

THE UNIVERSITY OF MANITOBA

HYDROLOGY AND CHEMISTRY OF THE SHOAL LAKES BASIN,
INTERLAKE AREA, MANITOBA

by

KENNETH J. GOFF

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF EARTH SCIENCES

WINNIPEG, MANITOBA

October, 1971



ABSTRACT

Flow systems and hydrochemistry of groundwater in the glacial drift and shallow dolostone bedrock, and a water budget of three closed lakes located in a zone of active groundwater discharge are discussed in this study of the Shoal Lakes basin in south-central Manitoba.

The southerly movement of groundwater in the dolostone as concluded from the distribution of hydraulic head is confirmed by hydrochemical data. The Shoal Lakes and adjacent low-lying areas are located in a zone of active groundwater discharge marked by flowing wells in the dolostone and discharge gradients in the glacial drift.

Groundwater is supersaturated with respect to calcite and dolomite and the concentrations of Ca^{++} , Mg^{++} , and HCO_3^- in general exceed values anticipated using a dolomite dissolution model. The precipitation of calcite as a result of CO_2 degassing in the unsaturated zone accounts for supersaturations with respect to both calcite and dolomite and observed $\text{Ca}^{++}/\text{Mg}^{++}$ ratios less than 1. Small amounts of halite and gypsum disseminated throughout the drift and bedrock account for observed concentrations of Na^+ , Cl^- , and $\text{SO}_4^{=}$. Excess Na^+ is due to cation exchange.

A decline of 9cm (3.5 in) in the level of North Shoal Lake occurred during a four month period when net evaporation losses totaled 53 cm (20.8 in). Groundwater input to the lake, as a significant portion of the lake budget, is postulated on the basis of piezometric and hydrochemical data.

CONTENTS

	Page
INTRODUCTION.....	1
ACKNOWLEDGEMENTS.....	2
PHYSIOGRAPHIC AND GEOHYDROLOGIC SETTING.....	2
METHODS OF INVESTIGATION.....	4
Drilling and Farm Well Inventory.....	4
Piezometry.....	5
Hydrometeorology.....	6
Water Chemistry.....	6
Water Temperature.....	10
HYDROSTRATIGRAPHY.....	10
Bedrock.....	11
Glacial Drift.....	14
GROUNDWATER FLOW SYSTEM.....	17
Construction of Groundwater Flow Diagrams.....	17
Flow Pattern Interpretation.....	19
Groundwater Temperature Profiles.....	20
GROUNDWATER CHEMISTRY.....	21
Major Processes and Environmental Controls....	21
DISTRIBUTION OF MAJOR IONS, pH, AND PCO ₂	23
The Glacial Drift.....	23
The Dolostone.....	24
MINERALOGIC SOURCES OF IONS.....	25
The Glacial Drift.....	25

The Dolostone.....	30
WATER BUDGET OF NORTH SHOAL LAKE.....	33
Water Budget Components.....	33
The Groundwater Component in North Shoal Lake..	35
The Groundwater Component from the Darcy Equation.....	36
LAKE AND INTERSTITIAL WATER CHEMISTRY.....	38
Chemistry of the Shoal Lakes.....	38
Chemistry of the Interstitial Water.....	40
SATUROMETRY.....	41
SUMMARY OF CONCLUSIONS.....	43
FIGURES.....	45
REFERENCES CITED.....	74
APPENDICES.....	77

LIST OF FIGURES

	Page
1 Location and geology of the Shoal Lakes basin.....	45
2 Drift isopach and bedrock outcrop map.....	46
3 Locations of farm well sampling stations.....	47
4 Details of piezometer construction.....	48
5 Piezometer nest locations.....	49
6 Shoal Lakes basin and vicinity with locations of hydrometric stations.....	50
7 Lakewater sampling locations.....	51
8 Hydrogeologic cross-section CD.....	52
9 Hydrogeologic cross-section EF.....	53
10 Piezometric surface map of the dolostone aquifer with inferred directions of groundwater movement.....	54
11 Zone of groundwater discharge and hydrogeologic cross section locations.....	55
12 Temperature variations with increasing depth below the ground surface for recharge and discharge areas in the glacial drift.....	56
13 Major ion composition of groundwater in the glacial drift.....	57
14 Geochemical trends along inferred flow paths in the glacial drift.....	58
15 PCO ₂ and pH variations in the dolostone and glacial drift.....	59

16	Major ion composition of groundwater in the dolostone.....	60
17	Areal distribution of anions in the dolostone (arbitrary contours have been drawn to emphasize increasing concentrations toward the southwest).....	61
18	Areal distribution of cations in the dolostone.....	62
19	The depth dependance of hydrochemistry in the dolostone aquifer.....	63
20	Major ion concentrations in samples collected from flowing wells in the dolostone.....	64
21	pH and HCO_3^- , Ca^{++} , Mg^{++} concentrations in the dolostone compared to the dolomite dissolution model..	65
22	The degree of saturation (100 = saturation) with respect to calcite and dolomite in groundwater in the glacial drift.....	66
23	pH and HCO_3^- , Ca^{++} , Mg^{++} concentrations in the carbonate aquifer, Shoal Lakes basin, compared to the dolomite dissolution model.....	67
24	The degree of saturation (100 = saturation) with respect to calcite and dolomite in groundwater in the dolostone.....	68
25	Hydrograph of lake level and precipitation for North Shoal Lake.....	69
26	Variations in the major ion concentrations in North Shoal Lake for summer and winter periods.....	70

27	The major ion composition of lakewater in the Shoal Lakes basin.....	71
28	A chemical comparison of lake and interstitial waters in North Shoal Lake.....	72
29	A frequency distribution of ionic strength in surface and groundwater.....	73

INTRODUCTION

An investigation of the groundwater chemistry and hydrology of a portion of the Interlake area in south-central Manitoba (Cherry pers.comm. 1968), suggested that the Shoal Lakes (Fig.1) are situated in an area of groundwater discharge. Goff and Webb (1968) and Averill (1968) established that these shallow, marshy lakes contain total dissolved solids in the range of 2150 to 2675 mg/l and that they occur in a region of net annual precipitation deficiency. A more intensive study was undertaken to:

- (1) define the groundwater flow systems in the basin,
- (2) relate the flow systems, the geology, and the chemistry,
- (3) estimate the magnitude of the groundwater contribution to the lakes, and
- (4) interpret the chemistry of the lakewater and the interstitial water in the bottom sediment.

Between May and September, 1969, 150 field analyses of pH and HCO_3^- were completed on samples of surface and subsurface water. Additional field work included an inventory of water wells, installation and maintenance of:

- (i) a weather station, (ii) piezometer network (iii) a lake level gauge on North Shoal Lake.

Many conclusions reached in this study are applicable to other closed basins in the Interlake area of Manitoba.

ACKNOWLEDGEMENTS

I wish to thank Dr. J. Cherry for his suggestions throughout the investigation and for his critical review of the manuscript. The thesis was also read critically by Drs. R.W. Newbury, G.J. Brunskill, and Mr. F.W. Render who provided numerous comments and suggestions. Officers of the water Resources Branch of the Manitoba Department of Mines and Natural Resources made helpful comments and provided water level recorders. The Meteorological Branch, Ministry of Transport loaned and installed weather station equipment through its International Hydrologic Decade project assistance plan. Able field assistance was rendered by Mr. J. Lebedinski. Power augering services of Great Plains Drilling Limited, Saskatoon, were obtained under contract. I am grateful to my wife, Betty for her continued encouragement and assistance throughout the investigation. Financial support for this project was provided by the National Research Council under Grant No. A4210.

PHYSIOGRAPHIC AND GEOHYDROLOGIC SETTING

The Shoal Lakes basin is situated in south-central Manitoba, 65 km (40 mi) northwest of Winnipeg (Fig. 1). Because there is no well developed drainage network, the basin was defined on the basis of topographic divides.

The basin includes numerous, minor topographic sub-basins centred on small lakes and sloughs.

The terrain is flat to undulating. Northwest trending alignments which reflect the direction of the most recent glacial advance and the alignment of interbeach zones of Lake Agassiz are evident in the shapes of lakes, sloughs, and low ridges. Total relief within the basin does not exceed 18 m (60 ft) and local relief is less than 3m (10 ft). Silurian dolostones of the Undivided Interlake Group (Baillie 1951) underlie the area (Fig. 1). Data collected during an inventory of existing water wells and test drilling have shown that the bedrock is overlain by glacial deposits which vary in thickness between 0 and 30 m (100 ft) over most of the study area. These deposits are composed mainly of silty till with occasional sandy or gravelly lenses.

Hydrophytes thrive in the many sloughs which are ringed by natural hay pastures. Apart from the Shoal Lakes themselves, growth-free water surfaces are a rarity. Cleared and farmed areas are not extensive due to the frequency of low-lying ground.

An account of early settlement in the Interlake area (Kristjanson 1965) refers to the existence of a single Shoal Lake in 1890 with dimensions of 48 km (30 mi) by 16 km (10 mi). Discussions with local residents in the course of field work verified that the present three

lakes had formed a single lake in the early years of this century and that a steam-driven boat operated on that lake. It is estimated that a rise of 1.5 m (5 ft) in present lake levels would fill existing natural channelways between North and East Shoal Lakes. Residents estimate that in 1940 after several years of below normal rainfall, only 16 hectares (40 a) of North Shoal Lake remained. The present surface of North Shoal Lake is approximately 4000 hectares (9500 a) and the present average lake depth is between 122 and 152 cm (48 and 60 in) based on numerous measurements and on observed increases in ion concentrations during winter.

METHODS OF INVESTIGATION

Drilling and Farm Well Inventory

Drilling was conducted using a 7.6 cm (3 in) diameter portable power auger, and a 15.2 cm (6 in) diameter truck-mounted auger for deeper work. The deepest hole at each piezometer site was augered as near to the dolostone surface as practical. Overburden samples were obtained from material adhering to the bottom-most auger section but sampling of bedrock was not possible. Outcropping bedrock was observed in roadcuts and in the Inwood quarry (Fig. 2).

It is estimated that the 70 farm wells which were sampled in 1969 together with 16 wells from the previous year (Cherry written comm; 1968) account for approximately 85 percent of the rural wells in the basin (Fig. 3). Appendix A summarises inventory data which includes name and address of owner, a legal description of the well location, well depth, depth to bedrock, and static water level.

Piezometry

The open standpipe type of piezometer used in this study is shown in Fig. 4 together with an illustration of a typical piezometer nest. Hvorslev (1951) indicates that "lag times" for this type of piezometer vary directly with the intake section diameter. The piezometers were constructed throughout of 2.03 cm (0.8 in) diameter, semi-rigid, polyvinyl chloride tubing. Although a smaller diameter of tubing would have decreased response times, the water sampling technique would have been considerably more difficult.

Nineteen nests of piezometers, each nest containing 2 to 4 individual piezometers, were installed at points throughout the basin (Fig. 5) to obtain water samples and to measure the distribution of hydraulic head. Piezometric levels were recorded twice a week although

some conveniently located nests were measured more frequently. Measurements were made with a weighted steel tape and all readings were referenced to ground level.

Hydrometeorology

A weather station was established at a central location in the basin between North and East Shoal Lakes (Fig. 6). Instrumentation included a Class A evaporation pan, maximum and minimum thermometers for air and water, a standard rain gauge, and a wind totalizing anemometer. The station was attended daily and standard meteorological data forms from the Meteorological Branch, Ministry of Transport, were completed (Appendix D). A "Stevens" water level recorder with a weekly chart provided a continuous record of lake level. The recorder float was shielded in a rectangular crib to minimise wave effects. Daily readings on an adjacent staff gauge were obtained as well.

Water Chemistry

A battery operated pH meter (Radiometer Model PHM4), combination glass and calomel electrode, and a commercial field chemistry kit (Hach Chemical Co.) were used to measure pH, HCO_3^- , Ca^{++} , and Mg^{++} . pH electrodes were

standardized to commercial buffers (pH 4 - 10). The buffer solution and sample were maintained at well head temperature in an ice bath. True pH values were computed by the method indicated by Barnes (1964). Results of potentiometric titrations with 0.01639 N H_2SO_4 were used to graph arithmetic curves of pH versus titrant volume. End points were selected by visually estimating maximum slopes from the curves. After each pH and HCO_3^- determination, standard buffer solutions were remeasured. If before and after readings differed by more than ± 0.005 pH unit, then the analysis was repeated. Reported pH values are considered correct to ± 0.015 pH unit and HCO_3^- values are reproduceable to ± 1 mg/l.

An EDTA titration (Hach Chemical Co.), was used to determine Ca^{++} and Mg^{++} . Results were reproduceable to within ± 5 mg/l. Random spot checks of Ca^{++} and Mg^{++} concentrations, using an atomic absorption spectrophotometer (Perkin-Elmer Model 303), confirmed the validity of the EDTA technique.

Sodium and K^+ concentrations were determined using and atomic absorption spectrophotometer. Repeated testing indicated that values were reproduceable to $\pm 5\%$.

The Mohr method was used for Cl^- determination. Using concentrated silver nitrate solution, the method was shown to be reproduceable to within $\pm 3\%$. No test of accuracy was made with the dilute silver nitrate

solution, however, $\pm 1\%$ is reported (Rainwater and Thacher 1960).

A turbidometric method (Hach Chemical Co.), was used to determine $\text{SO}_4^{=}$ concentrations. Samples were diluted so that $\text{SO}_4^{=}$ concentrations were between 20 and 50 mg/l since it was found that reproduceability was within $\pm 5\%$ in this range.

Of 105 ion change balances, 85 are within 90% agreement, 40 within 95% agreement, and 100 within 85% agreement. Of the total 154 water samples analyzed during the field season, 71 were obtained from farm wells 50 from piezometers, 25 from lakes, and 8 were squeezed from lake sediments. In 12 analyses of water samples from piezometers the pH was greater than 9.0 and the largest measured pH was 12.3. This alkaline condition is regarded as an indication of contamination by cement grout which was used in the piezometer construction.

For groundwater samples, determination of HCO_3^- , pH, Ca^{++} , and Mg^{++} were completed at the well and piezometer sites within minutes of sample collection. Before collecting samples for chemical analyses, farm wells were pumped for a sufficient time to replace the water estimated to be present in pressure systems, lines and well casing. As an additional check, pumping was continued until water temperature approached the regional groundwater temperature of approximately 5°C (41°F).

Water samples from piezometers were obtained using a stainless steel sampling tube with a one-way valve fitted in its base. Each piezometer was bailed with the sampling tube prior to collection.

Several samples were obtained from the Shoal Lakes periodically during the field season (Fig. 7). Since no hydrochemical variations were observed with depth, (Goff and Webb 1968) samples were collected by submerging sample bottles approximately 0.3 m (1 ft) beneath the lake surface.

Samples of saturated lake sediment were obtained by thrusting a 5 cm (2 in) diameter steel tube equipped with a piston, into the bottom mud and extracting tube and sediment core together. A sediment squeezer modified from the design of Reeburgh (1965) was used to extract interstitial water from the sediment. Sediment sampling locations are shown on Fig. 7.

No appreciable difference between on site and field laboratory results were noted in the case of lake and interstitial water analyses. Because sampling was done from a boat, determinations of HCO_3^- , Ca^{++} , Mg^{++} , and pH were conducted at the field laboratory in Inwood (Fig. 6) for reasons of convenience.

Water Temperature

Water temperatures were measured at most wells (Appendix A) using a resin thermistor bead underwater thermometer accurate to $\pm 0.02^{\circ}\text{C}$. Temperature determinations in flowing wells were considered to represent the groundwater temperature in the area. Prior to measurement, the piezometers were bailed so that temperatures representative of surrounding groundwater could be obtained. Lake water temperatures were measured at all sampling stations. A 122 m (400 ft) cable was placed in North Shoal Lake connecting a thermistor bead with the shore to enable daily temperature measurements of the lake.

HYDROSTRATIGRAPHY

The dolostone and the glacial drift constitute distinct hydrogeologic units because each possesses distinctive mineralogic and textural compositions and hydraulic properties. The drift consists primarily of sandy till which is characterized by relatively uniform texture, mineralogy, and low permeability. A water table is present within a few feet of the ground surface in most parts of the basin and confined conditions appear with increased depth. Groundwater movement in the drift

occurs via interstitial pore spaces and porosity values in the range of 30 to 50% are typical of unconsolidated sediments. Movement is influenced primarily by the distribution of hydraulic head since the permeability distribution is considered to be isotropic.

Porosity in the dolostone is secondary and consists of fractures, joints, and solution channels and it is normally in the range of 1.0 to 10%. Groundwater in the dolostone is normally under confined conditions and groundwater movement is controlled by the distribution of porosity and permeability as well as by hydraulic head.

Bedrock

The upper portion of the dolostone bedrock constitutes a major aquifer in south-central Manitoba. In the Shoal Lakes basin it is the source of rural, domestic, and livestock water supplies. Render (1970) reports transmissivities of 150 - 1500 m²/day, (10⁴ to 10⁵ gal/day/ft) for the upper 15.2 m (50 ft) of the dolostone aquifer in the Winnipeg area. Transmissivities representative of the dolostone aquifer in the basin were not specifically determined but variations are probably large because of the considerable range in reported well yields.

Carbonate aquifers commonly possess secondary porosity and permeability due to solution of the rock material along cracks and fractures. Permeability is normally best developed in the upper portions of the carbonate section and may have topographic expression in sinkholes and small caves (Rhoades and Sinacore 1941; Swinnerton 1949; LeGrand and Stringfield 1966).

Sinkholes are common in the upland area immediately to the northeast of the Shoal Lakes basin. Baillie (1951) describes a sinkhole approximately 8 km (5 mi) north of Inwood which exposes "massive and highly porous dolomite". Baillie also describes the 11 m (23 ft) thick section visible in Inwood quarry as follows: "poorly bedded to massive fragmental dolomite containing bun-shaped stromatolites, minor lenses of red and green clay containing fragments or nodules of dolomite, and a dense, yellowish dolomite which contains small spheres of white dolomite".

Goudge (1944) identified the Silurian sequence in the Interlake as consisting of dolostones separated in several localities by a thick belt of gypsiferous shales. At the Inwood quarry, analyses (Table I) indicate the upper 7.6 m (25 ft) are relatively pure dolomite whereas at the bottom of the excavation the dolomite is impure. In 1944, when Goudge collected samples for analyses, the quarry was only 7.9 m (26 ft) in depth. Other analyses from the Inwood area are included in Table I.

Table I Chemical Compositions of Dolostone Samples*
Collected in the Shoal Lakes Basin and Vicinity

	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	Ca ₃ (PO ₄) ₂	CaCO ₃	MgCO ₃	S	CaO/MgO
1.	0.30	0.33	0.12	0.02	55.25	44.58	Tr	1.45:1
2.	0.24	0.21	0.05	0.02	54.59	45.07	0.01	1.42:1
3.	0.36	0.14	0.18	0.04	54.59	44.84	0.01	1.42:1
4.	0.22	0.30	0.06	0.02	55.25	44.67	Tr	1.44:1
5.	0.22	0.28	0.08	0.02	55.77	44.28	Tr	1.46:1

1. Silurian dolomite to a depth of 0.61 m (2 ft) in small pits on Section 34, Township 17, Range 1W.
2. Silurian dolomite; top 3.6 m (12 ft) in quarry owned by Building Products and Coal Company Limited at Inwood.
3. Interval 3.6 - 7.2 m (12 - 25 ft) in the same quarry.
4. Silurian dolomite; top 2.1 m (7 ft) in abandoned quarry on Section 10, Township 18, Range 1W.
5. Bottom 1.2 m (4 ft) in same quarry.

* Collected by Goudge in 1944.

Glacial Drift

Thickness of the glacial deposits in the basin varies from 0 to 30 m (100 ft). The average thickness is estimated to be 12 m (35 ft), however an irregular bedrock surface causes large variations over relatively short distances (Fig. 2). The upper 7.5 m to 15 m (25 ft to 50 ft) of the overburden is a light olive-brown silty till and may be an oxidized phase of the greyish-brown till beneath. The color change is accompanied by no apparent changes in texture or mineralogy. Clay content in the drift was visually estimated to be less than 25%. Mineralogic analyses were not conducted in the present investigation; however, analyses by other workers are available (Ehrlich and Rice 1955; Wicks 1965). Analyses of till in the Winnipeg area (Wicks 1965) indicate an average composition of 40 to 50% dolomite, 5 to 20% clay minerals, approximately 15% each of quartz and feldspar, and traces of gypsum (<1%). Ehrlich and Rice (1955) describe soil horizons developed in the upper 122 cm (48 in) of a "strongly calcareous" till at Komarno, 16 km (10 mi) east of Inwood (Table II). Montmorillonite and illite are the most abundant clay minerals and the CaCO_3 content increases with depth (Table III).

Hvorslev (1951) tests were conducted on the piezometers to obtain average hydraulic conductivities at points

Table II Mechanical Analyses, CaCO_3 Content, and pH of
Soil Profiles in Glacial Drift at Komarno,
Manitoba (Ehrlich and Rice 1955).

Soil Horizon	A ₂	B ₂	B ₃	C ₁	C ₂
Depth of Soil (cm)	0-5	5-12.7	12.7-35.5	35.5-71	71-122
Horizon (in)	0-2	2- 5	5 -14	14 -28	28-48
2mm Rock Particles	3.6	3.4	11.6	15.5	24.6
0.5-2.0 mm Coarse Sand	10.1	7.5	8.4	7.9	12.4
0.1-0.5 mm Fine and Medium Sand	27.6	16.8	13.5	12.9	20.5
0.002-0.1 mm Silt and Fine Sand	51.1	52.6	60.1	63.5	58.0
0.002 mm Clay	11.3	24.2	18.0	16.7	9.1
CaCO_3 Content	0.03	1.30	40.10	50.50	65.00
pH	6.8	6.6	7.6	7.9	8.3

Table III Mineralogical Composition in Percent Dry Weight
of the Clay Fraction Present in the C Soil Horizon*
at Komarno, Manitoba (Ehrlich and Rice 1955).

Montmorillonoids	25 - 30
Chlorites	10 - 15
Micas	5 - 10
Illite	13 - 18
Kaolinites	3 - 8
Quartz	30 - 35
Feldspars	12 - 17
Al ₂ O ₃ Compounds	10 - 15
Apatite	trace
Sepiolite	1 - 5
Talc	trace

* The C soil horizon is 35.5 to 122 cm (14 to 48 in)
below ground surface.

in the drift section. Hydrographs of piezometer levels were used to ascertain that water levels were stable before proceeding with the tests. An arithmetic mean of 1.9×10^{-6} cm/sec (6.2×10^{-8} ft/sec) was computed from 16 individual determinations of hydraulic conductivity (Table IV) which range between 2.3×10^{-8} cm/sec (7.5×10^{-10} ft/sec) and 1.4×10^{-5} cm/sec (4.6×10^{-7} ft/sec). Similar trends were obtained by Freeze (1967) who reported 14 values with a median of 1.2×10^{-6} cm/sec (3.9×10^{-8} ft/sec) for tills near Good Spirit Lake, Saskatchewan.

GROUNDWATER FLOW SYSTEM

Construction of Groundwater Flow Diagrams

Groundwater flow diagrams (Figs. 8 and 9) have been drawn perpendicular to the principal groundwater flow direction in the dolostone. Groundwater flow nets for homogeneous, isotropic media are formed by equipotential lines and flow lines which intersect at right angles if no vertical scale exaggeration is used. However, if vertical exaggerations are used, then the angles of intersection will be other than 90° . Van Everdingen (1963) has prepared nomographs which permit calculation of intersection angles in diagrams with vertical exaggerations up to 10 times. The nomographs are applicable when the

Table IV Hydraulic Conductivities as Determined by
Hvorslev (1951) Test on Piezometers Installed
in the Glacial Drift.

Piezometer	Hydraulic Conductivity	
	ft/sec	cm/sec
P- 3-67.90	1.9×10^{-9}	5.8×10^{-8}
-46.30	6.6×10^{-9}	2.0×10^{-7}
-30.83	2.0×10^{-9}	6.2×10^{-8}
P- 4-26.35	7.5×10^{-10}	2.3×10^{-8}
-16.20	9.2×10^{-8}	2.8×10^{-6}
P- 6-38.25	8.5×10^{-10}	2.6×10^{-6}
-20.60	9.8×10^{-10}	3.0×10^{-8}
P-10-33.30	1.9×10^{-7}	5.7×10^{-6}
P-12-45.50	1.7×10^{-7}	5.2×10^{-6}
-23.55	9.8×10^{-10}	3.0×10^{-8}
P-13-43.60	8.5×10^{-10}	2.6×10^{-8}
-22.70	1.2×10^{-9}	3.5×10^{-8}
P-14-24.92	1.4×10^{-9}	4.1×10^{-8}
P-15-53.13	4.6×10^{-7}	1.4×10^{-5}
-15.90	1.5×10^{-9}	4.7×10^{-6}
P-16-28.63	2.8×10^{-8}	8.6×10^{-7}
-15.77	5.6×10^{-9}	1.7×10^{-7}

hydrogeologic units are assumed to be isotropic. In Figs. 8 and 9 a 100 times vertical exaggeration is used to illustrate the hydrogeology where topographic relief is low. Flow arrows shown in the figures are modified, however, the 100 times exaggeration cannot be quantitatively accommodated by Van Everdingen's treatment. The glacial drift is treated as an isotropic medium and the permeability difference between drift and bedrock is emphasized by the refraction of the equipotential lines at the geological contact.

Flow Pattern Interpretation

The dolostone which underlies the Shoal Lakes basin is part of a regional aquifer system which drains much of the Interlake area. Recharge occurs primarily in the poorly drained Interlake upland where glacial deposits are thin and sinkholes are frequent.

Aquifer zones in the dolostone are confined either by glacial deposits, by less permeable layers of dolostone or by combinations of both. A piezometric surface map of the dolostone aquifer within the basin was prepared (Fig.10) using piezometric data and water level data gathered on farm wells. The configuration of the piezometric surface indicates groundwater flow from northeast to southwest. Piezometric highs indicate areas of recharge. The principal

high in the north corresponds to a topographic high where glacial deposits are thin or absent and where sinkholes are common. The sinkholes provide a means of rapid recharge to the dolostone.

The basin has been divided into recharge and discharge areas (Fig. 11) on the basis of: (a) piezometric levels, (b) the relative elevations of the piezometric levels in the dolostone and (c) the water table in the drift. Low-lying portions of the basin, including the lakes and adjacent areas are discharge areas for groundwater flow systems originating in the dolostone. Numerous flowing wells occur within the discharge area and many others which have a history of discontinuous flow are located near the recharge-discharge boundary. This boundary fluctuates with long-term precipitation trends. Residents near the boundary reported a history of flowing and non-flowing conditions which correlate with long-term precipitation trends.

Groundwater Temperature Profiles

The temperatures of groundwater in several piezometers were measured on July 11 and 14, 1969. Temperatures were found to increase with increasing depth, however the rate of increase was less in discharge areas as compared to recharge areas. The temperature trends

(Fig. 12) are the result of the combined effects of diffusion and convection which differ between recharge and discharge areas in the summer. Shallow groundwater is warmer in recharge areas because of a downward convection of heat. In discharge areas where the downward transmittal of heat depends on conduction alone and the rate of temperature decrease with depth is more pronounced. The temperature profiles support the interpretation of recharge and discharge areas which were inferred from piezometry.

GROUNDWATER CHEMISTRY

Major Processes and Environmental Controls

The chemistry of groundwater at a particular point in a shallow flow system is the result of many geochemical processes. The work of several authors (Charron 1965, 1967; Rozkowski 1967; and Toth 1966) suggest that in the upper units of the Western Canadian sedimentary basin the most important geochemical processes are:

- (a) the chemical composition of precipitation; (b) the generation of gases in soil horizons of recharge areas;
- (c) the dissolution of minerals present in porous media;
- (d) the precipitation of mineral phases within the pore network; (e) the exchange of ions between pore solutions

and minerals in the porous media; and (f) reduction-oxidation reactions.

These processes are largely interdependant and are strongly influenced by: (i) temperature; (ii) rates of fluid movement; (iii) pressure; (iv) position in the flow system; (v) mineralogy of the porous media; and (vi) the order in which the pore fluids come in contact with minerals. As a result of these factors there usually is a progressive increase in ionic strength and a continuing modification of ionic composition as groundwater moves along flow paths.

Solution chemistry is valuable in understanding relationships which exist between groundwater chemistry, the geochemistry of the geologic environment, and position in the flow system. It is the purpose of this section to investigate these relationships as they occur in the shallow groundwater regime of the Shoal Lakes basin. This hydrochemical investigation has the following objectives: to determine some of the specific geochemical processes operating in the groundwater system, and to utilize the distribution of major-ion concentrations in groundwater and lakewater as a means of furthering the interpretation of hydrologic processes operating in the basin.

DISTRIBUTION OF MAJOR IONS, pH, AND PCO₂

The Glacial Drift

Large variations in ionic concentrations characterize groundwater in the glacial drift (Fig. 13). In 20 of 32 analyses, Na⁺ is the major anion while SO₄⁼ and HCO₃⁻ are the major cations in 31 analyses. Forty-one percent of waters sampled and analyzed are of the sodium-sulphate type. Ca⁺⁺/Mg⁺⁺ molar ratios are approximately 0.5 or less while Na⁺/Cl⁻ molar ratios are normally less than 1.

Hydrochemical correlations with respect to groundwater flow direction were possible to some degree in most piezometer nests and consistent trends are best illustrated in piezometer nests 3, 12, 13, and 22 (Fig. 14). Recharge and discharge situations are each represented by two examples. The cumulative increases in ionic constituents occurs in the direction of flow and the ions most sensitive to position in the flow system are Na⁺ and SO₄⁼.

Most pH values in the drift vary between 7.5 and 8.5 but in several analyses the measured pH was as large as 12.4 (Fig. 15). Since the analytical technique for measuring pH is believed to be reliable it is assumed that values in excess of 8.5 are improbable and result from contamination by cement grout used in piezometer

construction. All values are recorded as measured (Appendix C) however, values of pH greater than 8.5 have been omitted from most figures.

Partial pressures of carbon dioxide (PCO_2) were calculated for all analyses using measured values of pH and HCO_3^- and the procedures outlined on page 42. The range of PCO_2 in the overburden is 5×10^{-4} to 5×10^{-2} (Fig. 15). Values most commonly fall in the range 10^{-3} to 10^{-2} and are considerably larger than the atmospheric PCO_2 which is about 3×10^{-4} atm. The calculated PCO_2 values for analyses where pH exceeded 8.5 are 5×10^{-4} atm and have been omitted from graphs and diagrams.

The Dolostone

Most dolostone waters are of the magnesium-bicarbonate type. The concentration levels of Ca^{++} , Mg^{++} , and HCO_3^- are uniform while Na^+ , Cl^- , and $\text{SO}_4^{=}$ show considerable variation (Fig. 16). Sodium, Cl^- , and $\text{SO}_4^{=}$ concentrations increase in the general direction of groundwater movement (Fig. 17) however, Ca^{++} , Mg^{++} , and HCO_3^- concentrations vary only slightly and no areal patterns or trends are evident (Fig. 18).

Groundwater tends to contain larger percentages of Na^+ , Cl^- , and $\text{SO}_4^{=}$ in wells which penetrate more than

30 m (100 ft) of dolostone (Fig. 19). Several shallower wells in the dolostone (12, 24, 65, 66, and 67) also contain increased levels of Na^+ , Cl^- , and $\text{SO}_4^{=}$. These wells are located together in a recharge area (Fig. 10) and the anomolous increase in Na^+ , Cl^- , and $\text{SO}_4^{=}$ concentrations is due to the addition of groundwater which has passed through the drift to the dolostone water. As mentioned previously, groundwater in the drift is richer in Na^+ , Cl^- , and $\text{SO}_4^{=}$ as compared with groundwater in the dolostone.

The flowing wells (Fig. 20) are characterized by reduced concentrations of Na^+ , Cl^- , and $\text{SO}_4^{=}$.

Most values of pH in the dolostone groundwater are between 7.0 and 8.2 with a median of about 7.5 (Fig. 15). Values of PCO_2 are similarly uniform and range between 10^{-3} and 5×10^{-2} (Fig. 15). The PCO_2 in the dolostone is, on the average, an order of magnitude larger than in the overburden. In the flowing wells, PCO_2 varies from 1.14×10^{-3} to 2.15×10^{-3} atm and is lower than in most other wells.

MINERALOGIC SOURCES OF IONS

The Glacial Drift

As indicated previously, the glacial deposits

consist primarily of dolomite which is moderately soluble in water. From procedures outlined in Garrels and Christ (1965) and the solubility products of Langmuir (1971), concentrations of Ca^{++} , Mg^{++} , and HCO_3^- were calculated and graphed as functions of pH at various PCO_2 for an aqueous solution of dolomite at 5°C (Fig. 21). Plotting Ca^{++} , Mg^{++} , and HCO_3^- field data on the same graph, it is observed that Ca^{++} and HCO_3^- concentrations are slightly above anticipated values while the Mg^{++} concentrations are well above equilibrium values.

Groundwater in the drift tends to be richer in Mg^{++} and poorer in Ca^{++} than expected from simple dissolution of dolomite. The $\text{Ca}^{++}/\text{Mg}^{++}$ ratio averages about 0.6 in spite of the fact that the overburden is derived primarily from a dolomite which locally has a $\text{Ca}^{++}/\text{Mg}^{++}$ ratio of slightly greater than 1 (Table I). A ratio less than 1 is unexpected for the additional reason that gypsum is probably present in the drift (Wicks 1965) and a contributor of Ca^{++} .

