C-83-1	0.97	2.22	-0.31	3.02	0.35
3-C-83-1	1.28	2.71	0.04	8.13	0.49
5179-M-1	0.60	0.82	-1.17	5.89	1.55
342-C-3	-1.68	14.00	-2.77	15.85	2.81
X̄	0.38	0.57	-1.19	7.19	1.27
S	1.06	2.40	1.00	4.65	0.88

SITE	SATURATION INDICIES CALCITE	DOLOMITE	GYPSUM	pCO2x10-3	Ca:Mg RATIO
Ktc n=7					
5075-M-1	1.13	2.31	-0.21	6.17	0.61
345-C-3	1.06	2.24	-0.10	11.75	0.52
5226-M-2	0.15	-0.01	-1.78	1.91	1.33
341-C-2	0.97	1.63	-1.22	3.80	1.35
341-C-3	1.01	1.61	-0.58	5.25	1.73
342-C-2	0.71	1.13	-1.05	3.24	1.27
343-C-2	0.44	0.55	-1.28	3.39	1.36
$\overline{X}$	0.78	1.35	-0.89	5.07	1.17
S	0.37	0.86	0.61	3.26	0.44
Kc n=10					
5079-M-1	1.06	2.31	-1.25	0.20	0.43
2066-E-1	0.61	0.79	-1.33	2.09	2.05
345-C-2	0.86	1.60	-2.24	2.95	0.86
344-C-1	0.67	1.16	-0.89	5.25	1.00
343-C-1	0.26	0.30	-1.56	4.07	1.08
342-C-1	0.76	1.34	-1.65	4.37	0.97
341-C-1	1.02	1.92	-1.95	5.89	0.89
5226-M-1	0.03	-0.22	-1.84	2.34	1.23
5181-M-1	0.08	0.15	-2.26	0.95	0.67
345-C-1	0.51	0.53	-1.46	5.62	2.03
$\overline{X}$	0.59	0.99	-1.64	3.37	1.12
S	0.37	0.82	0.44	1.98	0.53

COMPLETION DETAILS OF GROUNDWATER INSTRUMENTATION - Continued

Borehole Number	Installation Number	Installation Type[a]	Installed By[b]	Total Length of Pipe (m)	Elevation of Tip (m)
[illegible]	1	P	ADA	65.20	912.42
	2	P	ADA	50.80	926.77
	3	P	ADA	41.40	936.26
	4	P	ADA	21.01	955.72
	5	W	ADA	8.85	968.65
[illegible]	1	P	ADE	91.44	1006.00
	2	W	CHI	2.09	1095.11
[illegible]	1	P	CHI	24.35	1007.22
	2	P	ADE	15.45	1016.02
	3	P	CHI	8.50	1023.07
	4	W	CHI	5.78	1025.77
[illegible]	1	P	CHI	22.63	1011.44
	2	P	CHI	15.32	1016.82
	3	W	CHI	5.47	1028.71
[illegible]	1	P	CAM	53.03	950.71
	2	P	CAM	47.85	957.05
	3	P	CAM	34.75	969.07
	4	P	CHI	16.39	968.27
	5	P	CHI	6.50	998.30
	6	W	CHI	5.17	999.58
[illegible]	1	P	CAM	61.26	924.34
	2	P	CAM	41.50	944.07
	3	P	CAM	25.70	960.10
	4	P	CAM	10.90	975.01
	5	P	CHI	6.83	979.04
	6	W	CHI	4.72	981.22
[illegible]	1	P	CAM	71.63	913.92
	2	P	CAM	56.08	929.54
	3	P	CAM	26.82	958.87
	4	P	CHI	8.80	976.89
	5	W	CHI	4.55	981.07
[illegible]	1	P	CAM	57.61	968.47
	2	P	CAM	29.87	996.16
	3	P	CHI	15.57	1010.53
	4	W	CHI	5.85	1020.17
[illegible]	1	P	CAM	57.61	985.01
	2	P	CAM	42.59	999.26
	3	P	CAM	20.42	1022.61
	4	P	CHI	10.60	1032.07
	5	W	CHI	3.64	1039.01
[illegible]	1	P	CHI	5.15	1030.70
	2	P	CHI	4.09	1031.85
	3	W	CHI	3.52	1032.48
[illegible]	1	P	CHI	19.76	1001.8
	2	P	CHI	4.65	1017.29
	3	W	CHI	2.85	1018.96
[illegible]	1	P	ADA	22.40	998.30
	2	P	CHI	11.90	1011.29
	3	P	CHI	5.90	1017.42
	4	W	CHI	3.36	1019.78
[illegible]	1	P	CHI	29.03	1025.81
	2	P	CHI	13.33	1040.5
	3	P	CHI	6.25	1047.86
	4	W	CHI	4.54	1049.54

[a] P - piezometer
W - water table well

[b] ADA - Alberta Department of Agriculture
ADE - Alberta Department of Environment
CHI - Chinako Drilling
CAM - Camfield Drilling

COMPLETION DETAILS OF GROUNDWATER INSTRUMENTATION

Borehole Number	Installation Number	Installation Type[a]	Installed By[b]	Total Length of Pipe (m)	Elevation of Tip (m)
5074-M	1	P	CHI	20.36	[illegible]
	2	P	ADA	18.25	[illegible]
	3	P	ADA	12.2[illegible]	[illegible]
	4	P	CHI	12.5[illegible]	[illegible]
	5	P	CHI	9.0[illegible]	[illegible]
	6	P	ADA	5.5[illegible]	[illegible]
	7	W	CHI	[illegible]	[illegible]
5075-M	1	P	ADA	20.[illegible]	[illegible]
	2	P	CHI	11.[illegible]	[illegible]
	3	P	CHI	8.50	[illegible]
	4	W	CHI	5.[illegible]	[illegible]
5077-M	1	P	ADA	14.[illegible]	[illegible]
	2	P	ADA	14.64	[illegible]
	3	P	ADA	10.[illegible]	[illegible]
5078-M	1	P	ADA	20.20	1011.[illegible]
	2	P	ADA	7.66	[illegible]
	3	W	CHI	6.10	[illegible]
5079-M	1	P	ADA	60.50	[illegible]
	2	P	ADA	35.30	[illegible]
	3	P	ADA	30.24	[illegible]
	4	P	ADA	21.00	[illegible]
	5	W	ADA	9.10	[illegible]
5142-M	1	P	CHI	6.8[illegible]	[illegible]
	2	W	ADA	[illegible].56	[illegible]
5143-M	1	P	CHI	9.3[illegible]	[illegible]
	2	W	ADA	6.00	[illegible]
5144-M	1	P	CHI	11.51	[illegible]
	2	P	ADA	7.81	[illegible]
	3	W	CHI	3.51	[illegible]
5179-M	1	P	ADC	22.95	[illegible]
	2	P	CHI	15.61	[illegible]
	3	P	CHI	10.23	[illegible]
	4	W	CHI	5.90	[illegible]
5180-M	1	P	ADA	13.15	[illegible]
	2	P	CHI	7.65	[illegible]
	3	W	CHI	5.90	[illegible]
5181-M	1	P	ADA	18.7[illegible]	[illegible]
	2	P	CHI	11.62	[illegible]
	3	P	CHI	9.33	[illegible]
	4	P	CHI	7.67	[illegible]
	5	W	CHI	3.16	[illegible]
5182-M	1	P	ADA	[illegible]	[illegible]
	2	P	CHI	[illegible]	[illegible]
	3	P	CHI	10.16	[illegible]
	4	W	CHI	[illegible]	[illegible]
5183-M	1	P	ADA	10.[illegible]	[illegible]
	2	P	CHI	6.5[illegible]	[illegible]
	3	W	CHI	[illegible]	[illegible]

APPENDIX D

HYDRAULIC CONDUCTIVITY AS DETERMINED BY SINGLE WELL RESPONSE TESTS

HYDRAULIC CONDUCTIVITY AS DETERMINED BY SINGLE WELL RESPONSE TESTS

Borehole Number	Installation No.	Installation Elevation	Hydraulic Conductivity (m/sec)	Texture	Formation
5074-M	2	1037.14	2.35×10^{-8}	Clay	Till
	3	1043.65	8.51×10^{-8}	Clay	Till
	4	1044.20	4.12×10^{-8}	Clay	Till
	5	1047.88	4.71×10^{-8}	Clay Loam	Till
5075-M	1	1031.78	9.29×10^{-7}	Sandstone	Telegraph Creek
5078-M	1	1018.65	5.57×10^{-10}	Sandy Mudstone	Deadhorse Coulee
	2	1039.47	3.80×10^{-9}	Sandy Mudstone	Deadhorse Coulee
5079-M	1	926.92	1.80×10^{-9}	Mudstone	Colorado
	2	951.92	2.41×10^{-7}	Sandstone	Vergille
	4	966.38	6.78×10^{-8}	Gravel	Alluvium
5179-M	1	986.75	5.14×10^{-8}	Sandstone	Vergille
	2	994.70	5.74×10^{-8}	Sandy Clay Loam	Till
	3	999.45	1.11×10^{-8}	Sandy Clay Loam	Till
5181-M	2	1013.39	3.19×10^{-7}	Sandy Clay Loam	Alluvium
	3	1015.81	2.26×10^{-8}	Sandy Clay Loam	Alluvium
	4	1017.54	1.91×10^{-7}	Sandy Clay Loam	Alluvium
5182-M	1	990.60	3.13×10^{-8}	Sandstone	[illegible]
	2	1009.81	6.88×10^{-8}	Clay Loam	Till
	3	1013.59	5.40×10^{-8}	Loamy Sand	Alluvium
5226-M	1	912.42	6.97×10^{-10}	Claystone	Colorado
	4	956.72	8.59×10^{-10}	Silty Claystone	Deadhorse Coulee
341-C	1	950.78	5.46×10^{-9}	Silty Mudstone	Colorado
	2	957.05	3.53×10^{-9}	Silty Mudstone	Telegraph Creek
	3	969.02	2.55×10^{-7}	Sandstone	Telegraph Creek
	4	988.27	1.56×10^{-7}	Sandstone	Vergille
342-C	1	924.34	2.67×10^{-8}	Sandy Mudstone	Colorado
	2	944.07	1.97×10^{-9}	Claystone	Telegraph Creek
	3	960.10	2.61×10^{-6}	Silty Sandstone	Vergille
343-C	1	913.92	3.19×10^{-8}	Shale	Colorado
	2	929.54	3.73×10^{-9}	Sandstone (Ledge)	Telegraph Creek
344-C	1	968.47	3.62×10^{-9}	Claystone	Colorado
	2	996.16	1.85×10^{-9}	Sandstone (Ledge)	Vergille
345-C	1	985.01	1.24×10^{-9}	Clayey Mudstone	Colorado
	2	999.20	1.53×10^{-9}	Clayey Mudstone	Colorado
	3	1022.61	1.45×10^{-7}	Silty Sandstone	Telegraph Creek
2-C-83	1	1030.78	6.76×10^{-7}	Sandstone	Deadhorse Coulee
6-C-83	1	[illegible]	2.19×10^{-7}	Sand and Gravel	[illegible]
	2	1011.29	3.38×10^{-6}	Clay Loam	Till
	3	1017.42	2.48×10^{-6}	Sand and Gravel	[illegible]
7-C-83	1	1025.87	1.06×10^{-7}	Sandstone	Vergille

APPENDIX E

GROUNDWATER ELEVATIONS

GROUNDWATER ELEVATIONS

Borehole Number	Installation No.	Installation Type	Installation Depth	Dec. 16 1981	Jan. 25 1982	Feb. 12 1982	March 2 1982	April 6 1982	May 2 1982	June 10 1982	June 29 1982
5075-M	1	P	29.57	1041.81	1041.87	1042.08	1042.07	1042.08	1042.07	1042.09	1042.01
	2	P	11.57								
	3	P	8.50								
	4	W	5.88								
5077-M	1	P	14.85	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	14.63								
	3	P	10.57								
5078-M	1	P	29.26	1018.84	1019.01	1019.73	1020.26	1021.26	1022.05	1022.88	1023.26
	2	P	8.66	1044.11	1043.83	1043.75	1043.63	1043.62	1043.72	1043.83	1043.9[illegible]
	3	W	6.10								
2066-E	1	P	91.44								
	2	W	2.09								
2067-E	1	P	24.35								
	2	P	15.45	1021.93	1021.92	1021.86	1021.85	1021.85	1021.91	1021.89	1021.91
	3	P	8.50								
	4	W	5.78								
341-C	1	P	53.03					986.90	986.90	986.80	986.80
	2	P	47.85					986.75	986.71	986.75	986.72
	3	P	34.75					986.20	986.20	986.20	986.20
	4	P	16.39								
	5	P	6.50								
	6	W	5.17								
342-C	1	P	61.26					969.70	969.43	969.55	969.45
	2	P	41.50					978.82	978.57	978.31	978.17
	3	P	25.70					973.00	964.02	964.09	964.12
	4	P	10.90								
	5	P	6.83								
	6	W	4.72								
343-C	1	P	71.63					983.75	983.59	983.45	983.33
	2	P	56.08					974.32	973.04	971.82	971.32
	3	P	26.82					DRY	DRY	DRY	DRY
	4	P	8.80								
	5	W	4.55								
344-C	1	P	57.61					1014.74	1014.58	1014.41	1014.31
	2	P	29.87					1005.82	1005.36	1005.14	1005.02
	3	P	15.57								
	4	W	5.85								
345-C	1	P	57.61					1028.16	1025.26	1022.96	1022.06
	2	P	43.59					1036.88	1035.10	1033.11	1032.22
	3	P	20.42					1024.89	1024.75	1024.74	1024.71
	4	P	10.60								
	5	W	3.64								

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	Aug. 9 1982	Sept.28 1982	Oct. 27 1982	Dec. 14 1982	Jan. 10 1983	Feb. 9 1983	Mar.23 1983	May 25 1983
5075 M	1	P	29.57	1042.22	1042.29	1042.48	1042.47	1042.37	1042.40	1042.34	1042.16
	2	P	11.57								
	3	P	8.50								
	4	W	5.88								
5077 M	1	P	14.85	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	14.63								
	3	P	10.57								
5078 M	1	P	29.26	1024.10	1024.58	1025.30	1021.10	1022.11	1023.25	1024.41	1024.81
	2	P	8.66	1043.88	1043.79	1043.88	1043.69	1043.61	1043.50	1043.32	1043.37
	3	W	6.10								
2066-F	1	P	91.44	1027.00							
	2	W	2.09								
2067-F	1	P	24.35								
	2	P	15.45	1021.76	1021.78	1021.81	1021.86	1021.87	1021.93	1021.89	1021.81
	3	P	8.50								
	4	W	5.78								
341 C	1	P	53.03	986.01	986.77	986.94	983.83	985.80	986.30	986.54	986.36
	2	P	47.85	986.71	986.74	986.81	986.78	986.80	986.85	986.84	986.81
	3	P	34.75	986.55	986.52	986.66	986.62	986.64	986.75	986.68	986.63
	4	P	16.39								
	5	P	6.50								
	6	W	5.17								
342 C	1	P	61.26	969.51	969.51	969.43	963.09	966.41	968.97	969.44	969.65
	2	P	41.50	977.95	977.93	977.51	968.52	969.06	969.12	969.12	969.04
	3	P	25.70	964.13	964.00	964.05	964.12	964.09	964.19	964.13	963.41
	4	P	10.90								
	5	P	6.83								
	6	W	4.72								
343 C	1	P	71.63	983.17	982.85	982.83	943.67	944.39	-	946.74	-
	2	P	56.08	970.52	969.81	969.54	965.60	966.33	966.89	967.47	967.04
	3	P	26.82	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	4	P	8.80								
	5	W	4.55								
344 C	1	P	57.61	1014.15	1013.85	1013.85	1003.88	1003.70	1003.81	1003.92	1002.98
	2	P	29.87	1004.91	1004.81	1004.77	1002.72	1004.02	1004.20	1004.29	1004.12
	3	P	15.57								
	4	W	5.85								
345 C	1	P	57.61	1020.57	1019.12	1018.60	1012.50	1012.71	1013.15	1013.56	1013.42
	2	P	43.59	1030.51	1024.50	1024.45	1110.33	1010.93	-	1012.39	1012.70
	3	P	20.42	1024.67	-	-	1024.48	1024.42	1024.38	1024.24	1024.10
	4	P	10.60								
	5	W	3.64								