Negligible differences in Ca^{++} , Mg^{++} , and HCO_3^- concentrations between recharge and discharge areas (Fig. 18) and along flow paths indicates that dolomite dissolution occurs relatively rapidly during infiltration. It is possible that the generally supersaturated condition with respect to calcite and dolomite and the $\text{Ca}^{++}/\text{Mg}^{++}$ ratio imbalance are due to partial

CO₂ degassing in the unsaturated zone. During initial phases of infiltration in the unsaturated zone, groundwater becomes charged with CO₂ generated in the plant root zone. Carbonate dissolution to saturation occurs almost immediately, catalyzed by the dissolved CO₂. As the water infiltrates downward it encounters larger porosities and reduced CO₂ partial pressures. Carbon dioxide escapes from the water and causes the groundwater to become supersaturated with respect to calcite and dolomite. Calcite precipitates resulting in the removal of Ca⁺⁺ and HCO₃⁻ ions from solution and a decrease in the Ca⁺⁺/Mg⁺⁺ molar ratio. Dolomite is presumably not precipitated because of slower solution kinetics (Holland et al 1964). Most analyses are highly supersaturated with respect to dolomite but only slightly oversaturated with respect to calcite (Fig. 22). Other factors which support the degassing theory are increases in CaCO₃ and pH (Table II) with depth in upper soil horizons as reported by Ehrlich and Rice (1955). The increase in pH may be the result of calcite precipitation (Table II). Calcium carbonate precipitate was observed on the undersides of pebbles in a zone only a few feet below ground level in shallow gravel pits along the western basin boundary. Degassing is thought to have been the mechanism which caused the CaCO₃ to precipitate.

Groundwater in the glacial drift contains moderate to high concentrations of Na^+ , Cl^- , and $\text{SO}_4^{=}$ and it is evident that not only dolomite dissolution influences the hydrochemistry. The (1) incongruent dissolution of dolomite, the (2) presence of readily soluble magnesium minerals, (3) ion exchange with montmorillonoid and illite clay minerals, and (4) solution of silicate minerals may contribute to the ion composition of groundwater in the drift.

Impurities of Na^+ , K^+ , Cl^- , and $\text{SO}_4^{=}$ at concentrations of several hundred parts per million in dolomite crystal lattices have been identified in Paleozoic carbonates in Northern Canada (Fritz and Jackson 1972) however the simple dissolution of dolomite crystals would not be capable of producing significant concentrations of Na^+ , K^+ , Cl^- , and $\text{SO}_4^{=}$ relative to the concentrations of Ca^{++} , Mg^{++} , and HCO_3^- . It is reasoned therefore that highly soluble chloride and sulphate minerals are present in the drift and are responsible for most of the Na^+ , K^+ , Cl^- and $\text{SO}_4^{=}$ and also contribute some of the excess Ca^{++} and Mg^{++} . Dissolution of silicate minerals is considered to be capable of producing only small concentrations of Na^+ , K^+ , Ca^{++} , and Mg^{++} under the pH and temperature conditions in the basin (Strumm and Morgan 1970).

It is assumed that Cl^- concentrations are the result of minute amounts of halite (NaCl) present in the drift. Combining Na^+ with Cl^- on a gram equivalent basis results in an excess of Na^+ over Cl^- .

Gypsum is a likely source mineral for $\text{SO}_4^{=}$ and if excess Ca^{++} is combined with $\text{SO}_4^{=}$, a large excess of $\text{SO}_4^{=}$ remains. Excess Ca^{++} is the total measured concentration of Ca^{++} minus the Ca^{++} contributed by dolomite dissolution.

In most analyses, significant concentrations of Mg^{++} , Na^+ , and $\text{SO}_4^{=}$ must be accounted for. Two plausible mechanisms are; (1) that all the $\text{SO}_4^{=}$ is obtained from gypsum or anhydrite dissolution with much of the Ca^{++} subsequently lost to exchange for Na^+ or Mg^{++} on clay minerals, or (2) that other highly soluble minerals such as mirabilite ($\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$), epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), and glauberite ($\text{Na}_2\text{Ca}(\text{SO}_4)_2$) are also present and contribute Na^+ , Ca^{++} , Mg^{++} , and $\text{SO}_4^{=}$ ions.

Montmorillonite and illite have relatively large exchange capacities and are major components in the clay fraction of the glacial drift in the vicinity of the basin (Table III). When water is in contact with clays with exchangeable Na^+ , Ca^{++} tends to be adsorbed on the clays in preference to Na^+ providing the concentration of Na^+ is less than that of Ca^{++} in the groundwater. Also, if the $\text{Ca}^{++}/\text{Mg}^{++}$ ratio is not too small

Ca^{++} will be adsorbed in preference to Mg^{++} (Wiklander 1964). It seems reasonable that in the drift dissolution of gypsum and/or anhydrite could be accompanied by exchange of Ca^{++} and Mg^{++} on clay minerals.

Impurities in the silica sand used in the piezometer construction may also have contributed to the ion composition of some samples collected from piezometers. Since most cements contain about 3% gypsum, unusually large Ca^{++} and $\text{SO}_4^{=}$ concentrations as in P-6 (Appendix C) may also be the result of contamination.

The Dolostone

A relatively pure dolomite (Table I) is the major rock forming mineral in the dolostone which underlies the Shoal Lakes basin. The availability of Ca^{++} , Mg^{++} , and HCO_3^- is virtually unlimited and concentrations in the groundwater depend on solution kinetics, the partial pressure of carbon dioxide, and the solubility of dolomite. Calcium, Mg^{++} , and HCO_3^- were graphed as functions of pH for dolostone waters (Fig. 23) at various PCO_2 for aqueous solutions of calcite, dolomite, and a calcite-dolomite mixture at 5°C. The chemical data best approached calculated values for a dolomite model. The field data normally plot above the theoretical equilibrium

lines of the dolomite model based on Langmuir's (1971) dolomite solubility values. The model indicates that the simple solution of dolomite would produce equivalent molar concentrations of Ca^{++} , Mg^{++} , and HCO_3^- and a $\text{Ca}^{++}/\text{Mg}^{++}$ ratio of 1 or slightly greater than 1 since the $\text{Ca}^{++}/\text{Mg}^{++}$ molar ratio in the bedrock is slightly greater than 1 (Table I). The apparent excess of all three ions but especially of Mg^{++} and a $\text{Ca}^{++}/\text{Mg}^{++}$ ratio which averages about 0.6 suggest that other processes than the simple solution of dolomite effect the hydrochemistry of groundwater in the dolostone.

Because there is no apparent correlation between directions of groundwater movement and the concentration levels of Ca^{++} , Mg^{++} , and HCO_3^- ions it is reasoned that dolomite dissolution to saturation occurs rapidly during initial phases of infiltration. It is suggested that the overall supersaturation with respect to calcite and the large supersaturations with regard to dolomite (Fig. 24) occur because of CO_2 degassing after saturation has been reached. This process, described in the previous section, is especially applicable in upland areas where water infiltrates thin soil cover to reach the water table which is generally several meters below the top of a highly porous aquifer.

Relatively large concentrations of Na^+ , Cl^- , and $\text{SO}_4^{=}$ are present in the dolostone groundwaters and the

concentration levels of these ions are sensitive to position in the flow system (Fig. 17). Minerals which donate these ions are readily soluble and since ion concentrations depend on flow path length and residence time, it is concluded that these minerals are disseminated in small amounts throughout the dolostone. Since most flowing wells are relatively shallow, the flow systems are also regarded as being shallow and the groundwater movement relatively rapid. The resultant limited contact with the bedrock environment results in reduced concentrations of Na^+ , Cl^- , and $\text{SO}_4^{=}$ ions in flowing well analyses tending to confirm that disseminated trace minerals are responsible for much of the Na^+ , Cl^- , and $\text{SO}_4^{=}$ present. Deeper groundwater, in general contains increased percentages of Na^+ , Cl^- , and $\text{SO}_4^{=}$ (Fig. 19) due to increased residence time and longer flow paths.

It is assumed that all the Cl^- present is the result of halite (NaCl) dissolution. Combining Na^+ with Cl^- on a gram equivalent basis results in an excess of Na^+ .

A probable $\text{SO}_4^{=}$ donor mineral is gypsum and/or anhydrite. If available Ca^{++} is combined with gram equivalent amounts of $\text{SO}_4^{=}$, an abundance of $\text{SO}_4^{=}$ results.

It is improbable that cation exchange is a significant geochemical process in the carbonate rock aquifer. The Na^+ and $\text{SO}_4^{=}$ concentrations in the aquifer may have been derived from sodium-sulphate minerals in the

dolostone or during recharge through the glacial drift.

WATER BUDGET OF NORTH SHOAL LAKE

Water Budget Components

Hydrometric data collected in the Shoal Lakes basin are used to estimate water budget components for North Shoal Lake. Rainfall and evaporation were measured from May 23 to September 28, 1969, using standard rain gauges and a Class A evaporation pan (Table V). A record of lake stage for North Shoal Lake was kept for the period June 25 to October 5, 1969. Total measured precipitation at the weather station (Fig. 6) for the May 23 to September 28 period was 26.92 cm (10.60 in) compared to a 30-year average for the same period at the Winnipeg International Airport of 27.48 cm (10.82 in). Net water loss from the evaporation pan during this period totaled 64.06 cm (25.22 in). Applying empirical corrections to the monthly net pan evaporation values (McKay and Stichling 1961) resulted in a corrected net evaporation estimate of 52.91 cm (20.83 in) from North Shoal Lake. During the period for which net evaporation and lake stage are available (June 25 to September 28) the corrected net evaporation

Table V Meteorological Data from Shoal Lakes Weather
Station.

	May*	June	July	August	September**
Mean air temp. °C	6.4	10.6	18.1	20.0	11.8
°F	43.5	51.5	64.5	68.0	53.3
Mean pan water temp. °C	14.4	14.7	20.3	22.9	13.8
°F	58.0	58.5	68.6	73.3	57.0
Mean lake temp. °C		16.4	18.3	18.4	14.1
°F		61.5	64.9	65.1	57.4
Mean daily wind km	295.3	200.0	149.4	197.5	213.1
mile	183.5	124.3	92.8	122.7	132.4
Total pre-cipitation cm	2.41	4.92	10.82	6.69	2.01
in	0.95	1.94	4.26	2.66	0.79
Net water loss cm	5.78	15.82	15.88	17.36	9.22
in	2.28	6.23	6.25	6.84	3.63
Corrected net water loss cm	4.92	13.66	12.52	13.03	8.76
in	1.94	5.38	4.93	5.13	3.45
Rainfall for measured period.....					26.92 cm
					10.60 in
Net water loss for measured period.....					64.06 cm
					25.22 in
Corrected estimate of the net water loss					
for measured period.....					52.90 cm
					20.83 in

* Beginning May 23, 1969

** ending September 28, 1969

from the lake was 35.14 cm (14.23 in). A hydrograph of North Shoal Lake (Fig. 25) indicates that lake stage remained relatively constant until late August when a decline of approximately 9 cm (3.5 in) was recorded.

Transpiration losses in marginal swamplands are not known and surface runoff to the lakes could not be measured because of large tracts of sloughs adjacent to the lakes and the absence of well defined stream channels.

The Groundwater Component in North Shoal Lake

Knowing ice thickness (approx. 1 m) and the relative increase in ionic concentrations during the winter period (Fig. 26), the average lake depth is probably in the range of 122 to 152 cm (4 to 5 ft). During the period June 6 to August 20, 1969, hydrometric measurement indicated the loss of 33 cm (13 in) of water from the lake surface but in that same period there was no observable net change in lake level, necessitating 33 cm (13 in) of input to maintain the lake level.

The Cl^- concentration together with hydrometric measurements are used to estimate the Cl^- concentration of the input component. Chloride ion was selected because it is not subject to complexing, does not participate in exchange reactions, forms no slightly soluble

precipitates, and does not usually take part in biological reactions. In order to end with the measured Cl^- concentration of 205 mg/l on August 20, the 33 cm (13 in) of input must have contained between 90 and 115 mg/l of Cl^- .

The evaporation estimate of 33 cm (13 in) may be small since transpiration losses from fringing swamp areas was neglected. If evaporation losses were arbitrarily increased to 38 cm (15 in), then the Cl^- in the input would range between 80 and 100 mg/l depending on lake depth.

Chloride ion concentrations in groundwater from the glacial drift are in the range of 80 to 115 mg/l and it is considered that groundwater inflow to the lake comprises the major portion of the input component.

The Groundwater Component from the Darcy Equation

Flowing wells and discharge gradients observed in piezometers have been used to outline recharge-discharge areas in the basin (Fig. 11). Discharge gradients exist adjacent to the lakes and probably continue beneath the lakes. Groundwater discharge to the lake is estimated from values of hydraulic conductivity and discharge gradients obtained from piezometers adjacent to North

Shoal Lake.

The arithmetic average of hydraulic conductivity values obtained in piezometer nests P-3, P-4, and P-10 (Table IV) is 1.5×10^{-6} cm/sec (5×10^{-8} ft/sec). Discharge gradients in these piezometers ranged between 0.1 and 0.7 with an arithmetic average of 0.4. Applying the Darcy equation, yields an average groundwater seepage flux of 6×10^{-7} cm/sec (2.6×10^{-8} ft/sec) which, for the period May 23 to September 28 would contribute 6.4 cm (2.5 in) to the lake. Using maximum hydraulic conductivity and gradient values results in a maximum seepage flux of 27.2 cm (10.7 in) while minimum values result in the addition of only 1.3×10^{-4} cm (5×10^{-5} in).

The necessary input of 33 cm (13 in) cannot be fully accounted for by Darcy calculations; however, discharge from springs and flowing wells has not been considered. Local residents report that during drought periods numerous springs flowed on the dry lake bottom. Discharge from such springs on the lake bottom probably continues augmented by discharge from flowing wells which drain into the lake. Some direct surface runoff during storms may also have added to the lake level.

LAKE AND INTERSTITIAL WATER CHEMISTRY

Chemistry of the Shoal Lakes

North, East and West Shoal Lakes are chemically similar (Fig. 27). Analyses are characteristically low in Ca^{++} while Mg^{++} and Na^+ are present in approximately equivalent amounts. Bicarbonate is the major anion.

The concentration levels of most ions increased from November, 1968 to September, 1969. While incomplete, the winter analyses from North Shoal Lake indicates two to threefold increases in Mg^{++} , Na^+ , and $\text{SO}_4^{=}$ concentrations (Fig. 26) with the formation of the ice layer which measured approximately 0.9 m (3 ft) thick. There was no significant increase in the single winter time determination of Ca^{++} . A HCO_3^- determination on a sample collected through ice on East Shoal Lake on April 4, 1969, measured 3730 mg/l; approximately a threefold increase as compared with summer values which varied between 1075 and 1182 mg/l.

Reduced Ca^{++} concentrations and a low $\text{Ca}^{++}/\text{Mg}^{++}$ ratio in the lakewater in a system where dolomite is the principal ion donor suggests that Ca^{++} is being removed from solution by precipitation of CaCO_3 .

This view is supported by the failure of the Ca^{++} ion concentration to change significantly from summer to winter. Slow solution kinetics presumably prevent dolomite from precipitating since calculated supersaturations with regard to dolomite are several orders of magnitude greater than for calcite. The pH of lake water in winter decreased to 8.7 as compared to a summer maximum of 9.2. Summer levels of HCO_3^- and pH result in a calculated PCO_2 for the lakewater of 6×10^{-4} atm, or approximately twice atmospheric (3.2×10^{-4} atm). Generation of CO_2 by decaying organic matter on the lake bottom is probably the reason for higher than atmospheric PCO_2 . In winter, when ice prevents escape of the CO_2 and equilibrium with atmospheric conditions, the CO_2 level increases as evidenced by the decline in pH. This decline will be aided if ion exchange and precipitation of CaCO_3 are taking place.

The $(\text{Na}^+ + \text{K}^+)/\text{Cl}^-$ ratio in lakewater is only slightly greater than unity suggesting that halite is probably a major source mineral for these ions. Excess Na^+ may be a product of ion exchange with Ca^{++} although insufficient Na^+ is available to account for the exceptionally low concentrations of Ca^{++} . Alternately, Na^+ and K^+ may originate from dissolution of silicate minerals in this relatively high pH environment. Unfortunately, no silica determinations were made and it is

recommended that future work include SiO_2 analyses.

The very small $\text{Ca}^{++}/\text{Mg}^{++}$ molar ratio probably results from the formation of CaCO_3 precipitate. Magnesium ion is present in relatively large concentrations because of sluggish dolomite precipitation kinetics. Gypsum is a likely $\text{SO}_4^{=}$ donor; the extra Ca^{++} being consumed in the CaCO_3 precipitation.

Chemistry of the Interstitial Water

The interstitial water contains larger concentrations of the major ions as compared to the lakewater, although the ion ratios between interstitial and lakewaters remain relatively unchanged (Fig. 28). The calculated PCO_2 in interstitial water sample NSL-8 is 1.4×10^{-2} atm, however this value is probably small since some measure of equilibration with atmospheric conditions probably occurred during pH and HCO_3^- titrations. Increased concentrations of Ca^{++} , Mg^{++} , and HCO_3^- are due to the increased PCO_2 which is nearly 400 times that in the lakewater. This PCO_2 increase is reflected in a reduction of pH in the interstitial water.

It has been demonstrated that groundwater discharges to the lake. The groundwater chemistry thereby

affects that of the lakewater and interstitial water and since the lake bottom sediments are mainly reworked drift, the interstitial waters have access to much the same mineral assemblage as groundwater in the drift. Halite (NaCl) and gypsum (CaSO_4) are probably the major donors of Cl^- , Na^{++} , and SO_4^{--} ions. Reasons for the small $\text{Ca}^{++}/\text{Mg}^{++}$ ratio have been discussed in previous sections and are applicable here also.

SATUROMETRY

Equilibrium activity products for dolomite and calcite were derived from the Law of Mass Action assuming the activities of the solid mineral phase and H_2O to be unity. The degree of saturation with respect to calcite and dolomite were calculated for all analyses by dividing the ion activity products by the equilibrium activity products. Activity coefficients from Garrels and Christ (1965) were used for Ca^{++} , HCO_3^- , and CO_3^{--} , and from Hosteller (1964) for Mg^{++} . Activities of CO_3^{--} were computed from field measurements of pH, HCO_3^- , and temperature using dissociation constants calculated by Back (1961, 1964). Calcite and dolomite dissociation constants are from Langmuir (1968, 1971).

The partial pressures of dissolved carbon dioxide in the groundwater were derived from the relationships:

$$K_{H_2CO_3} = \frac{a_{H^+} a_{HCO_3^-}}{a_{H_2CO_3}},$$

$$\text{and } K = \frac{a_{H_2CO_3}}{a_{CO_2} a_{H_2O}}.$$

The assumption that the activity of CO_2 = fugacity of CO_2 = partial pressure of CO_2 (PCO_2) is justified for total pressures less than about 10 atmospheres (Garrels and Christ 1965).

The effects of complexing or ion-pairing on the saturation indices with regard to certain minerals can be significant when ionic strength values exceed 0.1 (Van Everdingen 1971). Since approximately 95% of calculated ionic strength values are less than 0.05 (Fig. 29), ion-pairing is not considered further.

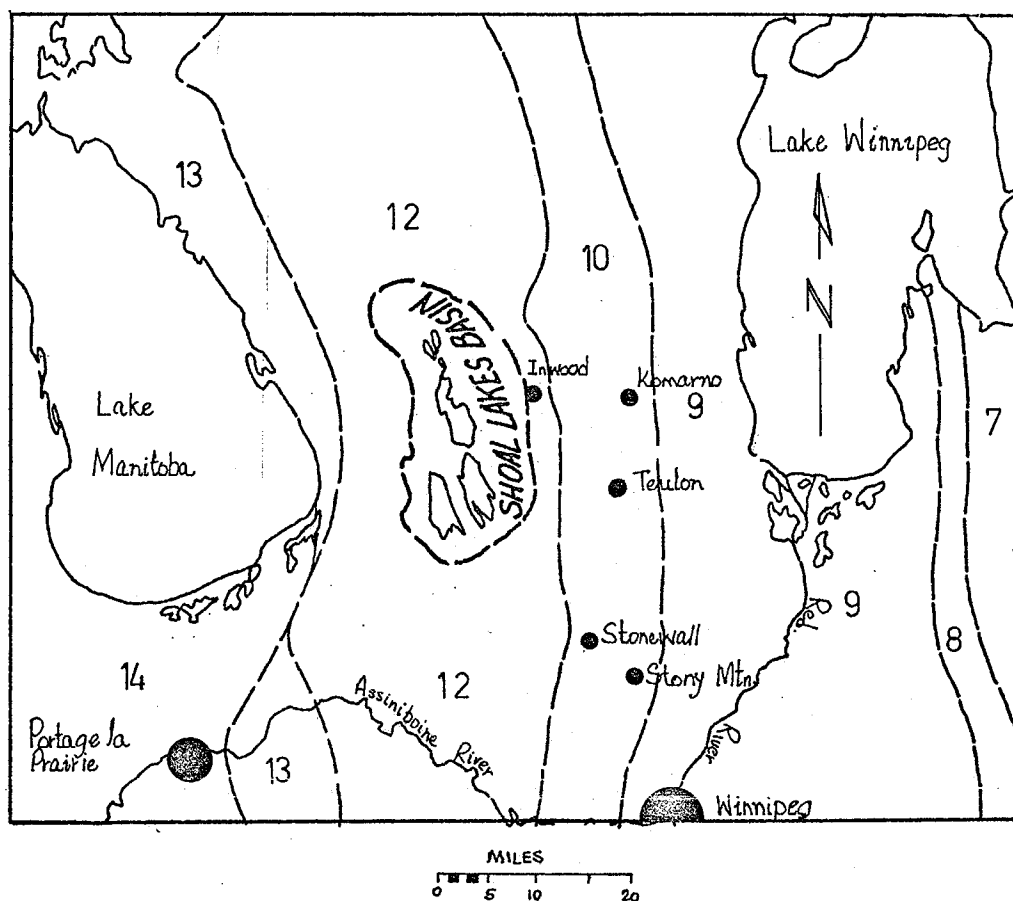
SUMMARY OF CONCLUSIONS

Glacial drift overlies Paleozoic dolostone in the Shoal Lakes basin in south-central Manitoba.

Upland areas where the glacial drift is thin or absent are effective recharge areas to the dolostone. Groundwater movement in the dolostone is southward as evidenced by hydrochemistry and the interpretation of hydraulic head data. The Shoal Lakes and adjacent low-lying areas are located in a zone of active groundwater discharge marked by flowing wells in the dolostone and discharge gradients in the glacial drift.

The carbonate hydrochemistry field data in both the drift and dolostone groundwaters most closely fit a simple dolomite dissolution model; however, Ca^{++} , Mg^{++} , and HCO_3^- concentrations in the groundwater exceed anticipated model concentrations and the $\text{Ca}^{++}/\text{Mg}^{++}$ ratio in the groundwater is less than 1. Calcite precipitation in the unsaturated zone as a result of CO_2 degassing explains the supersaturated condition of the groundwater with respect to the calcite and dolomite as well as the decreased concentration of Ca^{++} ion. The widespread presence of highly soluble sulphate and chloride minerals is inferred from the hydrochemical data.

Despite a corrected net evaporation of 33 cm (13 in), the water level of North Shoal Lake remained essentially unchanged between June 6 and August 20, 1969. It is postulated that groundwater discharge to the lake was the source of most of the 33 cm (13 in) deficit. While the calculated amount of discharge through the drift is less than 33 cm (13 in), additional discharge from springs and flowing wells could supply requirements. Direct surface runoff may also be a factor especially during summer storms.



Geologic Legend

Mesozoic	Jurassic	14	Amaranth Fm.	shales, sandstones, calcareous shales limestones, gypsum, anhydrite.
Paleozoic	Devonian	13		limestone, dolomite, and minor red shale
	Silurian	12	Interlake Grp.	dolomite and minor, thin argillaceous beds
	Ordovician	10	Stony Mtn. Fm.	argillaceous limestone, dolomite, argillaceous dolomite
	Ordovician	9	Red River Fm.	dolomitic limestone, dolomite
	Ordovician	8	Winnipeg Fm.	sandstone, shale
Precambrian		7		granite, granodiorite, quartz diorite

Fig.1 Location and geology of the Shoal Lakes basin.

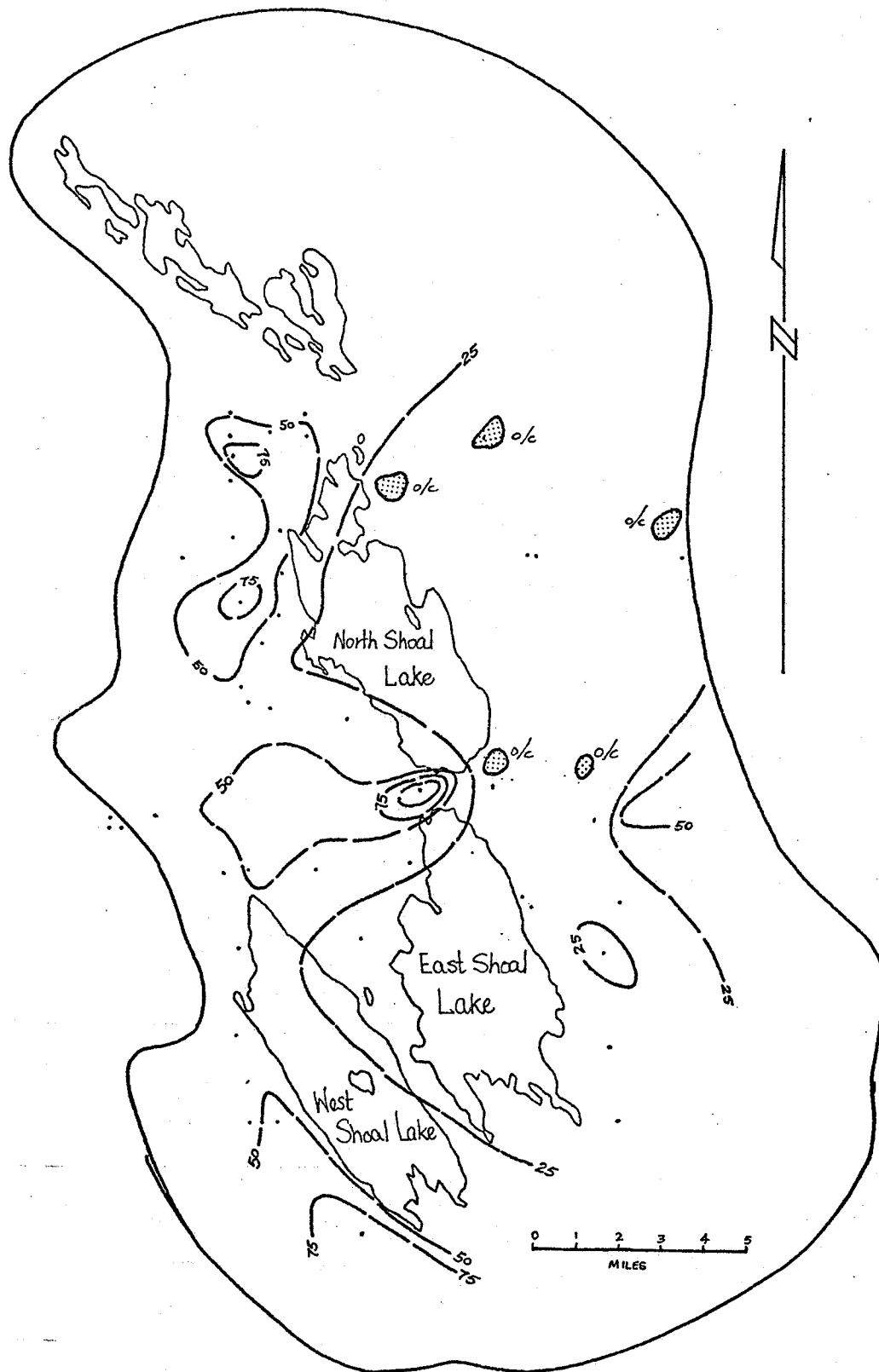


Fig. 2 Drift isopach and bedrock outcrop map.

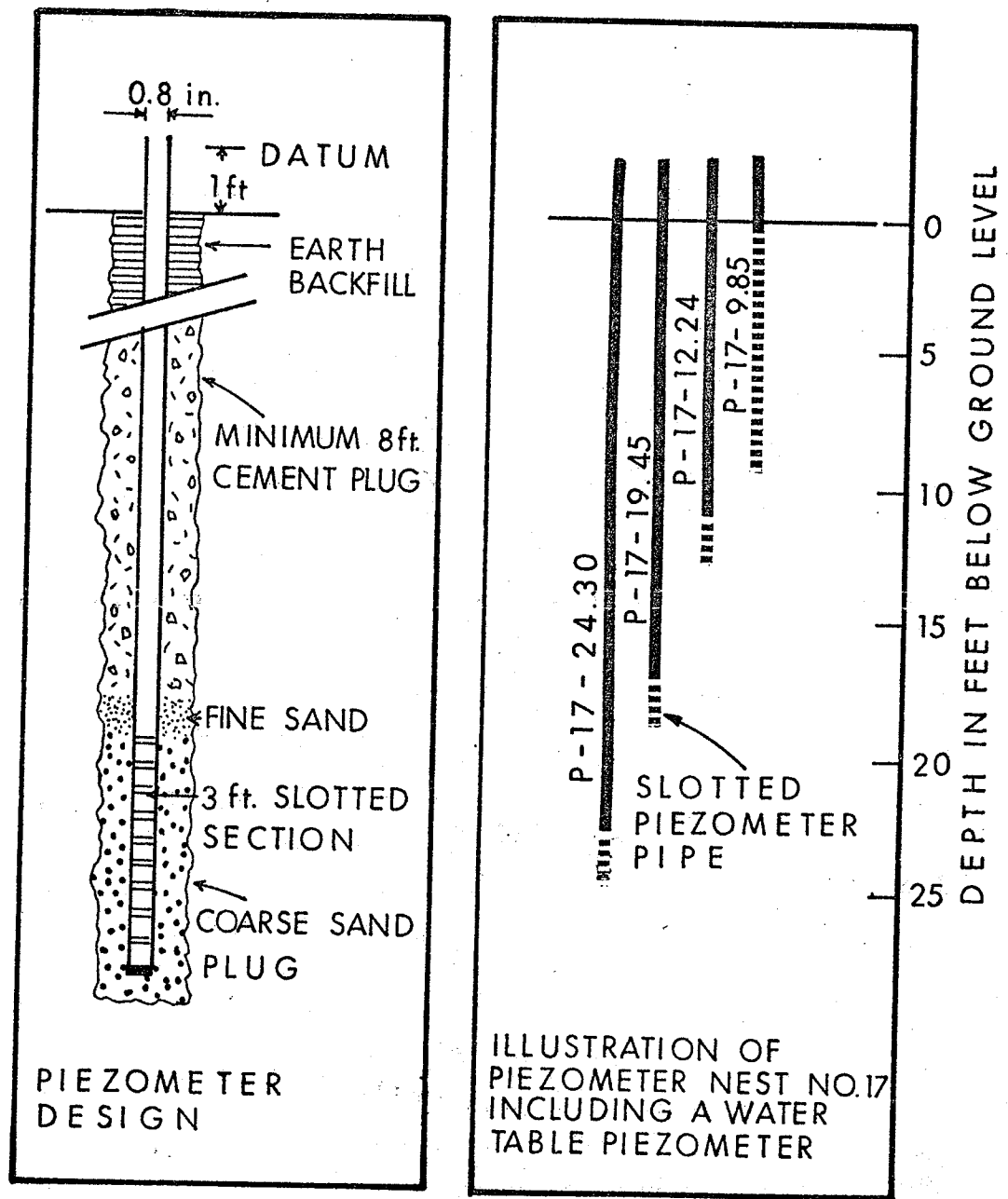


Fig. 4 Details of piezometer construction.

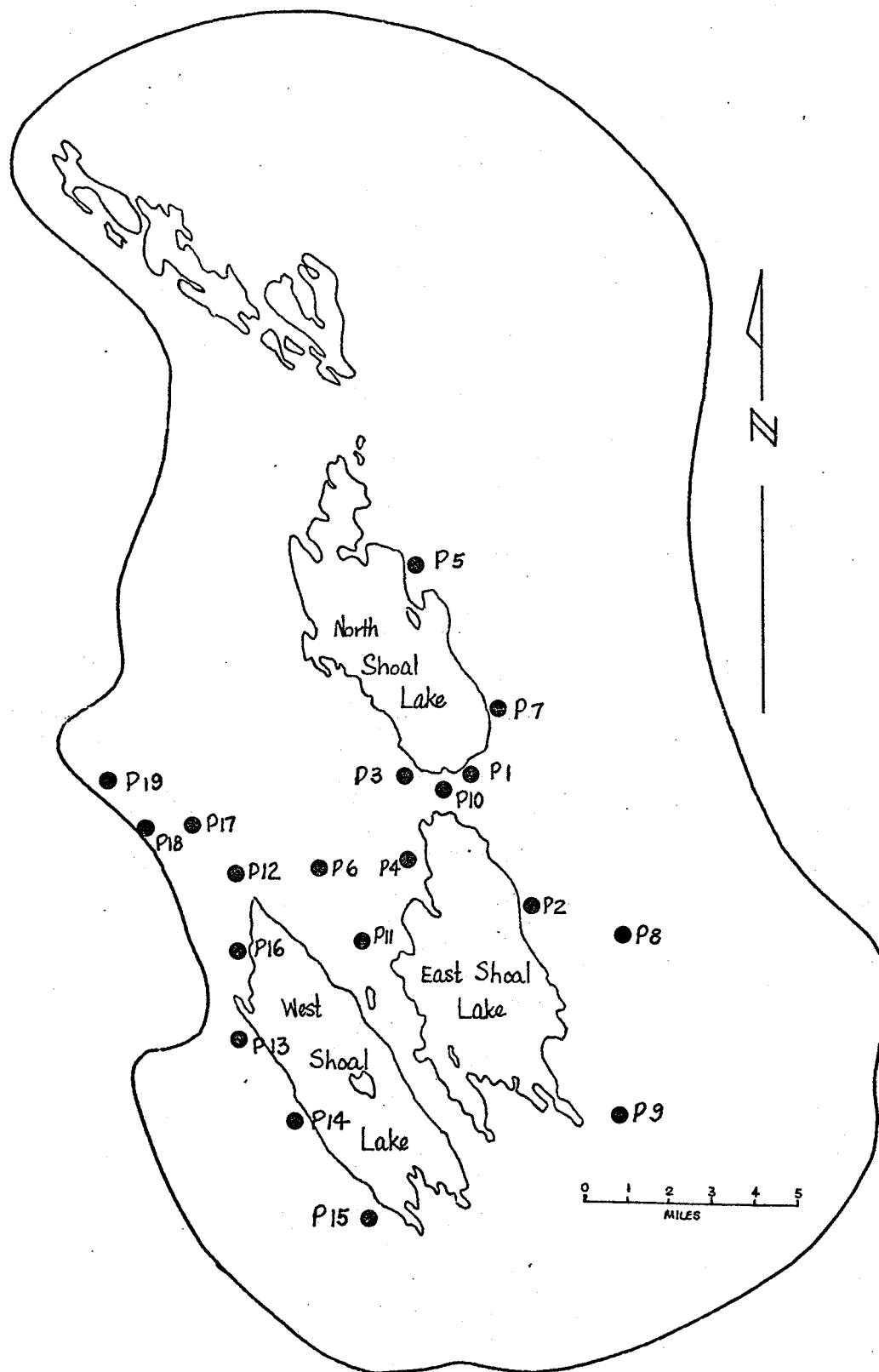


Fig. 5 Piezometer nest locations.