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	June 14 1983	July 14 1983	Aug. 17 1983	Sept. 29 1983	Nov. 18 1983	Dec. 6 1983	Jan. 9 1984	Feb. 3 1984
5075-M	1	P	29.57	1042.10	1042.18	1041.26	1041.08	1040.86	1040.90	1040.56	1040.10
	2	P	11.57								DRY
	3	P	8.50								DRY
	4	W	5.88								DRY
5077-M	1	P	14.85	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	14.63								
	3	P	10.57								
5078-M	1	P	29.26	1025.19	1025.63	1026.03	1026.26	1026.22	1026.28	1026.13	1025.56
	2	P	8.66	1043.38	1043.39	1043.34	1043.13	1043.18	1043.16	1042.94	1042.[illegible]
	3	W	6.10								
2066-E	1	P	91.44	1027.00							
	2	W	2.09								
2067-E	1	P	24.35								
	2	P	15.45	1021.78	1021.75	1021.70	1021.69	1021.83	1021.83	1021.81	1021.81
	3	P	8.50								
	4	W	5.78								
341-C	1	P	53.03	986.45	986.54	986.58	986.61	986.63	986.64	986.58	986.15
	2	P	47.85	986.80	986.80	986.78	986.77	986.80	986.80	986.71	986.69
	3	P	34.75	986.58	986.66	986.64	986.56	986.66	986.66	986.54	986.47
	4	P	16.39								988.82
	5	P	6.50								DRY
	6	W	5.17								DRY
342-C	1	P	61.26	969.83	969.76	969.71	969.58	969.70	969.69	969.65	969.65
	2	P	41.50	969.04	969.03	969.03	969.00	969.05	969.05	969.15	968.27
	3	P	25.70	963.32	963.24	964.06	963.99	964.02	964.07	963.80	963.84
	4	P	10.90								
	5	P	6.83								DRY
	6	W	4.72								DRY
343-C	1	P	71.63			950.02	950.89	951.85	952.57	953.03	952.58
	2	P	56.08	967.21	967.42	967.62	967.77	967.95	967.97	968.19	967.80
	3	P	26.82	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	4	P	8.80								
	5	W	4.55								
344-C	1	P	57.61	1003.05	1003.15	1003.25	1003.36	1003.49	1003.58	1003.63	1003.15
	2	P	29.87	1004.23	1004.36	1004.86	1004.49	1004.53	1004.68	1004.53	1004.23
	3	P	15.57								DRY
	4	W	5.85								DRY
345-C	1	P	57.61	1013.62	1013.83	1014.05	1014.21	1014.38	1014.49	1014.51	1013.92
	2	P	43.59	1013.03	1013.22	1013.93	1014.38	1015.08	1015.25	1015.27	1014.92
	3	P	20.42	1024.18	1024.78	1024.63	1024.80	1024.65	1024.63	1024.35	1024.33
	4	P	10.60								DRY
	5	W	3.64								DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Installation Type	Installation Depth	March 22 1984	April 9 1984	May 2 1984	June 14 1984	Sept. 11 1984	Dec. 4 1984
5075-M	1	P	29.57	1040.16	1039.73	1039.57	1039.30	1038.64	1038.06
	2	P	11.57	DRY	DRY	DRY	DRY	DRY	DRY
	3	P	8.50	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	5.88	DRY	DRY	DRY	DRY	DRY	DRY
5077-M	1	P	14.89	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	14.63	DRY	DRY	DRY	DRY	DRY	DRY
	3	P	10.57	DRY	DRY	DRY	DRY	DRY	DRY
5078-M	1	P	29.26	1019.66	1019.91	1020.19	1020.71	1021.53	1022.08
	2	P	8.66	1042.74	1042.75	1042.67	1042.67	1042.67	1042.59
	3	W	6.10	1042.67	1042.82	1042.91	1043.73	DRY	DRY
2066-E	1	P	91.44				1027.00		
	2	W	2.09	DRY	DRY	DRY	DRY	DRY	DRY
2067-E	1	P	24.35	1007.60	1007.69	1008.02	1008.48	1008.97	1009.11
	2	P	15.45	1021.86	1021.86	1021.85	1021.75	1021.72	1021.75
	3	P	8.50	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	5.78	DRY	DRY	DRY	DRY	DRY	DRY
[illegible] C	1	P	53.03	986.33	986.32	986.32	986.47	986.49	986.42
	2	P	47.85	986.68	986.68	986.66	986.62	986.59	986.57
	3	P	34.75	986.47	986.48	986.47	986.47	986.44	986.41
	4	P	16.39	988.54	988.52	988.59	DESTROYED		
	5	P	6.50	DRY	DRY	DRY	DRY	DRY	DRY
	6	W	5.17	DRY	DRY	DRY	DRY	DRY	DRY
342-C	1	P	61.26	969.71	969.69	969.80	969.84	969.84	970.21
	2	P	41.50	968.93	968.99	969.04	969.05	969.07	969.01
	3	P	25.70	963.82	963.85	963.96	963.82	963.87	DESTROYED
	4	P	10.90	DRY	DRY	DRY	975.56	975.57	DESTROYED
	5	P	6.83	DRY	DRY	DRY	DRY	DRY	DRY
	6	W	4.72				DRY	DRY	DRY
343-C	1	P	71.63	952.75	952.60	952.94	954.42	955.71	956.55
	2	P	56.08	968.01	968.16	968.25	968.40	968.54	968.62
	3	P	26.82	DRY	DRY	DRY	DRY	DRY	DRY
	4	P	8.80	DRY	DRY	DRY	DRY	DRY	DRY
	5	W	4.55	DRY	DRY	DRY	DRY	DRY	DRY
344-C	1	P	57.61	1003.37	1003.32	1003.38	1003.48	1003.72	1003.90
	2	P	29.87	1004.35	1004.44	1004.48	1004.53	1004.57	1004.59
	3	P	15.57	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	5.85	DRY	DRY	DRY	DRY	DRY	DRY
345-C	1	P	57.61	1014.19	1014.26	1014.35	1014.47	1014.65	1014.71
	2	P	43.59	1015.30	1015.44	1015.59	1014.87	1016.26	1016.52
	3	P	20.42	1024.07	1024.22	1024.16	1024.10	1023.98	1023.91
	4	P	10.60	DRY	DRY	DRY	DRY	DRY	DRY
	5	W	3.64	DRY	DRY	DRY	DRY	DRY	DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	Jan. 28 1985	May 9 1985	Sept. 23 1985
5075-M	1	P	29.57	1037.83	1038.02	1037.24
	2	P	11.57	DRY	DRY	DRY
	3	P	8.50	DRY	DRY	DRY
	4	W	5.88	DRY	DRY	DRY
5077-M	1	P	14.89	DRY	DRY	DRY
	2	P	14.63	DRY	DRY	DRY
	3	P	10.57	DRY	DRY	DRY
5078-M	1	P	29.26	1019.88	1020.86	1021.83
	2	P	8.66	1042.28	1041.96	1042.09
	3	W	6.10	DRY	DRY	DRY
2066-E	1	P	91.44			
	2	W	2.09	DRY	DRY	DRY
2067-E	1	P	24.35	1008.52	1008.79	1008.33
	2	P	15.45	1021.78	1021.89	1021.59
	3	P	8.50	DRY	DRY	DRY
	4	W	5.78	DRY	DRY	DRY
341-C	1	P	53.03	985.39	986.29	988.46
	2	P	47.85	986.49	986.49	986.59
	3	P	34.75	986.37	986.29	985.80
	4	P	16.39			
	5	P	6.50	DRY	DRY	DRY
	6	W	5.17	DRY	DRY	DRY
342-C	1	P	61.26	963.49	968.47	970.20
	2	P	41.50	968.02	968.07	968.63
	3	P	25.70	963.85	964.02	963.80
	4	P	10.90		975.88	974.99
	5	P	6.83	DRY	DRY	DRY
	6	W	4.72	DRY	DRY	DRY
343-C	1	P	71.63	941.40	944.80	948.28
	2	P	56.08	968.21	968.73	968.67
	3	P	26.82	DRY	DRY	DRY
	4	P	8.80	DRY	DRY	DRY
	5	W	4.55	DRY	DRY	DRY
344-C	1	P	57.61	992.63	993.61	994.75
	2	P	29.87	1004.47	1004.57	1004.67
	3	P	15.57	DRY	DRY	DRY
	4	W	5.85	DRY	DRY	DRY
345-C	1	P	57.61	1010.07	1013.92	1014.75
	2	P	43.59	1010.77	1012.95	1014.80
	3	P	20.42	1023.79	1023.61	1023.97
	4	P	10.60	DRY	DRY	DRY
	5	W	3.64	DRY	DRY	DRY

GROUNDWATER ELEVATIONS

Borehole Number	Installation No.	Type	Depth	Jan. 10 1983	Feb. 9 1983	March 23 1983	May 2 1983	June 14 1983	July 14 1983	Aug. 17 1983	Sept.29 1983
5074-M	1	P	20.35								
	2	P	18.25	1039.91	1039.88	1039.78	1039.37	1039.36	1038.94	1039.02	1039.07
	3	P	12.25	1048.20	1048.32	1048.15	1047.97	1047.86	1047.85	1047.80	1047.69
	4	P	12.30								
	5	P	9.00								
	6	P	5.50	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	7	W	4.50		DRY	DRY	1052.32	1052.53	1052.43	1052.14	DRY
5142-M	1	P	4.83		DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	W	3.56	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5143-M	1	P	9.39								
	2	W	6.00		DRY	DRY	DRY	DRY	DRY	DRY	DRY
5144-M	1	P	11.51	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	7.81	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.51	DRY	DRY	DRY	DRY	DRY	DRY	1015.42	1015.42
2-C-83	1	P	5.15		1031.21	1031.17	1031.55	1031.58	1031.54	1031.41	1031.18
	2	P	4.09		DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.52		DRY	DRY	DRY	DRY	DRY	DRY	DRY
3-C-83	1	P	19.76								
	2	P	4.65		DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	2.85		DRY	DRY	DRY	DRY	DRY	DRY	DRY
6-C-83	1	P	22.40						1018.87	1018.84	1018.75
	2	P	11.90		1018.57	1018.64	1018.59	1018.74	1018.68	1018.50	1018.42
	3	P	5.90		1019.49	1019.50	1019.50	1019.85	1019.63	1019.31	1019.29
	4	W	3.36		DRY	DRY	DRY	DRY	DRY	DRY	DRY
7-C-83	1	P	29.03								
	2	P	13.33		DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	P	6.25		DRY	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	4.54		DRY	DRY	DRY	DRY	DRY	DRY	DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	Nov. 18 1983	Dec. 6 1983	Jan. 10 1984	Feb. 3 1984	March 22 1984	April 9 1984	May 2 1984
5074-M	1	P	20.35			DRY	DRY	DRY	DRY	DRY
	2	P	18.25	1039.03	1039.04	1038.93	1038.51	1038.54	1038.52	1038.54
	3	P	12.25	1047.74	1047.74	1047.66	1047.54	1047.49	1047.50	1047.54
	4	P	12.30			1051.54	1051.45	1051.43	1051.47	1051.58
	5	P	9.00			1051.64	1051.49	1051.43	1051.47	1051.55
	6	P	5.50	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	7	W	4.50	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5142-M	1	P	4.83	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	W	3.56	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5143-M	1	P	9.39				DRY	DRY	DRY	DRY
	2	W	6.00	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5144-M	1	P	11.51	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	7.81	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.51	DRY	DRY	1015.44	1015.46	1015.46	1015.45	1015.45
2-C-83	1	P	5.15	1031.03	1031.05	1030.90	1030.90	1030.91	1030.91	1030.93
	2	P	4.09	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.52	DRY	DRY	DRY	DRY	DRY	DRY	DRY
3-C-83	1	P	19.76				1011.60	1011.60	1011.60	1011.57
	2	P	4.65	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	2.85	DRY	DRY	DRY	DRY	DRY	DRY	DRY
6-C-83	1	P	22.40	1017.93	1017.92	1017.88	1017.83	1017.85	1017.86	1017.89
	2	P	11.90	1018.43	1018.45	1018.40	1018.37	1018.39	1018.44	1018.48
	3	P	5.90	1019.28	1019.28	1019.33	1019.31	1019.33	1019.41	1019.47
	4	W	3.36	DRY	DRY	DRY	DRY	DRY	DRY	DRY
7-C-83	1	P	29.03				1030.48	1030.48	1030.43	1030.43
	2	P	13.33	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	P	6.25	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	4.54	DRY	DRY	DRY	DRY	DRY	DRY	DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	June 14 1984	Sept. 11 1984	Dec. 3 1984	Jan. 28 1985	May 9 1985	Sept. 23 1985
5074 M	1	P	20.35	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	18.25	1038.54	1038.48	1038.41	1038.20	DRY	DRY
	3	P	12.25	1047.34	1047.34	1047.10	1047.23	1047.04	1046.86
	4	P	~~12~~.30	1051.58	1051.53	1051.18	1051.15	1051.00	1051.36
	5	P	9.00	1051.47	1051.52	1051.16	1051.16	1050.89	1051.16
	6	P	5.50	DRY	DRY	DRY	DRY	DRY	DRY
	7	W	4.50	DRY	DRY	DRY	DRY	DRY	DRY
5142 M	1	P	4.83	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	3.56	DRY	DRY	DRY	DRY	DRY	DRY
5143 M	1	P	9.39	DRY	DRY	DRY	DRY	DRY	DRY
	2	W	6.00	DRY	DRY	DRY	DRY	DRY	DRY
5144-M	1	P	11.51	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	7.81	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.51	1015.44	1015.45	1015.44	1015.46	1015.45	
2-C-83	1	P	5.15	1030.99	DRY	DRY	DRY	DRY	DRY
	2	P	4.09	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	3.52	DRY	DRY	DRY	DRY	DRY	DRY
3-C-83	1	P	19.76	1011.53	1011.47	1011.41	1011.35	1011.25	1011.10
	2	P	4.65	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	2.85	DRY	DRY	DRY	DRY	DRY	1018.97
6-C-83	1	P	22.40	1017.89	1017.82	1017.79	1017.63	1017.62	1017.74
	2	P	11.90	1018.39	1018.24	1018.17	1018.14	1018.21	1018.23
	3	P	5.90	1019.46	1019.18	1019.12	1019.15	1019.29	1019.19
	4	W	3.36	DRY	DRY	DRY	DRY	DRY	DRY
7-C-83	1	P	29.03	1030.33	1030.25	1030.07	1030.08	1029.93	1029.70
	2	P	13.37	DRY	DRY	DRY	DRY	DRY	DRY
	3	P	6.25	DRY	DRY	DRY	DRY	DRY	DRY
	4	W	4.54	DRY	DRY	DRY	DRY	DRY	DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation			Sept. 11 1984	Oct. 24 1984	Nov. 9 1984	Nov. 13 1984	Nov. 29 1984	Jan. 7 1985
	No.	Type	Depth						
5079-M	1	P	60.90	970.24	969.97	969.90	967.75	967.10	954.58
	2	P	35.30	958.70	957.92	957.87	957.90	957.87	957.39
	3	P	30.24	958.73	957.90	957.87	957.87	957.88	DRY
	4	P	21.00	985.31	983.25	982.79	979.85	978.98	DRY
	5	W	9.10	983.15	983.01	982.96	983.00	982.96	982.42
5226-M	1	P	65.20	957.70		955.25	955.07	954.44	940.51
	2	P	50.80	937.54		929.75	929.75	929.77	928.27
	3	P	41.40	950.81		DRY	DRY	DRY	DRY
	4	P	21.01	974.59		974.22	969.80	969.11	958.92
	5	W	8.85	969.29		968.85	968.84	968.74	DRY

GROUNDWATER ELEVATIONS - Continued

Borehole Number	Installation No.	Type	Depth	Jan. 28 1985	Feb. 20 1985	March 20 1985	May 9 1985	Sept. 16 1985	Nov. 16 1985
5075 M	1	P	60.90	955.01	955.04	955.07	955.14	955.27	955.32
	2	P	35.30	957.88	957.89	957.92	957.98	958.17	958.08
	3	P	30.24	957.83	957.87	[illegible].89	957.99	958.08	958.06
	4	P	21.00	967.58	967.55	967.53	967.45	967.40	967.38
	5	W	9.10	982.88	982.87	982.80	982.85	982.77	982.77
5226 M	1	P	65.20	940.49	940.47	940.44		940.44	971.11
	2	P	50.80	929.75	929.77	927.72		929.76	929.77
	3	P	41.40	DRY	DRY	DRY		DRY	DRY
	4	P	21.01	960.70	960.66	960.62		960.42	976.27
	5	W	6.8	DRY	DRY	DRY		DRY	DRY

GROUNDWATER ELEVATIONS

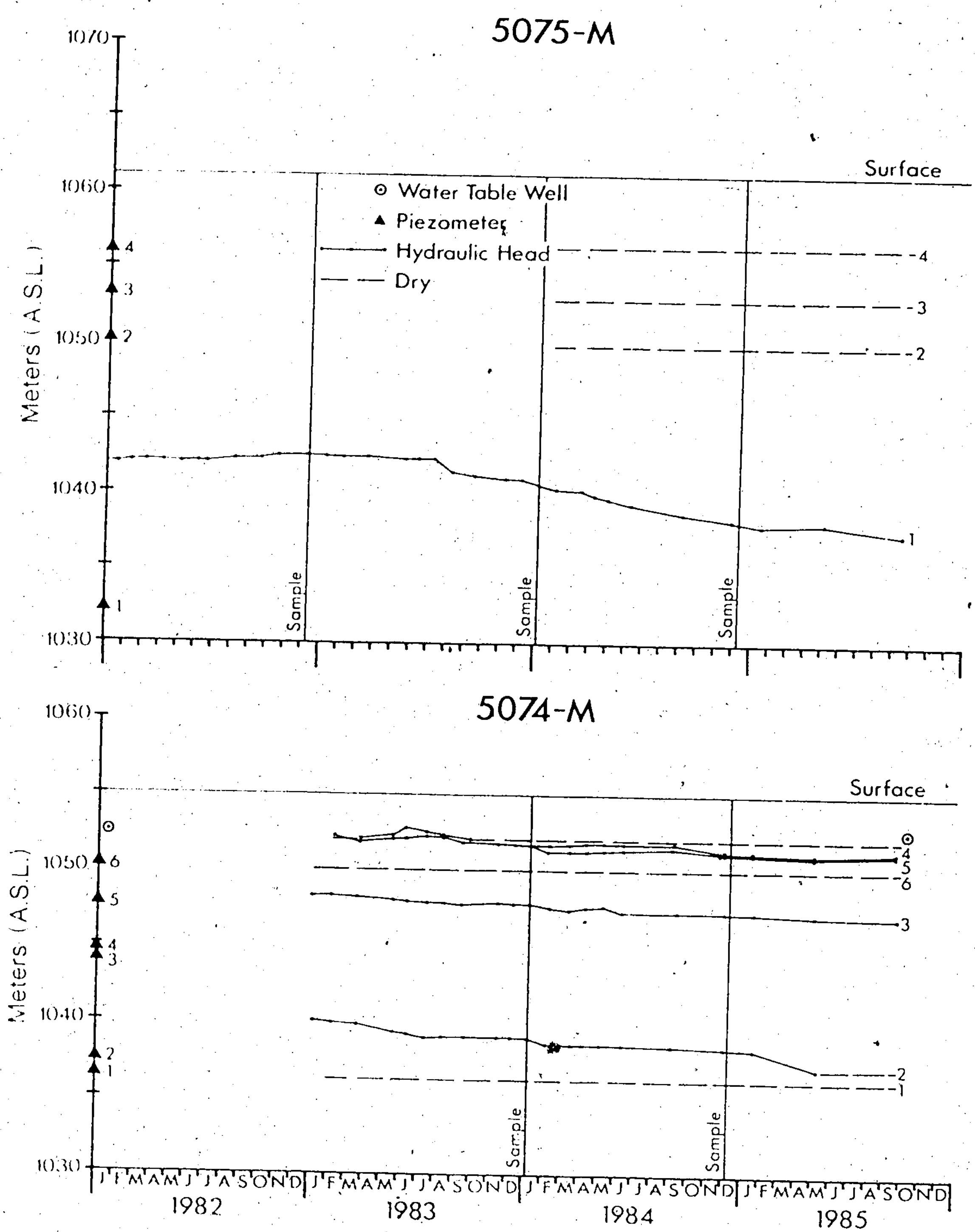
Borehole Number	Installation No.	Type	Depth	July 14 1983	Aug. 17 1983	Sept. 29 1983	Nov. 18 1983	Dec. 6 1983	Jan. 10 1984	Feb. 3 1984	Mar. 22 1984
5179-M	1	P	22.95	1006.13	1005.82	1005.61	999.85	999.86	999.86	999.85	999.89
	2	P	15.01							999.41	1000.15
	3	P	10.23							1000.11	1001.02
	4	W	5.90							DRY	DRY
5180-M	1	P	13.15	1008.77	1008.46	1008.21	999.88	999.84	995.74	995.68	999.58
	2	P	7.69							DRY	DRY
	3	W	5.90							DRY	DRY
5181-M	1	P	18.74	1026.45	----	----	FLOWING WELL				1026.15
	2	P	11.82							1022.70	1022.95
	3	P	9.33							1022.75	1022.96
	4	P	7.67							1022.70	1022.88
	5	W	3.86							1022.76	1022.88
5182-M	1	P	33.15	1013.29	1012.76	1012.63	1011.93	1012.34	1012.62	1012.42	1012.55
	2	P	13.93							1014.72	1014.72
	3	P	10.10							1014.83	1014.81
	4	W	4.65							DRY	DRY
5183-M	1	P	10.15	999.93	999.57	999.35	995.78	995.72	995.68	995.68	995.59
	2	P	6.51							DRY	DRY
	3	W	4.28							DRY	DRY
2069-E	1	P	22.63								
	2	P	15.32								
	3	W	5.47								

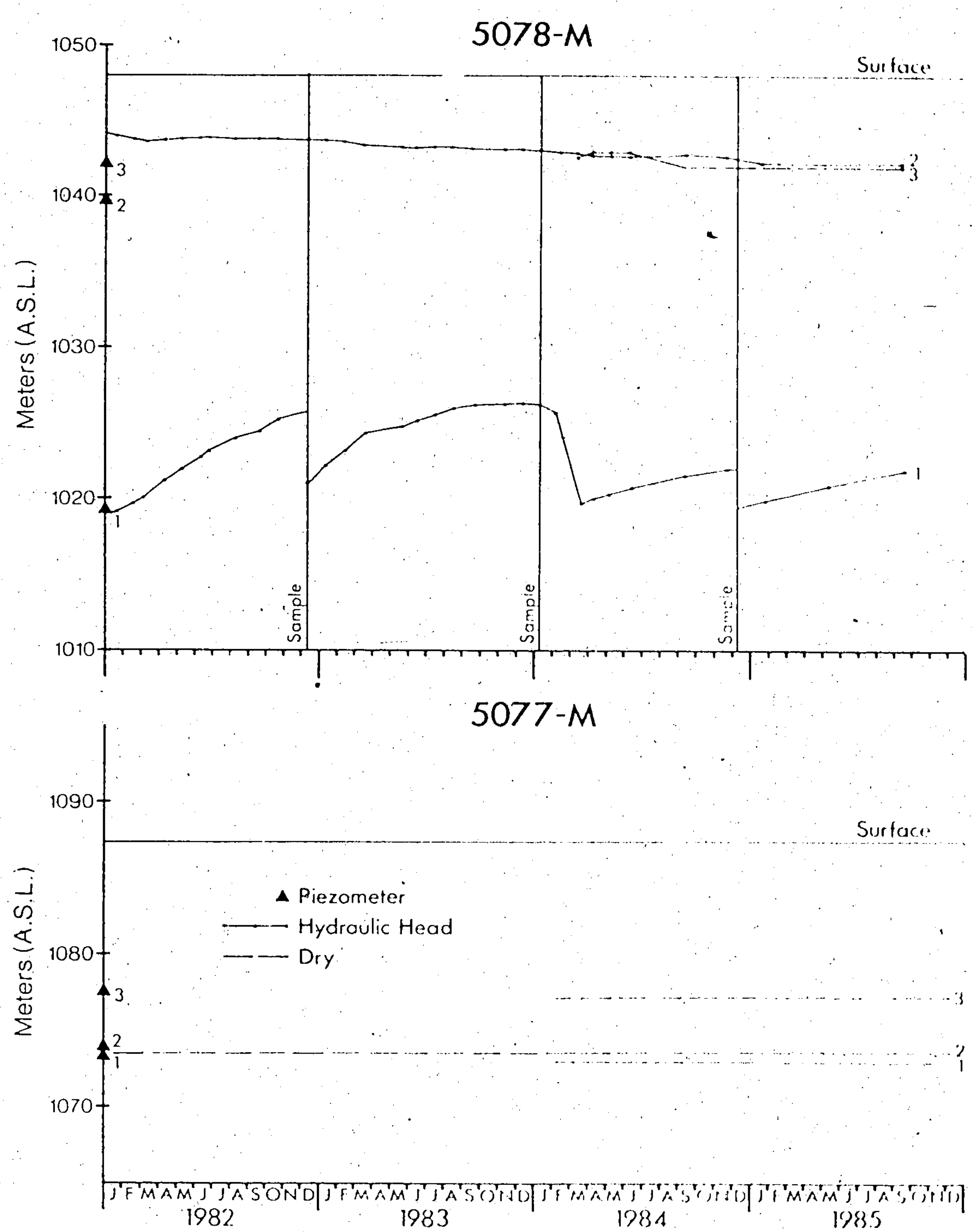
GROUNDWATER ELEVATIONS – Continued

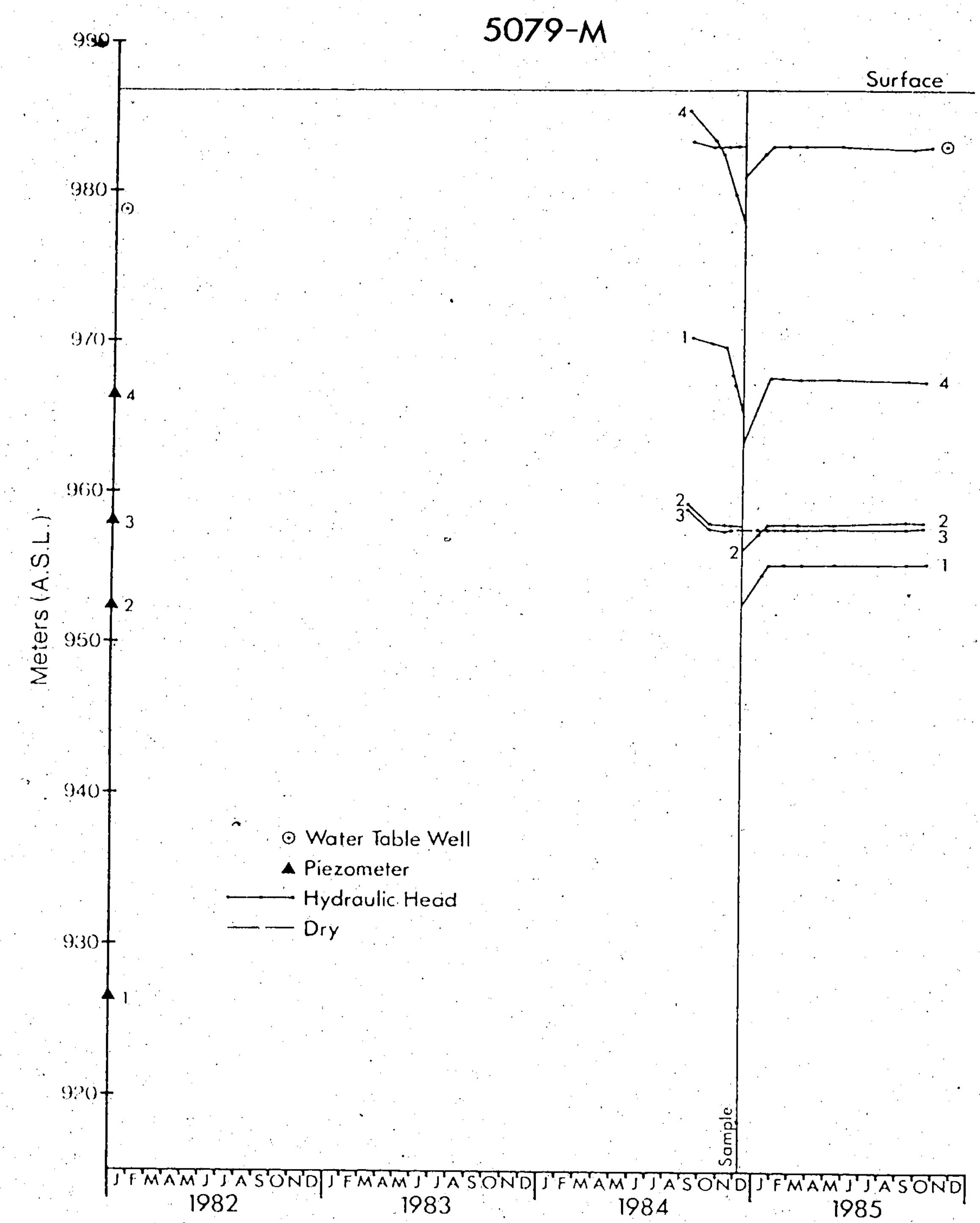
Borehole Number	Installation No.	Type	Depth	April 9 1984	May 2 1984	June 14 1984	Sept. 11 1984	Nov. 30 1984	Jan. 28 1985	May 9 1985
5179 M	1	P	22.95	997.87	999.85	999.86	999.84	999.82	999.70	999.70
	2	P	15.01	1000.16	1000.17	1000.18	1000.19	1000.12	1000.02	999.98
	3	P	10.23	1001.06	1001.02	1000.05	1001.00	1000.96	1000.85	1000.73
	4	W	5.90	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5180 M	1	P	13.15	999.57	999.55	999.50	999.41	DRY	DRY	DRY
	2	P	7.69	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	5.90	DRY	1004.73	1004.71	DRY	DRY	DRY	DRY
5181 M	1	P	18.74	FLOWING	1026.15	1026.15	FLOWING	FLOWING	FLOWING	FLOWING
	2	P	11.82	1023.07	1023.08	1022.77	1022.20	1022.33	1022.23	1022.54
	3	P	9.33	1023.01	1023.03	1022.78	1022.20	1022.35	1022.24	1022.54
	4	P	7.67	1023.04	1023.06	1022.79	1022.22	1022.35	1022.24	1022.61
	5	W	3.86	1022.97	1022.95	1022.79	1022.22	1022.35	1022.25	1022.58
5182 M	1	P	33.15	1012.62	1012.69	1012.80	1012.93	1013.00	1012.36	1012.60
	2	P	13.93	1014.74	1014.74	1014.69	1014.63	1014.55	1014.52	1014.43
	3	P	10.10	1014.81	1014.82	1014.78	1014.71	1014.64	1014.60	1014.51
	4	W	4.65	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5183 M	1	P	10.15	995.55	995.52	DRY	DRY	DRY	DRY	DRY
	2	P	6.51	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	3	W	4.28	DRY	DRY	DRY	DRY	DRY	DRY	DRY
206[illegible] I	1	P	22.63	DRY	DRY	DRY	DRY	DRY	DRY	DRY
	2	P	15.32		1027.28	1027.16	1027.29	1027.30	1027.24	1027.11
	3	W	5.47		DRY	DRY	DRY	DRY	DRY	DRY