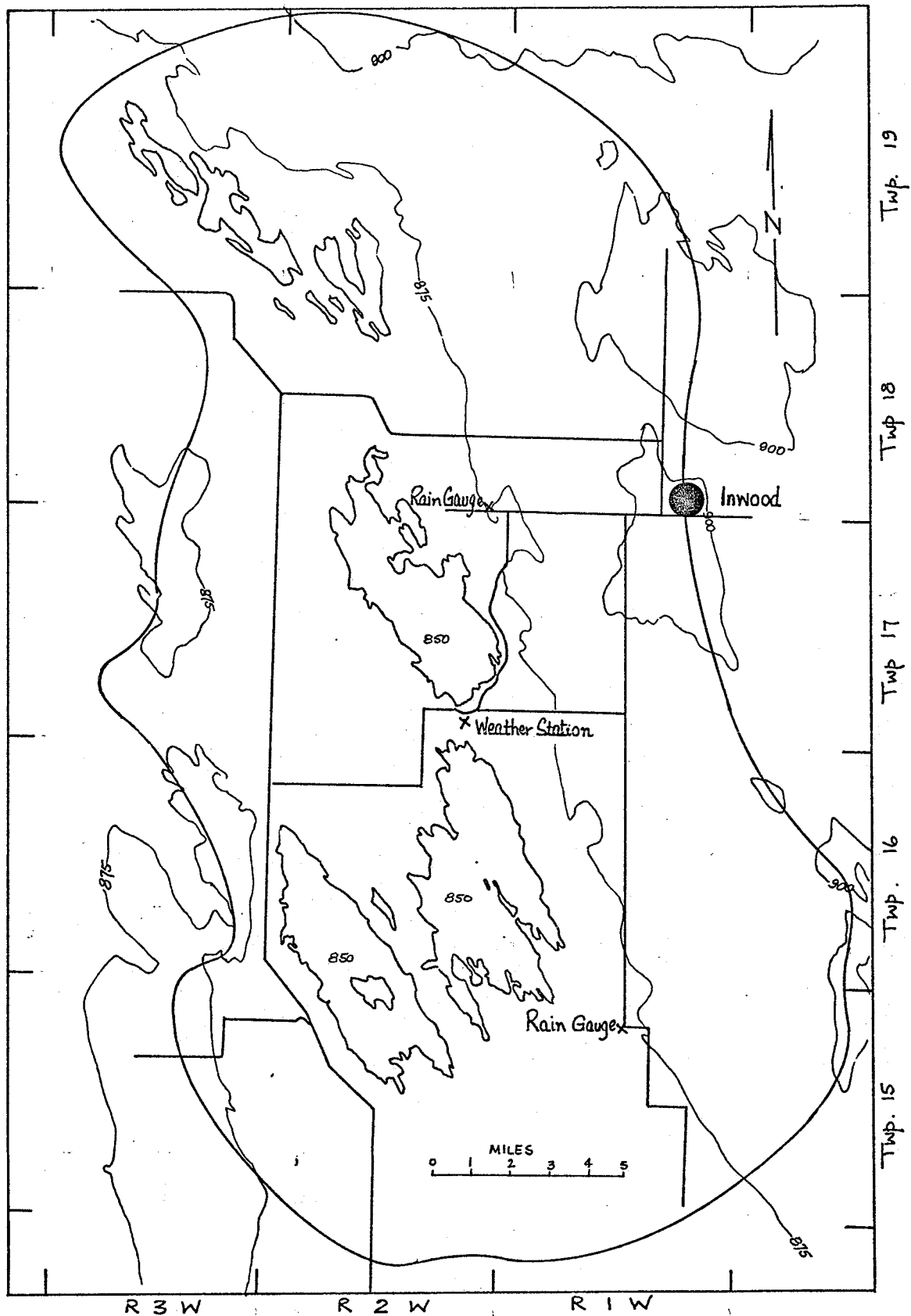


Fig. 6 Shoal.Lakes basin and vicinity with locations of hydrometric stations.

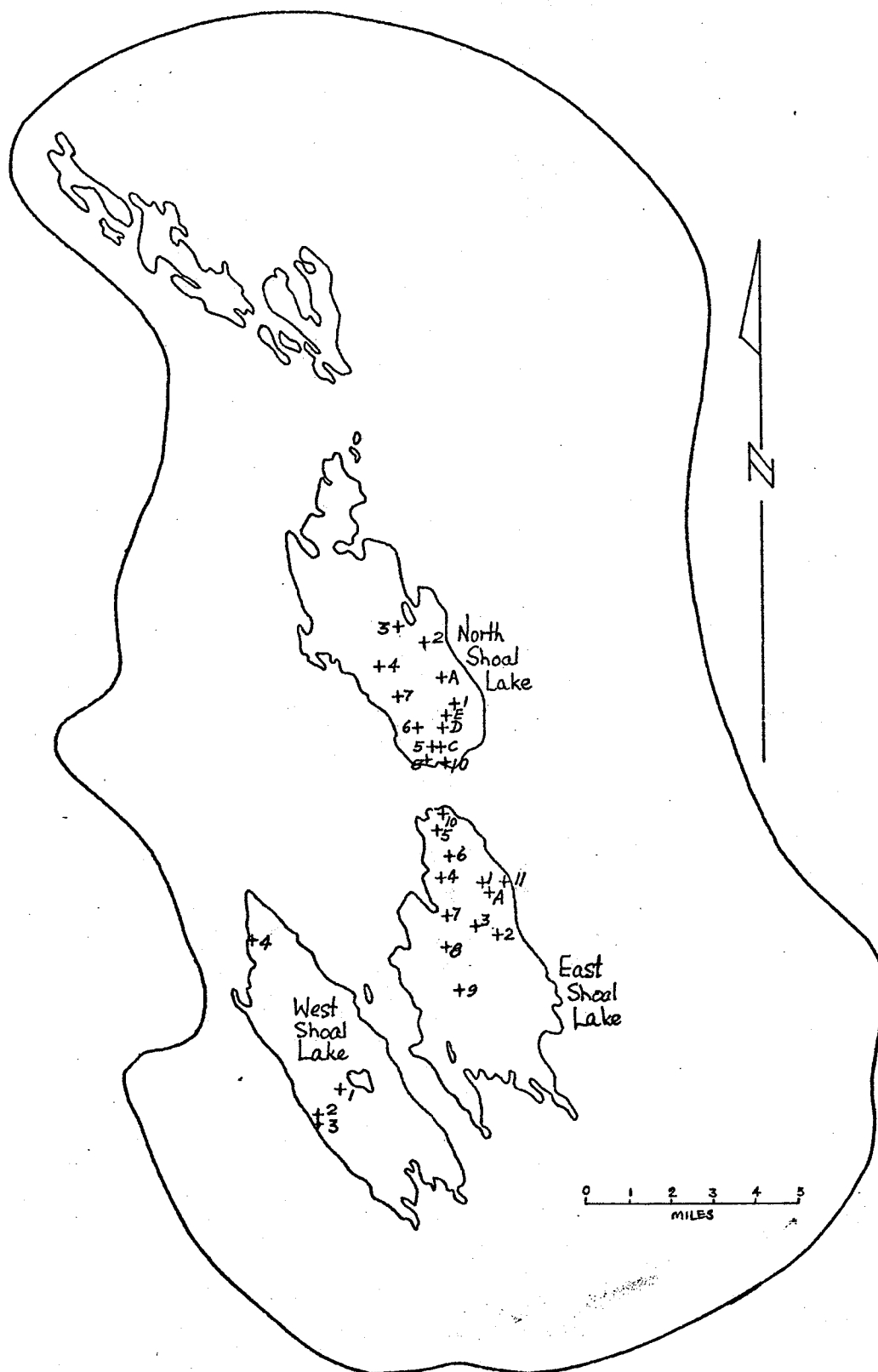
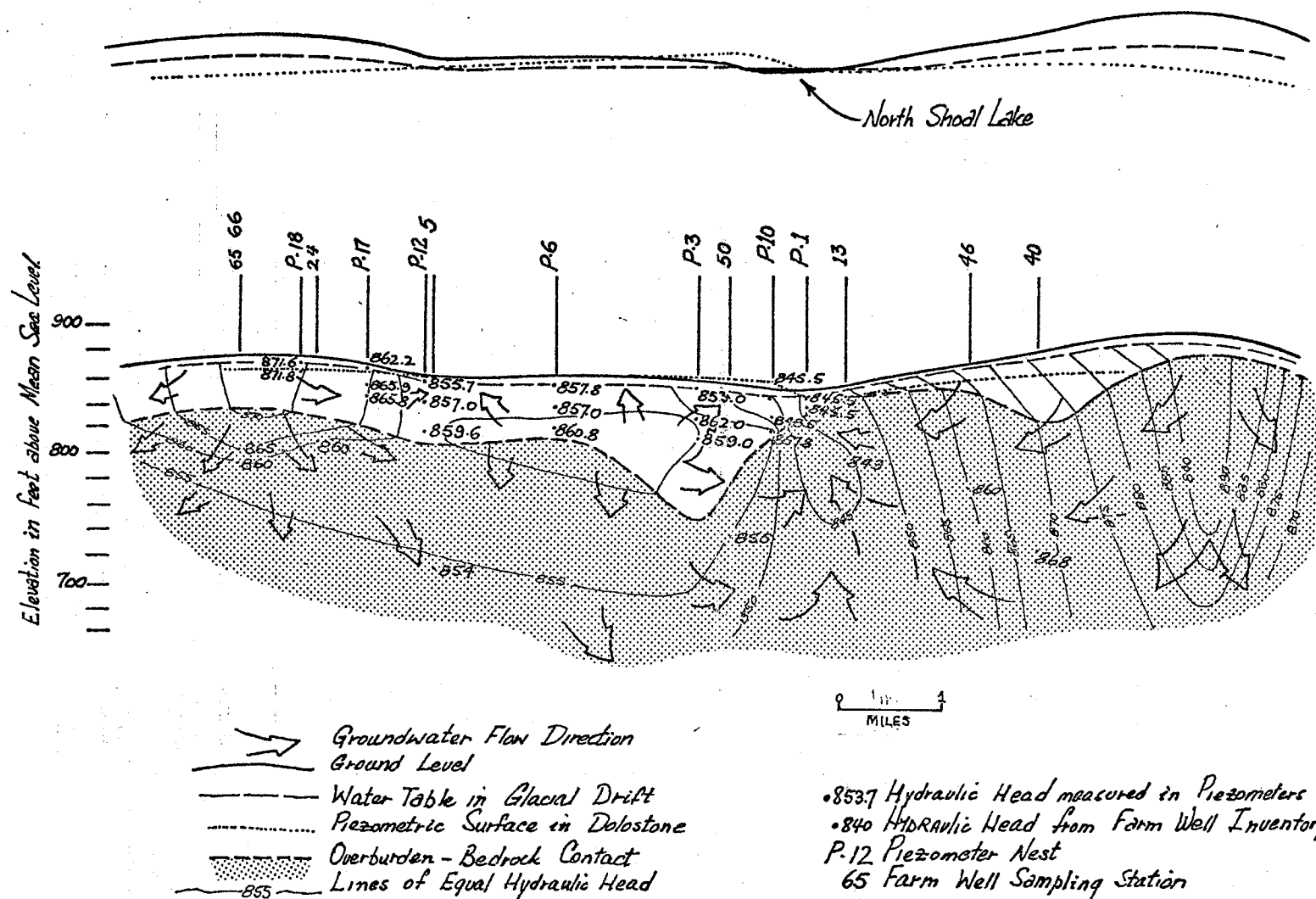


Fig. 7 Lakewater sampling locations.

Fig. 8 Hydrogeologic cross-section CD.



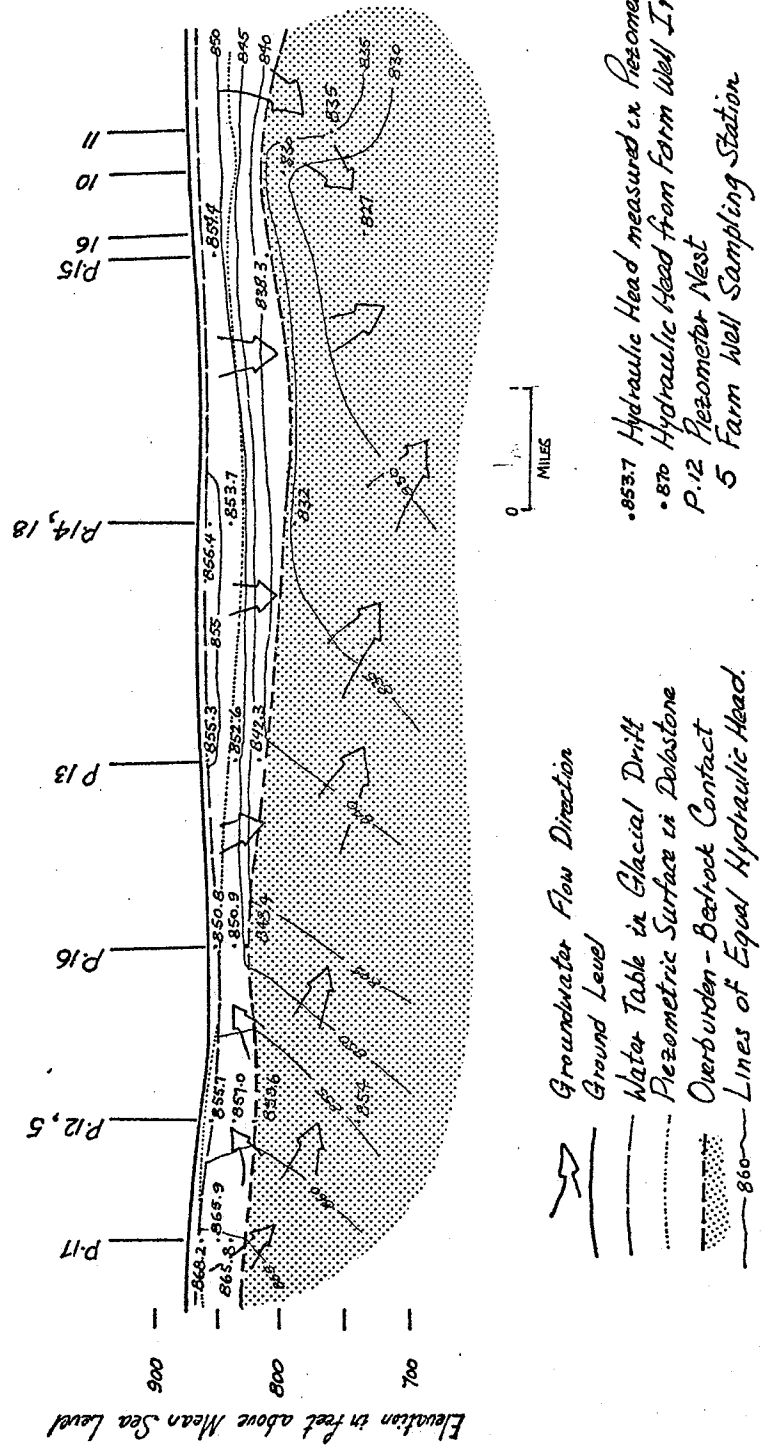


Fig. 9 Hydrogeologic cross-section EF.



Fig. 10 Piezometric surface map of the dolostone aquifer with inferred directions of groundwater movement.

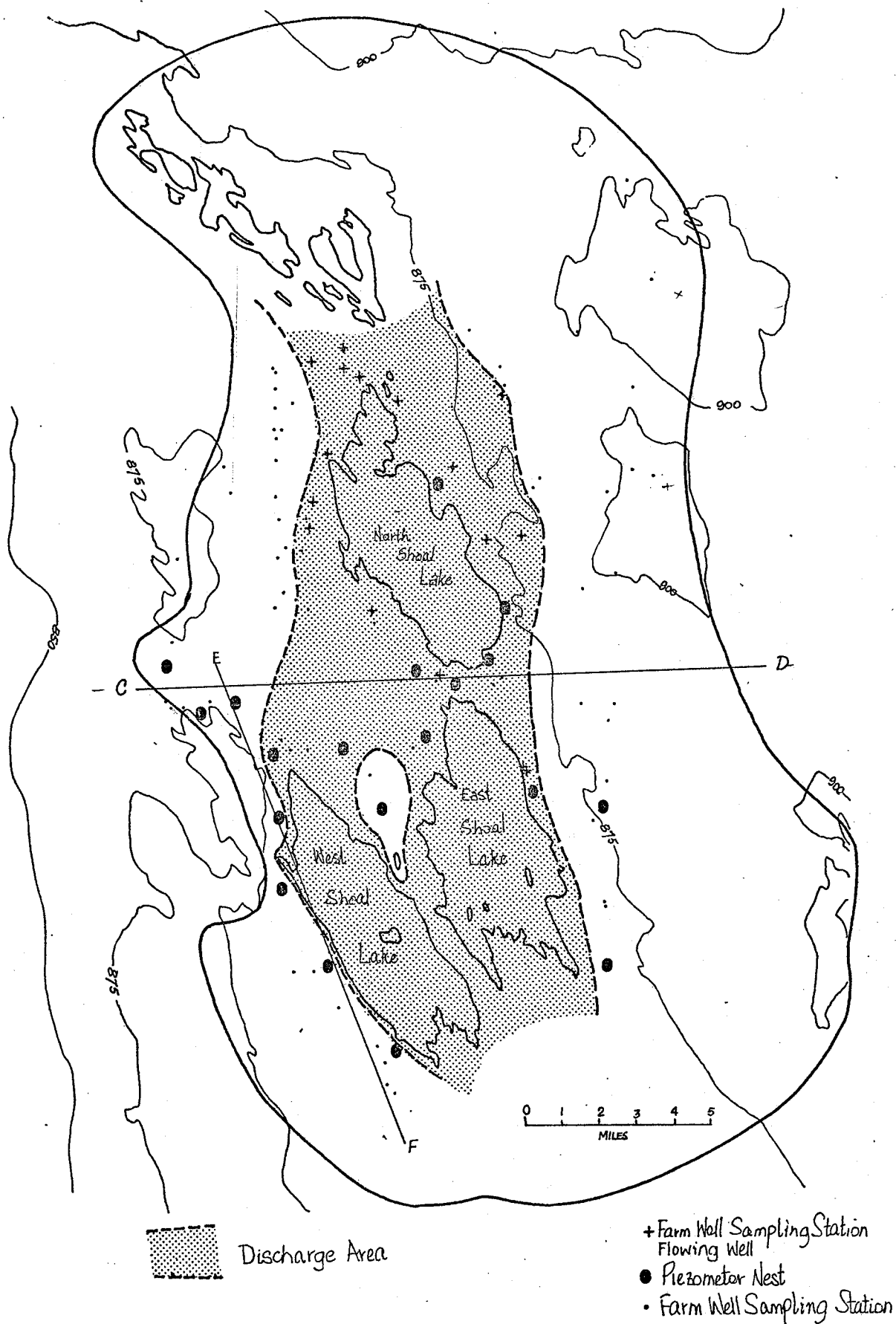


Fig. 11 Zone of groundwater discharge and hydrogeologic cross section locations.

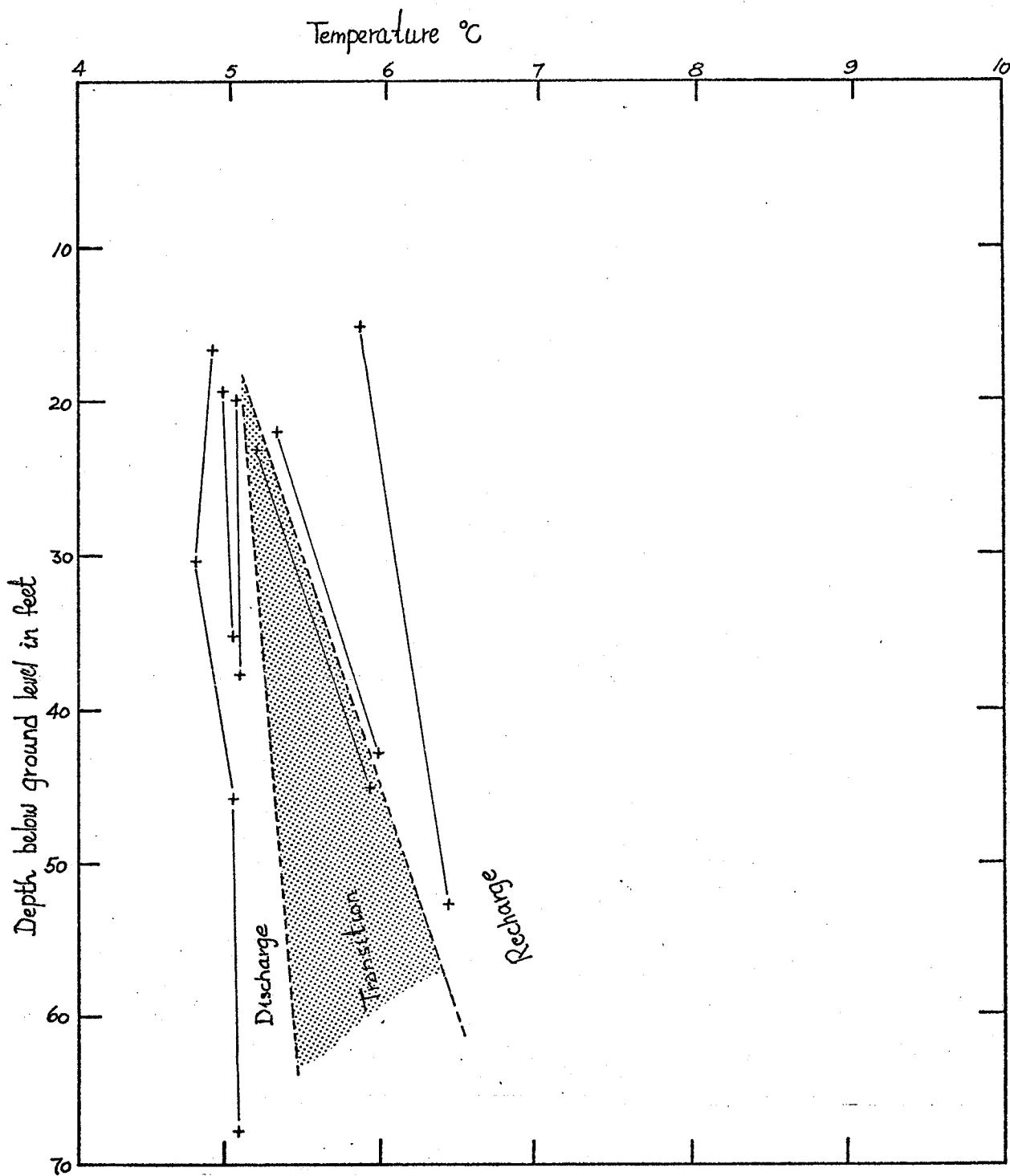


Fig. 12 Temperature variations with increasing depth below the ground surface for recharge and discharge areas in the glacial drift.

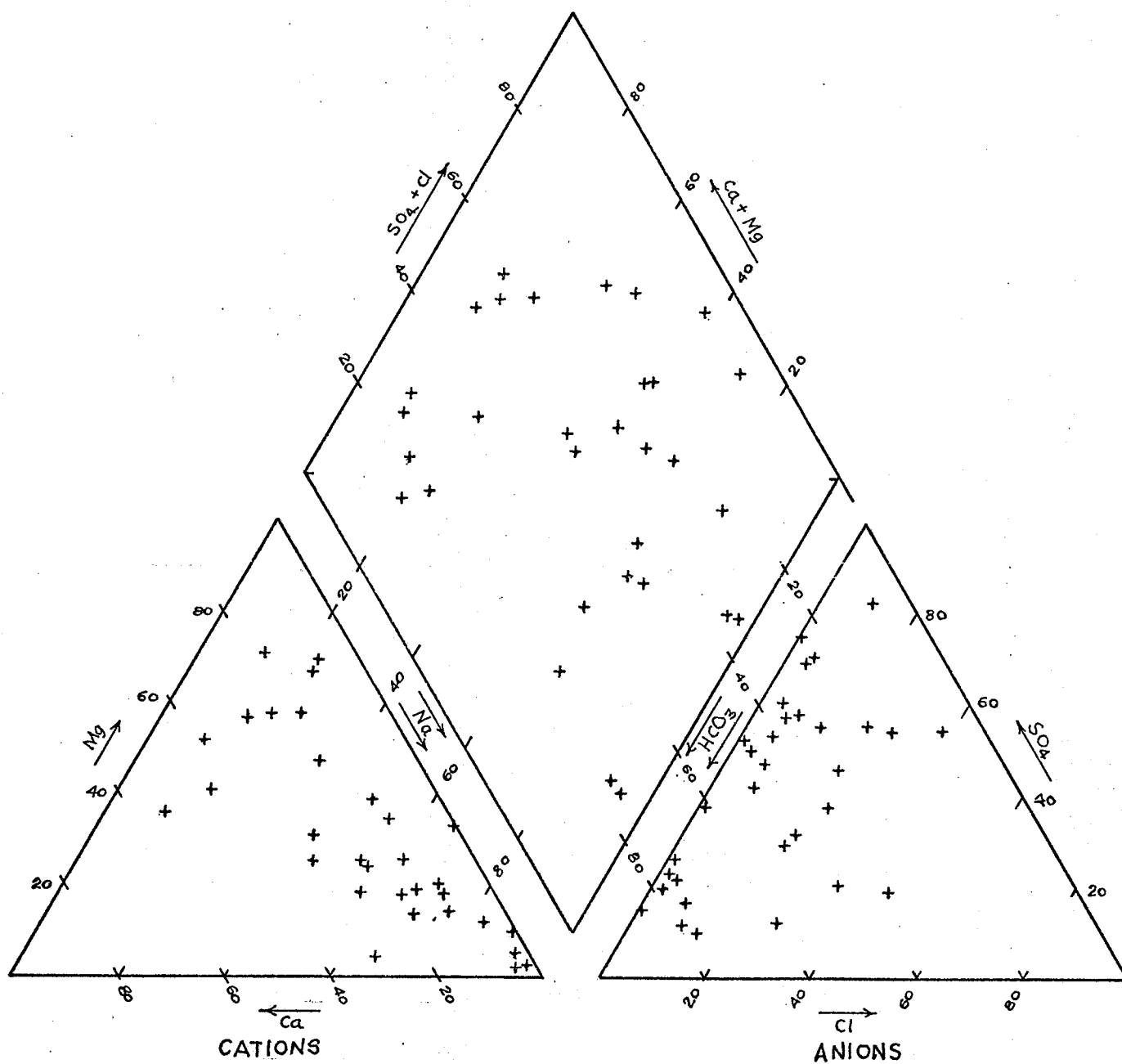


Fig. 13 Major ion composition of groundwater in the glacial drift.

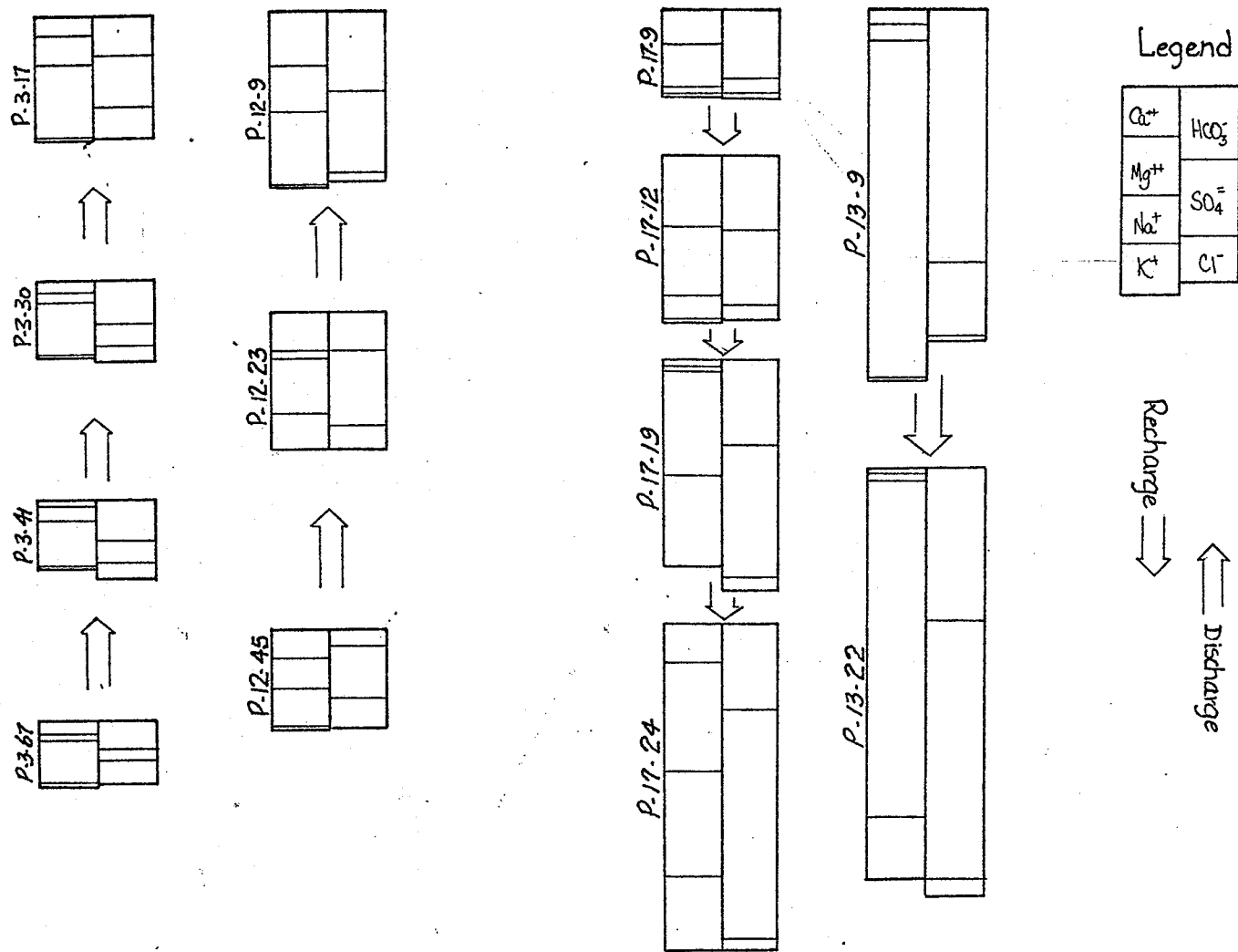


Fig. 14 Geochemical trends along inferred flow paths in the glacial drift.

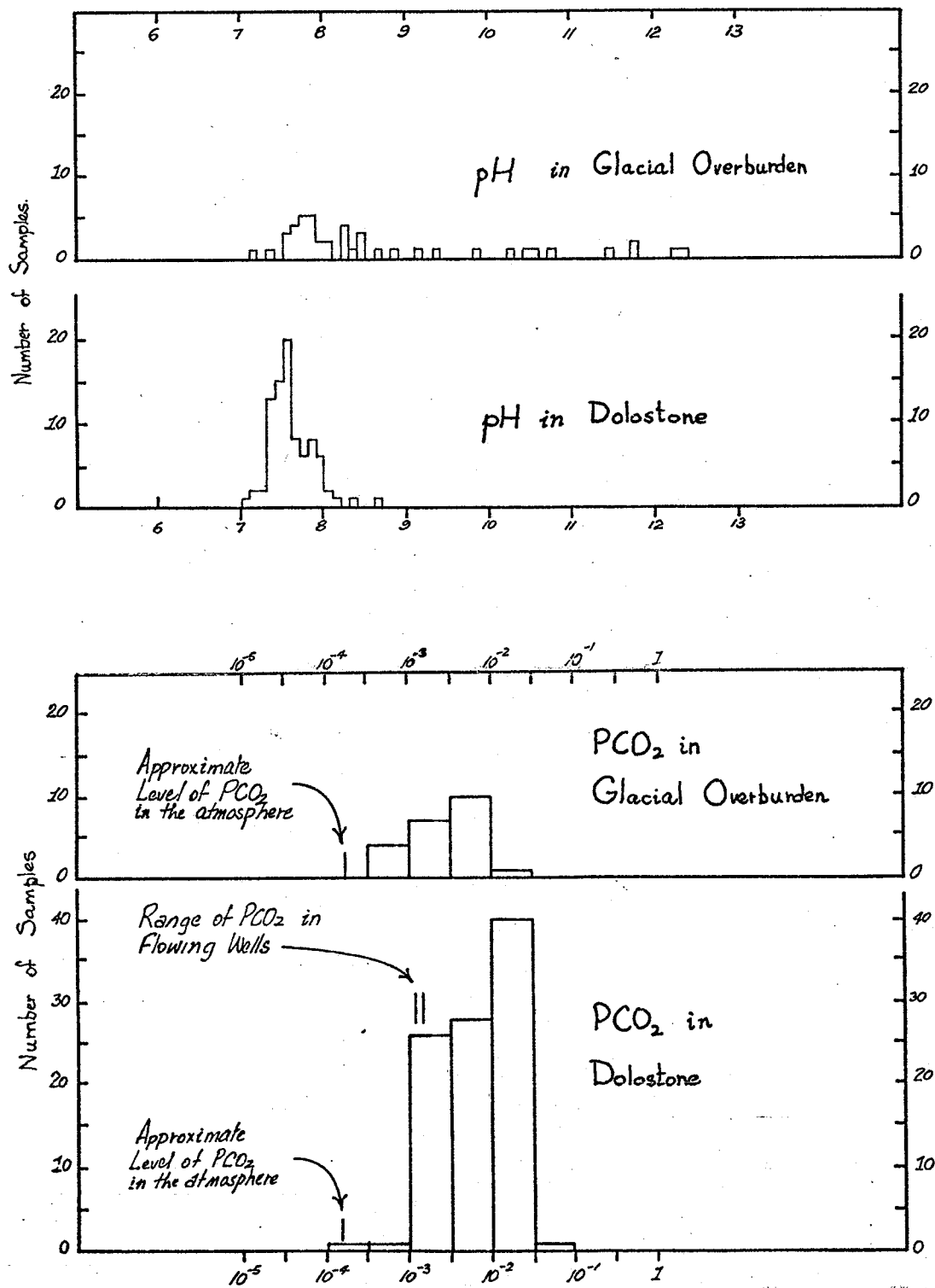


Fig. 15 PCO₂ and pH variations in the dolostone and glacial drift.