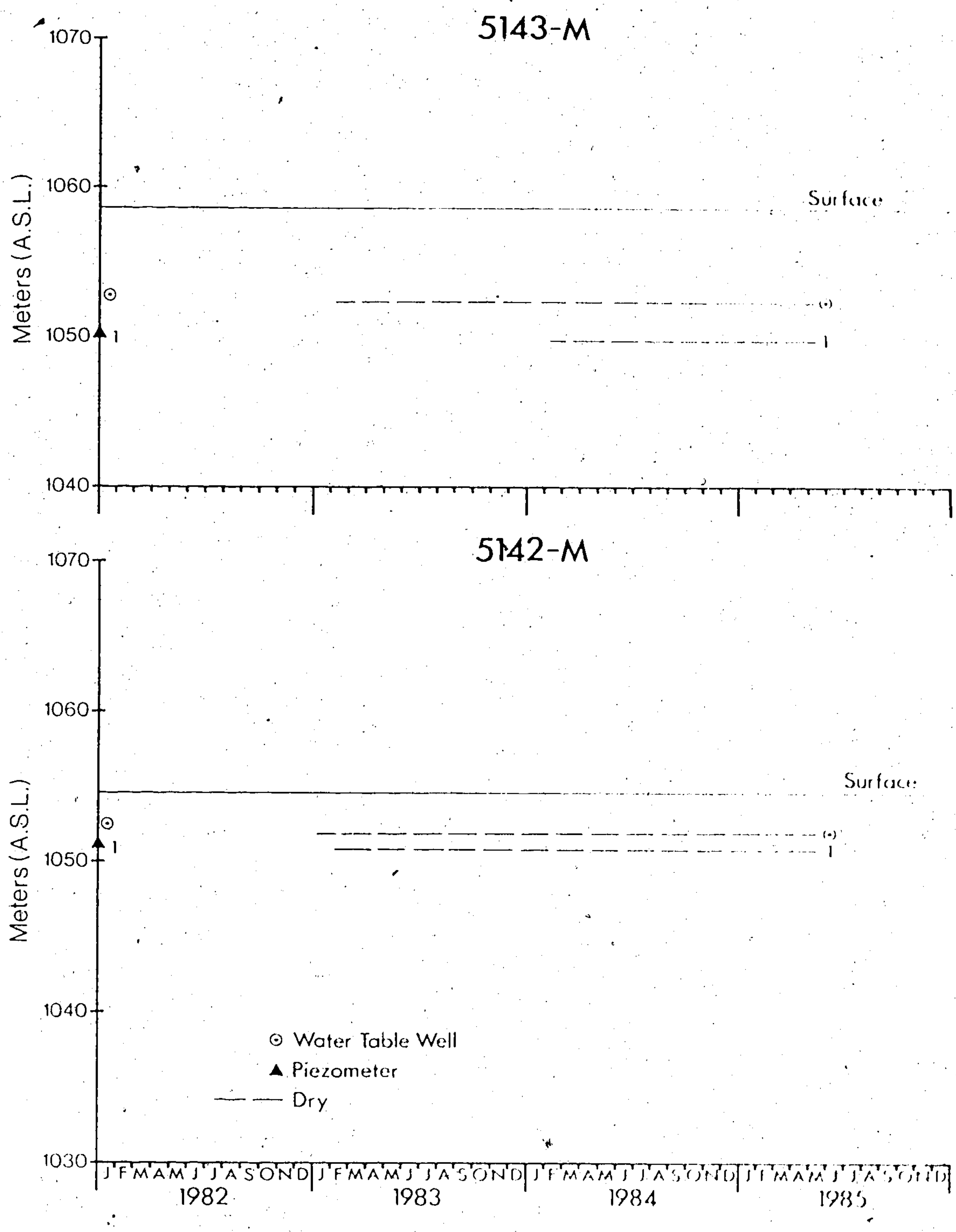
APPENDIX F

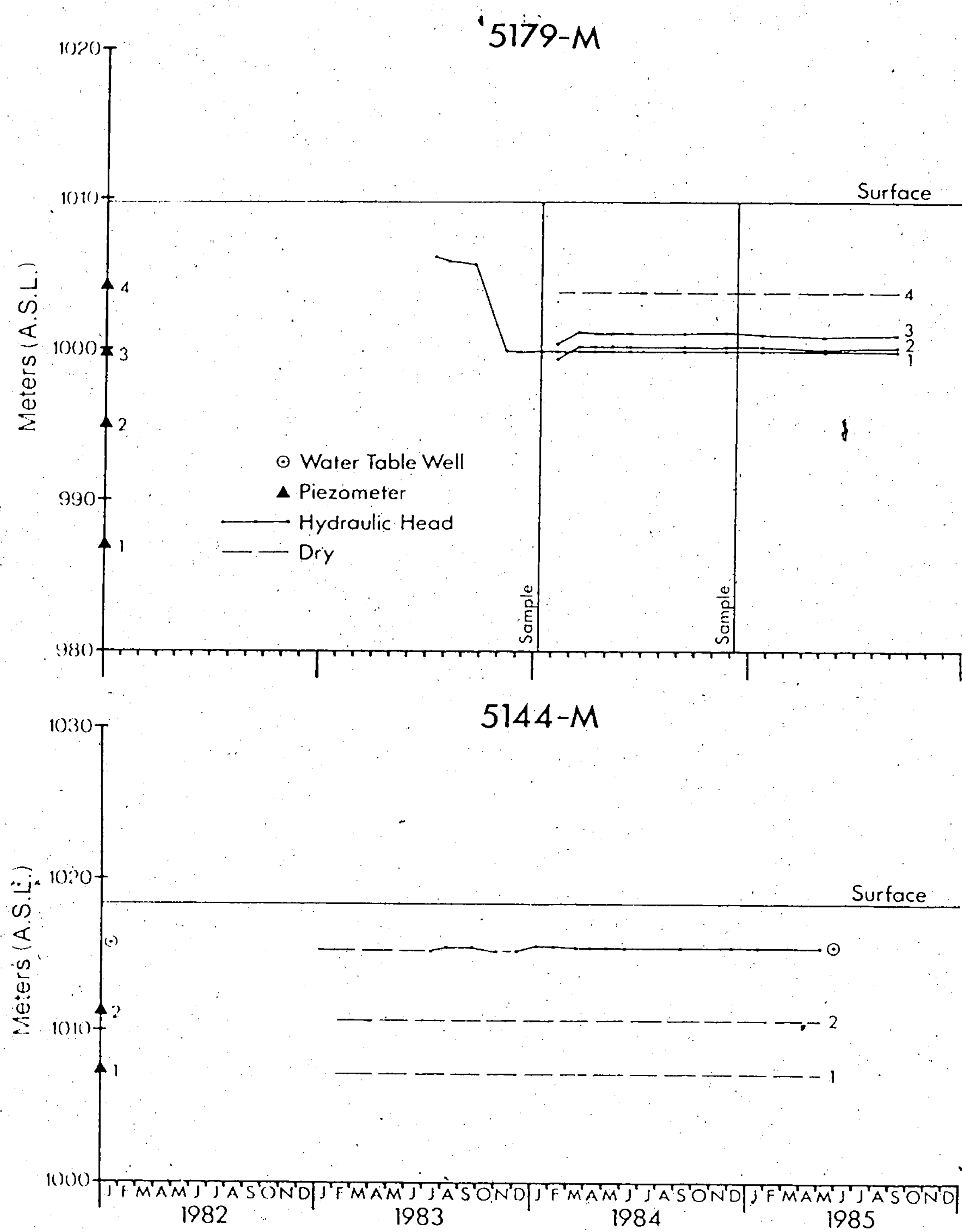
HYDROGRAPHS

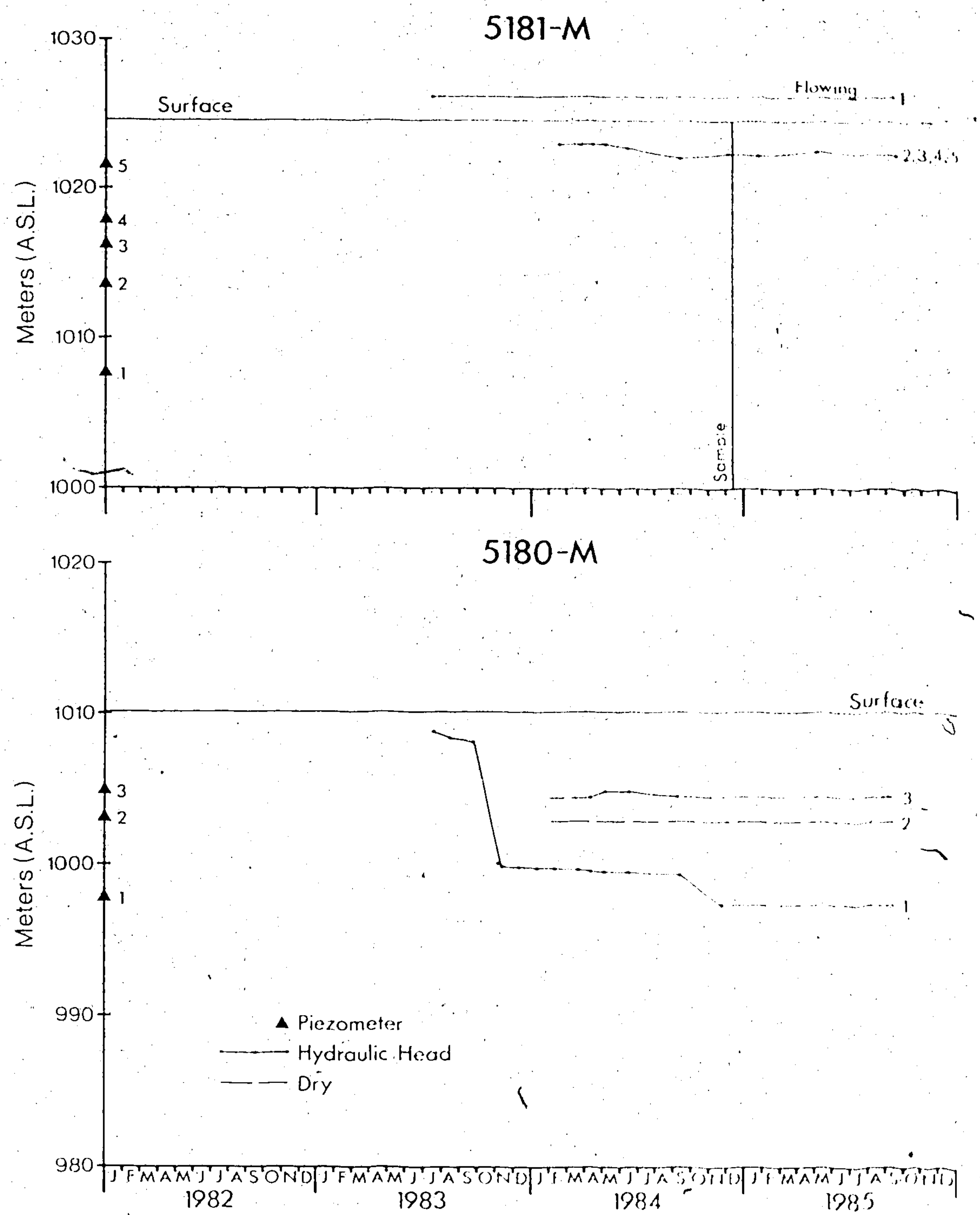

5075-M
Surface
Water Table Well
Piezometer
Hydraulic Head
Dry
Meters (A.S.L.)
1070
1060
1050
1040
1030
Sample
Sample
Sample
4
3
2
1
5074-M
Surface
1060
1050
1040
1030
6
5
4
3
2
1
Sample
Sample
J F M A M J J A S O N D
1982
1983
1984
1985


5078-M
Surface
1050
1040
1030
1020
1010
Meters (A.S.L.)
Sample
Sample
Sample
5077-M
Surface
1090
1080
1070
Meters (A.S.L.)
Piezometer
Hydraulic Head
Dry
J F M A M J J A S O N D
1982
1983
1984
1985


5079-M
Surface
Meters (A.S.L.)
990
980
970
960
950
940
930
920
Water Table Well
Piezometer
Hydraulic Head
Dry
Sample
J F M A M J J A S O N D
1982
1983
1984
1985


5143-M
1070
1060
1050
1040
Meters (A.S.L.)
Surface
1
5142-M
1070
1060
1050
1040
1030
Meters (A.S.L.)
Surface
1
Water Table Well
Piezometer
Dry
J F M A M J J A S O N D
1982
1983
1984
1985


5179-M
1020
1010
1000
990
980
Meters (A.S.L.)
Surface
4
3
2
1
Water Table Well
Piezometer
Hydraulic Head
Dry
Sample
Sample
5144-M
1030
1020
1010
1000
Meters (A.S.L.)
Surface
2
1
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1982
1983
1984
1985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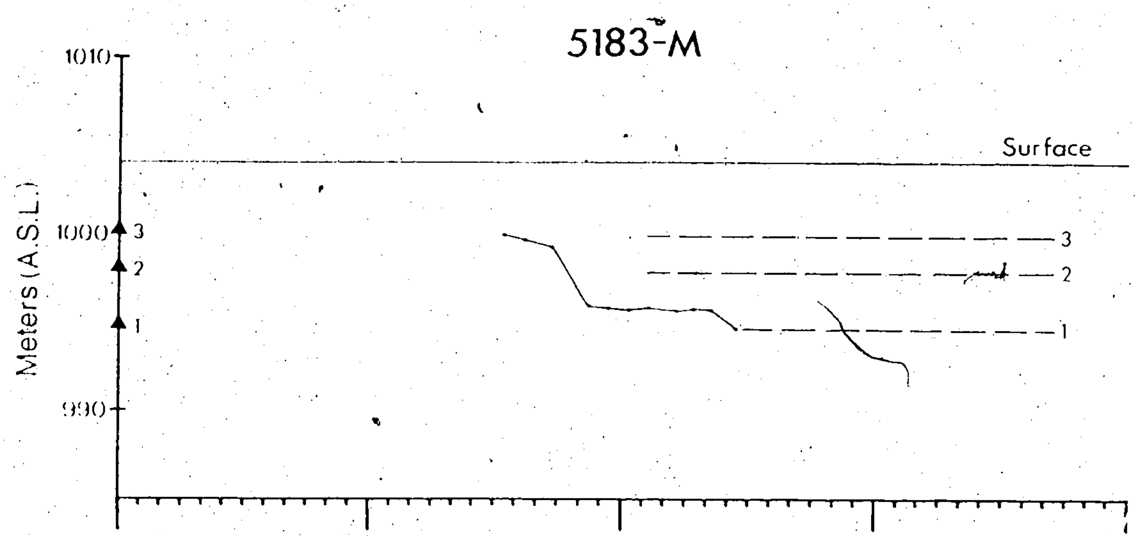
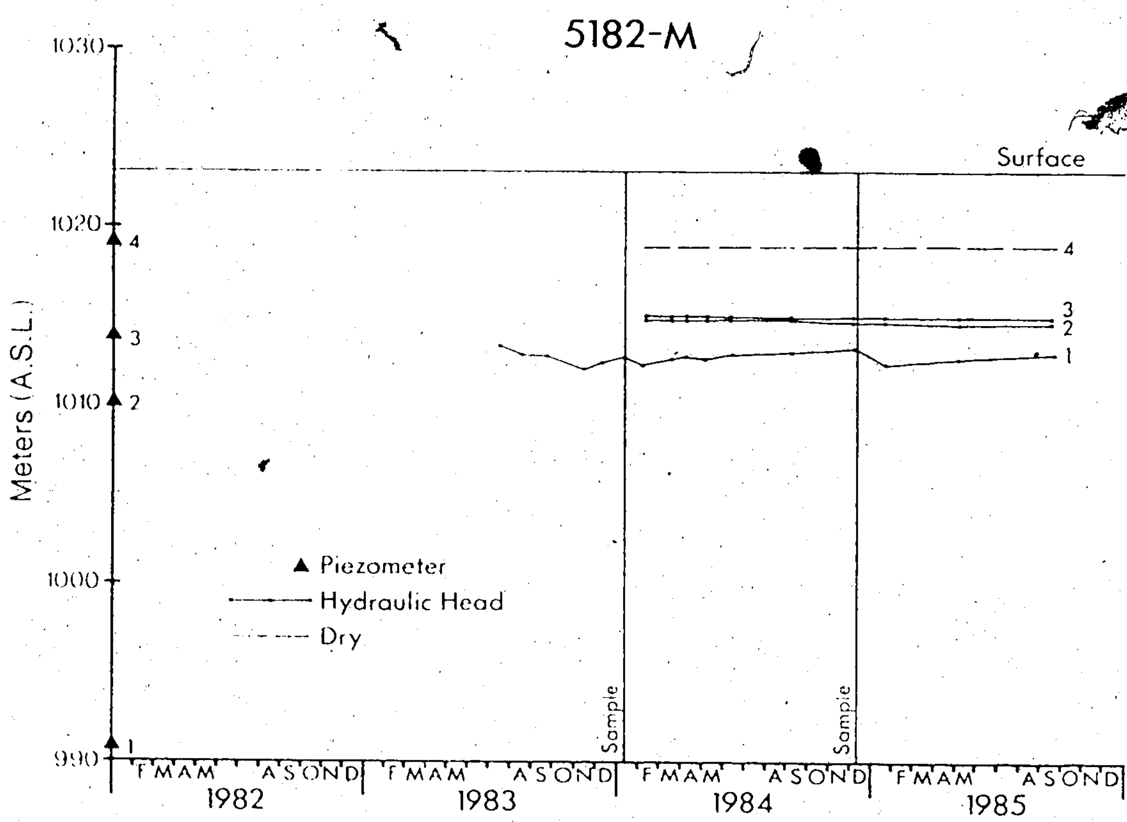
1030
1020
1010
1000
Meters (A.S.L.)
Surface
Flowing
1
2,3,4,5
5
4
3
2
1
Sample
5180-M
1020
1010
1000
990
980
Surface
3
2
1
Piezometer
Hydraulic Head
Dry
J F M A M J J A S O N D
1982
1983
1984
1985


5183-M
Surface
Meters (A.S.L.)
1010
1000
990
3
2
1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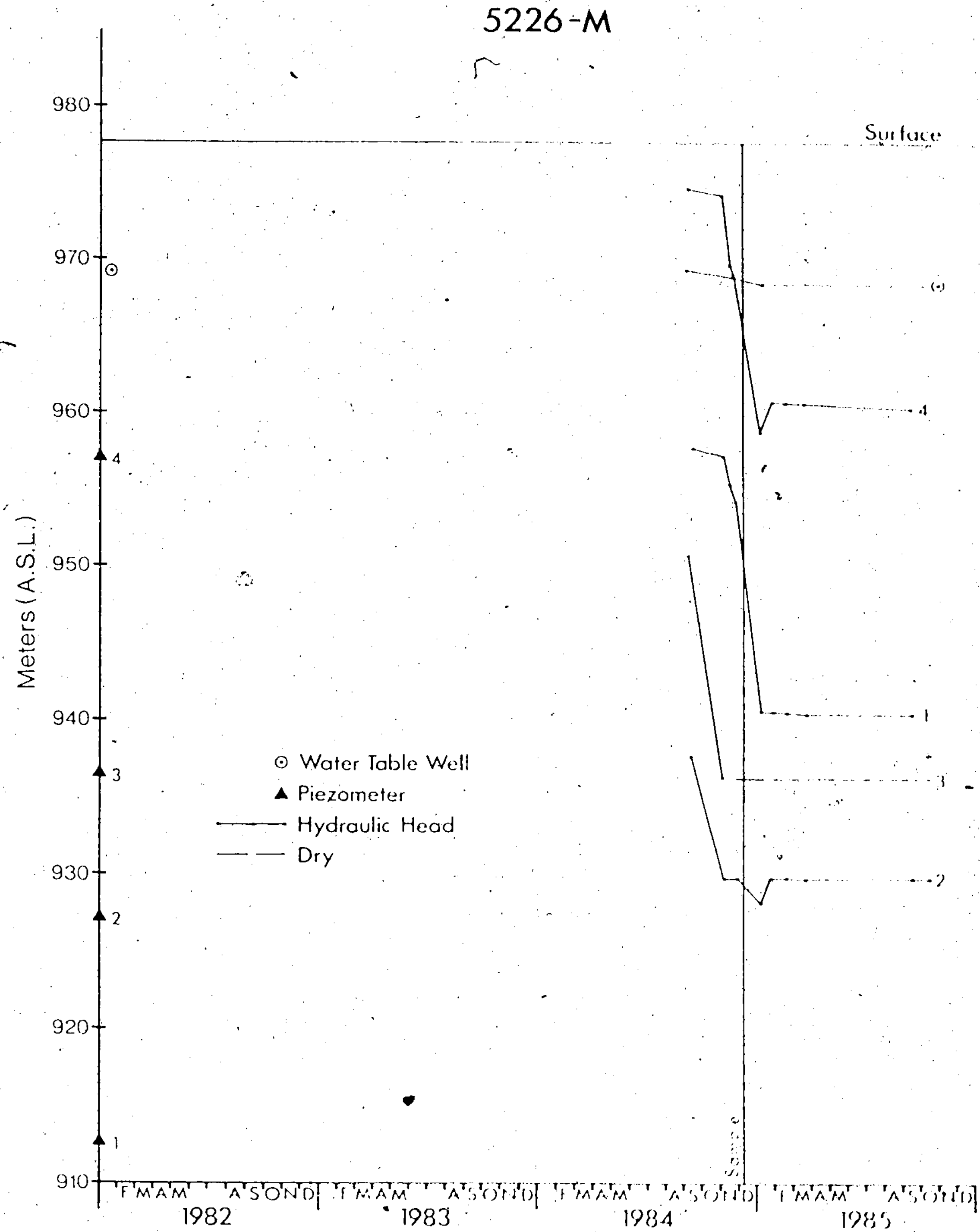
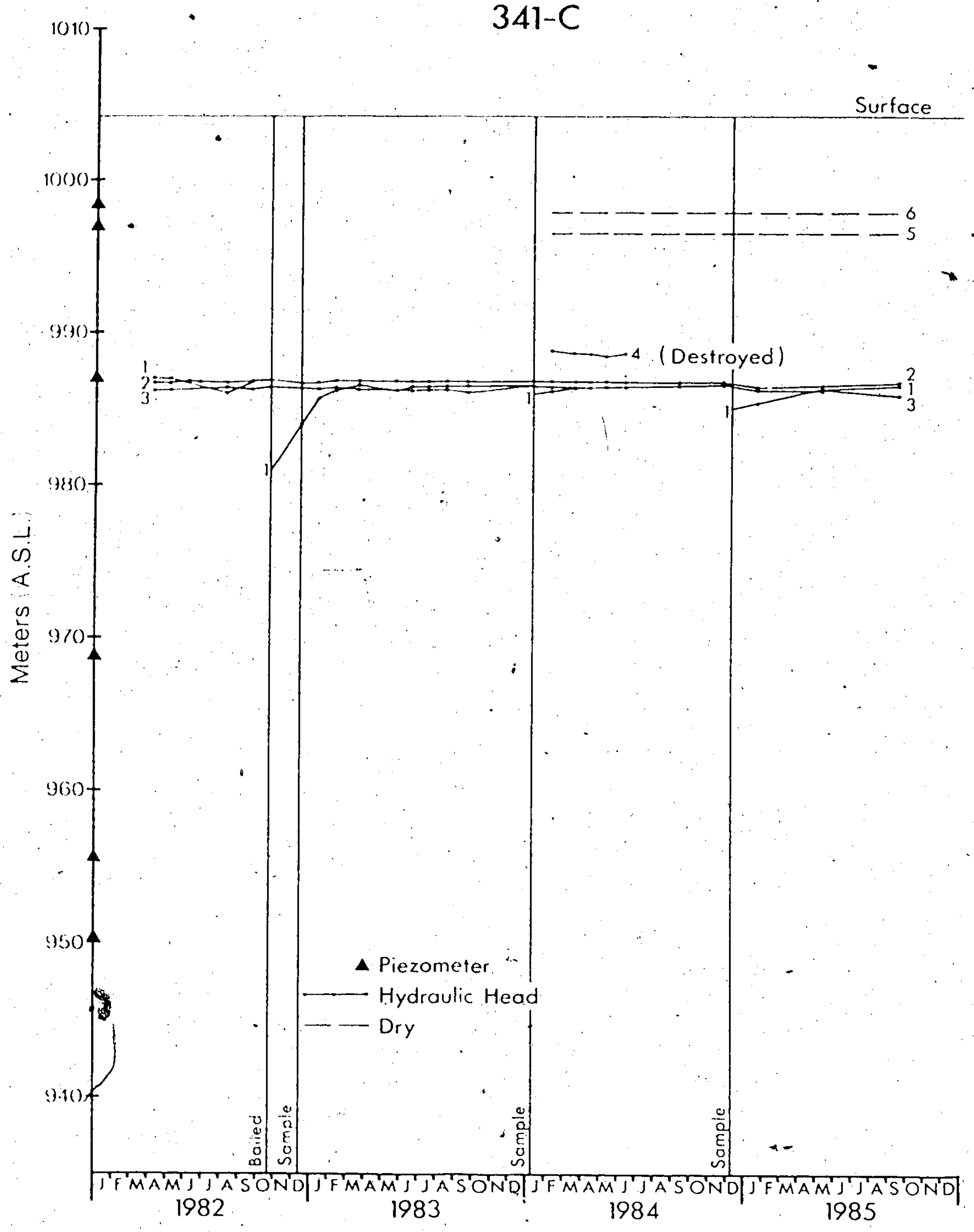
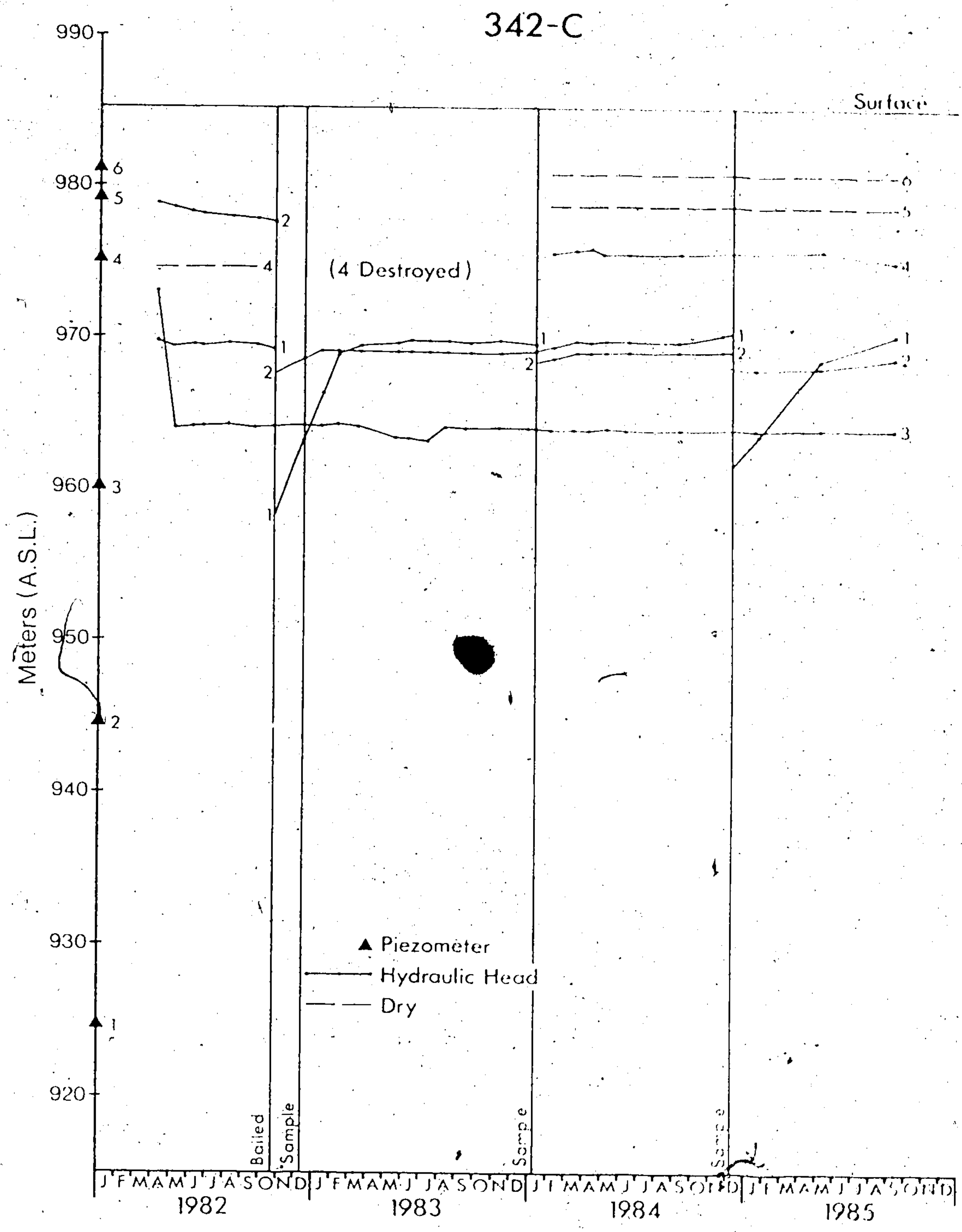
Surface
Meters (A.S.L.)
1030
1020
1010
1000
990
4
3
2
1
Piezometer
Hydraulic Head
Dry
Sample
Sample
F M A M A S O N D
1982
1983
1984
1985