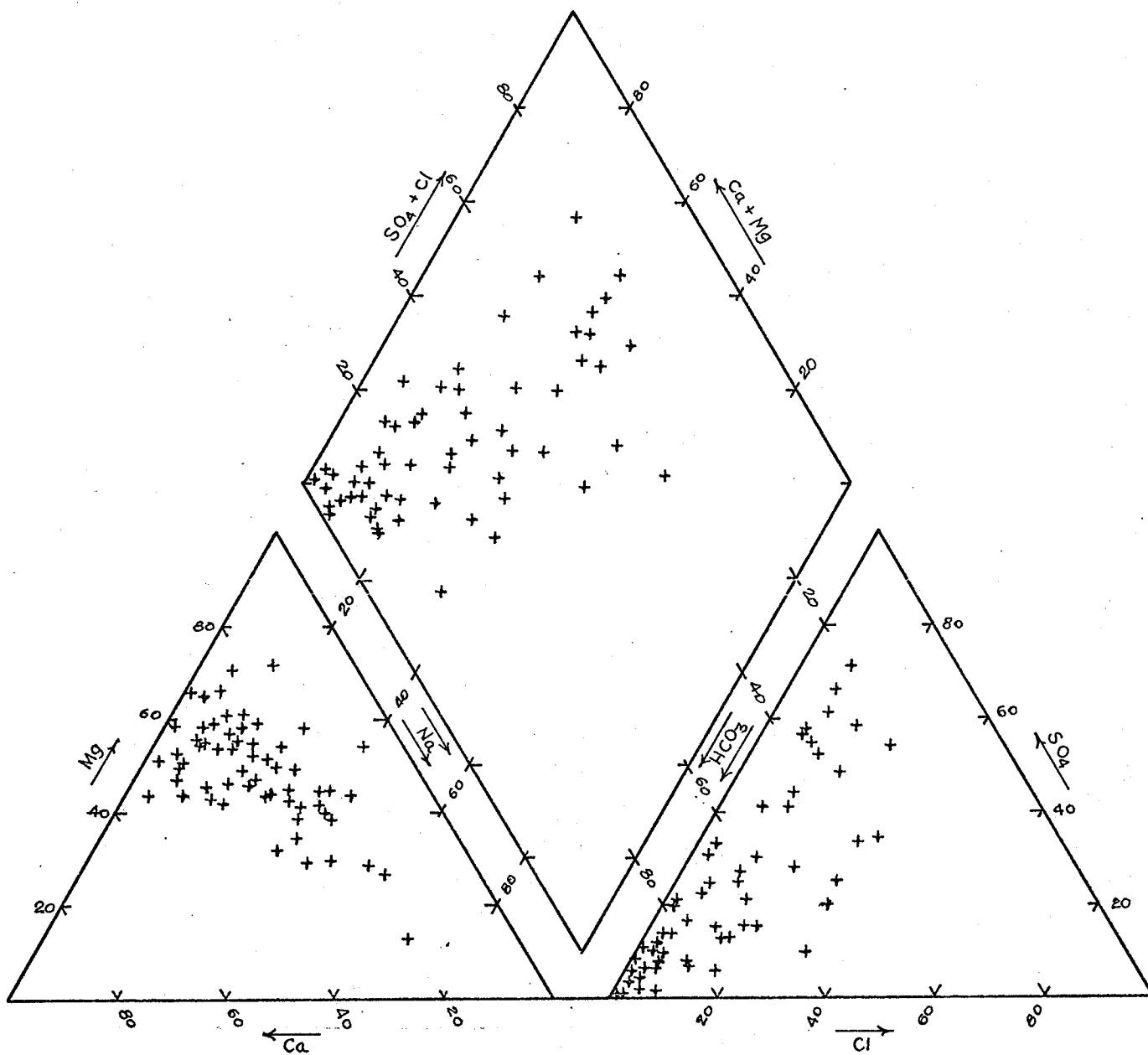


Fig. 16 Major ion composition of groundwater in the dolostone.

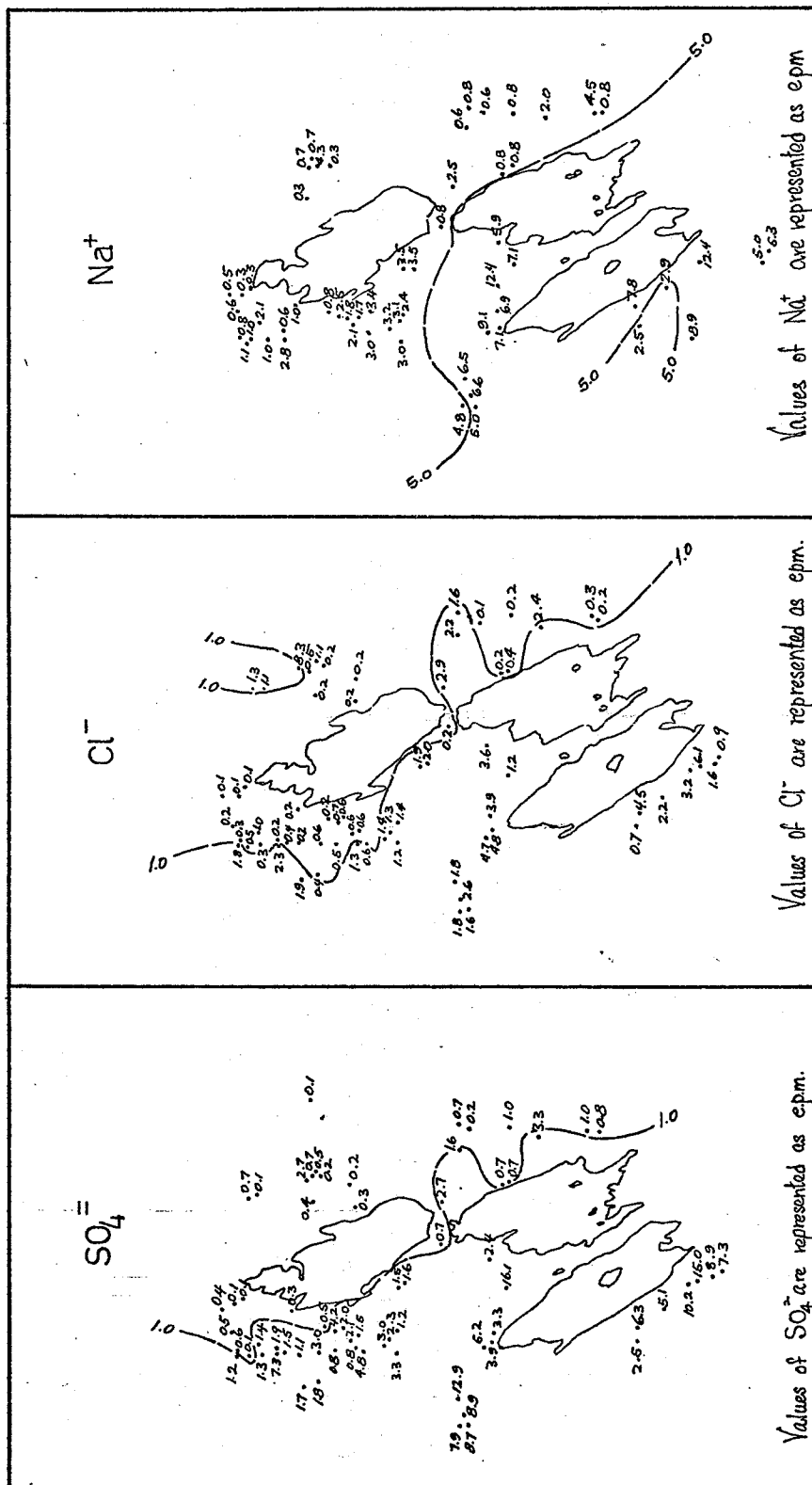


Fig. 17 Areal distribution of anions in the dolostone (arbitrary contours have been drawn to emphasize increasing concentrations toward the southwest).

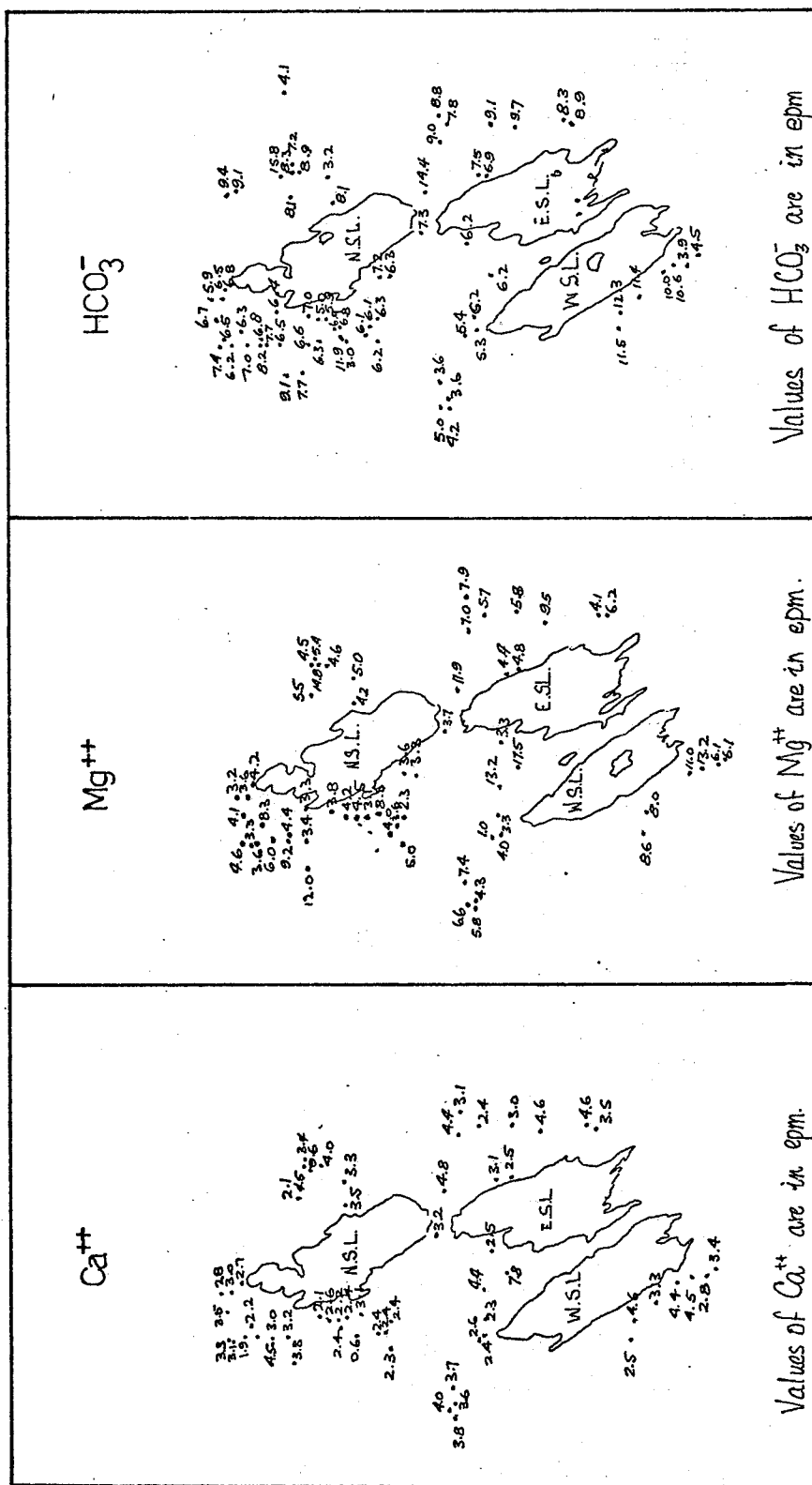


Fig. 18 Areal distribution of cations in the dolostone.

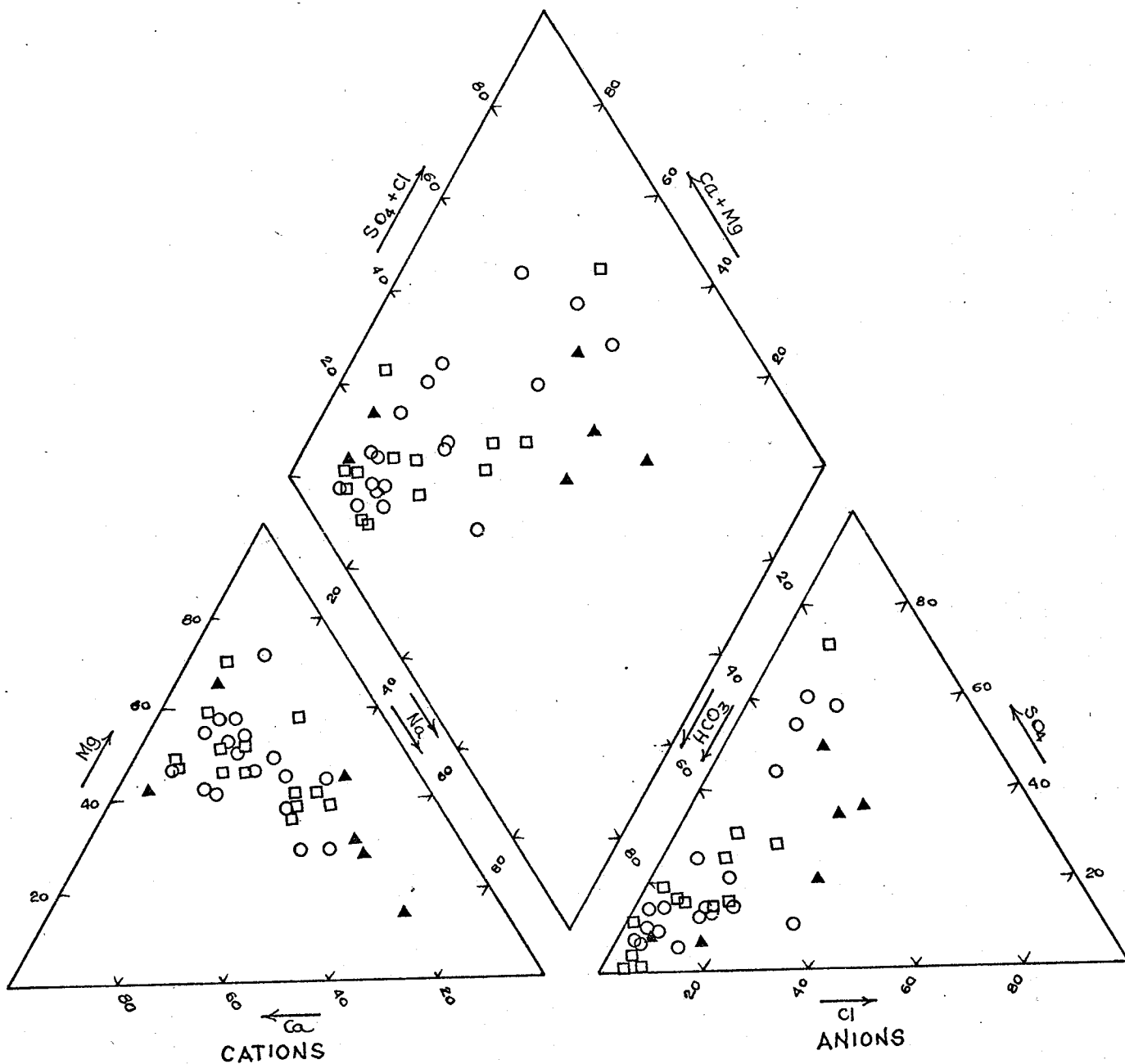


Fig. 19 The depth dependance of hydrochemistry in the dolostone aquifer.

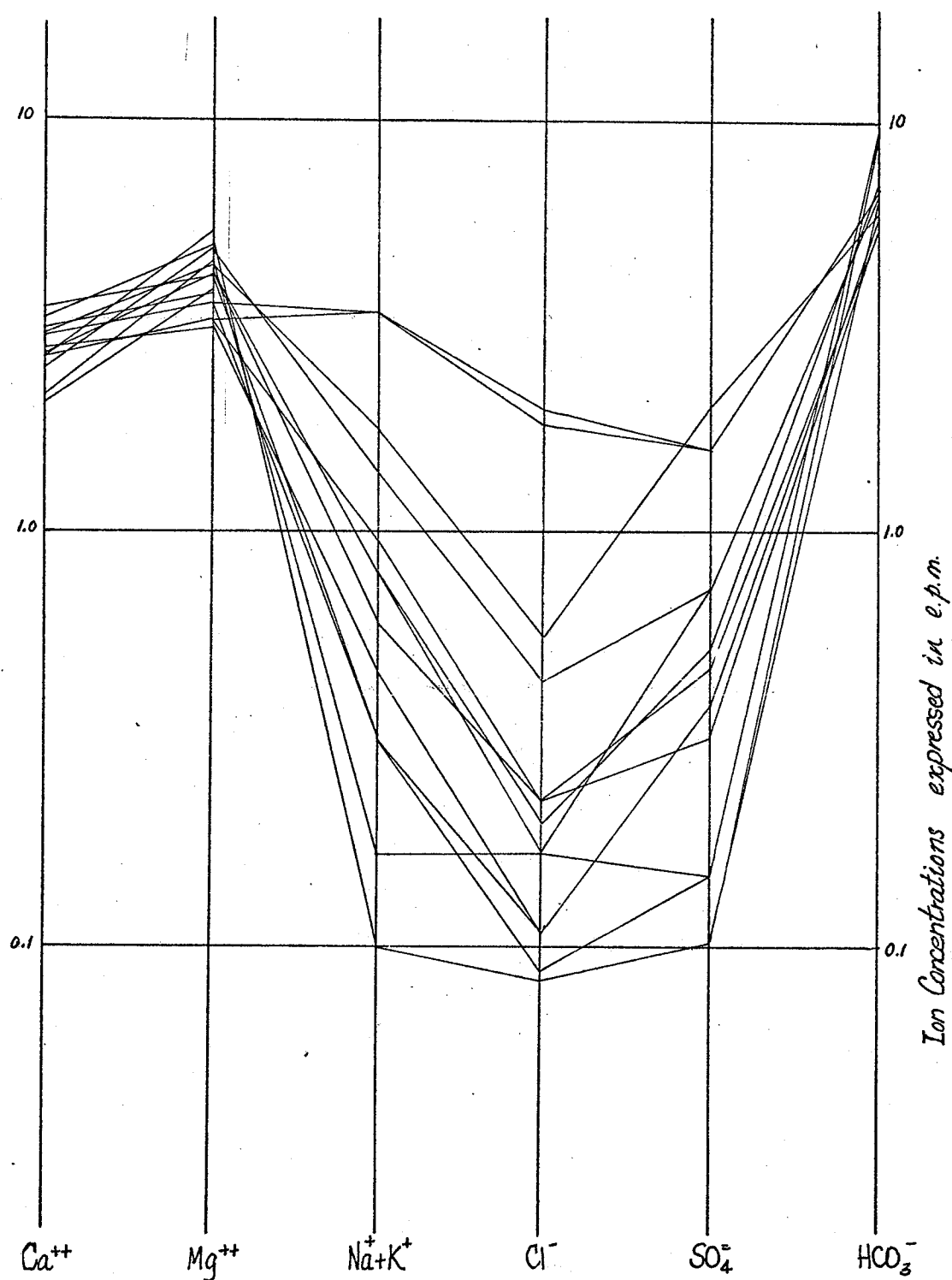


Fig. 20 Major ion concentrations in samples collected from flowing wells in the dolostone.

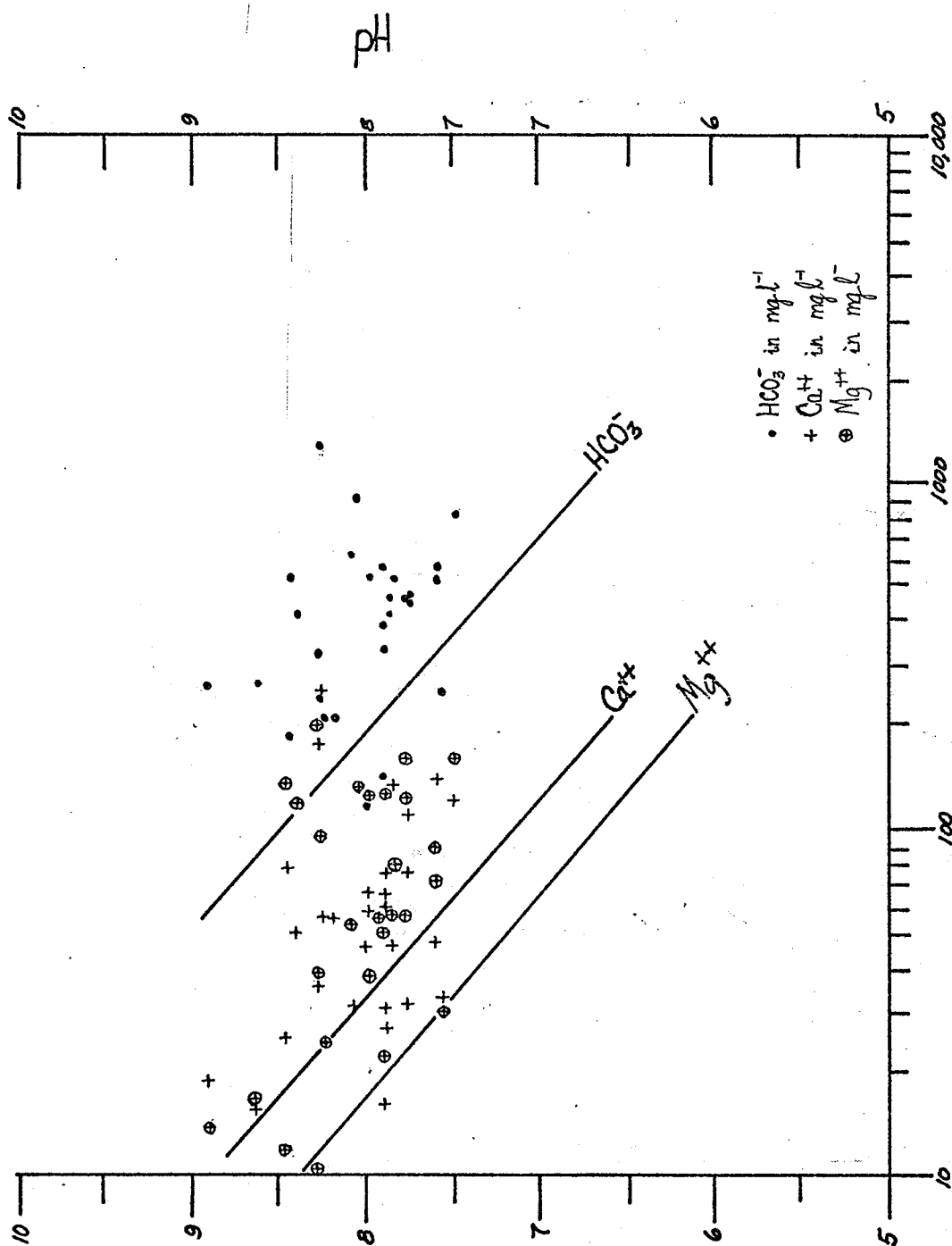


Fig. 21 pH and HCO_3^- , Ca^{++} , Mg^{++} concentrations in the dolostone compared to the dolomite dissolution model.

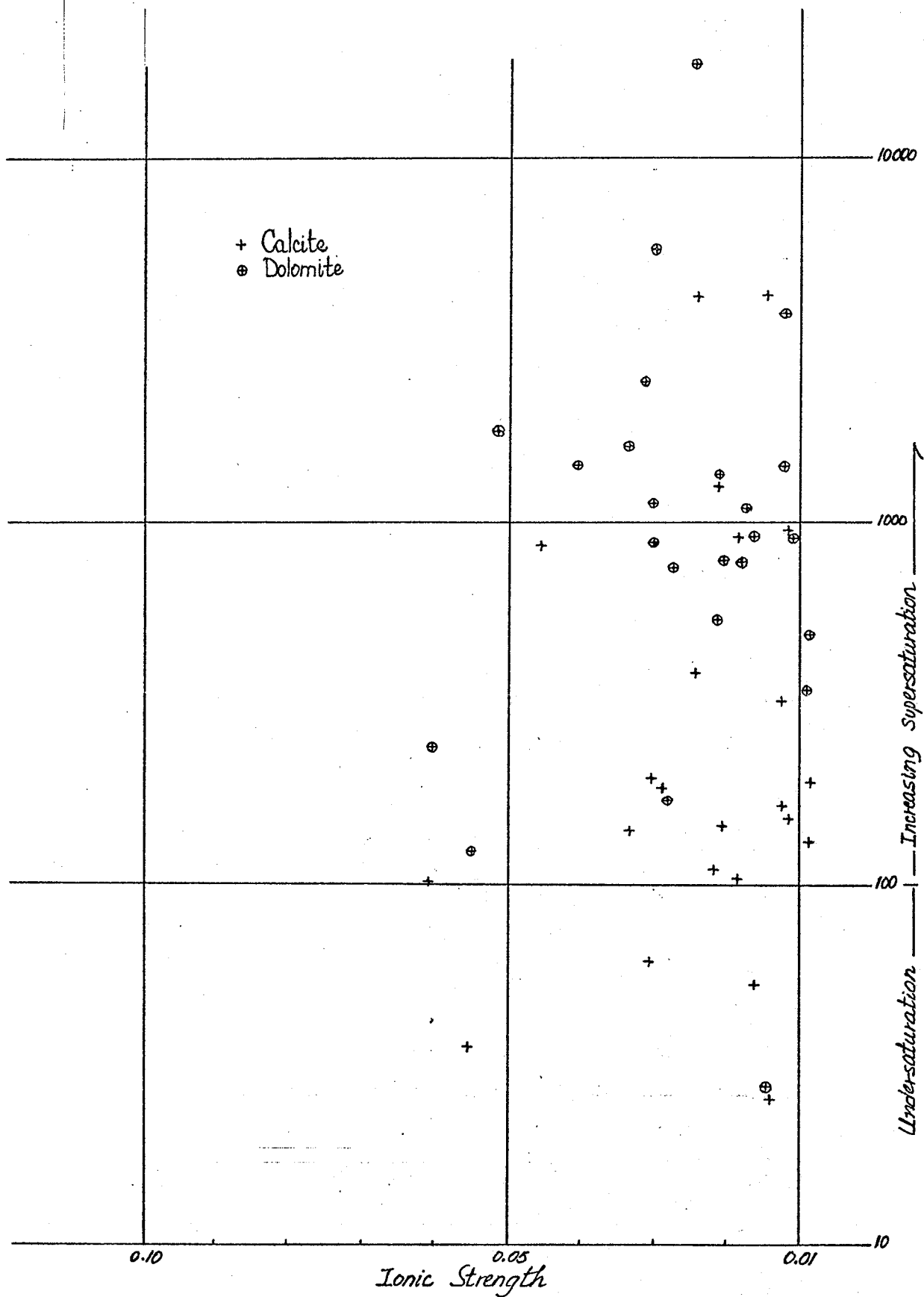


Fig. 22 The degree of saturation (100 = saturation) with respect to calcite and dolomite in groundwater in the glacial drift.

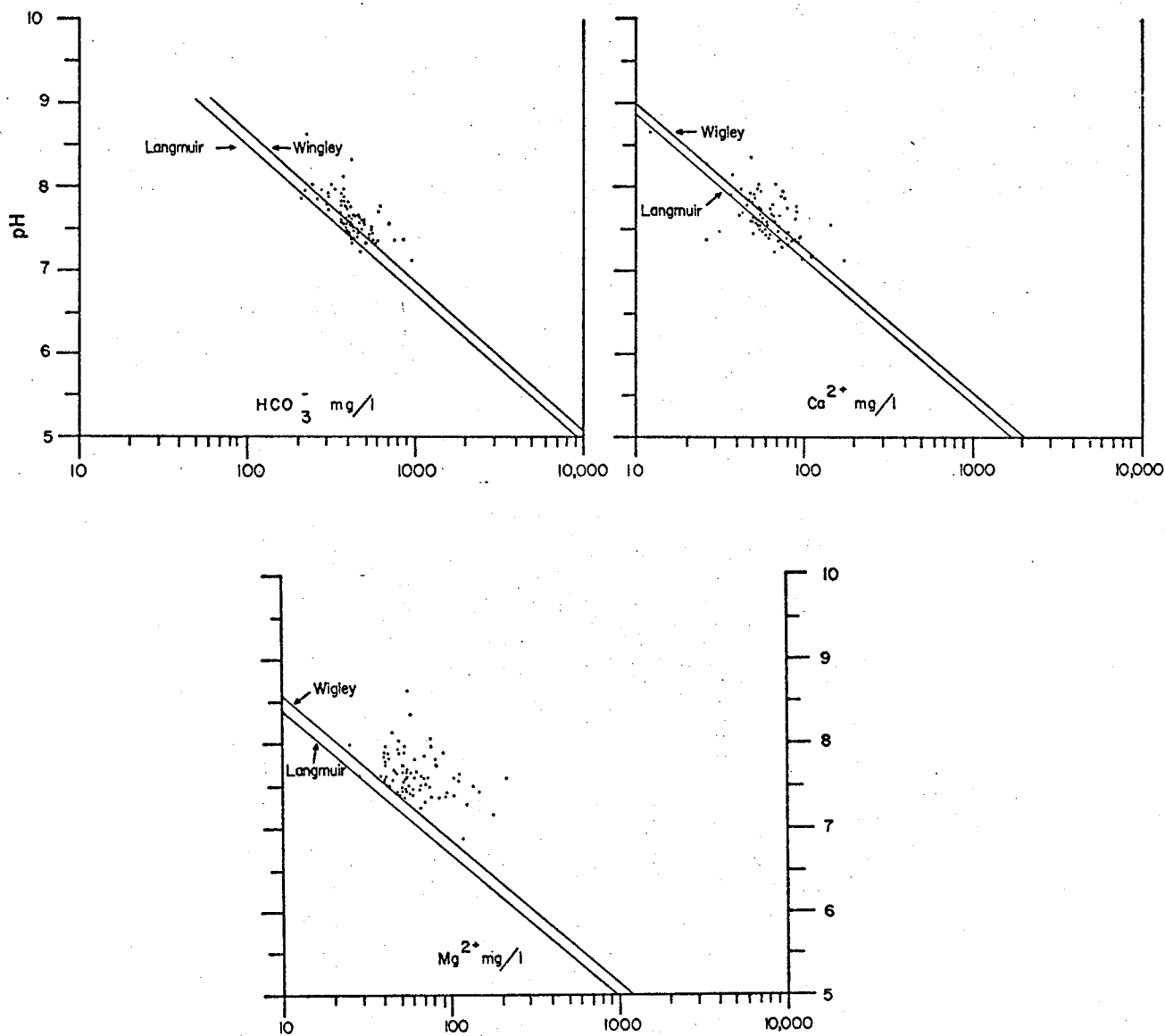


Fig. 23 pH and HCO_3^- , Ca^{++} , Mg^{++} concentrations in the carbonate aquifer, Shoal Lakes basin, compared to the dolomite dissolution model.

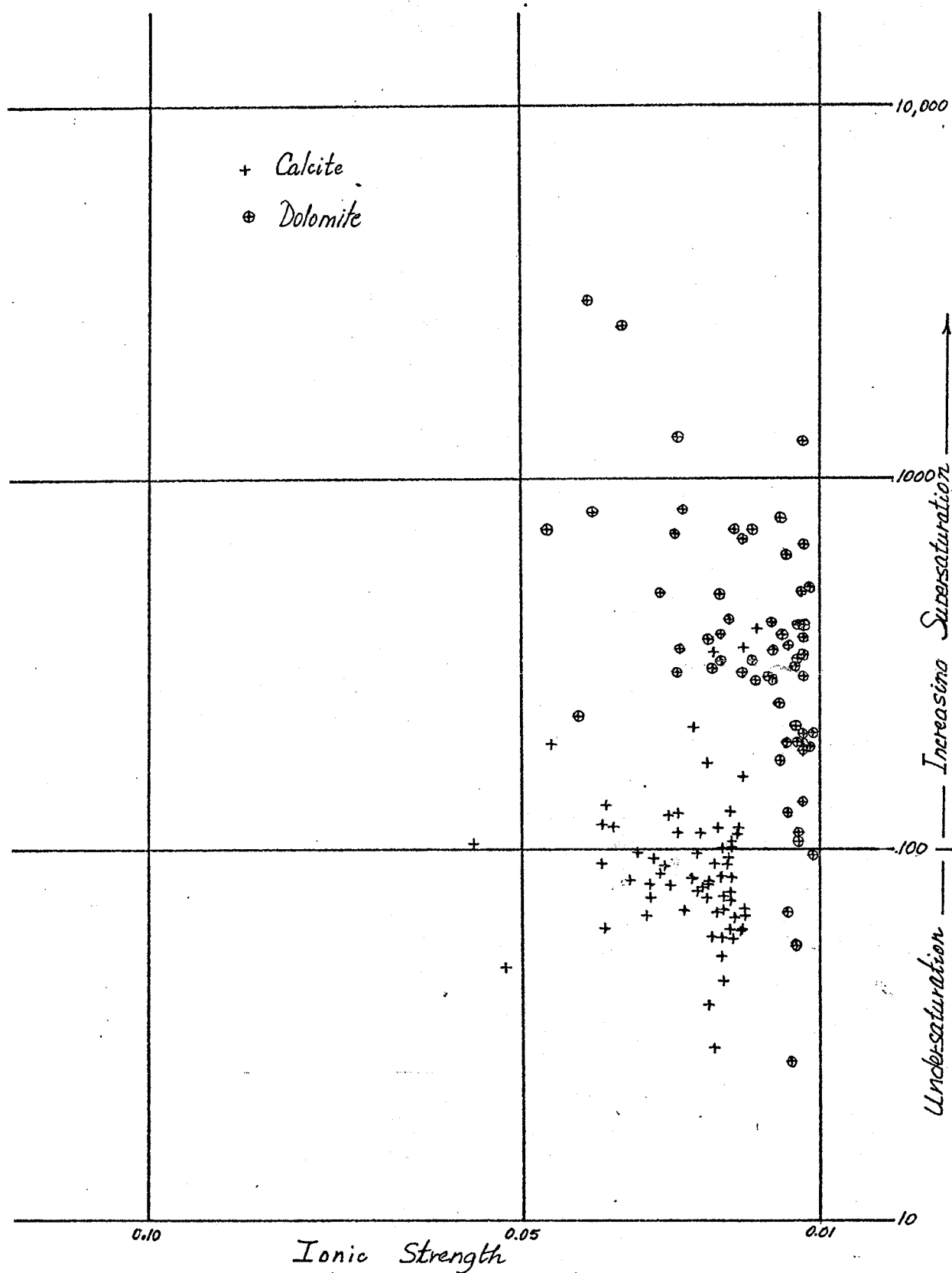


Fig. 24 The degree of saturation (100 = saturation) with respect to calcite and dolomite in groundwater in the dolostone.