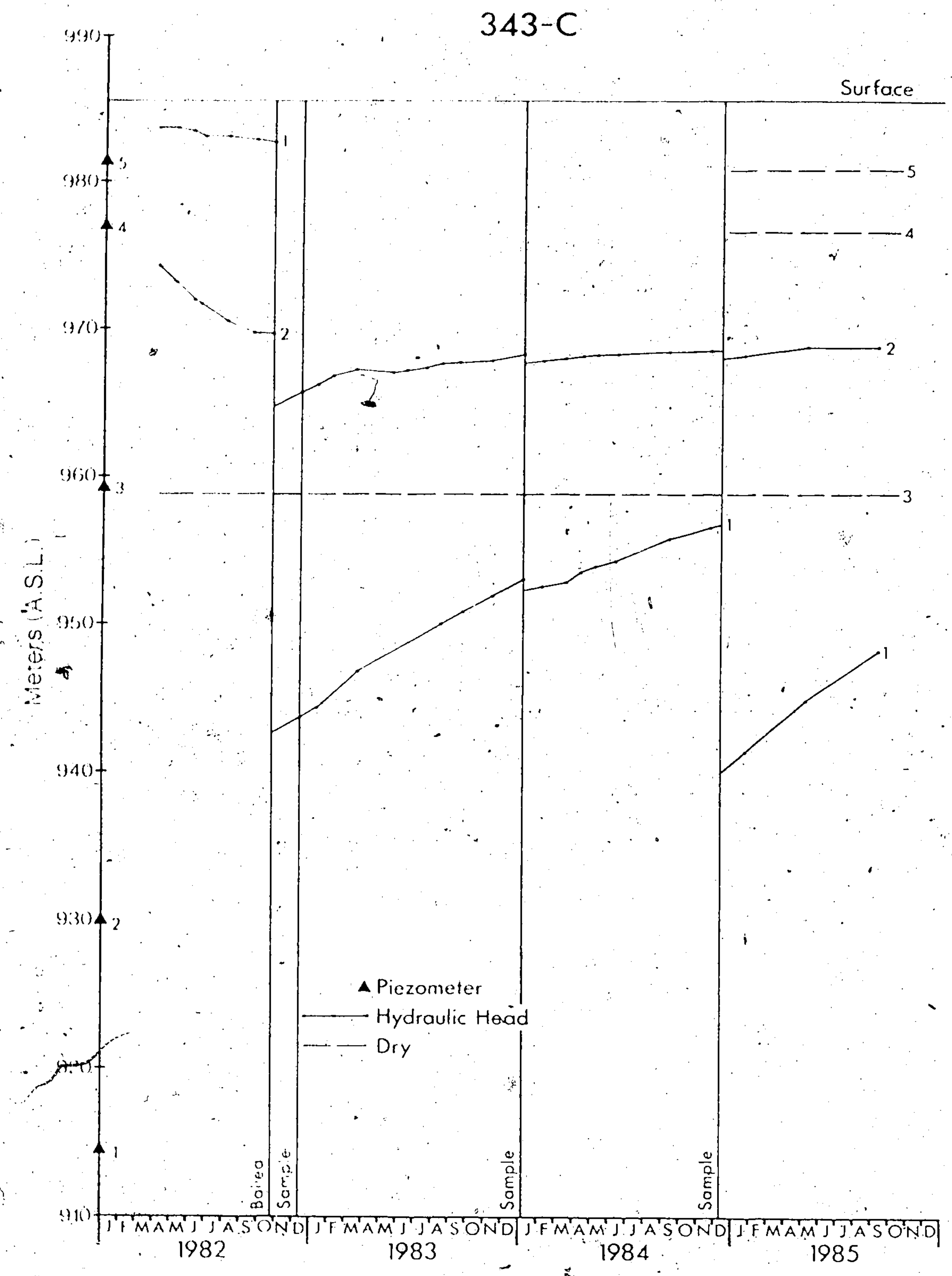
5226-M

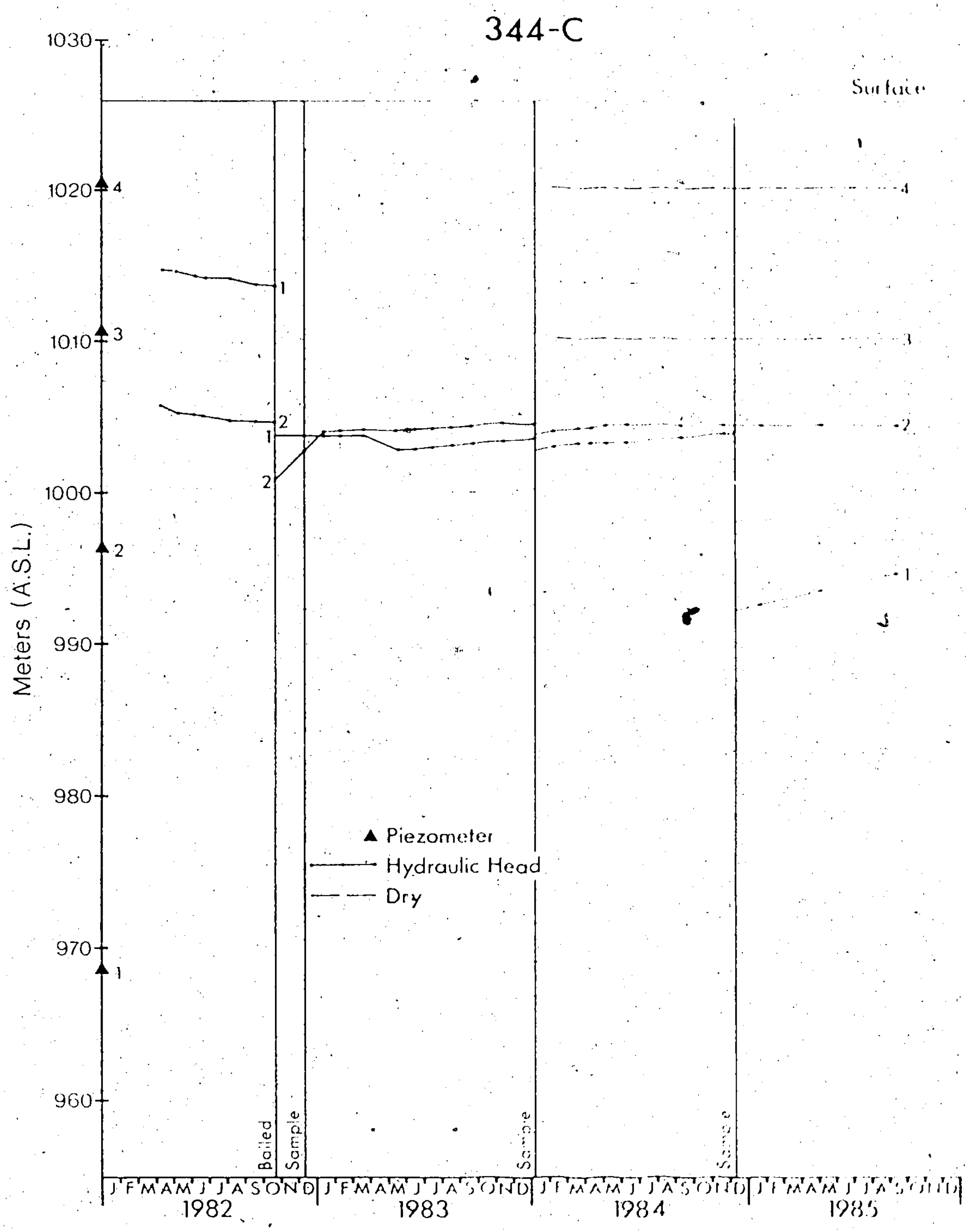


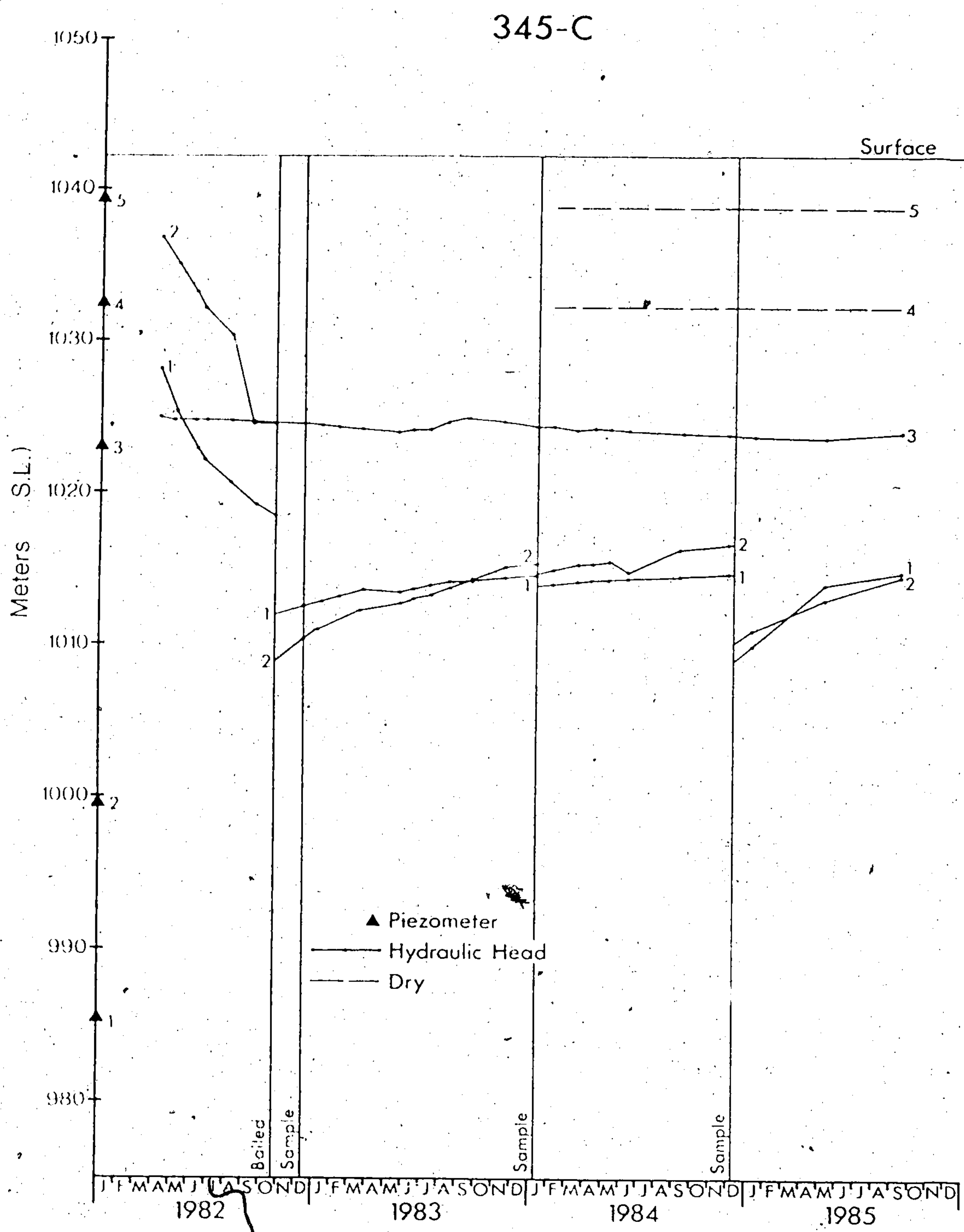
Surface
Meters (A.S.L.)
980
970
960
950
940
930
920
910
4
3
2
1
Water Table Well
Piezometer
Hydraulic Head
Dry
F M A M A S O N D
1982
1983
1984
1985

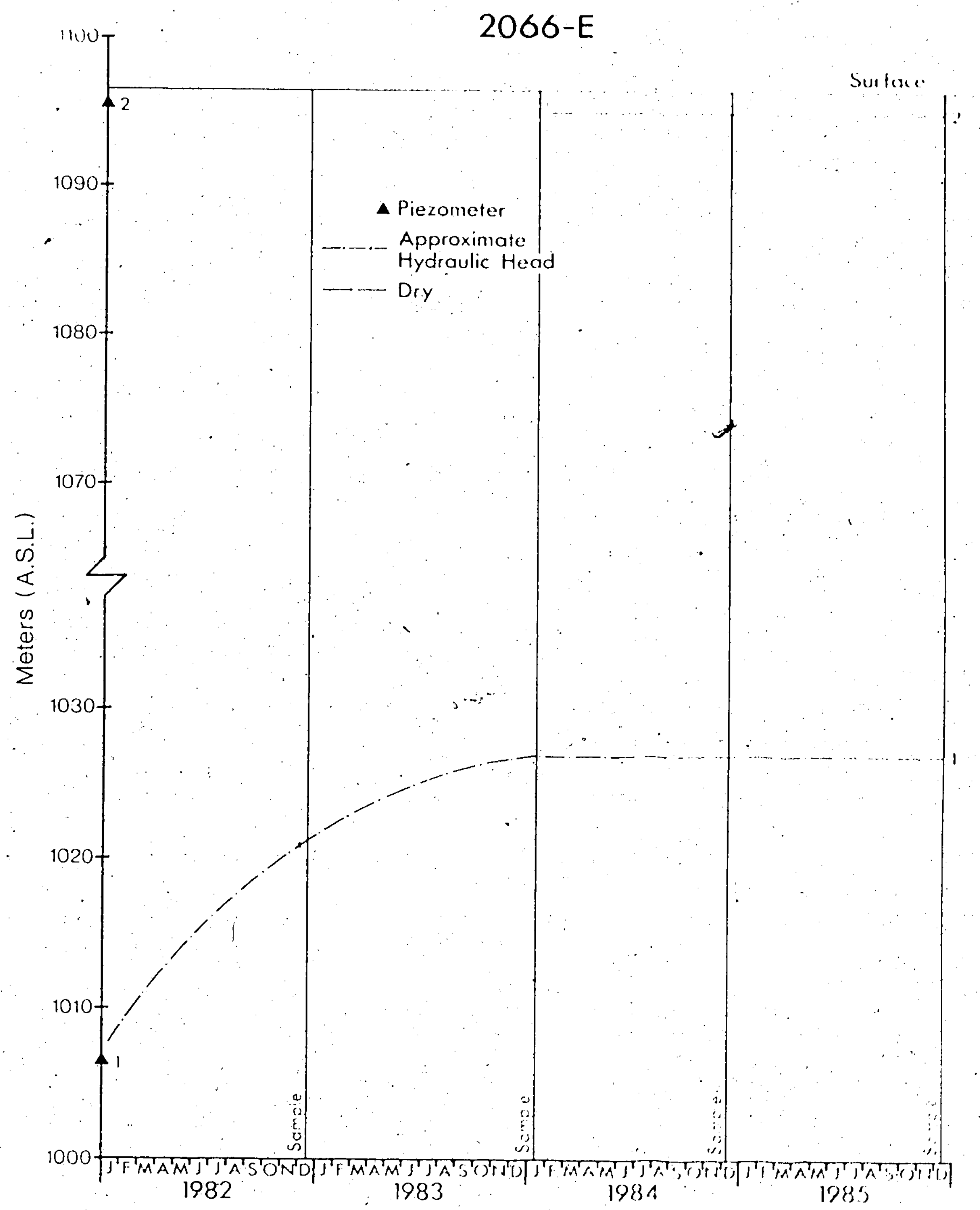

341-C
Surface
1010
1000
990
980
970
960
950
940
Meters (A.S.L.)
6
5
4 (Destroyed)
1
2
3
Piezometer
Hydraulic Head
Dry
Bailed
Sample
Sample
Sample
J F M A M J J A S O N D
1982
1983
1984
1985

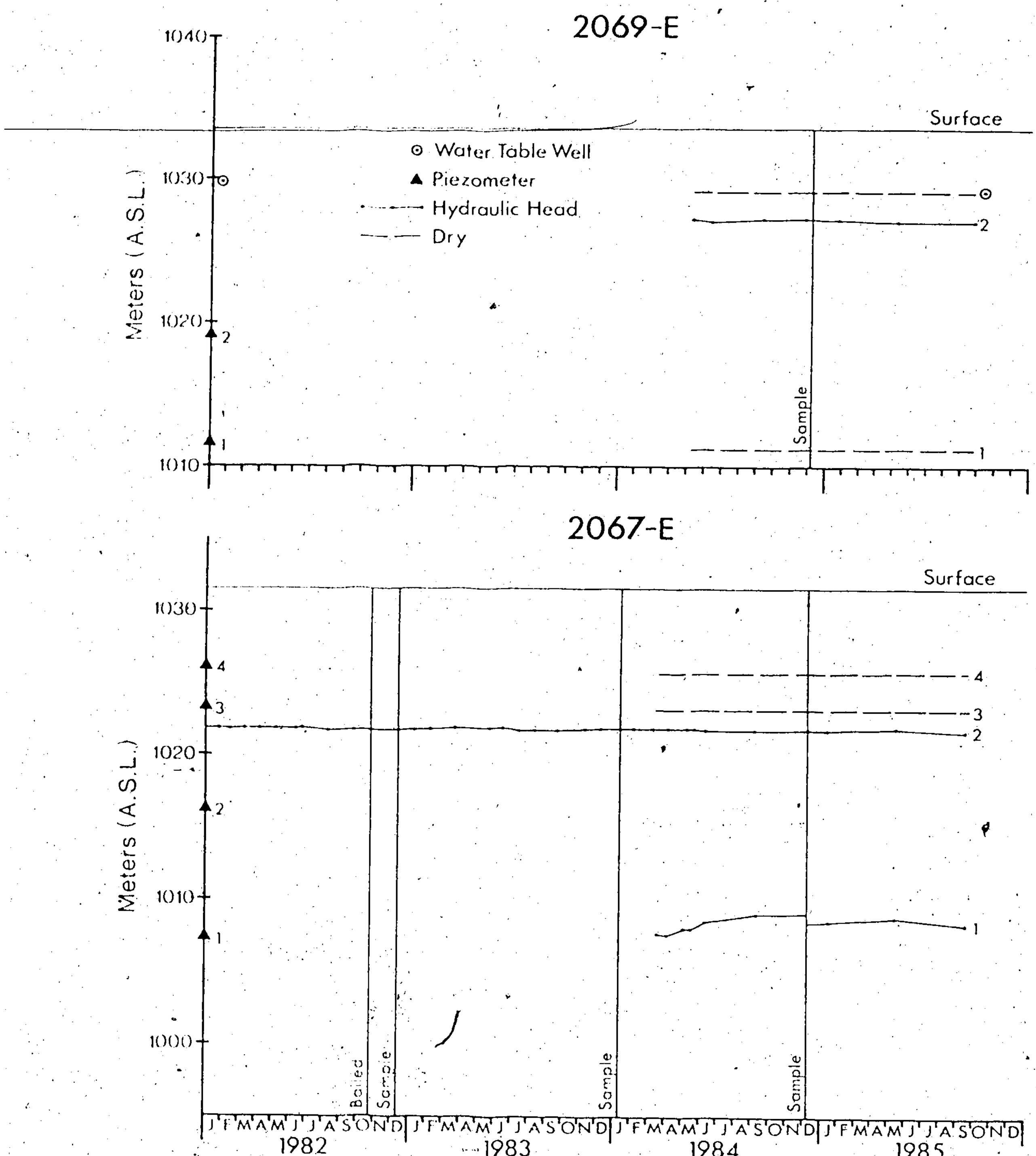

342-C
990
980
970
960
950
940
930
920
Meters (A.S.L.)
Surface
(4 Destroyed)
▲ Piezometer
Hydraulic Head
Dry
Bailed
Sample
Sample
Sample
J F M A M J J A S O N D
1982
1983
1984
1985

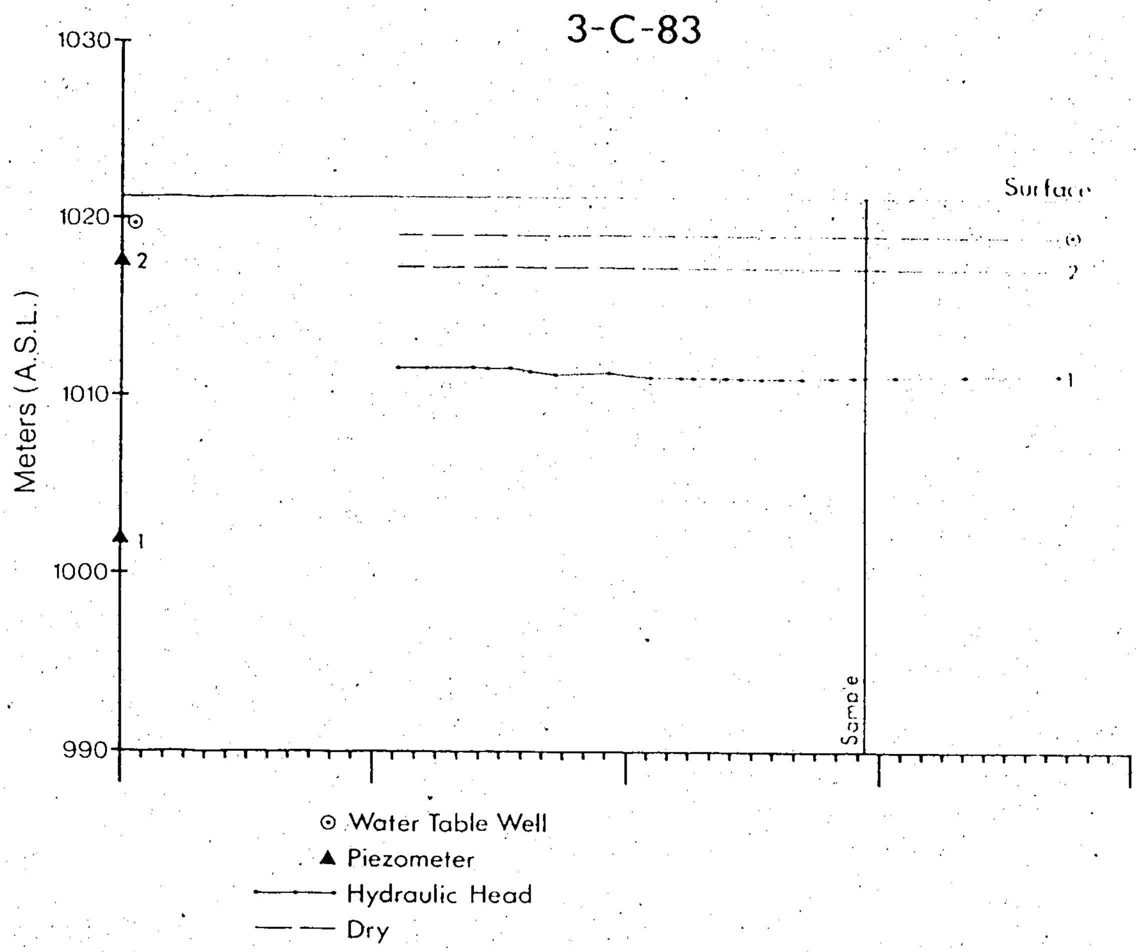

343-C
Surface
Meters (A.S.L.)
990
980
970
960
950
940
930
910
▲ Piezometer
Hydraulic Head
Dry
Borea
Sample
Sample
Sample
J F M A M J J A S O N D
1982
1983
1984
1985

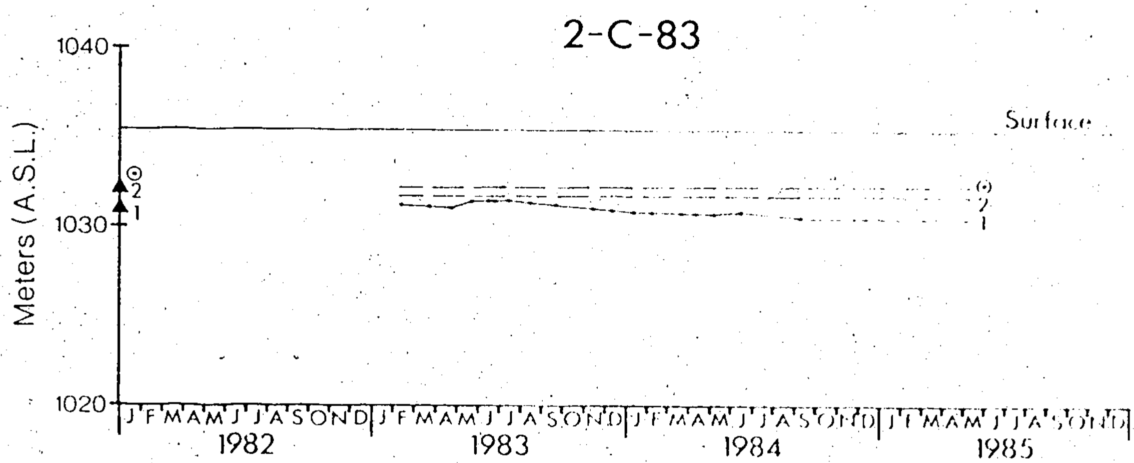

344-C
Surface
Meters (A.S.L.)
1030
1020
1010
1000
990
980
970
960
Bailed
Sample
Sample
Sample
▲ Piezometer
Hydraulic Head
Dry
J F M A M J J A S O N D
1982
1983
1984
1985

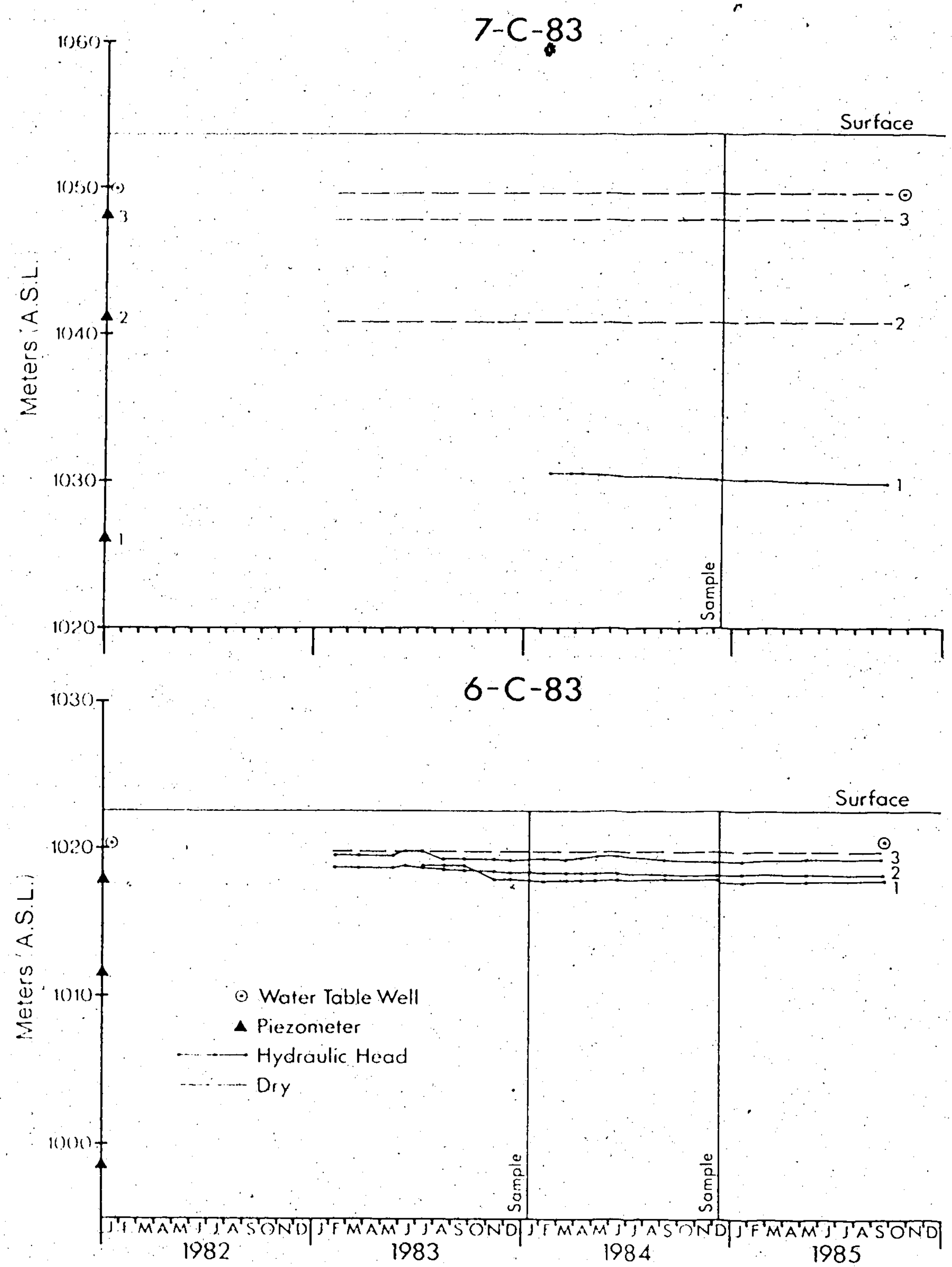

345-C
Surface
Meters (M.S.L.)
1050
1040
1030
1020
1010
1000
990
980
Piezometer
Hydraulic Head
Dry
Bailed
Sample
Sample
Sample
J F M A M J J A S O N D
1982
1983
1984
1985


2066-E
Surface
Piezometer
Approximate Hydraulic Head
Dry
Meters (A.S.L.)
1100
1090
1080
1070
1030
1020
1010
1000
2
1
Sample
J F M A M J J A S O N D
1982
1983
1984
1985


2069-E
Surface
Water Table Well
Piezometer
Hydraulic Head
Dry
Meters (A.S.L.)
1040
1030
1020
1010
Sample
2067-E
Surface
1030
1020
1010
1000
Meters (A.S.L.)
Bailed
Sample
Sample
Sample
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1982
1983
1984
1985


3-C-83
1030
1020
1010
1000
990
Meters (A.S.L.)
Surface
2
1
Sample
Water Table Well
Piezometer
Hydraulic Head
Dry


2-C-83
1040
1030
1020
Meters (A.S.L.)
Surface
2
1
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1982
1983
1984
1985


7-C-83
1060
1050
1040
1030
1020
Meters (A.S.L.)
Surface
3
2
1
Sample
6-C-83
1030
1020
1010
1000
Meters (A.S.L.)
Surface
3
2
1
Sample
Sample
Water Table Well
Piezometer
Hydraulic Head
Dry
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1982
1983
1984
1985

APPENDIX G

Methods of Sampling and Analysis

In preparation for sampling, all standing water was removed from the piezometers and water-table wells. This allowed fresh formation water to enter the pipe. After water removal, the well was allowed to recover before water samples were collected. Initially water removal and sampling was done with a bailer. This was found to be too time consuming. As a result, the introduction of compressed nitrogen was used to remove standing water and to collect the water samples. This method, which is detailed by Ulmer (1988), did not prove successful in all cases. In piezometers completed in permeable zones, the standing water was forced back into the formations when the piezometer was pressurized with gas. In these cases, a bailer was used for removal and sampling of water. Because of the low permeability of some units it was necessary to sample more than once in order to collect enough sample for analysis. It was not possible in these cases to do field measurement of pH and electrical conductivity. Therfore for consistance no other field measurements were conducted.

Water samples were collected in sterilized 250 ml polypropelene sample bottles. The bottles were washed three times with formation water before the sample was collected. The bottle was then filled with formation water. Samples, if turbid, were then filtered to remove any suspended sediment, capped tightly and refrigerated. Samples were shipped in insulated packaging to the analytical laboratories.

Water samples were analysed for all major anions and cations as well as for pH, electrical conductivity (EC) and for sodium absorption ratio (SAR). Major ion analysis were conducted on water samples by Chemex Ltd. and by Norwest Labs (Alberta) Ltd. both of Calgary. A full analysis included total ionic concentration, determination for calcium

(Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}), chloride (Cl^{-}), sulphate (SO_4^{2-}) and nitrate-nitrogen (NO_3^{-}-N) ions. In some cases iron (Fe), manganese (Mn) and ammonium (NH_4^{+}) concentrations were also determined.

Methods used to analyse the samples for ions are described by Alberta Environment (1981). Ca^{2+}, Mg^{2+} and Fe were determined using automated atomic absorption; Na^{+} and K^{+} by automated flame photometry; CO_3^{2-} and HCO_3^{-} by titration; Cl^{-} by automated methylthymal blue method; NO_3^{-}-N by automated cadmium reduction method; and NH_4 by automated colorimetric phenate method.

Isotopic analysis for ^{18}O was done using an automated mass spectrometer (Fritz et al, 1986). Machine reproducibility on individual runs is better than ±0.05‰ with overall reproducibility of 0.15‰. For ^{2}H analysis a semiautomatic deuterium mass-spectrometer was used. For analysis water flows over a gold plated hot plate where it forms a vapour film which is sampled continuously by a high temperature probe. This vapour passes over hot uranium directly into the mass spectrometer. Isotopic differences between distilled and undistilled samples are within overall analytical error (±2‰) if the salinity does not exceed approximate seawater values (Fritz et al, 1986).

APPENDIX H

WATER ANALYSIS RESULTS

WATER ANALYSIS RESULTS

Borehole No. 5074-M

Instrumentation, No.		2		3		4		5	
Date/Property		Jan. 10 1984	Dec. 12 1984	Jan. 10 1984	Dec. 12 1984	Jan. 10 1984	Dec. 10 1984	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		6.82	5.42	7.82	5.88	7.72	6.03	9.51	6.99
pH		7.73	8.27	7.27	7.95	7.34	7.59	7.51	8.00
Bicarbonate (HCO_3)		12.06	8.64	8.56	7.56	10.15	8.42	9.45	7.84
Carbonate (CO_3)		<0.04	<0.01	<0.04	<0.01	<0.04	<0.01	<0.04	<0.01
Chlorides (Cl)		5.08	5.36	4.91	4.91	6.09	5.56	9.98	8.04
Sulfates (SO_4)		73.52	63.7	76.52	61.9	74.64	64.4	101.79	76.4
Phosphorous as P	- Total								
	- Soluble								
Nitrogen	Total Kjeldahl								
	Free Ammonia	3.1		0.12		<0.10		0.70	
	Nitrite								
	Nitrate	37.9	57.5	124	13.[illegible]	[illegible]	[illegible]	[illegible]	95.0
Metals	Potassium (K)	0.49	0.67	0.43	0.39	0.43	0.40	0.46	0.41
	Magnesium (Mg)	24.52	8.3	25.18	24.3	23.34	25.5	31.57	26.5
	Calcium (Ca)	12.66	29.5	19.06	17.5	19.36	19.5	18.16	17.0
	Sodium (Na)	41.76	41.3	46.98	41.3	[illegible]	41.3	[illegible]	55.2
	Iron (Fe)	0.03		0.03		0.02		0.03	
	Manganese (Mn)	0.275		0.20		0.165		0.233	
SAR		[illegible]	3.57	9.59	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note: Concentrations in mg/l except for Fe, Mn, and NH4-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

License No. [illegible]

Instrumentation No. 1

Date Property		Dec. 15 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		10.27	14.06	13.41
pH		7.64	7.35	8.17
Bicarbonate (HCO_3)		23.1	11.79	24.1
Carbonate (CO_3)		< 0.01	< 0.04	<0.01
Chlorides (Cl)		0.55	9.31	1.30
Sulfates (SO_4)		104	160.05	190
Phosphorous As P	- Total			
	- Soluble			
Nitrogen	Total Kjeldahl			
	Free Ammonia		3.2	
	Nitrite			
	Nitrate	3.30	11.9	36.0
Metals	Potassium (K)	0.35	0.40	0.43
	Magnesium (Mg)	9.87	13.99	16.4
	Calcium (Ca)	7.29	7.63	10.2
	Sodium (Na)	102	156.16	176
	Iron (Fe)		0.05	
	Manganese (Mn)		0.24	
SAR		34.9	47.49	48.2

Note: Concentrations in mg/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5078-M

Instrumentation No.		1			2		
Date/Property		Dec. 14 1982	Jan. 9 1984	Dec. 12 1984	Dec. 14 1982	Jan. 9 1984	Dec. 12 1984
Conductivity mS/cm		3.62	5.87	8.36	32.45	35.70	29.2
pH		8.36	9.56	8.48	7.59	7.86	8.11
Bicarbonate (HCO_3)		20.8	19.26	4.90	22.0	23.73	20.8
Carbonate (CO_3)		<0.01	1.94	8.50	<0.01	<0.04	<0.01
Chlorides (Cl)		0.60	0.62	1.21	5.65	10.32	9.59
Sulfates (SO_4)		20.6	45.70	86.2	360	414.38	422
Phosphorous as P	- Total						
	- Soluble						
Nitrogen	Total Kjeldahl						
	Free Ammonia	[illegible]	2.2			2.5	
	Nitrite						
	Nitrate	0.39	0.5	3.45	640	537	520
Metals	Potassium (K)	0.13	0.16	0.23	1.10	[illegible]	[illegible]
	Magnesium (Mg)	0.07	0.79	1.17	33.1	32.50	5.76
	Calcium (Ca)	0.62	0.68	2.05	13.0	11.43	[illegible]
	Sodium (Na)	[illegible]	67.97	[illegible]	327	[illegible]	[illegible]
	Iron (Fe)		0.14			[illegible]	
	Manganese (Mn)		0.043			[illegible]	
SAR		[illegible]	70.89	[illegible]	[illegible]	[illegible]	[illegible]

Note: [illegible] except for Fe, Mn, and [illegible] ppm

WATER ANALYSIS RESULTS - Continued

Borehole No. [illegible]

Instrumentation No.		1		2				WTW	
Date Property		Nov. 29 1984	Dec. 12 1984	Nov. 29 1984	Dec. 12 1984	Nov. 29 1984	Dec. 12 1984	Nov. 29 1984	Dec. 12 1984
Conductivity mS/cm		4.98	4.43	0.75	1.96	0.55	0.60	4.85	5.37
pH		9.11	9.18	8.02	7.96	.12	7.93	7.91	7.94
Bicarbonate (HCO_3)		6.77	6.18	4.00	13.2	3.67	4.28	6.06	7.42
Carbonate (CO_3)		2.68	2.76	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorides (Cl)		3.39	3.39	0.23	1.28	0.10	0.17	0.21	0.35
Sulfates (SO_4)		41.[illegible]	36.5	3.62	7.89	2.23	2.73	58.7	72.5
Phosphorous as P	- Total								
	- Soluble								
Nitrogen	Total Kjeldahl								
	Free Ammonia								
	Nitrite								
	Nitrate	0.01	0.01	0.01	0.01	0.006	0.25	0.48	1.84
Metals	Potassium (K)	0.43	0.39	0.06	0.09	0.04	0.07	0.18	0.19
	Magnesium (Mg)	8.96	3.13	1.74	1.06	1.39	1.46	24.9	29.1
	Calcium (Ca)	1.63	1.42	2.06	1.27	2.05	2.15	14.0	17.2
	Sodium (Na)	48.7	44.8	4.31	20.9	2.57	3.44	29.6	32.6
	Iron (Fe)								
	Manganese (Mn)								
SAR		21.2	29.7	3.12	19.4	1.96	2.56	6.70	6.78