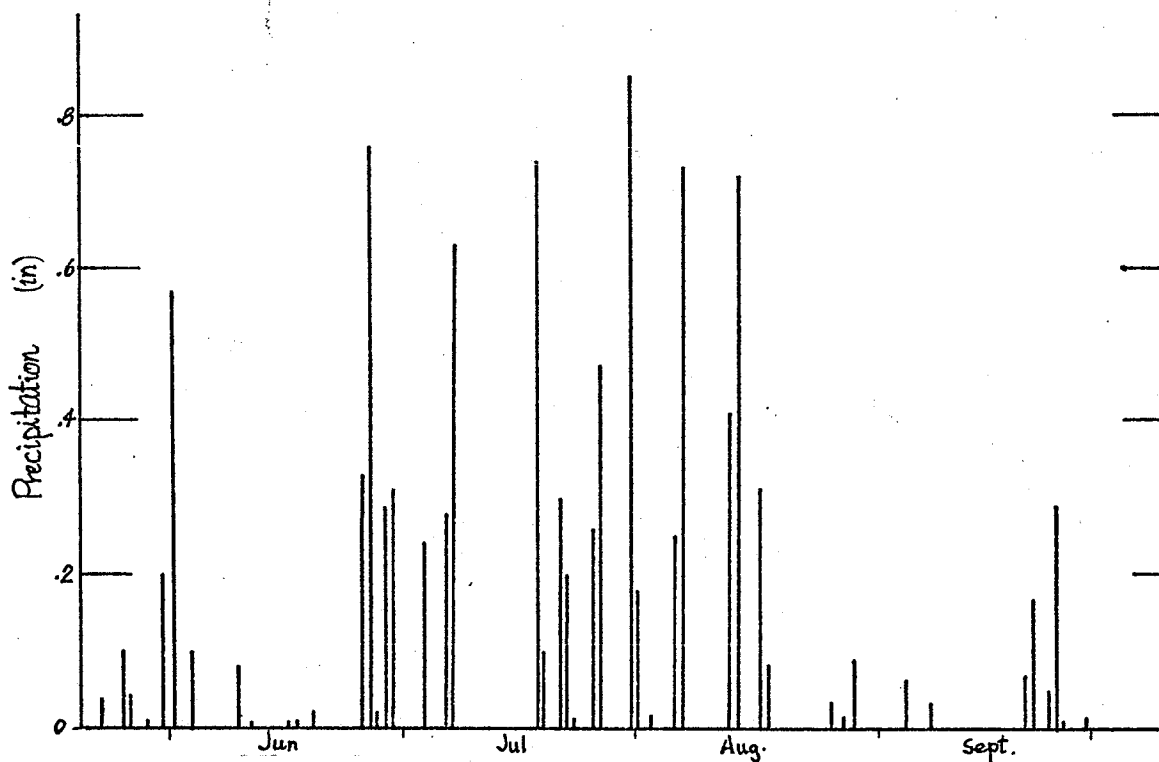
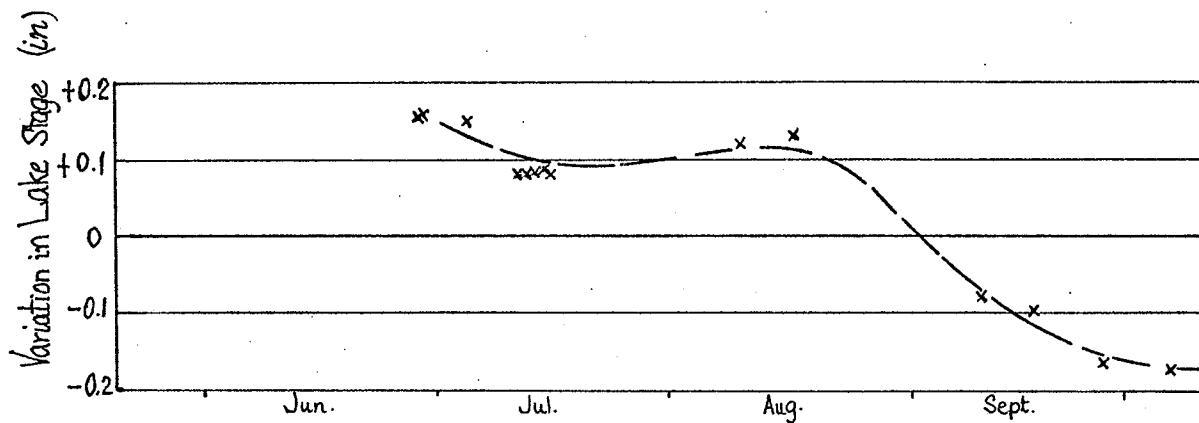


Fig. 25 Hydrograph of lake level and precipitation for North Shoal Lake.

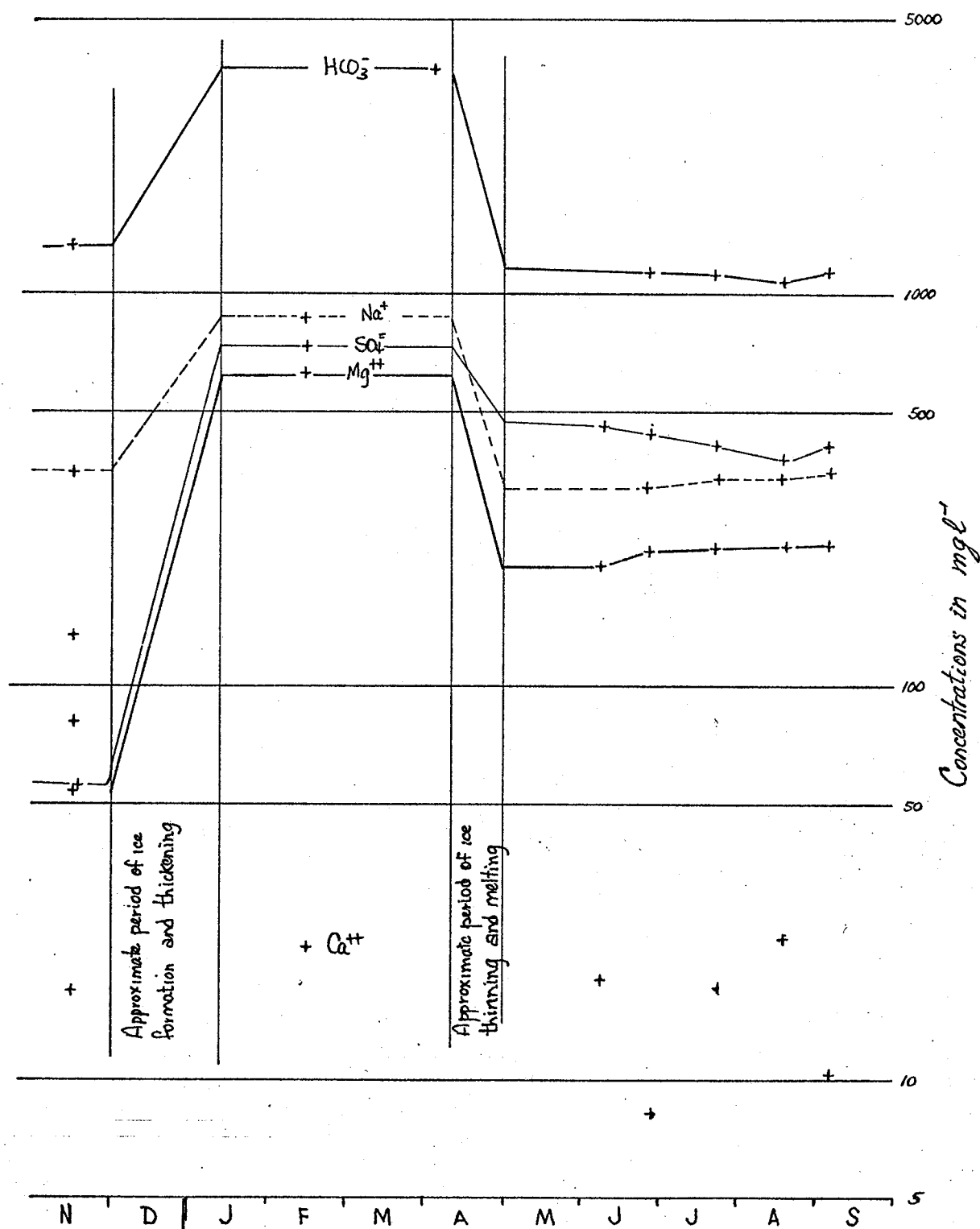


Fig. 26 Variations in the major ion concentrations in North Shoal Lake for summer and winter periods.

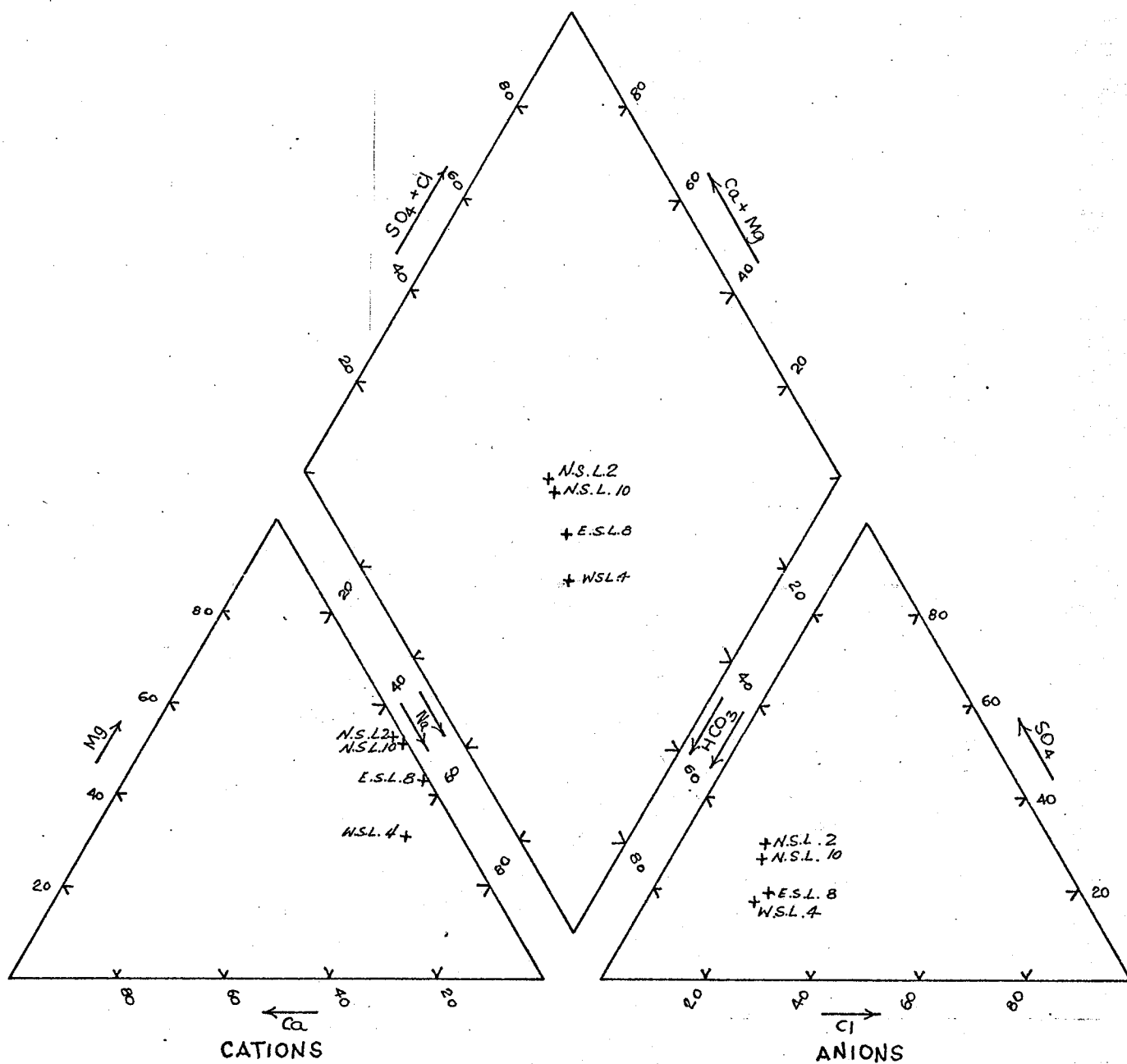


Fig. 27 The major ion composition of lakewater in the Shoal Lakes basin.

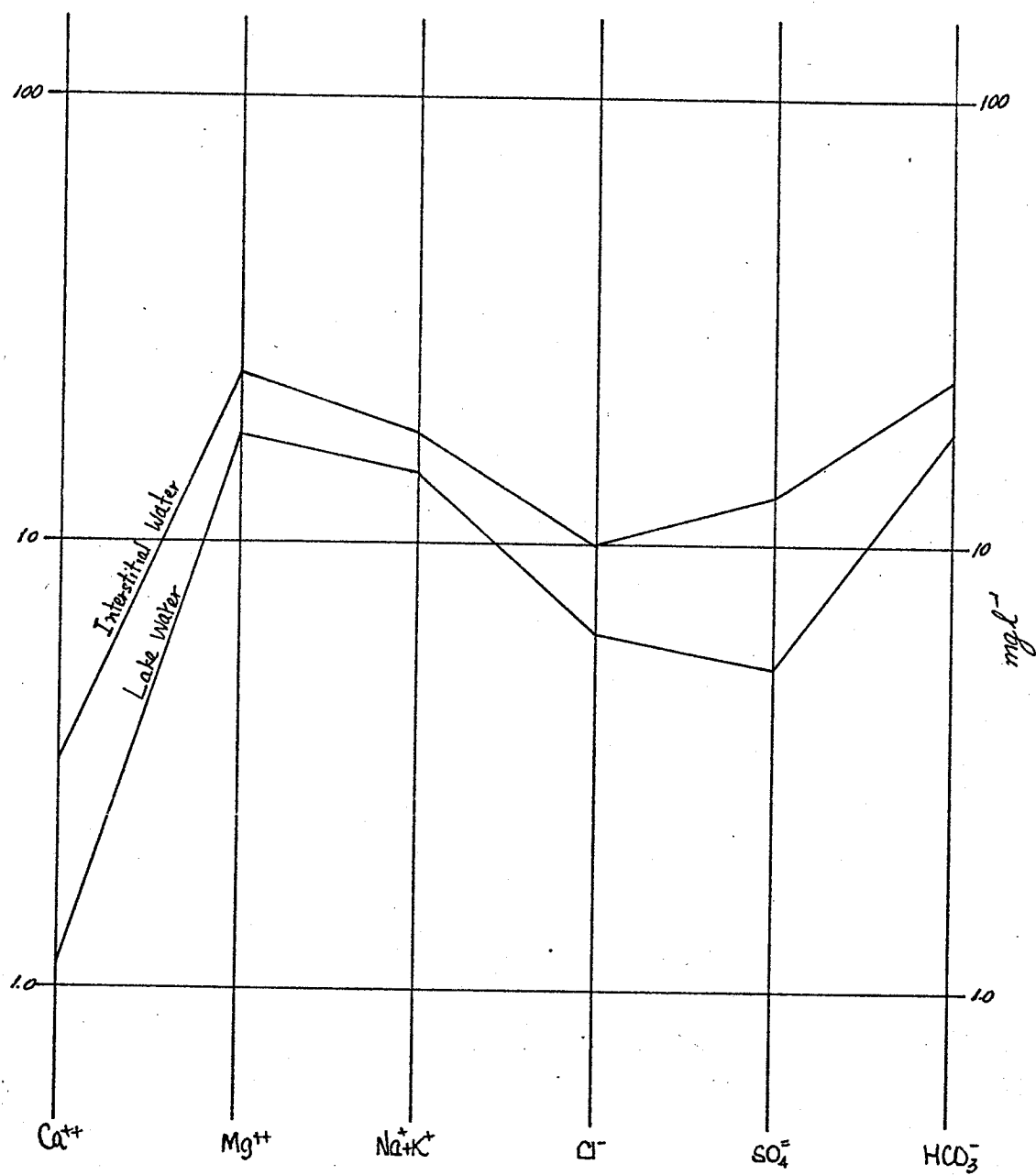


Fig. 28 A chemical comparison of lake and interstitial waters in North Shoal Lake.

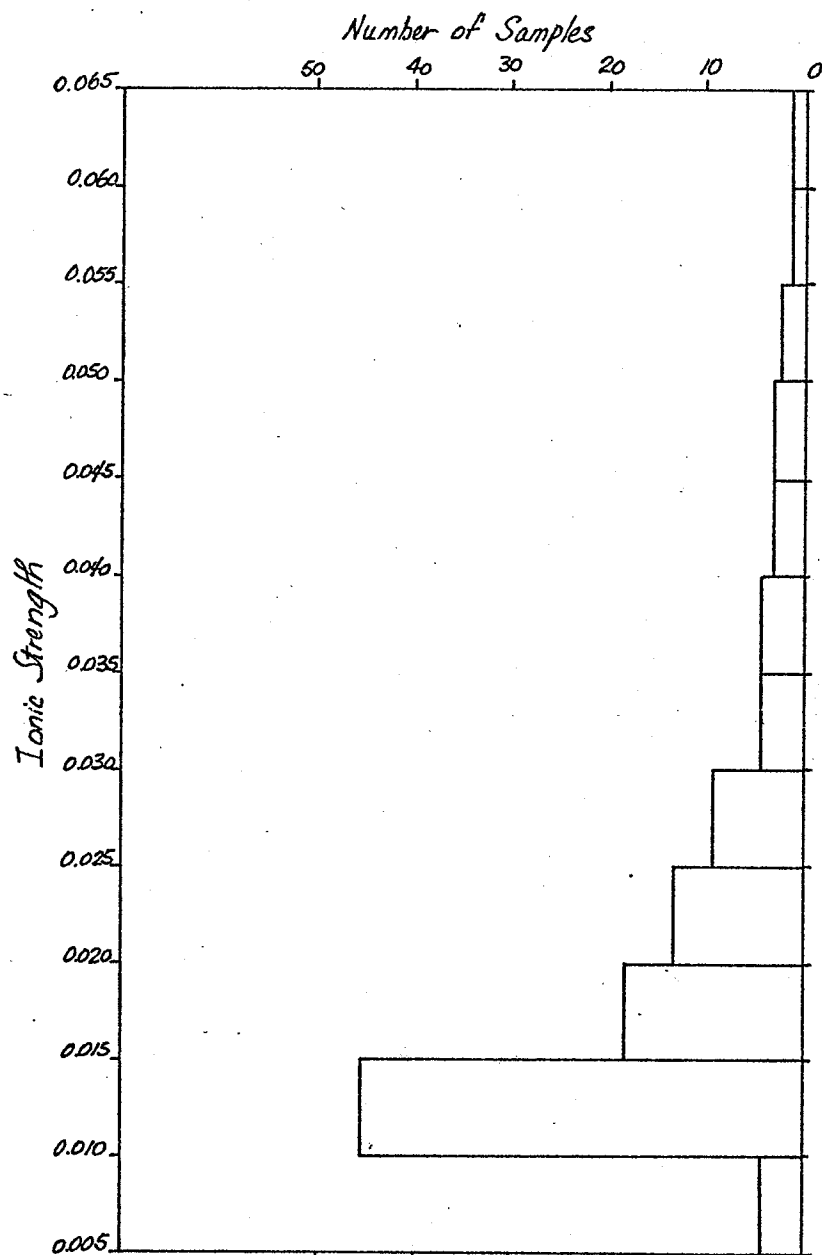


Fig. 29 A frequency distribution of ionic strength in surface and groundwater.

REFERENCES CITED

- Averill, S., 1968. Interrelation of evaporation and geochemistry for the Shoal Lakes area, Manitoba. Dept. Earth Sciences, Univ. Man. Term Pap. Geol. 455 unpublished, 20pp.
- Back, W., 1961. Calcium carbonate saturation in groundwater from routine analyses. U.S. Geol. Survey, Wat. Supply Pap. 1535-D, 14pp.
- Back, W. and Barnes, I., 1964. Dolomite solubility in groundwater. U.S. Geol. Survey, Prof. Pap. 475-D, p179-180.
- Baillie, A.D., 1951. Silurian geology of the Interlake area, Manitoba. Man. Dept. Mines Nat. Res., Mines Br. pub. 50-1. 81pp.
- Barnes, I., 1964. Field measurement of alkalinity and pH. U.S. Geol. Survey. Wat. Supply Pap. 1535-H, 17pp.
- Charron, J.E., 1965. Groundwater resources of Winnipeg area, Manitoba. Geol. Survey Canada Pap. 64-23, 30pp.
- Charron, J.E., 1967. Groundwater resources of Steinbach area, Manitoba. Geol. Survey Canada Pap. 66-6, 34pp.
- Cherry, J.A., 1968. Preliminary results of a groundwater geochemistry study of a portion of the Southern Interlake area, Manitoba. Dept. Earth Sciences, Univ. Man. unpublished.

- Ehrlich, W.A. and Rice, H.M., 1955. Postglacial weathering of Mankato till in Manitoba. Jour. Geol. v.63, p.527-537.
- Fritz, P. and Jackson, S.A., 1972. Geochemical and isotropic characteristics of Middle Devonian dolomite from Northern Canada. Proc.XXIV, Int.Geol.Cong. Montreal (in press).
- Garrels, R.M. and Christ, C.L., 1965. Solutions, minerals and equilibria. Harper and Row, New York, 450pp.
- Goff, K.J. and Webb, M., 1968. Some aspects of the hydrogeology of the Shoal Lakes area, Manitoba. Univ.Man. Term Pap.Geol.455, unpublished, 22pp.
- Goudge, 1944. Limestones of Canada, Part IV, Western Canada. Mines and Geol. Br., Bureau of Mines, Can. Rept.811.
- Hostetler, P.B., 1964. The degree of saturation of magnesium and calcium carbonate minerals in natural waters. Publ.64, Int.Assoc. Scient. Hydrol., Comm. Subterranean Waters, p.34-49.
- Hvorslev, M.J., 1951. Time lag and soil permeability in groundwater observations. U.S.Army Corps of Engineers. Waterways Expt. Stat. Bull.36.
- Kristjanson, W., 1965. The Icelandic People in Manitoba. A Manitoba Saga., Wallingford Press, Winnipeg. 557pp.
- Langmuir, D., 1971. The geochemistry of some carbonate groundwater in Central Pennsylvania, Geochem.Cosmochim. Acta, v.35, pp.1023-1045.

- McKay, G.A. and Stichling, W., 1961. Evaporation computations for prairie reservoirs. Proc. 2nd Hydrol. Symp. Toronto.
- Rainwater, F.H. and Thacher, L.L., 1960. Methods for collection and analysis of water samples. Geol. Survey Wat. Supply Pap. 1454.
- Render, F.W., 1970. Geohydrology of the Metropolitan Winnipeg area as related to groundwater supply and construction. Can. Geotechnical Jour., (in press).
- Rozkowski, A., 1967. The origin of hydrochemical patterns in hummocky moraine. Can. Jour. Earth Sciences, v.4, p.1065-1092.
- Strumm, W. and Morgan, J.J., 1970. Aquatic chemistry. Wiley Intersciences. 583pp.
- Swinnerton, A.C., 1949. Structural control of the form and distribution of sinkholes. Science New Ser., v.85, p.218-219.
- Toth, J., 1966. Mapping and interpretation of field phenomena for groundwater reconnaissance in a prairie environment, Alberta, Canada. Bull. Int. Assoc. Scient. Hydrol., v.9, p.20-68.
- Van Everdingen, R.O., 1963. Groundwater flow diagrams in sections with exaggerated vertical scale. Geol. Survey of Canada, Pap. 63-27.

Van Everdingen, R.O., 1969. Degree of saturation with respect to CaCO_3 , $\text{CaMg}(\text{CO}_3)_2$, and CaSO_4 for some thermal and mineral springs in the Southern Rocky Mountains, Alberta and British Columbia. Can.Jour. Earth Sciences v.6, pp1421-1430.

Wicks, F.J., 1965. Differential thermal analysis of the sediments of the Lake Agassiz basin in Metropolitan Winnipeg, Manitoba. M.S.Thesis. Dept.Geol., Univ. Man. unpublished, 232pp.

Wiklander, L., 1964. Cation and anion exchange phenomena in chemistry of the soil. Ed. F.E. Bear. pp163-205.

APPENDIX A

Inventory of Water Wells in the Shoal Lakes Basin

Appendix A - Records of Water Wells in the Shoal Lakes Basin

	Owner	Location	Elev.	Well Depth	SWL	Depth to Rock	Temp. °C.
1	Bar-4-Ranch	SE 30-16-1W	855	95	f	14	
2	G. Grose	NE 20-16-2W	855	90			
3	J. Crockatt	NE 30-16-2W	855	18	2		
4	W. Cady	NE 27-16-2W	855	180		80	
5	J. Friesen	NW 30-16-2W	860	150	6	55	
6	Milan	NW 16-15-2W	855	230	33	100	
7	D. Friesen	SW 31-16-2W	860	162	15		
8	R. Jeffery	NE 30-15-2W	855	75	28	59	
9	J. Hallett	NW 30-15-2W	860	65	28	48	
10	A. Lillies	NE 9-15-2W	860	70	35		
11	J. Carter	NW 3-15-2W	860	115	30		
12	P. Skihar	SE 16-15-2W	855	84		15	
13	H. Neil	NW 6-17-1W	855	59	12		
13*	H. Neil	NW 6-17-1W	855		f		
14	D. Hadfield	SE 25-17-2W	865	35	f		
15	A. Dupont	NE 30-17-1W	880	70	f		5.0
16	T. Bruce	SE 1-18-2W	875				
17	A. Morin	NE 31-17-1W	880				

SWL static water level (all measurements in feet)

f flowing well

* spring

	Owner	Location	Elev.	Well Depth	SWL	Depth to Rock	Temp. °C.
18	D. Tronrud	SE 6-18-1W	880	105	12	9	
19	A. Knapp	SW 5-18-1W	885	84	20	17	
20	C. Enstrom	NE 16-17-2W	855	37	f	30	5.0
21	C. Enstrom	SE 16-17-2W	855	49	1		
22	J. Gratton	SE 18-17-2W	865	120		40	
23	Ferndale Fm.	SE 19-17-2W	865	87	10	40	
24	C. Dyck	SW 2-17-3W	875	67	14	44	
25	F. Zacharias	NE 13-17-3W	865	48	6		
26	L. Larson	NW 18-17-2W	865	83	6	43	
27	School Well	SW 30-17-2W	880	30			5.0
28	B. Emms	SW 30-17-2W	875	30			3.5
29	B. Emms	SE 30-17-2W	875	50		24	6.0
30	J. Emms	NW 30-17-2W	880	38	8		4.5
31	A. Emms	NE 30-17-2W	870	108	f	48	5.0
32	D. Emms	SE 31-17-2W	870	30	10		5.0
33	H. Kessler	SW 31-17-2W	875	160		100	
34	Bendyck	NE 5-18-2W	870				5.0
35	F. Zeller	NW 32-17-2W	855	117	f	48	5.0
36	A. Emms	NE 35-17-3W	865	54		44	4.5
37	W. Ogilvie	NE 16-16-1W	875	104	8	40	4.5
38	Thorvardson	SE 2-18-3W	870	38	5	12	3.0
39	D. Dyck	NE 1-18-3W	870	106	8	30	5.0
40	E. Overby	SE 4-17-1W	885	160	14	60	5.0
41	Cloverdale	NE 4-16-1W	855		1	20	

	Owner	Location	Elev.	Well Depth	SWL	Depth to Rock	Temp. °C.
42	Bar-4-Ranch	SE 30-16-1W	855		f	14	5.5
43	J. Mitchell	SE 28-16-1W	875	65		20	5.0
44	Ditchfield	SW 8-18-2W	860	60	f	50	5.0
45	H. Crockatt	NW 7-18-2W	865	100	10		
46	J. Johnson	SW 4-17-1W	880	100	16	10	4.5
47	Gower	NE 33-16-1W	880	60			
48	J. Doerksen	SE 13-18-3W	860	110	15	20	
49	J. Wiens	NW 18-18-2W	855	100	6		5.0
50	H. Crockatt	NW 2-17-2W	850		f		4.5
51	H. Crockatt	NW 2-17-2W	850		4		5.0
52	School Well	NE 13-18-3W	855	102	2	80	5.5
53	H. Dyck	SW 12-18-3W	865	30			4.0
54	A. Eyolfson	SE 24-18-3W	855	160	10	70	
55	A. Eyolfson	SE 24-18-3W	855	163	10	70	
56		SE 12-18-3W	865	15	5		
57	W. Duda	SE 19-18-2W	860	86	f	60	
58	H. Chartrand	SW 20-18-2W	860	58	0	56	
59	J. Chartrand	NW 16-18-2W	860		f		5.0
60	G. Chartrand	NE 20-18-2W	860	40	f	40	4.0
61	J. Carman	SE 13-18-2W	885				
62	J. Sherred	SW 18-18-1W	900	95	30		
63	J. Carman	SE 14-18-2W	870		f		5.0
64	Enstrom	SW 2-18-1W	905	78	14	18	
65	R. Bernard	SW 3-17-3W	870	82	15	40	

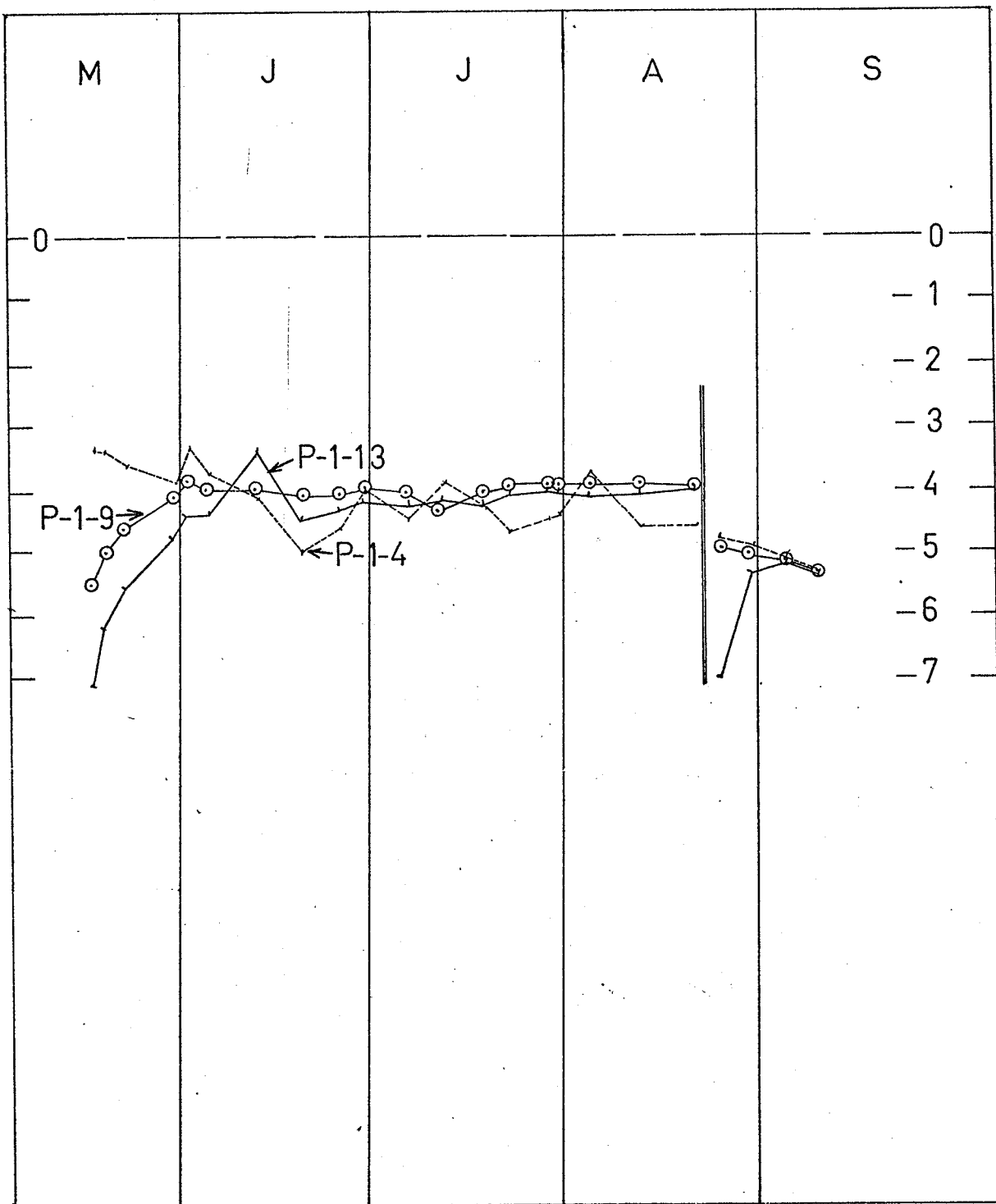
	Owner	Location	Elev.	Well Depth	SWL	Depth to Rock	Temp. °C.
66	Weibe	NW 34-16-3W	870	72	8	42	
67		NE 34-16-3W	870	132		40	
68	Cloverdale	NE 4-16-1W	855				
69	H. Enns	NE 20-15-2W	855				

The following data have been taken from Cherry (1968).

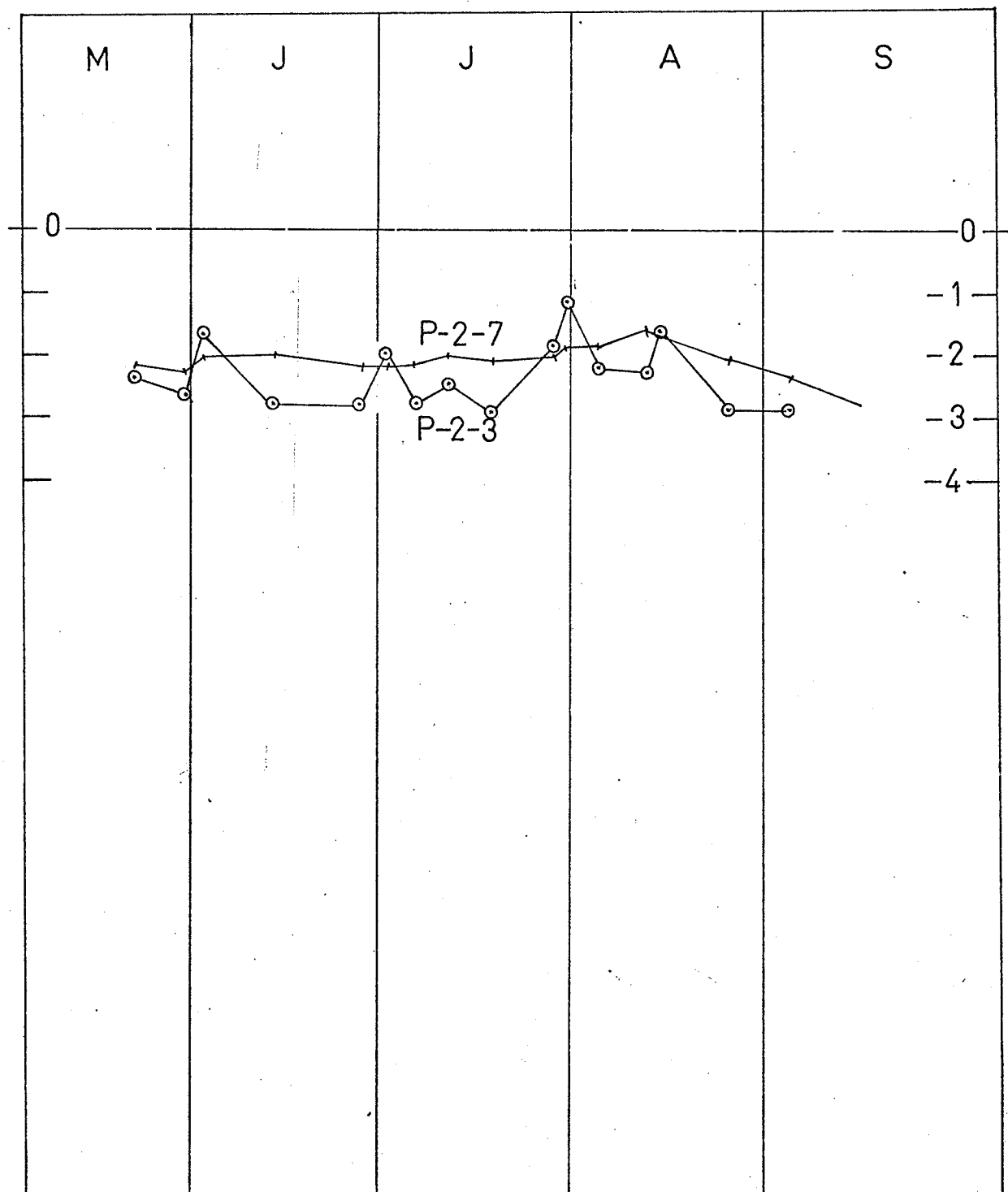
A 2	D. Dupont	SW 22-17-1W	900	60			
A 3	W. Masko	SE 15-18-1W	895	65	27	10	
A 4		SE 5-18-1W	885	85		17	
A 6	P. Morand	NE 12-17-1W	900	80	50		
A 9		SW 35-18-1W	910	90	50		
A 10	Kunzelman	NW 21-18-1W	900	85	35	12	
A 11	S. Kogan	SW 19-18-1W	900	90	12	10	
A 12	L. Anderson	SW 25-18-2W	890	114	24	30	
A 13	M. McKague	SW 15-18-2W	860	100	f		
A 16	Caspelein	SW 21-17-1W	885		12		
A 17		NE 2-18-2W	860	65	f		
B 24	A. Tillenius	SW 15-19-1W	900	68	20	12	
SL 11	J. Wall	NW 10-17-3W	875	120	18	40	
SL 14	W. McKague	NE 33-17-1W	895	103	40	20	
SL 15	W. Kitching	NE 34-17-1W	910	66	40		
SL 19	A. Dyck	SE 27-17-3W	880	76	18	25	

APPENDIX B

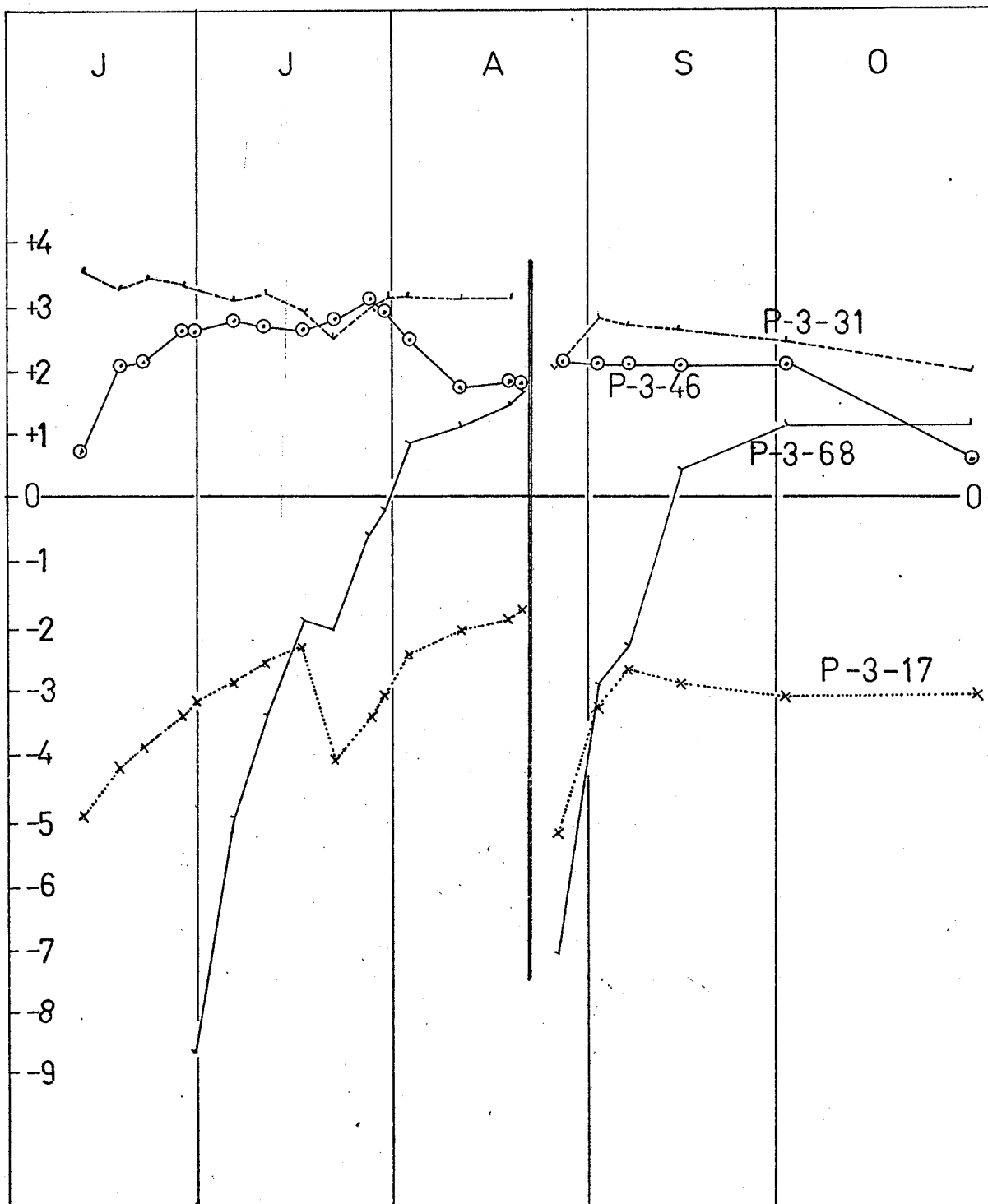
Hydrographs of Piezometers in the Shoal Lakes Basin



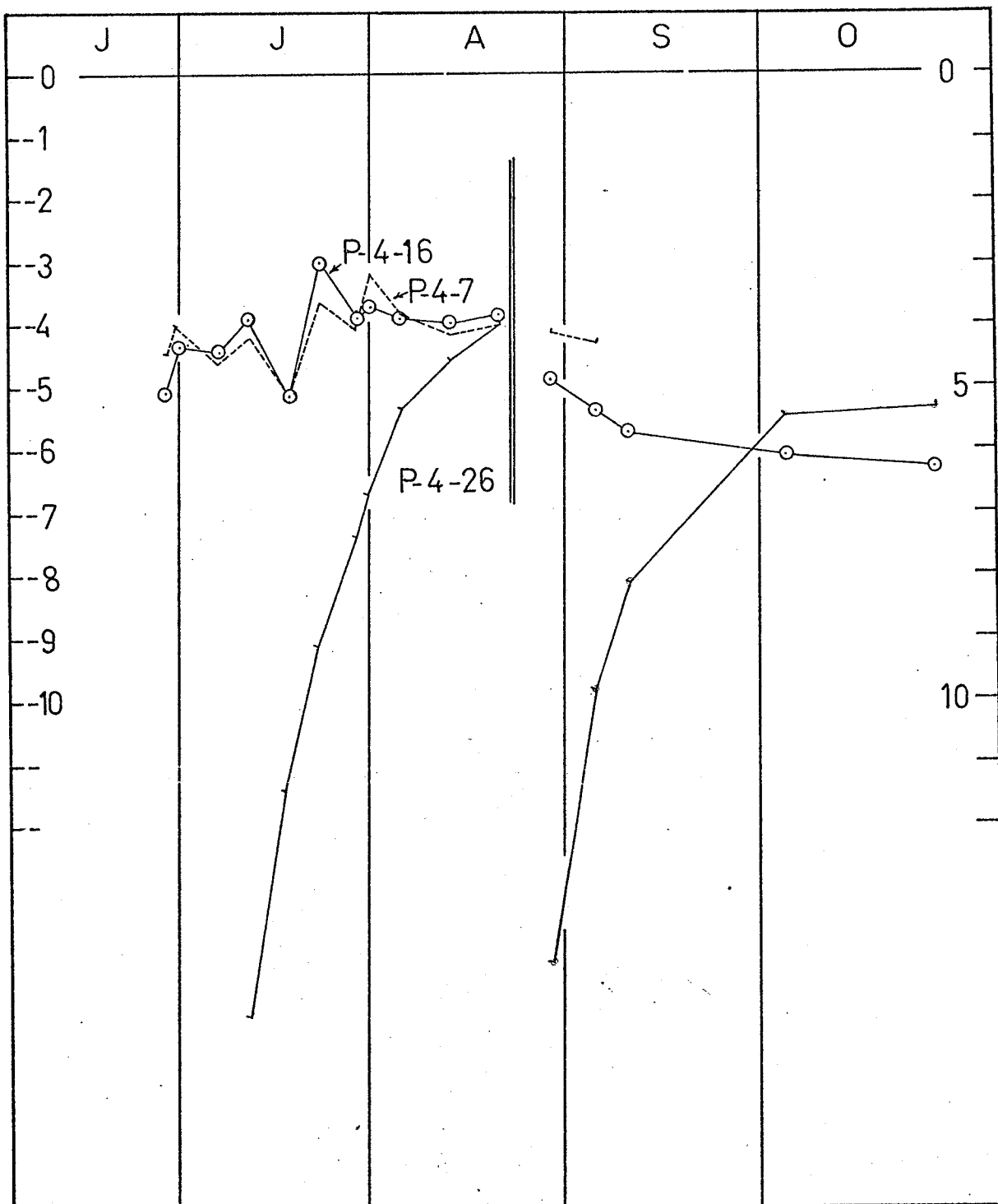
Piezometer Nest No. 1 (P-1). Location SE 12-17-2W



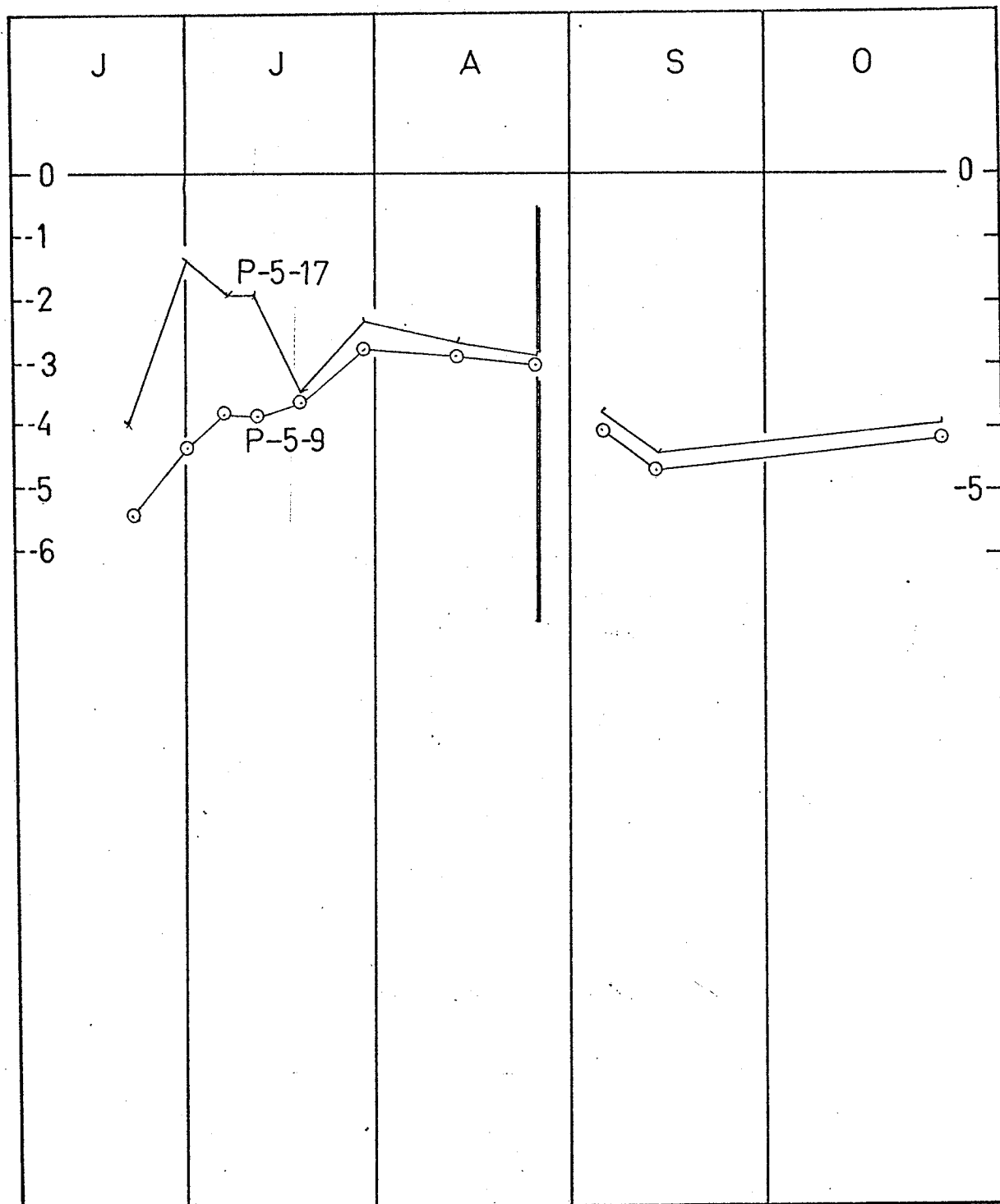
Piezometer Nest No. 2 (P-2). Location NE 19-16-1W



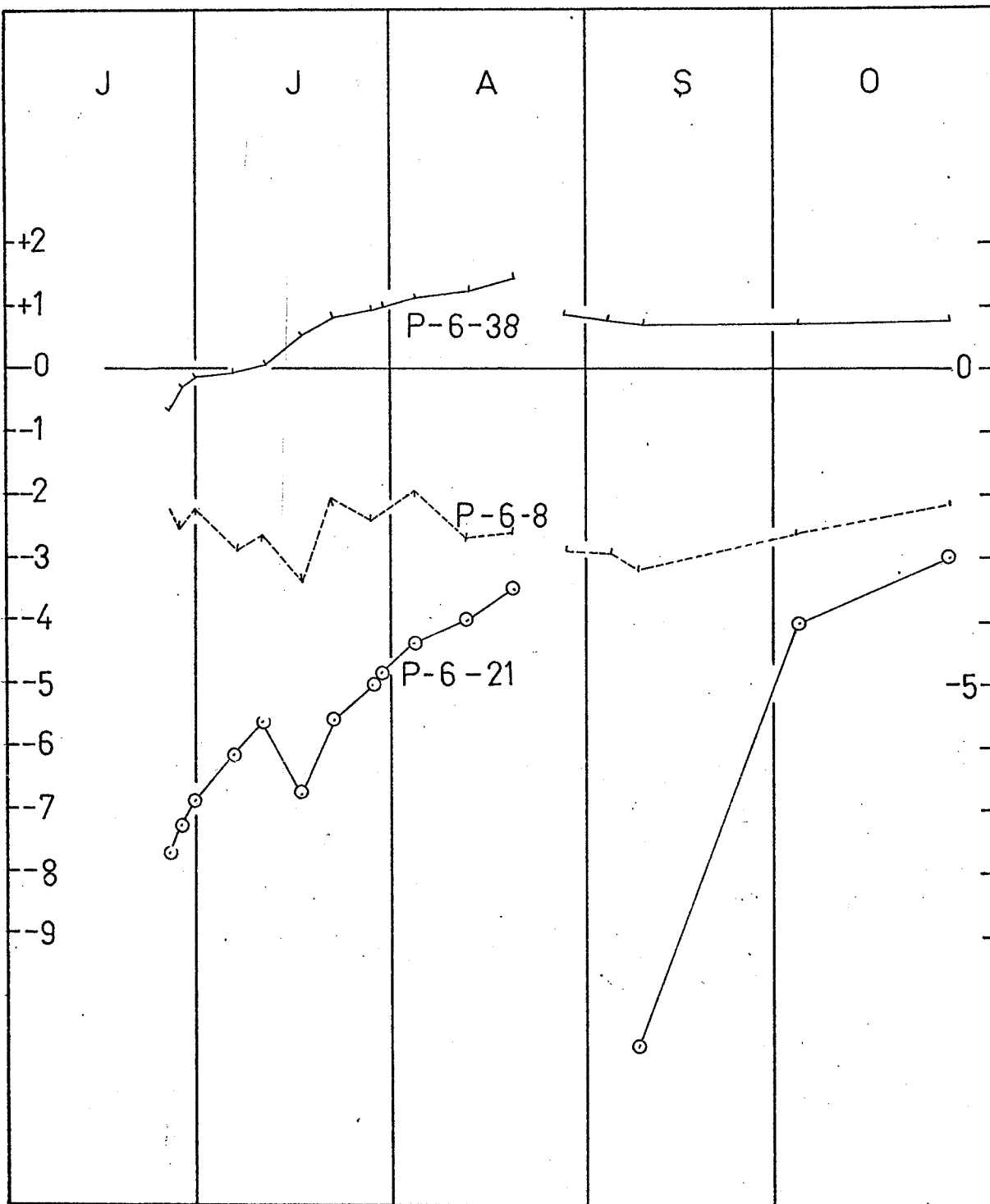
Piezometer Nest No. 3 (P-3). Location 10-17-2W



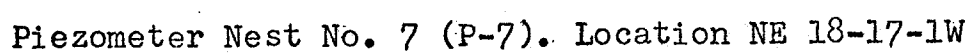
Piezometer Nest No. 4 (P-4). Location SW 34-17-2W

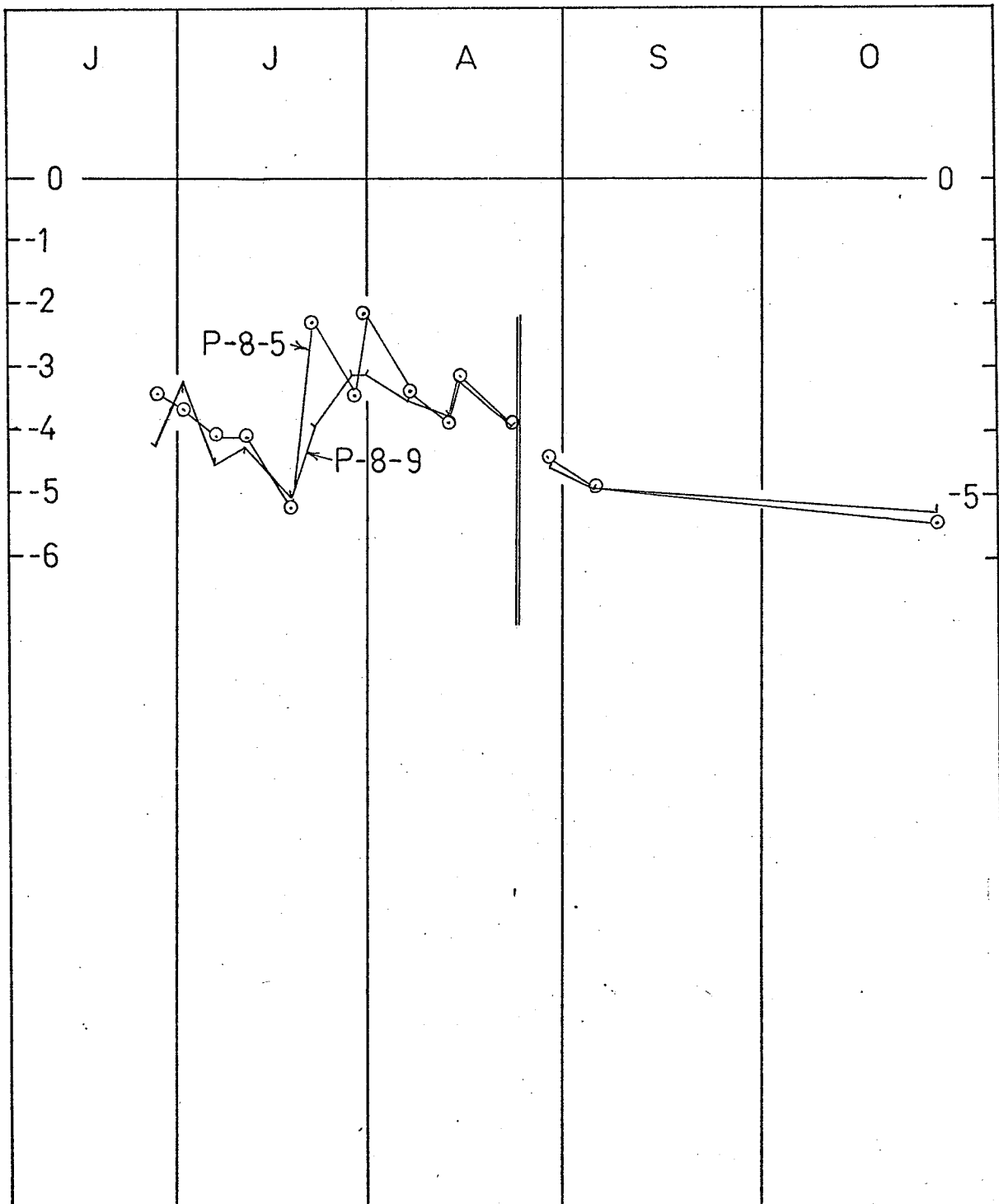


Piezometer Nest No. 5 (P-5). Location SW 2-18-2W

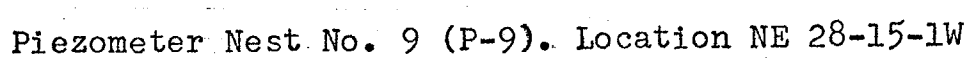


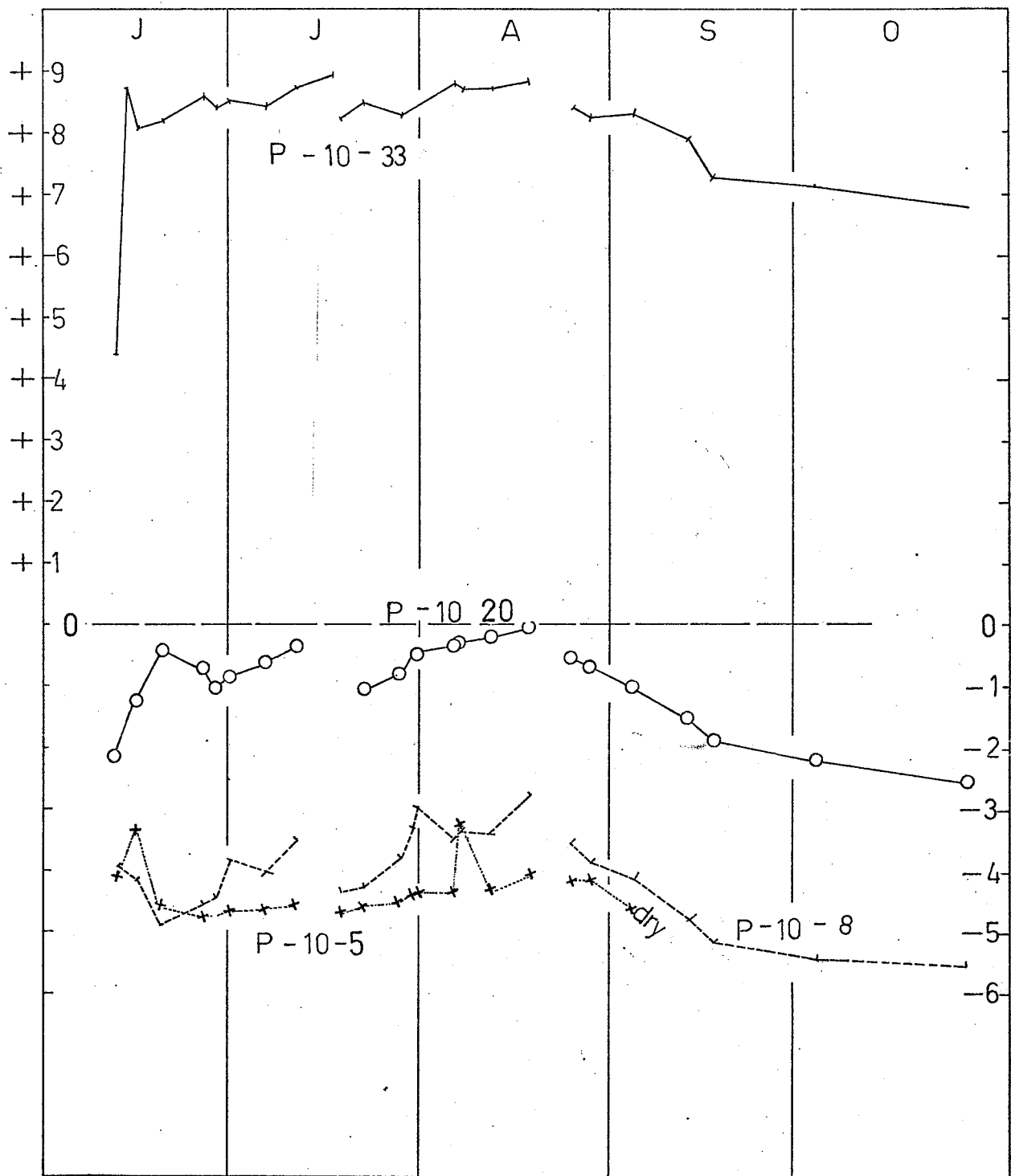
Piezometer Nest No. 6 (P-6). Location NW 32-16-2W