Note: Concentrations in mg/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5179-M

Instrumentation No.		1		2		3	
Date/Property		Jan. 9 1984	Dec. 12 1984	Dec. 12 1984	Dec. 13 1985	Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		2.45	2.03	1.73	1.72	1.67	1.76
pH		7.69	7.95	8.01	7.8	7.82	7.5
Bicarbonate (HCO_3)		11.67	11.7	11.8	11.2	40.9	11.7
Carbonate (CO_3)		<0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorides (Cl)		0.49	0.52	0.54	0.5	[illegible]	[illegible]
Sulfates (SO_4)		15.82	11.0	8.54	7.2	6.92	7.6
Phosphorus as P	- Total						
	- Soluble						
Nitrogen	Total						
	Free Ammonia	[illegible]			[illegible]		[illegible]
	Nitrite						
	Nitrate	<0.2	0.009	[illegible]	[illegible]	[illegible]	[illegible]
Metals	Potassium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Magnesium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Calcium	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Sodium	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
	Iron	[illegible]			[illegible]		[illegible]
	Manganese	[illegible]			[illegible]		1.53
SAR		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5138-W

Instrumentation No.		1	2		3		4	
Date Property		Dec. 12 1984	Dec. 12 1984	Dec. 13 1985	Dec. 12 1984	Dec. 13 1985	Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		1.81	1.45	1.51	1.81	1.95	1.09	1.09
pH		8.64	8.09	7.7	7.95	7.5	8.05	7.7
Bicarbonate (HCO_3)		8.64	7.82	7.6	6.97	7.3	6.90	6.6
Carbonate* (CO_3)		0.98	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorides (Cl)		0.40	0.48	0.4	1.13	0.9	0.37	0.3
Sulfates (SO_4)		10.4	8.81	9.9	15.4	14.5	4.95	5.4
Phosphorous as P	- Total							
	- Soluble							
Nitrogen]	Total Kjeldahl							
	Free Ammonia			<0.05		<0.05		<0.05
	Nitrite							
	Nitrate	0.47	0.03	0.06	0.008	<0.05	0.03	<0.05
Metals]	Potassium (K)	0.04	0.13	<0.10	0.15	0.12	0.13	<0.10
	Magnesium (Mg)	0.35	3.57	4.3	6.50	6.3	3.04	3.[illegible]
	Calcium (Ca)	0.24	8.53	9.1	12.0	12.8	6.29	7.0
	Sodium (Na)	20.0	4.57	4.5	4.57	4.4	2.35	2.5
	Iron (Fe)			0.16		0.11		<0.02
	Manganese (Mn)			0.58		0.21		<0.01
SAR		36.8	1.86	1.73	1.50	1.46	1.09	1.12

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5181-M

Instrumentation No. 5

Date/Property		Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		1.25	1.98
pH		7.97	7.7
Bicarbonate (HCO_3)		5.74	7.6
Carbonate (CO_3)		<0.01	<0.01
Chlorides (Cl)		1.16	1.5
Sulfates (SO_4)		7.35	15.0
Phosphorous as P	Total		
	Soluble		
Nitrogen	Total Kjeldahl		
	Free Ammonia		<0.05
	Nitrite		
	Nitrate	0.12	[illegible]
[illegible]	Potassium (K)	0.03	[illegible]
	Magnesium (Mg)	7.92	[illegible]
	Calcium (Ca)	5.34	[illegible]
	Sodium (Na)	7.13	[illegible]
	Iron (Fe)		[illegible]
	Manganese (Mn)		[illegible]
SAR		[illegible]	[illegible]

Note: Concentrations in [illegible] except K, Fe, Mn, and NH_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5132-W

Instrumentation No.		1		2		3	
Date/Property		[illegible]. 10 1984	Dec. 12 1984	Dec. 12 1984	Dec. 13 1985	Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		1.89	1.87	2.9	3.59	3.29	4.71
pH		9.74	8.25	7.89	7.5	7.93	7.9
Bicarbonate (HCO_3)		8.46	9.06	3.84	4.5	3.31	4.3
Carbonate (CO_3)		<0.04	<0.01	<0.01	<0.01	<0.01	<0.01
Chlorides (Cl)		1.97	2.64	1.90	1.8	2.31	4.2
Sulfates (SO_4)		11.5	9.39	35.6	49.9	41.0	62.7
Phosphorous as P	- Total						
	- Soluble						
Nitrogen]	Total Kjeldahl						
	Free Ammonia	0.51			0.19		0.09
	Nitrite						
	Nitrate	≤0.02	0.24	0.20	<0.05	2.45	0.31
Metals]	Potassium (K)	0.19	0.23	0.24	0.20	0.24	0.27
	Magnesium (Mg)	3.48	2.88	13.8	18.0	14.6	21.3
	Calcium (Ca)	5.09	5.49	20.0	24.7	18.8	29.1
	Sodium (Na)	11.35	12.4	7.35	9.2	12.3	18.8
	Iron (Fe)	<0.01			0.05		0.05
	Manganese (Mn)	0.643			2.70		0.55
SAR		5.48	6.06	1.79	2.00	3.01	3.75

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 5226-M

Instrumentation No.		1		4	
Date/Property*		Nov. 29 1984	Dec. 12 1984	Nov. 29 1984	Dec. 12 1984
Conductivity mS/cm		0.59	0.57	0.58	0.56
pH		8.02	7.91	8.10	7.99
Bicarbonate (HCO_3)		3.84	3.97	3.82	3.88
Carbonate (CO_3)		<0.01	<0.01	<0.01	<0.01
Chlorides (Cl)		0.11	0.13	0.13	0.12
Sulfates (SO_4)		2.40	2.21	2.21	2.29
Phosphorous as P	- Total				
	- Soluble				
Nitrogen	Total Kjeldahl				
	Free Ammonia				
	Nitrite				
	Nitrate	0.02	0.03	0.01	0.03
Metals	Potassium (K)	0.05	0.06	0.05	0.05
	Magnesium (Mg)	1.61	1.36	1.50	1.41
	Calcium (Ca)	2.20	1.67	2.06	1.88
	Sodium (Na)	2.70	3.17	2.65	2.83
	Iron (Fe)				
	Manganese (Mn)				
SAR		1.85	2.55	1.99	2.20

* Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 2066-E

Instrumentation No. 1

Date/Property		Dec. 14 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		1.57	1.74	1.99
pH		7.92	7.04	8.28
Bicarbonate (HCO_3)		8.69	8.75	8.47
Carbonate (CO_3)		<0.01	<0.04	<0.01
Chlorides (Cl)		0.56	0.52	0.65
Sulfates (SO_4)		7.19	8.62	12.8
Phosphorous as P	- Total			
	- Soluble			
Nitrogen	Total Kjeldahl			
	Free Ammonia		4.4	
	Nitrite			
	Nitrate	1.70	<0.2	2.80
Metals	Potassium (K)	0.14	0.13	0.28
	Magnesium (Mg)	0.53	0.43	0.86
	Calcium (Ca)	0.86	1.05	1.79
	Sodium (Na)	15.2	14.75	18.3
	Iron (Fe)		<0.01	
	Manganese (Mn)		0.008	
SAR		18.3	17.15	15.9

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 2067-E

Instrumentation No.		1		2	
Date/Property		Dec. 12 1984	Dec. 14 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		3.25	3.2	3.73	4.86
pH		8.46	7.87	8.41	9.05
Bicarbonate (HCO_3)		13.2	18.7	19.10	24.6
Carbonate (CO_3)		0.71	<0.01	0.16	6.49
Chlorides (Cl)		0.73	0.73	0.70	1.11
Sulfates (SO_4)		21.9	[illegible]	18.95	22.3
Phosphorous as P	- Total				
	- Soluble				
Nitrogen[1]	Total Kjeldahl				
	Free Ammonia			8.9	
	Nitrite				
	Nitrate	0.06	0.01	<0.2	0.0[illegible]
Metals[1]	Potassium (K)	0.09	0.13	0.11	0.19
	Magnesium (Mg)	0.23	0.70	0.38	0.28
	Calcium (Ca)	0.32	0.69	0.41	0.34
	Sodium (Na)	38.3	38.3	35.67	58.3
	Iron (Fe)			<0.01	
	Manganese (Mn)			0.053	
SAR		73.0	45.9	50.73	105

Note: [1]Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 2069-E

Instrumentation No.		2	
Date Property		Dec. 12 1984	Dec. 13 1985
Conductivity mS/cm		5.53	5.96
pH		7.85	7.5
Bicarbonate (HCO_3)		8.67	8.7
Carbonate (CO_3)		<0.01	<0.01
Chlorides (Cl)		6.66	5.4
Sulfates (SO_4)		65.4	65.8
Phosphorous as P	- Total		
	- Soluble		
Nitrogen	Total Kjeldahl		
	Free Ammonia		0.06
	Nitrite		
	Nitrate	15.3	1.11
Metals	Potassium (K)	0.58	0.45
	Magnesium (Mg)	26.3	23.8
	Calcium (Ca)	26.0	25.4
	Sodium (Na)	29.6	30.1
	Iron (Fe)		<0.02
	Manganese (Mn)		0.07
SAR		5.78	6.07

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 341-C

Instrumentation No.		1			2		
Date/Property		Dec. 14 1982	Jan. 10 1984	Nov. 29 1984	Dec. 14 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		1.84	2.06	3.27	1.56	1.60	1.69
pH		8.04	7.90	8.37	7.8	7.93	8.16
Bicarbonate (HCO_3)		8.79	9.26	31.1	9.05	9.34	12.2
Carbonate (CO_3)		<0.01	<0.04	<0.01	<0.01	<0.04	<0.01
Chlorides (Cl)		0.48	0.48	3.95	0.45	0.43	0.71
Sulfates (SO_4)		10.9	11.16	5.15	8.00	7.89	6.94
Phosphorous as P	- Total						
	- Soluble						
Nitrogen	Total Kjeldahl						
	Free Ammonia		9.8			[illegible]	
	Nitrite						
	Nitrate	0.01	<0.2	0.02	0.03	<0.2	0.02
Metals	Potassium (K)	0.15	0.17	0.15	0.12	[illegible]	<0.13
	Magnesium (Mg)	2.08	1.99	1.46	4.11	[illegible]	2.82
	Calcium (Ca)	1.90	1.65	1.26	4.69	3.89	3.79
	Sodium (Na)	17.4	15.79	37.0	8.09	7.66	11.3
	Iron (Fe)		<0.01			<0.01	
	Manganese (Mn)		0.030			0.027	
SAR		12.3	11.70	31.7	3.88	3.83	[illegible]

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 341-C

Instrumentation No. 3

Date/Property		Dec. 14 1982	Jan. 10 1984	Dec. 12 1984
Conductivity mS/cm		3.07	3.36	2.79
pH		7.73	7.42	8.00
Bicarbonate (HCO_3)		12.9	13.77	12.2
Carbonate (CO_3)		<0.01	<0.04	<0.01
Chlorides (Cl)		0.74	0.75	0.71
Sulfates (SO_4)		25.0	24.61	22.7
Phosphorous as P	- Total			
	- Soluble			
Nitrogen	Total Kjeldahl			
	Free Ammonia		7.7	
	Nitrite			
	Nitrate	0.04	<0.2	<0.003
Metals	Potassium (K)	0.22	0.21	0.20
	Magnesium (Mg)	10.4	8.64	4.85
	Calcium (Ca)	9.88	9.38	8.43
	Sodium (Na)	18.3	18.10	19.1
	Iron (Fe)		<0.06	
	Manganese (Mn)		0.626	
SAR		5.73	6.03	7.43

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 34[illegible]

Instrumentation No.	1			2			3	
Date/Property	Dec. 14 1982	Jan. 9 1984	Dec. 12 1984	Dec. 14 1982	Jan. 9 1984	Dec. 12 1984	Dec. 14 1982	Jan. 9 1984
Conductivity mS/cm	1.38	1.61	2.92	1.52	1.71	1.45	1.59	0.20
pH	8.06	8.32	8.32	7.84	8.00	8.04	7.77	6.78
Bicarbonate (HCO_3)	7.70	9.18	20.7	7.52	6.86	7.80	6.67	2.76
Carbonate (CO_3)	>0.01	0.16	>0.01	>0.01	>0.04	>0.01	>0.01	<0.04
Chlorides (Cl)	0.39	0.41	3.10	0.43	0.42	0.40	0.41	0.25
Sulfates (SO_4)	7.29	7.16	11.0	9.33	10.51	9.27	8.81	0.40
Phosphorous as P - Total								
Phosphorous as P - Soluble								
Nitrogen) Total Kjeldahl								
Nitrogen) Free Ammonia		[illegible]			1.0			3.5
Nitrogen) Nitrite								
Nitrogen) Nitrate	0.02	>0.2	0.02	<0.01	>0.2	0.008	<0.005	0.70
Metals) Potassium (K)	0.17	0.18	0.13	0.26	0.22	0.22	0.13	0.06
Metals) Magnesium (Mg)	3.29	2.92	1.21	4.93	5.00	3.35	4.28	0.22
Metals) Calcium (Ca)	3.34	2.54	1.17	4.59	4.69	4.23	4.84	0.70
Metals) Sodium (Na)	7.98	9.61	33.1	7.05	7.74	7.92	6.96	0.29
Metals) Iron (Fe)		>0.01			<0.01			0.14
Metals) Manganese (Mn)		0.073			0.182			0.155
SAR	4.37	5.81	30.3	3.23	3.52	4.05	3.26	[illegible]

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 34[illegible]C

Instrumentation No.

Date/Property		Dec. 14 1982	Jan. 9 1984	Dec. 12 1984	Dec. 14 1982	Jan. 9 1984	Dec. 12 1984
Instrumentation No.		1			2		
Conductivity mS/cm		1.23	1.52	1.41	1.39	1.31	0.99
pH		7.82	7.83	7.98	8.01	7.82	7.93
Bicarbonate (HCO_3)		7.03	8.09	8.44	7.51	7.39	6.31
Carbonate (CO_3)		>0.01	>0.03	>0.01	>0.01	>0.01	>0.01
Chlorides (Cl)		0.43	0.38	0.45	0.41	0.35	0.31
Sulfates (SO_4)		6.39	7.31	6.94	7.08	6.35	4.90
Phosphorous as P	- Total						
	- Soluble						
Nitrogen)	Total Kjeldahl						
	Free Ammonia		2.70			2.20	
	Nitrite						
	Nitrate	2.30	>0.20	0.009	0.72	>0.20	0.005
Metals)	Potassium (K)	0.13	0.17	0.19	0.17	0.11	0.01
	Magnesium (Mg)	3.78	1.66	1.40	2.31	3.89	2.34
	Calcium (Ca)	3.84	1.40	1.52	2.04	3.44	3.19
	Sodium (Na)	6.44	11.44	12.3	10.20	5.83	5.09
	Iron (Fe)		>0.01			>0.01	
	Manganese (Mn)		0.04			0.045	
SAR		3.30	9.25	10.2	6.90	3.16	3.06

Note: Concentrations in me/l except for Fe, Mn, and NO_3-N which are in ppm.

WATER ANALYSIS RESULTS - Continued

Borehole No. 344-C

Instrumentation No.		1			2	
Date/Property	Dec. 15 1982	Jan. 9 1984	Dec. 12 1984	Dec. 15 1982	Jan. 9 1984	Dec. 12 1984
Conductivity mS/cm	1.22	1.34	1.22	3.16	4.47	4.76
pH	7.91	8.64	8.07	7.76	8.11	8.11
Bicarbonate (HCO_3)	7.36	8.96	9.26	7.67	12.49	16.2
Carbonate (CO_3)	>0.01	1.09	>0.01	>0.01	>0.04	>0.01
Chlorides (Cl)	0.37	0.42	0.37	0.52	0.56	0.45
Sulfates (SO_4)	5.94	6.29	5.17	26.5	34.27	44.0
Phospherous as P - Total						
- Soluble						
Nitrogen: Total Kjeldahl						
Free Ammonia		7.2			[illegible]	
Nitrite						
Nitrate	0.04	2.5	0.007	[illegible]	[illegible]	[illegible]
Metals: Potassium (K)	0.17	0.17	0.19	0.29	0.32	0.42
Magnesium (Mg)	3.04	3.02	3.08	3.95	4.47	[illegible]
Calcium (Ca)	3.19	3.14	3.79	2.54	3.14	3.04
Sodium (Na)	6.83	9.22	7.35	[illegible]	[illegible]	[illegible]
Iron (Fe)		0.02			[illegible]	
Manganese (Mn)		0.043			[illegible]	
SAR	3.57	5.25	3.94	14.1	19.7	23.5

Note: Concentrations in [illegible] except for Fe, Mn, and NO_3-N which are in ppm.