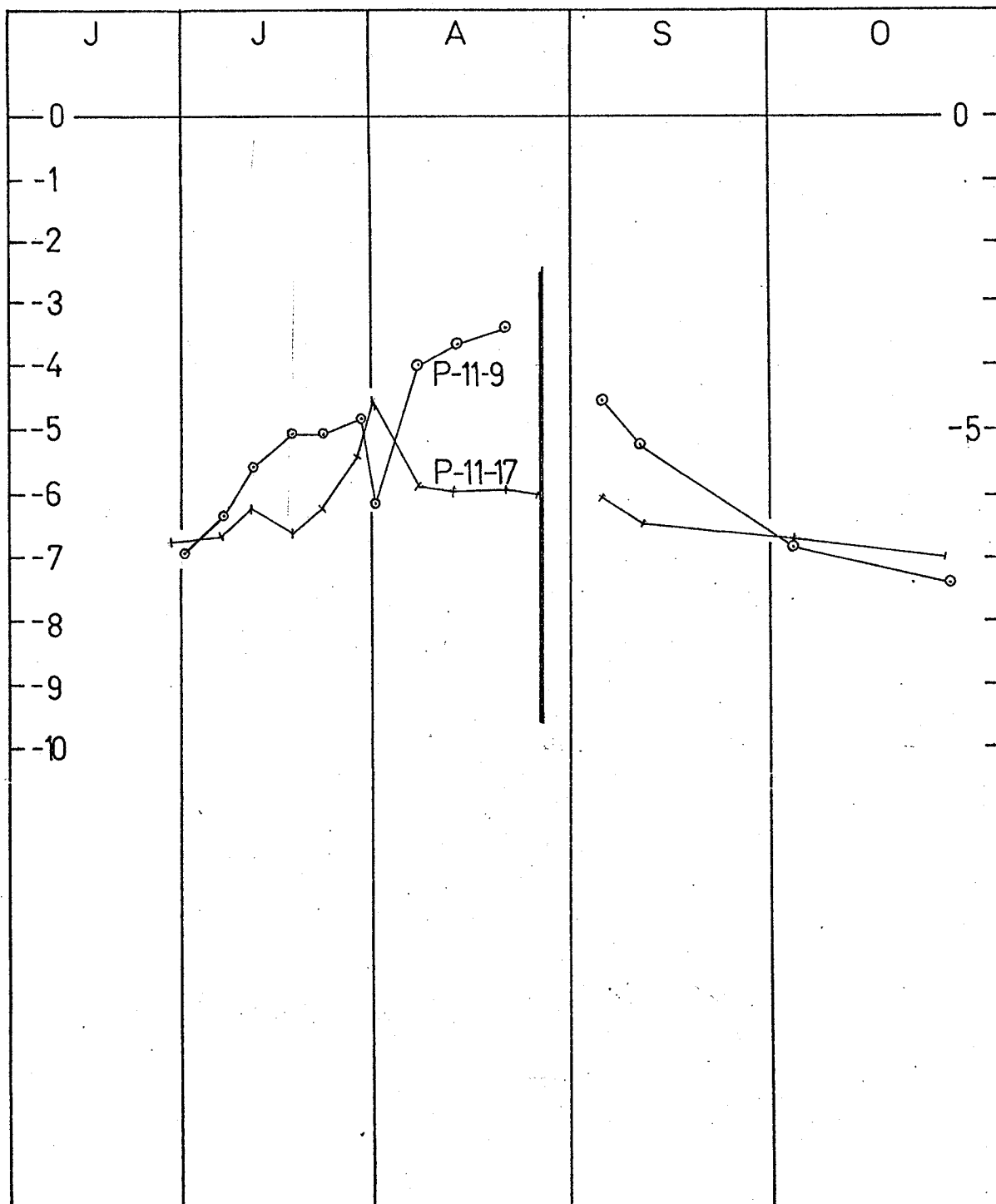


Piezometer Nest No. 8 (P-8). Location NE 21-16-1W

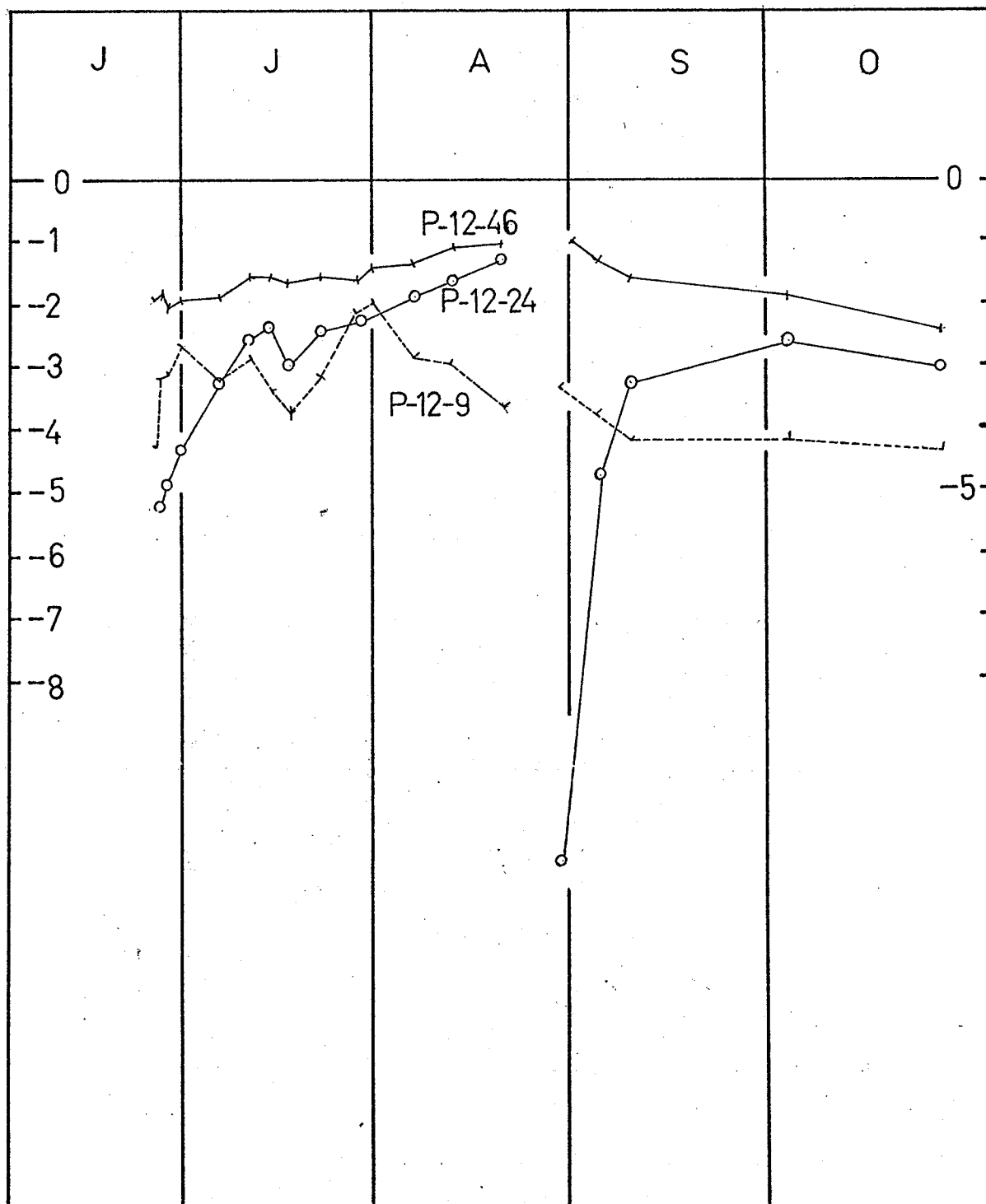




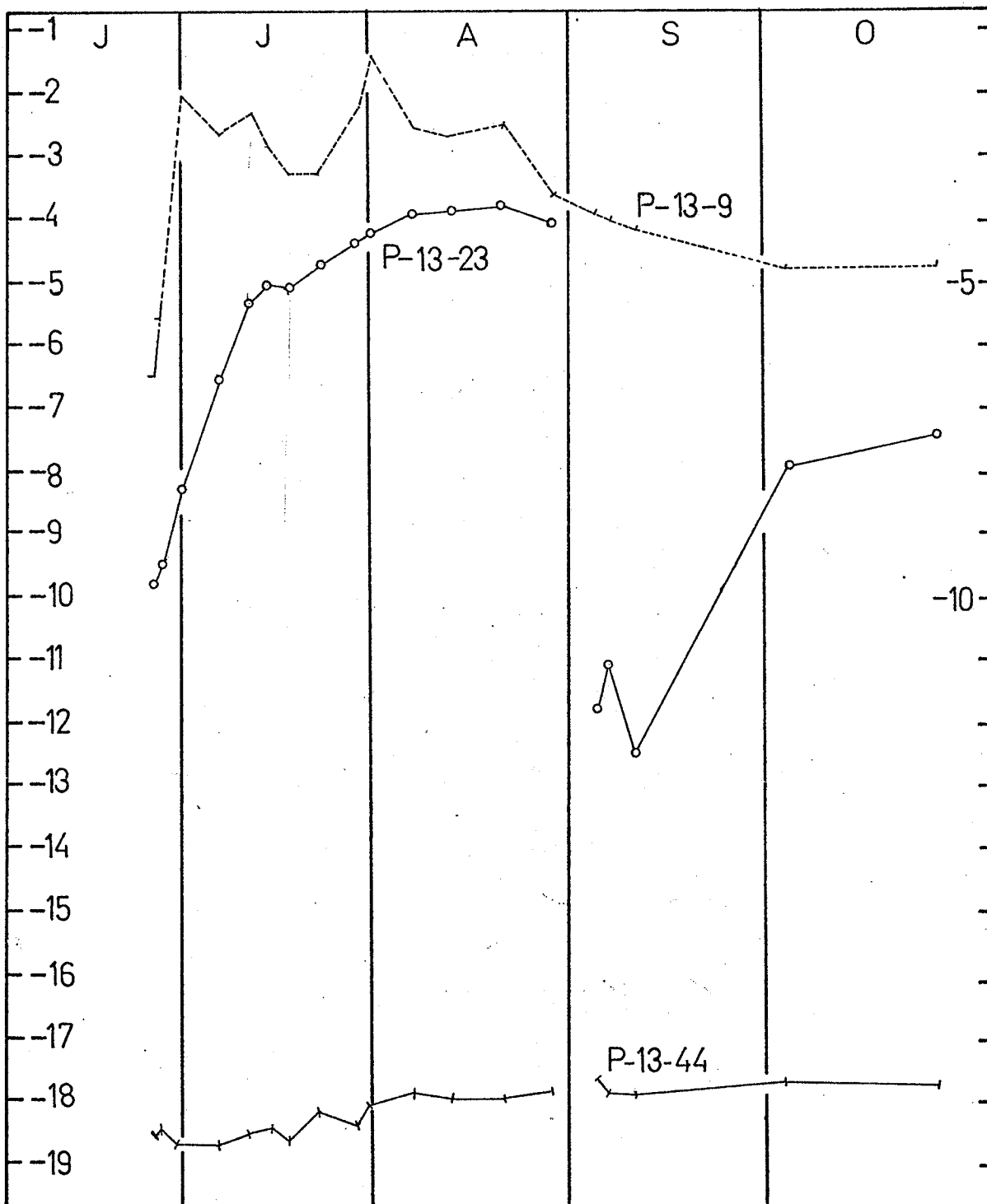
Piezometer Nest No. 10 (P-10). Location NE 2-17-2W



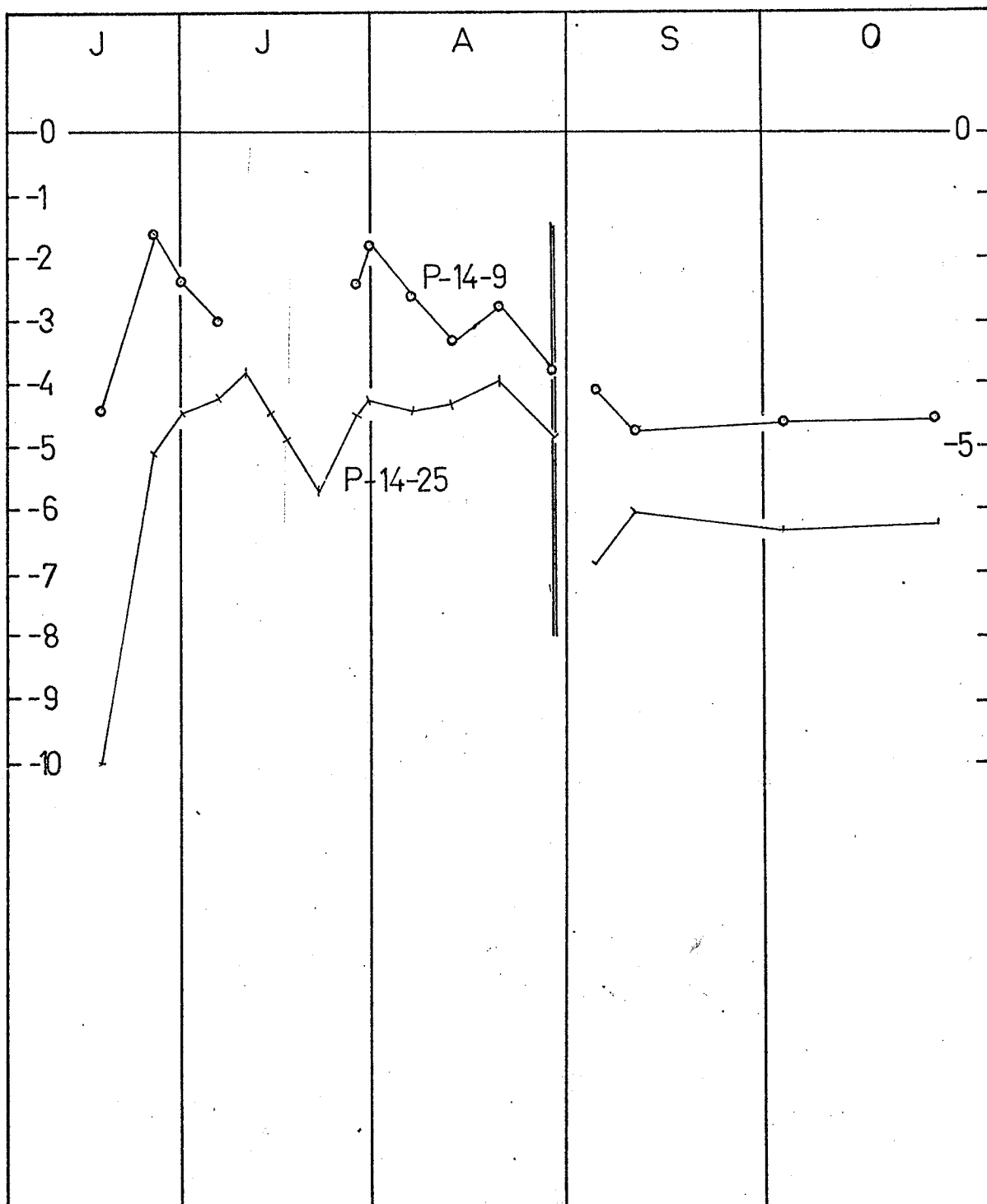
Piezometer Nest No. 11 (P-11). Location SE 21-16-2W



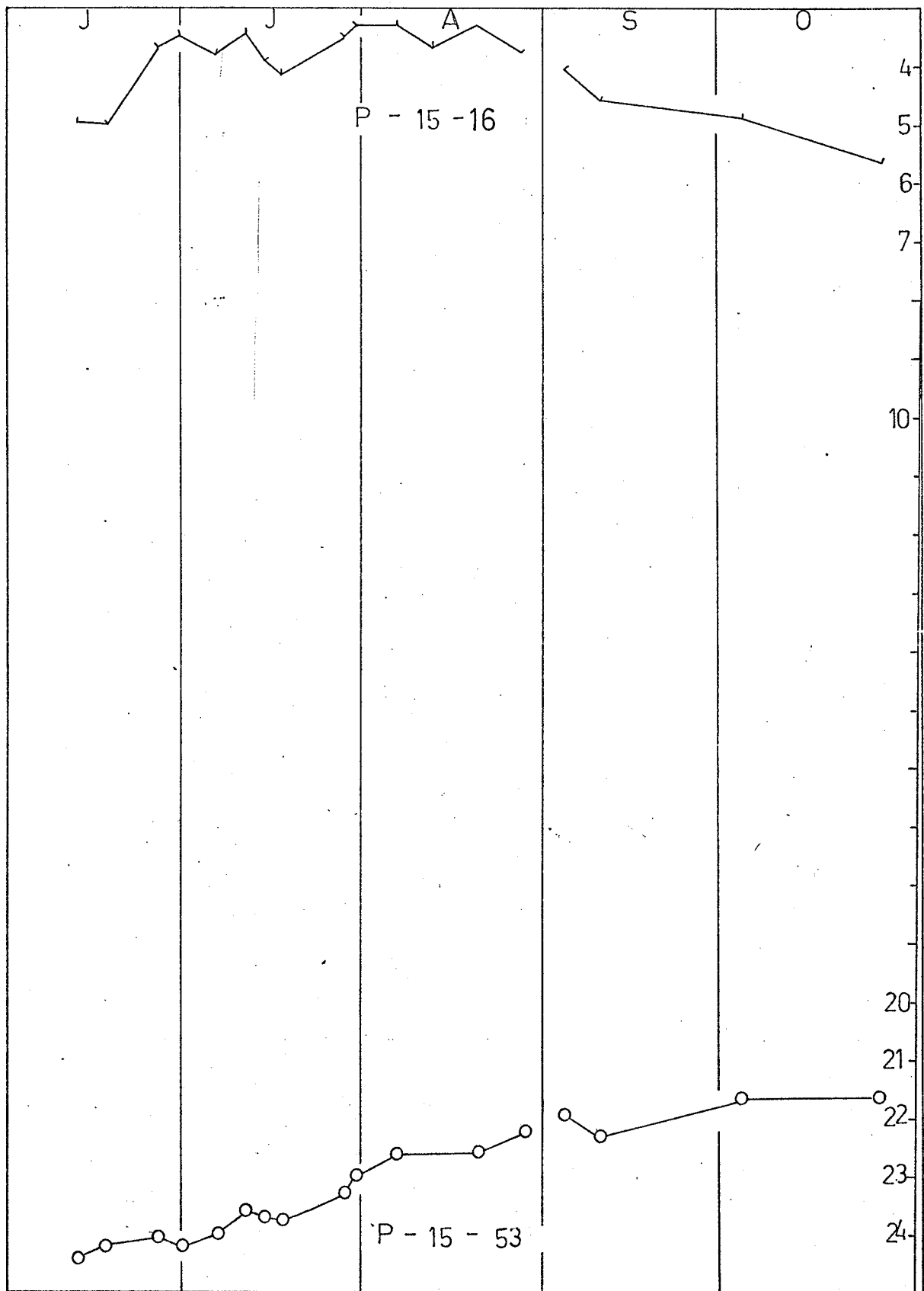
Piezometer Nest No. 12 (P-12). Location NW 30-16-2W



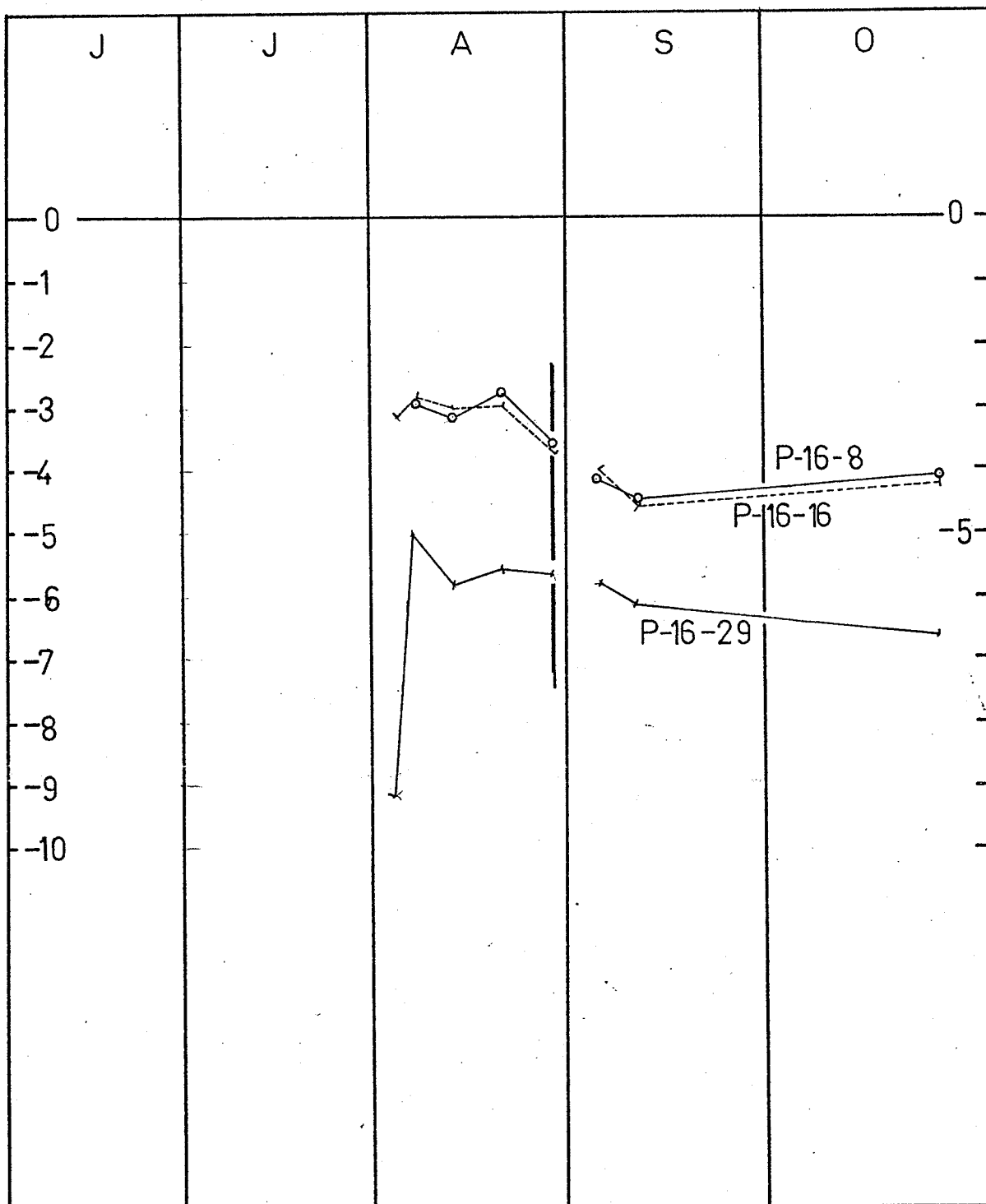
Piezometer Nest No.13 (P-13). Location SW 7-16-2W



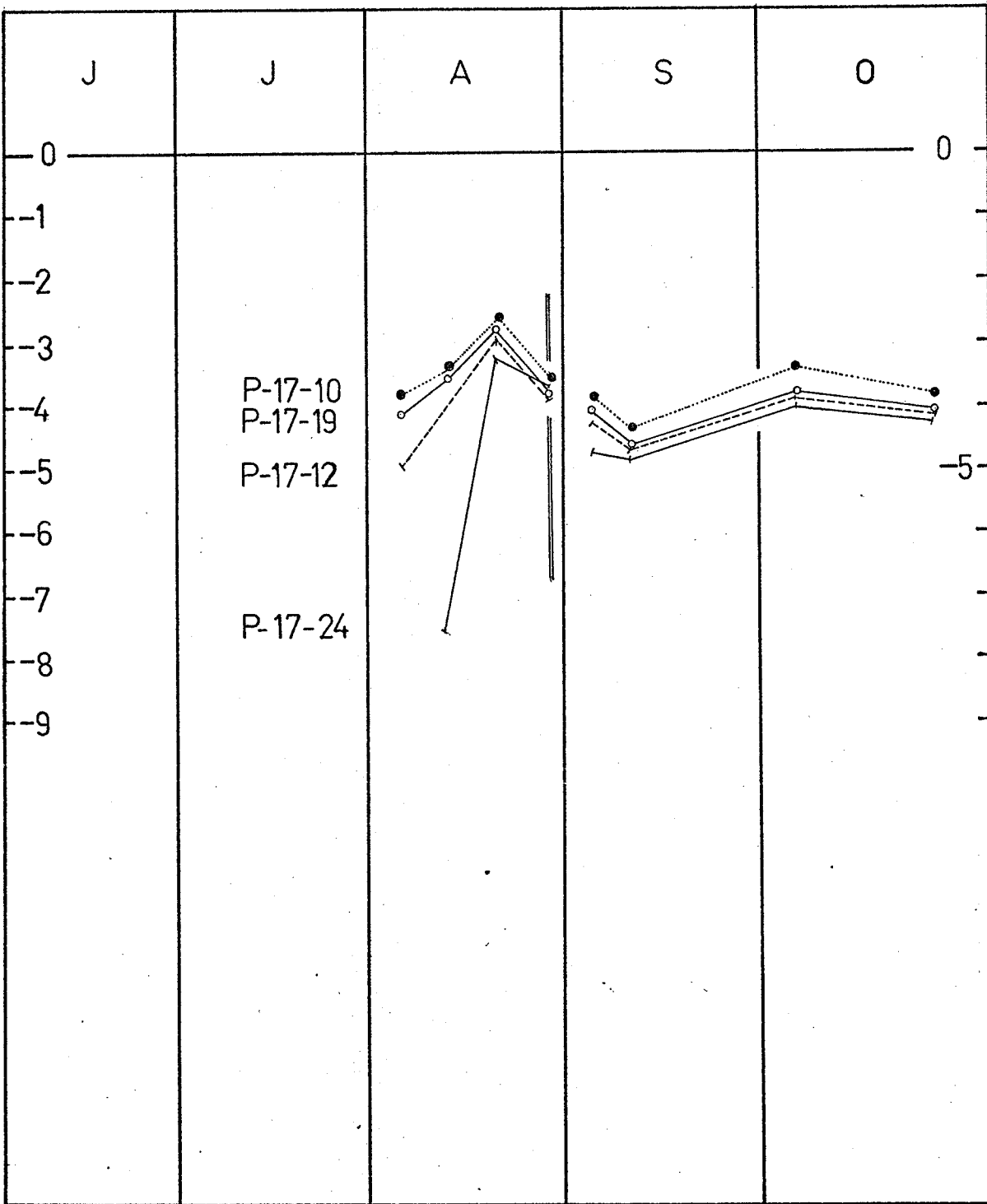
Piezometer Nest No. 14 (P-14). Location SW 32-15-2W



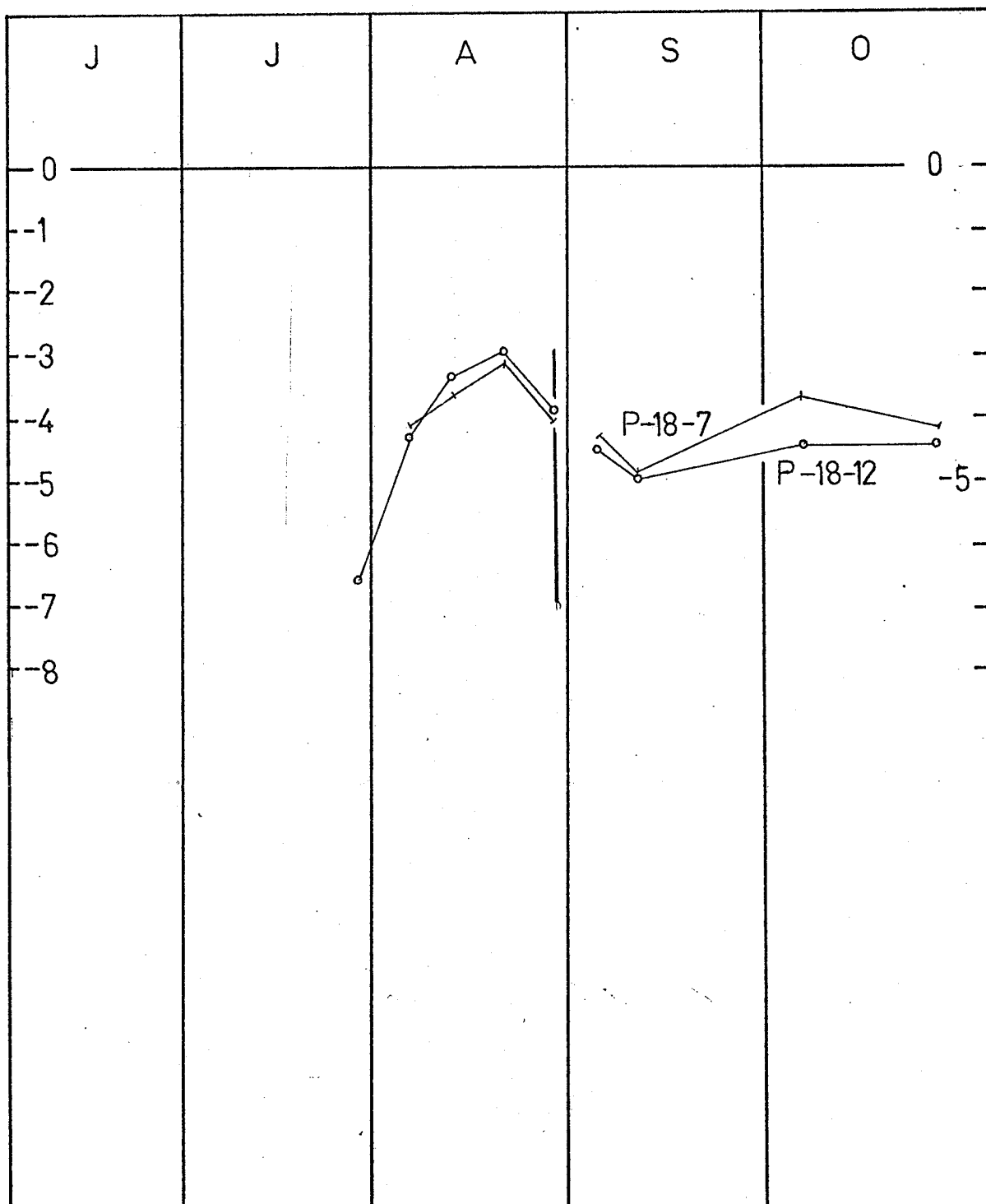
Piezometer Nest No. 15 (P-15). Location NW 15-15-2W



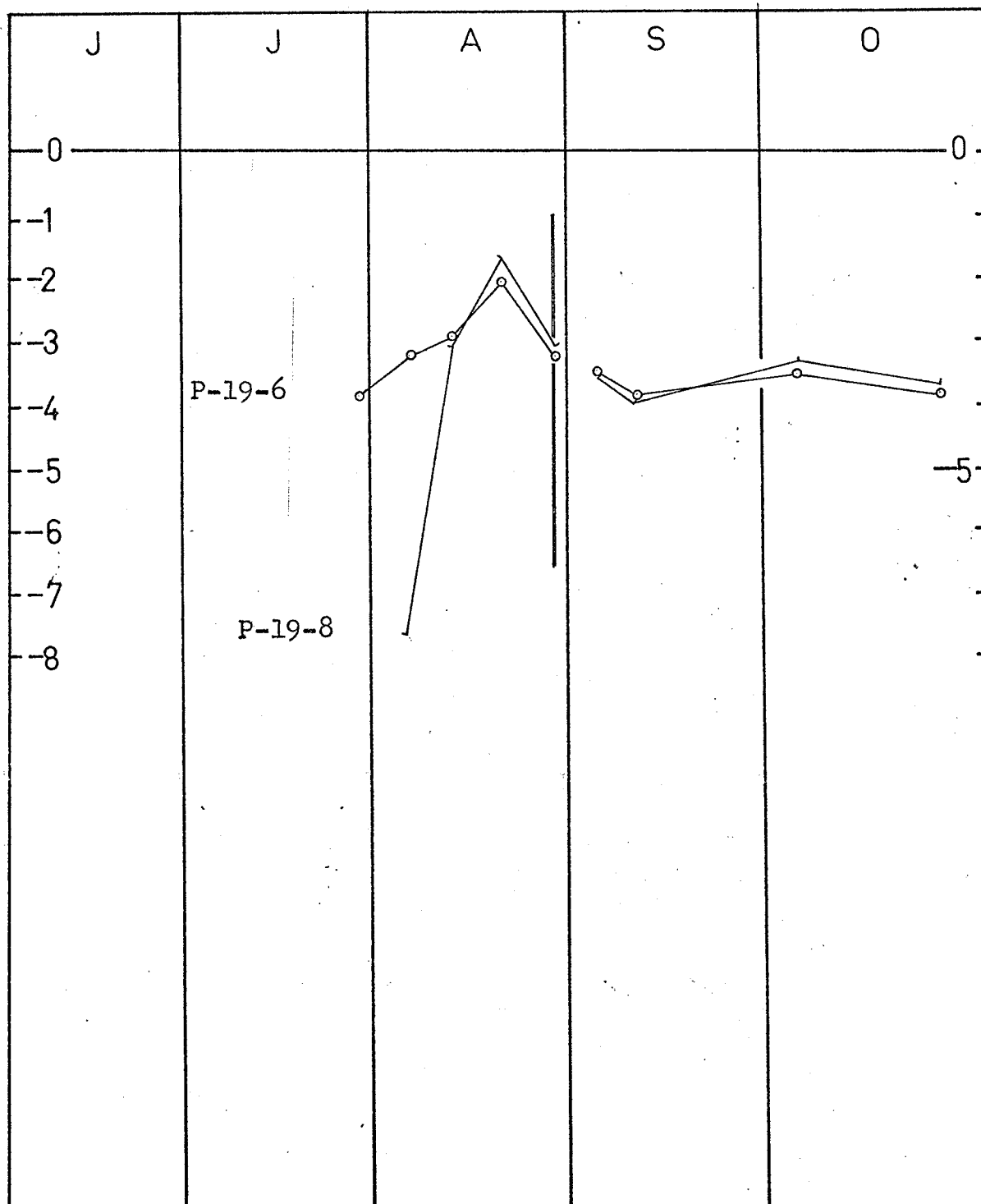
Piezometer Nest No. 16 (P-16). Location SW 19-16-2W



Piezometer Nest No. 17 (P-17). Location SW 1-17-3W



Piezometer Nest No. 18 (P-18). Location NE 34-16-3W



Piezometer Nest No. 19 (P-19). Location SW 10-17-3W

APPENDIX C

Chemical Analyses of Waters in the Shoal Lakes Basin

- I Farm Wells
- II Piezometers
- III Lake Waters
- IV Interstitial Waters

Appendix C - Chemical Analyses* of Water in the Shoal

Lakes Basin

I - Farm Wells

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond** @ 16°C.
1	50	58	32	6	16	423	35	7.412	413
2	144	212	163	2	255	380	775	7.525	2520
3	47	40	160	17	140	376	160	7.805	1024
4	50	40	136	16	128	376	114	7.875	849
5	53	48	163	12	138	322	230	8.000	1070
6	88	160	287	16	214	642	180	7.183	2120
7	53	24	208	15	164	332	250	7.963	1197
8	92	102	178	21	154	750	300	7.345	1450
9	51	104	56	9	26	700	104	7.540	829
10	55	74	114	5	30	273	350	7.930	1006
11	68	74	122	10	22	242	430	8.040	1104
12	90	134	205	16	114	612	490	7.745	1670
13	96	144	56	19	104	872	130	7.375	1210
13'	64	48	11	6	7	466	20	7.379	527
14	70	51	10	6	6	492	13	7.510	513
15	66	60	4	3	6	497	7	7.548	448
16	52	67	7	4	7	492	17	7.570	565

* - ion concentrations in mg/l

** - micromhos/cm at 16°C

' - spring

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond. @16°C.
17	80	56	7	4	7	544	11	7.375	559
18	92	54	16	3	18	504	35	7.665	607
18+	172	179	98	2	294	969	130	7.100	1780
19	68	65	16	10	38	476	26	7.180	668
20	58	44	80	12	64	436	77	7.470	799
21	54	40	79	11	70	400	77	7.721	759
22	48	28	67	11	50	389	68	7.585	612
23	48	48	73	8	50	372	145	7.910	794
24	74	90	148	8	62	204	620	7.850	1250
25	46	60	67	9	44	376	160	7.750	742
26	48	43	72	10	46	372	110	7.805	668
27	12	55	70	6	20	184	230	8.630	630
28	62	78	78	7	46	303	384	7.750	976
29	55	47	39	8	20	414	72	7.600	542
30	48	56	49	6	22	418	100	8.330	614
31	44	54	41	8	20	362	100	7.655	646
32	53	51	59	6	24	307	200	7.868	692
33	50	44	34	7	16	397	38	7.825	575
34	55	50	48	8	20	405	145	7.715	736
35	42	46	19	6	7	429	26	7.625	483
36	60	55	34	5	16	472	85	7.475	679
37	92	115	45	22	86	594	160	7.320	1052
38	65	146	26	6	84	552	68	7.425	1178
39	64	41	30	7	8	398	53	7.580	598
40	62	95	19	1	58	540	34	7.390	598

+ second well on property

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond. @ 16°C.
41	70	75	19	5	8	545	41	7.440	736
42	62	53	19	6	6	460	34	7.385	601
43	60	70	19	7	8	556	48	7.480	732
44	54	40	22	10	8	389	20	7.535	466
45	61	53	15	8	8	418	90	7.403	546
46	87	85	15	40	78	598	76	7.330	1071
47	48	69	15	2	4	478	8	7.560	539
48	26	73	22	8	10	424	65	7.360	602
49	44	40	48	13	34	378	65	7.960	626
50	64	45	19	9	6	444	35	7.635	590
51	44	31	53	5	8	-	50	8.170	539
52	38	44	22	9	16	380	7	8.095	487
53	90	111	67	10	82	502	350	7.590	1220
54	66	61	48	29	64	452	86	7.630	898
55	62	40	26	9	12	400	30	7.730	500
56	66	56	19	9	14	472	28	7.610	644
57	70	50	15	8	8	408	23	7.640	520
58	60	44	7	5	4	400	5	7.530	501
59	54	51	7	4	2	414	5	7.535	520
60	57	38	11	8	4	362	18	7.570	499
61	160	140	16	20	138	535	100	7.210	1590
62	72	91	11	31	46	576	38	7.350	923
63	54	64	2	1	2	456	7	7.470	573
64	74	49	7	3	6	252	3	7.355	596

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁼⁼	pH	Sp. Cond.
65	80	80	111	9	64	304	380	7.705	-
66	76	70	114	9	56	258	400	7.840	-
67	78	52	151	10	92	220	430	7.920	-
68	92	50	22	6	10	508	50	7.352	-
69	76	121	104	7	78	696	270	7.255	-

The following data have been taken from Cherry (1968).

A 2	51	48	13	-	7	317	18	7.560	-
A 3	82	47	8	-	17	386	5	7.460	-
A 4	68	69	26	-	52	420	46	7.280	-
A 6	48	53	43	-	5	321	150	7.550	-
A 9	61	39	3	-	4	366	3	7.510	-
A 10	52	72	6	-	21	415	21	7.560	-
A 11	120	147	47	-	139	599	120	7.450	-
A 12	66	43	10	-	9	333	11	7.590	-
A 13	60	58	7	-	3	412	21	7.380	-
A 16	56	51	4	-	68	413	14	7.528	-
A 17	56	51	7	-	2	421	17	7.440	-
B 24	80	52	12	-	31	424	11	7.408	-
SL 11	36	50	60	-	12	304	180	7.880	-
SL 14	32	64	4	-	8	378	20	7.460	-
SL 15	56	40	8	-	16	381	11	7.490	-
SL 19	76	71	11	-	8	362	9	7.380	-

Appendix C - Chemical Analyses*of Water in the Shoal

Lakes Basin

II - Piezometers

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond.** @ 16°C.
P-1-13	33	53	560	160	20	642	1600	8.095	3710
P-1- 9	36	33	215	10	6	276	130	7.520	1165
P-2- 7	54	131	35	5	10	606	50	7.871	-
P-2- 3	52	172	-	-	2	-	-	7.690	-
P-3-68	26	11	114	5	90	192	67	8.475	688
P-3-46	16	17	126	6	70	282	170	8.645	715
P-3-31	20	15	140	9	72	274	140	8.853	798
P-3-17	38	41	189	11	108	262	250	8.285	1143
P-4-26	64	44	126	104	30	188	440	9.163	1300
P-4-16	52	131	42	11	38	424	273	8.410	975
P-5-17	60	99	118	32	120	210	420	8.255	861
P-5- 9	34	174	89	32	171	466	340	7.760	1320
P-6-38	68	54	164	48	260	354	156	7.810	1094
P-6-21	960	-	800	104	2580	236	2700	7.660	13000
P-6- 8	400	-	1500	40	1050	404	2350	7.140	11140
P-7- 7	47	86	189	24	9	490	400	7.780	1660
P-8- 9	22	45	30	12	60	232	34	9.340	547
P-8- 5	48	74	45	8	6	594	76	7.685	741
P-9-17	1	57	152	112	26	690	165	10.245	1184
P-9- 7	46	155	74	32	16	912	175	8.015	1350

* - ion concentration in mg/l

** - micromhos/cm at 16°C

	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond. @ 16°C.
P-10-33	63	53	15	32	30	432	46	7.820	600
P-10-20	42	25	89	152	30	224	320	9.780	1056
P-10- 8	13	15	82	120	18	225	190	11.460	-
P-11-17	7	23	290	215	114	1022	103	10.425	1500
P-11- 9	244	10	1300	56	580	1500	700	8.340	4360
P-12-46	60	40	104	7	108	120	210	7.975	947
P-12-24	92	6	144	152	85	282	310	11.785	1820
P-12- 9	124	59	196	7	30	535	450	7.800	1450
P-13-44	17	79	460	16	148	156	1500	7.860	3770
P-13-23	8	10	880	270	88	1004	1400	12.240	4770
P-13- 9	29	22	880	14	20	1730	390	7.900	2760
P-14-25	14	5	280	375	20	1140	120	12.320	3470
P-15-53	44	2	267	120	34	400	440	11.795	1750
P-15-16	7	5	250	160	10	520	290	10.520	1380
P-16-29	59	25	11	5	4	222	49	8.245	2770
P-16-16	196	202	1030	350	1068	330	1875	8.295	8930
P-16- 8	-	-	1500	24	966	1160	2000	7.340	14800
P-17-24	86	151	275	330	58	588	800	8.455	2670
P-17-19	18	5	260	390	58	59	730	10.768	2200
P-17-12	158	94	63	24	54	508	360	7.610	1280
P-17-10	78	60	22	7	28	478	77	7.750	706
P-18-12	-	-	740	42	76	568	1750	7.515	11110
P-18- 7	70	124	-	-	42	574	4005	7.995	-
P-19- 8	114	134	56	12	52	478	410	7.750	1290
P-19- 6	128	170	-	-	34	880	360	7.550	-

Appendix C - Chemical Analyses*of Water in the Shoal

Lakes Basin

III - Surface Waters

			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁼⁼	pH	Sp. Cond.** @ 16°C.
NSL	*	11/68	17	54	350	-	135	1300	55	9.200	1800 @11°C.
NSL	A	15/ 2/69	22	635	880	-	-	-	730	8.700	2390
NSL	C	8/ 6/69	19	202	-	80	180	-	460	-	2450
NSL	D	8/ 6/69	18	204	-	80	182	-	480	-	2450
NSL	E	8/ 6/69	18	204	-	80	-	-	450	-	2450
NSL	1	28/ 6/69	8	225	320	79	192	1128	465	9.185	2430
NSL	2	28/ 6/69	8	225	320	82	190	1130	445	9.190	2435
NSL	3	28/ 6/69	7	223	330	80	190	1130	460	9.178	2495
NSL	4	28/ 6/69	10	221	325	80	190	1130	435	9.185	2435
NSL	5	28/ 6/59	8	220	325	81	190	1135	420	9.205	2450
NSL	6	24/ 7/69	18	224	340	81	188	1122	425	9.175	2450
NSL	7	24/ 7/69	16	220	340	79	188	1110	415	9.150	2445
NSL	8	20/ 8/69	24	211	340	80	220	1070	250	9.080	2450
NSL	9	20/ 8/69	23	212	340	80	230	1075	380	9.150	2445
NSL	10	4/ 9/69	10	230	355	82	210	1130	420	9.175	2445
WSL	1	15/ 7/69	16	169	-	97	250	-	290	-	2560
WSL	2	15/ 7/69	17	171	-	100	240	-	275	-	2555
WSL	3	15/ 7/69	16	169	-	97	250	-	-	-	2560
WSL	4	6/ 9/69	68	138	475	93	260	1360	290	9.265	2560

* - ion concentrations in mg/l

** - micromhos/cm at 16°C

NSL * - averages of 14 samples collected in November, 1968

NSL - North Shoal Lake; WSL - West Shoal Lake

				Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	Cl ⁻	HCO ₃ ⁻	SO ₄ ⁻⁻	pH	Sp. Cond. @ 16 °C.
ESL	A	4/ 4/69	-	-	-	-	-	-	3730	-	9.080	7500 @0°C.
ESL	1	12/ 7/69	10	174	335	77	204	1078	310		9.165	2360
ESL	2	12/ 7/69	12	171	335	75	204	1078	280		9.170	2360
ESL	3	12/ 7/69	12	173	335	73	204	1075	290		9.168	2360
ESL	4	12/ 7/69	11	174	340	77	204	1078	310		9.165	2360
ESL	5	12/ 7/69	10	174	340	75	204	1075	280		9.168	2355
ESL	6	9/ 8/69	16	158	340	77	230	1104	300		9.130	2355
ESL	7	9/ 8/69	20	156	340	80	230	1105	310		9.130	2355
ESL	8	9/ 8/69	20	156	340	80	230	1100	285		9.145	2355
ESL	9	9/ 8/69	20	156	340	79	230	1100	290		9.150	2355
ESL	10	4/ 9/69	90	118	335	80	240	1100	285		9.240	2365
ESL	11	22/ 9/69	-	-	-	-	-	1182	360		9.325	2360

Interstitial Waters*

NSL	6	24/ 7/69	-	-	-	-	360	-	-	-	-	-
NSL	8	20/ 8/69	64	290	410	-	340	1420	620		7.935	-
NSL	9	20/ 8/69	-	-	-	-	460	1850	980		7.830	-
WSL	1	15/ 7/69	-	-	-	-	1690	2400	-		8.610	-
WSL	2	15/ 7/69	-	-	-	-	1690	-	-		8.295	-
ESL	7	9/ 8/69	90	192	-	-	400	2030	400		8.265	-
ESL	8	9/ 8/69	162	166	-	-	420	-	750		8.450	-
ESL	9	9/ 8/69	172	158	-	-	420	1870	670		8.005	-

ESL - East Shoal Lake

* - sampling sites correspond to lakewater sampling sites

APPENDIX D

Meteorological Data Collected at Shoal Lakes Westher Station
Monthly Station Records

Bureau Central,
315 Ouest, Rue Bloor,
Toronto 5 (Ont.)

CLASS A PAN EVAPORATION - MONTHLY RECORD
ÉVAPORATION MESURÉE AU MOYEN DU BAC DE CLASSE "A" - RELEVÉ MENSUEL

Observer
Observateur *J. G. H.*

Month
Mois *May* 19 *69*

X) Date	Station <i>Shore Lake</i>		Province <i>Manitoba</i>		Observer Observateur <i>J. G. Smith</i>		Mois <i>May</i> 19 <i>57</i>							Remarks Remarques (15)	
	Water (in) Eau (po)		Rain Gauge Precip. (in) Précip. au pluviomètre (po) (3)	Net Water Loss from Pan (in) Perte d'eau nette du bac (po) (4)	Accum. Wind Mileage (miles) Parcours accumulé du vent (milles) (5)	Daily Wind Mileage (miles) Parcours quotidien du vent (milles) (6)	Water Temperature (°F) Temp. de l'eau (°F)			Air Temperature (°F) Temp. de l'air (°F)			(13)		(14)
	Added Ajoutée (1)	Removed Enlevée (2)					Max. (7)	Min. (8)	Mean Moyenne (9)	Max. (10)	Min. (11)	Mean Moyenne (12)			
			Last day of previous month Dernier jour du mois précédent												
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22			.035		70.87		64	34	54	72	30	51			
23	.28		-	.280	250.83	180.02	70	37	54	68	14	41		sun Am/cloud P.m	
24	.21		-	.210	350.23	99.34	68	36	52	43	21	32		cloudy	
25	.22		.100	.320	608.22	257.99	67	50	53	64	46	55		cloud & rain	
26	.24		.040	.280	748.36	140.14	85	62	74	84	58	71		sunny	
27	.41		-	.410	969.78	221.42	84	53	69	79	50	64		sunny	
28	.26		.005	.265	1126.88	157.12	73	51	62	56	44	50		partly cloudy	
29	.35		-	.350	1298.88	171.98	73	46	60	61	35	48		cloudy	
30		.11	.200	.030	1474.55	175.67	62	47	53	34	34	34		cloudy & rain	
31		.50	.570	.070	1782.64	208.09	49	36	43	46	20	33		cloudy & rain	
Total			.950	.215		1651.77			582			479			
Mean Moy.						183.53			58			13.5			

Time of reading of Rain
Gauge and Evaporation Pan
Heure de lecture du
pluviomètre et du bac
d'évaporation

Remarks:
Remarques:

(a.m.)
(du matin)

NOTE: ALL MORNING OBSERVATIONS ARE TO BE ENTERED ON THE LINE FOR THE PREVIOUS DAY
NOTE: TOUTES LES OBSERVATIONS DU MATIN DOIVENT ÊTRE INSCRITES SUR LA LIGNE DU JOUR PRÉCÉDENT

X) For "Evaporation Day"
X) Pour le "jour d'évaporation"

Bureau Central,
315 Ouest, Rue Bloor,
Toronto 5 (Ont.)

CLASS A PAN EVAPORATION MONTHLY RECORD
ÉVAPORATION MESURÉE AU MOYEN DU BAC DE CLASSE "A" - RELEVÉ MENSUEL

Observer
Observateur *Kenneth J. J.*

Month
Mois *June 1969*

X)	Station <i>Shoal Lakes</i>		Province <i>Manitoba</i>		Observer <i>Kenneth J. J.</i>		Mois <i>June</i>		19 <i>70</i>		Remarks Remarques				
	Water (in) Eau (po)		Rain Gauge Precip. (in) Précip. au pluviomètre (po) (3)	Net Water Loss from Pan (in) Perte d'eau nette du bac (po) (4)	Accum. Wind Mileage (miles) Parcours accumulé du vent (milles) (5)	Daily Wind Mileage (miles) Parcours quotidien du vent (milles) (6)	Water Temperature (°F) Temp. de l'eau (°F)		Air Temperature (°F) Temp. de l'air (°F)			(13)	(14)	(15)	
	Added Ajoutée (1)	Removed Enlevée (2)	Max. (7)	Min. (8)	Mean Moyenne (9)	Max. (10)	Min. (11)	Mean Moyenne (12)							
Date	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Last day of previous month Dernier jour du mois précédent				<i>1782.64</i>										
1	<i>.180</i>	.	.	<i>.180</i>	<i>1947.97</i>	<i>165.33</i>	<i>61</i>	<i>39</i>	<i>50</i>	<i>62</i>	<i>32</i>	<i>41</i>			<i>partly cloudy</i>
2	<i>.260</i>	.	.	<i>.260</i>	<i>2049.38</i>	<i>101.41</i>	<i>74</i>	<i>46</i>	<i>60</i>	<i>64</i>	<i>29</i>	<i>47</i>			<i>clear</i>
3	<i>.020</i>	.	<i>.100</i>	<i>.120</i>	<i>2180.75</i>	<i>131.37</i>	<i>63</i>	<i>47</i>	<i>55</i>	<i>63</i>	<i>36</i>	<i>50</i>			<i>cloud & showers</i>
4	<i>.250</i>	.	.	<i>.250</i>	<i>2275.44</i>	<i>94.63</i>	<i>77</i>	<i>42</i>	<i>60</i>	<i>62</i>	<i>47</i>	<i>63</i>			<i>sunny</i>
5	<i>.250</i>	.	.	<i>.250</i>	<i>2366.63</i>	<i>91.25</i>	<i>75</i>	<i>49</i>	<i>62</i>	<i>63</i>	<i>33</i>	<i>54</i>			<i>sunny</i>
6	<i>.150</i>	.	.	<i>.150</i>	<i>2453.56</i>	<i>86.87</i>	<i>68</i>	<i>45</i>	<i>57</i>	<i>66</i>	<i>30</i>	<i>48</i>			<i>clear AM / showers P.M.</i>
7	<i>.260</i>	.	.	<i>.260</i>	<i>2533.80</i>	<i>80.24</i>	<i>72</i>	<i>46</i>	<i>59</i>	<i>67</i>	<i>55</i>	<i>61</i>			<i>sunny</i>
8	<i>.300</i>	.	.	<i>.300</i>	<i>2629.27</i>	<i>95.47</i>	<i>79</i>	<i>53</i>	<i>66</i>	<i>75</i>	<i>53</i>	<i>64</i>			<i>sunny</i>
9	<i>.355</i>	.	<i>.080</i>	<i>.435</i>	<i>2846.26</i>	<i>116.39</i>	<i>80</i>	<i>44</i>	<i>62</i>	<i>80</i>	<i>23</i>	<i>52</i>			<i>partly cloudy</i>
10	<i>.180</i>	.	.	<i>.180</i>	<i>2986.82</i>	<i>140.56</i>	<i>65</i>	<i>42</i>	<i>59</i>	<i>55</i>	<i>32</i>	<i>44</i>			<i>cloudy AM / sunny PM</i>
11	<i>.270</i>	.	<i>.005</i>	<i>.275</i>	<i>3201.31</i>	<i>214.49</i>	<i>62</i>	<i>38</i>	<i>50</i>	<i>64</i>	<i>26</i>	<i>45</i>			<i>partly cloudy</i>
12	<i>.180</i>	.	.	<i>.180</i>	<i>3350.38</i>	<i>149.07</i>	<i>59</i>	<i>39</i>	<i>49</i>	<i>55</i>	<i>24</i>	<i>40</i>			<i>cloudy</i>
13	<i>.210</i>	.	.	<i>.210</i>	<i>3425.05</i>	<i>74.67</i>	<i>71</i>	<i>48</i>	<i>60</i>	<i>63</i>	<i>34</i>	<i>44</i>			<i>clear</i>
14	<i>.240</i>	.	.	<i>.240</i>	<i>3469.50</i>	<i>44.45</i>	<i>78</i>	<i>47</i>	<i>63</i>	<i>70</i>	<i>84</i>	<i>52</i>			<i>clear</i>
15	<i>.240</i>	.	.	<i>.240</i>	<i>3528.81</i>	<i>59.31</i>	<i>79</i>	<i>56</i>	<i>68</i>	<i>76</i>	<i>45</i>	<i>61</i>			<i>clear</i>
16	<i>.250</i>	.	<i>.010</i>	<i>.260</i>	<i>3672.50</i>	<i>143.63</i>	<i>70</i>	<i>48</i>	<i>59</i>	<i>66</i>	<i>39</i>	<i>53</i>			<i>cloudy</i>
17	<i>.160</i>	.	<i>.010</i>	<i>.170</i>	<i>3777.69</i>	<i>105.19</i>	<i>70</i>	<i>46</i>	<i>58</i>	<i>54</i>	<i>48</i>	<i>51</i>			<i>cloudy (changed water)</i>
18	<i>.270</i>	.	.	<i>.270</i>	<i>3991.20</i>	<i>213.51</i>	<i>65</i>	<i>43</i>	<i>54</i>	<i>48</i>	<i>42</i>	<i>45</i>			<i>cloudy</i>
19	<i>.090</i>	.	<i>.020</i>	<i>.110</i>	<i>4098.31</i>	<i>107.11</i>	<i>59</i>	<i>39</i>	<i>49</i>	<i>39</i>	<i>29</i>	<i>34</i>			<i>partly cloudy</i>
20	<i>.200</i>	.	.	<i>.200</i>	<i>4204.22</i>	<i>105.91</i>	<i>67</i>	<i>42</i>	<i>55</i>	<i>53</i>	<i>29</i>	<i>41</i>			<i>partly cloudy</i>
21	<i>.210</i>	.	.	<i>.210</i>	<i>4298.58</i>	<i>94.36</i>	<i>69</i>	<i>51</i>	<i>60</i>	<i>57</i>	<i>39</i>	<i>48</i>			<i>partly cloudy</i>
22	<i>.180</i>	.	.	<i>.180</i>	<i>4384.04</i>	<i>85.44</i>	<i>74</i>	<i>55</i>	<i>65</i>	<i>57</i>	<i>48</i>	<i>53</i>			<i>partly cloudy</i>
23	<i>.230</i>	.	.	<i>.230</i>	<i>4455.67</i>	<i>71.63</i>	<i>85</i>	<i>57</i>	<i>71</i>	<i>72</i>	<i>55</i>	<i>64</i>			<i>sunny</i>
24	<i>.250</i>	.	.	<i>.250</i>	<i>4557.42</i>	<i>101.75</i>	<i>81</i>	<i>59</i>	<i>70</i>	<i>73</i>	<i>55</i>	<i>64</i>			<i>cloudy + humid</i>
25	.	<i>.230</i>	<i>.330</i>	<i>.100</i>	<i>4807.70</i>	<i>250.38</i>	<i>65</i>	<i>57</i>	<i>61</i>	<i>57</i>	<i>57</i>	<i>57</i>			<i>cloudy + humid</i>
26	.	<i>.610</i>	<i>.760</i>	<i>.150</i>	<i>5009.95</i>	<i>201.25</i>	<i>67</i>	<i>58</i>	<i>57</i>	<i>59</i>	<i>50</i>	<i>54</i>			<i>cloudy + rain</i>
27	<i>.070</i>	.	<i>.020</i>	<i>.090</i>	<i>5120.20</i>	<i>111.25</i>	<i>61</i>	<i>48</i>	<i>54</i>	<i>50</i>	<i>38</i>	<i>44</i>			<i>cloudy + rain</i>
28	.	<i>.120</i>	<i>.290</i>	<i>.170</i>	<i>5193.38</i>	<i>73.18</i>	<i>76</i>	<i>53</i>	<i>65</i>	<i>57</i>	<i>52</i>	<i>54</i>			<i>partly cloudy</i>
29	.	<i>.210</i>	<i>.310</i>	<i>.100</i>	<i>5361.03</i>	<i>167.65</i>	<i>59</i>	<i>47</i>	<i>53</i>	<i>46</i>	<i>44</i>	<i>45</i>			<i>cloudy + rain</i>
30	<i>.230</i>	.	.	<i>.230</i>	<i>5510.91</i>	<i>149.88</i>	<i>71</i>	<i>51</i>	<i>61</i>	<i>61</i>	<i>52</i>	<i>56</i>			<i>partly cloudy</i>
31															
Total			<i>1.935</i>	<i>6.230</i>		<i>3728.27</i>			<i>1763</i>			<i>1545</i>			
Mean Moy.						<i>124.3</i>			<i>58.8</i>			<i>51.5</i>			

Time of reading of Rain
Gauge and Evaporation Pan
Heure de lecture du
pluviomètre et du bac
d'évaporation

8:30 (a.m.)
(du matin)

Remarks:
Remarques:

NOTE: ALL MORNING OBSERVATIONS ARE TO BE ENTERED ON THE LINE FOR THE PREVIOUS DAY
NOTE: TOUTES LES OBSERVATIONS DU MATIN DOIVENT ÊTRE INSCRITES SUR LA LIGNE DU JOUR PRÉCÉDENT

X) For "Evaporation Day"
X) Pour le "jour d'évaporation"

Bureau Central,
315 Ouest, Rue Bloor.
Toronto 5 (Ont.)

CLASS A PAN EVAPORATION MONTHLY RECORD
ÉVAPORATION MESURÉE AU MOYEN DU BAC DE CLASSE "A" - RELEVÉ MENSUEL

SHOAR LAKE

Province

Observer
K. Goff

Month
Mois

JULY 1969

X) Date	Station		Rain Gauge Precip. (in) Précip. au pluviomètre (po) (3)	Net Water Loss from Pan (in) Perte d'eau nette du bac (po) (4)	Accum. Wind Mileage (miles) Parcours accumulé du vent (milles) (5)	Daily Wind Mileage (miles) Parcours quotidien du vent (milles) (6)	Water Temperature (°F) Temp. de l'eau (°F)			Air Temperature (°F) Temp. de l'air (°F)			(13)	(14)	Remarks Remarques (15)
	Water (in) Eau (po)						Max.	Min.	Mean Moyenne (9)	Max.	Min.	Mean Moyenne (12)			
	Added Ajoutée (1)	Removed Enlevée (2)													
	Last day of previous month Dernier jour du mois précédent				5510 91										
1	.13			.13	5603.86	72.45	71	51	61	57	40	45			P.C.
2	.20			.30	5703.86	100.03	78	56	67	73	52	62			SUN.
3		.24	.24	.00	5790.83	86.97	72	65	64	66	49	58			CLOUD
4	.07			.07	5890.46	99.63	62	47	55	50	37	44			CLOUD
5	.24			.24	5977.40	86.94	75	57	63	54	41	48			SUN
6		.12	.26	.14	6055.90	78.50	70	53	62	55	52	54			P.C.
7		.48	.63	.15	6251.73	195.83	67	54	61	61	55	53			CLOUD
8	.17			.17	6365.13	113.40	78	54	69	73	57	65			CLOUD
9	.30			.30	6464.57	99.94	81	61	71	77	55	66			P.C.
10	.25			.25	6538.00	68.42	88	62	75	82	54	68			P.C.
11	.30			.30	6661.00	128.00	90	61	79	92	68	80			CLEAR / SUN.
12	.30			.30	6731.29	70.27	94	68	81	99	66	82			P.C. / CLEAR.
13	.25			.25	6792.01	60.72	87	64	72	92	52	72			P.C.
14	.08			.08	6835.48	43.47	75	63	69	79	52	66			P.C.
15	.24			.24	6901.77	66.29	84	57	71	84	47	66			SUN
16	.26			.26	6976.17	74.42	81	58	70	75	46	61			SUN.
17	.20			.20	7013.75	37.58	83	60	72	84	48	66			P.C.
18		.67	.74	.07	7068.67	54.92	64	59	62	61	62	62			CLOUDY
19	.025		.10	.125	7131.01	62.34	81	57	69	68	51	60			CLOUDY
20	.20			.20	7179.40	48.39	85	57	72	73	52	62			P.C.
21		.11	.30	.19	7371.25	191.95	75	63	69	77	61	69			P.C.
22	.04		.20	.24	7473.81	102.46	80	59	74	75	57	66			SUN
23	.18		.01	.19	7543.36	69.55	83	59	71	81	48	64			SUN / P.C.
24	.30			.30	7649.21	105.85	80	56	68	72	48	60			P.C.
25		.03	.26	.23	7736.26	87.05	82	56	69	66	48	57			SUN.
26		.42	.47	.05	7893.90	157.64	66	56	61	59	57	58			RAIN. - CLOUDY
27	.20			.20	7966.00	72.10	79	53	69	72	48	60			CLOUDY
28	.21			.21	8008.02	42.02	88	61	74	82	53	68			SUN.
29		.41	.85	.44	8152.84	144.62	82	65	74	90	63	76			P.C.
30	.06		.18	.24	8305.66	152.87	81	53	67	72	50	61			CLOUD-RAIN / P.C.
31	.28			.28	8387.17	83.51	78	57	68	72		67			CLEAR /
Total			4.26	6.25		62.85			68.6			64.5			
Mean															

Time of reading of Rain
Gauge and Evaporation Pan
Heure de lecture du
pluviomètre et du bac
d'évaporation

8:30

(a.m.)
(du matin)

Remarks:
Remarques:

NOTE: ALL MORNING OBSERVATIONS ARE TO BE ENTERED ON THE LINE FOR THE PREVIOUS DAY
NOTE: TOUTES LES OBSERVATIONS DU MATIN DOIVENT ÊTRE INSCRITES SUR LA LIGNE DU JOUR PRÉCÉDENT

X) For "Evaporation Day"
X) Pour le "jour d'évaporation"

Bureau Central,
315 Ouest, Rue Bloor,
Toronto 5 (Ont.)

CLASS A PAN EVAPORATION MONTHLY RECORD
ÉVAPORATION MESURÉE AU MOYEN DU BAC DE CLASSE "A" - RELEVÉ MENSUEL

X)	Station	Province	Observer	Month										
	Shoal Lakes	Manitoba	Kearney, Goff.	August 1969										
Date	Water (in) Eau (po)	Rain Gauge Precip. (in) Précip. au pluviomètre (po)	Net Water Loss from Pan (in) Perte d'eau nette du bac (po)	Accum. Wind Mileage (miles) Parcours accumulé du vent (milles)	Daily Wind Mileage (miles) Parcours quotidien du vent (milles)	Water Temperature (°F) Temp. de l'eau (°F)	Air Temperature (°F) Temp. de l'air (°F)	Remarks Remarques						
	Added Ajoutée (1)	Removed Enlevée (2)				Max. (7)	Min. (8)	Mean Moyenne (9)	Max. (10)	Min. (11)	Mean Moyenne (12)	(13)	(14)	(15)
			Last day of previous month Dernier jour du mois précédent	8389.17				✓			✓			
1	.25	.	.25	8477.33	88.16	84	66	72	82	54	68			CLEAR HOT
2	.22	.	.015	8540.98	63.68	90	65	78	83	60	74			CLEAR HOT
3	.11	.	.11	8624.49	83.51	81	63	71	83	60	72			CLOUD-RAIN
4	.30	.	.30	8741.20	116.71	87	62	75	84	56	70			CLEAR
5	.	.13	.25	8870.84	129.64	77	63	70	79	60	70			CLOUD
6	.	.53	.73	9011.47	200.63	80	56	68	77	55	66			CLOUD
7	.25	.	.25	9204.09	132.62	77	59	68	70	50	60			CLEAR/P.C. RAIN.
8	.20	.	.20	9245.21	41.12	88	63	76	79	53	66			CLEAR.
9	.33	.	.33	9310.76	35.55	86	66	76	83	59	74			CLEAR
10	.30	.	.30	9420.64	109.88	89	65	77	91	65	78			CLEAR.
11	.22	.	.02	9526.64	106.00	90	69	80	73	69	61			CLOUD
12	.	.13	.41	9629.80	103.16	83	61	75	82	64	73			CLEAR/CLOUD
13	.	.28	.72	9982.28	352.48	68	53	63	64	59	62			CLOUD-RAIN/
14	.20	.	.20	134.07	151.77	71	59	65	74	57	66			CLOUD
15	.24	.	.24	225.74	91.67	80	59	70	77	49	63			CLEAR
16	.	.05	.31	359.03	133.29	85	61	73	77	55	66			CLOUD RAIN/CLEAR.
17	.13	.	.08	499.55	149.52	74	53	64	61	48	54			CLOUD RAIN
18	.09	.	.09	573.25	73.70	75	56	66	64	52	58			CLOUD
19	.15	.	.15	691.78	118.53	77	58	67	66	55	60			CLEAR
20	.27	.	.27	860.34	162.56	83	63	73	77	64	70			CLEAR
21	.26	.	.26	1001.40	191.06	91	64	80	98	63	83			CLEAR
22	.30	.	.30	1096.10	94.70	72	63	78	100	57	80			CLEAR
23	.20	.	.20	1181.47	85.37	87	63	75	83	58	70			CLEAR
24	.25	.	.25	1311.80	130.33	86	62	74	79	63	71			CLEAR
25	.27	.	.03	1507.10	195.30	86	67	76	90	68	79			CLEAR
26	.20	.	.20	1581.37	74.21	81	60	71	82	53	66			CLOUD
27	.10	.	.01	1697.36	115.99	76	55	66	75	46	60			CLOUD SHOWERS/
28	.07	.	.07	1829.67	132.31	82	65	74	75	64	70			CLEAR.
29	.22	.	.22	1994.44	164.77	77	53	65	79	51	65			CLOUD.
30	.20	.	.20	2133.05	138.61	74	53	64	73	48	60			P.C.
31	.17	.	.17	219382	60.77	73	52	62	66	43	54			P.C.
Total			2.665	6835				2212			2109			
Mean Moy.								73.3			68.0			
Time of reading of Rain Gauge and Evaporation Pan Heure de lecture du pluviomètre et du bac d'évaporation				8:30	(a.m.) (du matin)	Remarks: Remarques:				NOTE: ALL MORNING OBSERVATIONS ARE TO BE ENTERED ON THE LINE FOR THE PREVIOUS DAY NOTE: TOUTES LES OBSERVATIONS DU MATIN DOIVENT ÊTRE INSCRITES SUR LA LIGNE DU JOUR PRÉCÉDENT				X) For "Evaporation Day" X) Pour le "jour d'évaporation"

Bureau Central,
315 Ouest, Rue Bloor,
Toronto 5 (Ont.)

CLASS A PAN EVAPORATION-MONTHLY RECORD
ÉVAPORATION MESURÉE AU MOYEN DU BAC DE CLASSE "A" - RELEVÉ MENSUEL

X)	Station	Province	Observer	Month												
	Chual Lakes	Manitoba	Thomson Galt	September 19 69												
	Water (in) Eau (po)	Rain Gauge Precip. (in) Précip. au pluviomètre (po)	Net Water Loss from Pan (in) Perte d'eau nette du bac (po)	Accum. Wind Mileage (miles) Parcours accumulé du vent (milles)	Daily Wind Mileage (miles) Parcours quotidien du vent (milles)	Water Temperature (°F) Temp. de l'eau (°F)			Air Temperature (°F) Temp. de l'air (°F)					Remarks Remarques		
Date	Added Ajoutée (1)	Removed Enlevée (2)				Max.	Min.	Mean Moyenne (9)	Max.	Min.	Mean Moyenne (12)	(13)	(14)	(15)		
			Last day of previous month Dernier jour du mois précédent	2193.82												
1	.20			.20	2314.11	120.29	74	53	64	72	64	68		P.C.		
2	.07			.07	2404.82	90.71	75	60	68	77	58	68		P.C.		
3	.14			.14	2615.30	210.48	76	62	68	71	60	68		C / CLEAR		
4	.03		.06	.14	2725.44	110.14	74	60	67	77	55	66		CLEAR		
5	.21			.21	2868.10	142.66	77	57	64	72	47	60		P.C.		
6	.14			.14	2929.69	61.59	73	52	63	68	41	54		CLEAR		
7	.09		.03	.12	3065.29	135.60	67	49	58	59	46	52		P.C.		
8	.07			.07	3109.58	44.29	63	48	54	59	39	49		P.C.		
9	.13			.13	3165.17	55.59	73	54	64	68	48	58		CLEAR		
10	.20			.20	3283.45	118.28	68	42	55	57	29	43		C		
11	.20			.20	3428.24	144.79	72	43	63	75	45	60		CLEAR		
12	.17			.17	3537.70	109.46	76	52	69	66	49	59		CLEAR		
13	.16			.16	3681.30	143.60	80	52	70	86	62	74		CLEAR		
14	.24			.24	3835.10	153.80	84	53	69	82	49	66		CLEAR		
15	.20			.20	3921.55	86.45	64	42	53	61	32	46		P.C.		
16	.17			.17	4054.97	133.42	61	37	50	54	32	43		P.C.		
17	.12			.12	4121.00	67.03	65	41	53	57	35	46		CLEAR		
18	.14			.14	4373.02	252.02	67	41	54	63	35	49		C		
19	.20			.20	4586.27	213.25	67	53	63	69	57	62		P.C.		
20	.09		.07	.16	4743.68	157.41	75	54	65	71	52	62		CLEAR		
21		.06	.17	.11	4911.46	167.78	66	46	56	65	42	57		C		
22	.04		.01	.05	5117.70	206.24	50	36	43	44	32	38		P.C.		
23			.06	.05	5255.32	131.62	58	33	48	47	33	40		C RAIN		
24		.24	.29	.04	5464.05	209.73	41	42	44	45	42	44		C RAIN		
25	.02		.01	.03	5561.40	97.35	57	45	49	48	44	46		C		
26	.08			.08	5659.27	97.87	54	41	48	48	32	40		C		
27	.05			.05	5734.02	74.75	55	33	46	52	25	38		C		
28		.06	.10	.04	5901.61	167.57	49	43	46	48	37	42		C		
29																
30																
31																
Total			0.79	3.63		3807.77			161.3			149.2				
Mean Moy.						130			57.6			53.3				
Time of reading of Rain Gauge and Evaporation Pan Heure de lecture du pluviomètre et du bac d'évaporation			(a.m.) (du matin)			Remarks: Remarques: NOTE: ALL MORNING OBSERVATIONS ARE TO BE ENTERED ON THE LINE FOR THE PREVIOUS DAY NOTE: TOUTES LES OBSERVATIONS DU MATIN DOIVENT ÊTRE INSCRITES SUR LA LIGNE DU JOUR PRÉCÉDENT									X) For "Evaporation Day" X) Pour le "jour d'évaporation"	

P.C. = partly cloudy.
C = Cloud.