THE GEOLOGICAL AND HYDROLOGICAL ENVIRONMENT
OF THE
WHITEWATER LAKE BASIN, MANITOBA

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ABSTRACT

The Whitewater Lake Basin is located in southwestern Manitoba within the Interior Plains region of western Canada. The main hydrologic feature of the basin is Whitewater Lake, a shallow closed basin lake less than 5 feet deep occupying 25 square miles in the centre of the basin.

The lake lies within the Boissevain Till Plain and is underlain by Cretaceous Shales of the Riding Mountain Formation. A Late Cretaceous-Tertiary outlier of Boissevain Formation sandstone overlain by sandstones and shales of the Turtle Mountain Formation occurs on Turtle Mountian immediately south of the lake. The origin of the basin is due to a collapse feature caused by the solution of salt from Devonian evaporite deposits and/or to a Pre-Jurassic erosion feature on the Mississippian "escarpment" underlying the basin. During Tertiary- Early Pleistocene time a major preglacial river existed under the present location of Whitewater Lake.

Three till sheets were deposited in the basin during the Pleistocene separated by interglacial deposits of sand and gravel. During final deglaciation a glacial lake formed in the basin and extensive outwash deposits of sand and gravel were deposited on the north slope of Turtle Mountain. Recent sediments up to 18 inches (46 cm.) in thickness indicate post-glacial deposition has been slow and uniform. The accumulation of calcareous bioclasts and plant fragments is an important bio-sedimentological process operating in the lake.

The major portion of the annual precipitation falls as rain during the period April to August. The mean annual precipitation at Whitewater Lake in 1970 was 17.2 inches (43.8 cm.) and the mean seasonal rainfall at the lake in 1971 was 15.9 inches (40.2 cm.).

Lake evaporation determined from Class "A" pan evaporation data was 21.7 inches (55.1 cm.) in 1970 and from 19.5 to 22.0 inches (49.5 to 56.0 cm.) in 1971. Combined with estimated tranpiration losses a moisture deficit of 11.4 to 14.9 inches (29.0 to 37.7 cm.) was determined for the open-water season of 1971.

Eight intermittent creeks flow off the north slope of Turtle Mountain into marshland bordering Whitewater Lake. Peak flow rates range from 100 to 200 cubic feet per second (3 to 6 cubic metres per second) during the early spring. The creeks usually become dry by early summer.

Lake levels rise steadily after spring breakup to maximum levels in July. They then drop steadily until the end of August remaining steady until freeze-up in early November.A comparison of lake level changes and minimum evapotranspiration losses in 1970 and 1971 indicates additional quantities of water entered the lake via the groundwater regime.

Areally, shallow groundwater flow is toward the centre of the lake basin from Turtle Mountain and the region north of the lake. Groundwater recharge occurs on Turtle Mountain with shallow groundwater moving downward and laterally through the Boissevain Formation into outwash sand and gravel deposits under Whitewater Lake. Seepage from these deposits southwest and southeast of the lake is a major source of water for the lake. A major groundwater outlet for the basin occurs northeast of the lake within the thalweg of a buried valley.

Rainfall is the calcium-magnesium-bicarbonate type while snow is the sodium-magnesium-sulphate type. The main source of relatively high amounts of Ca^{2+}, Na^{+}, Mg^{2+} and SO_4^{2-} in the rain samples is soil dust. Electrolytic conductivity values range from 6 to 390 micromhos.cm.$^{-1}$ at 25°C. The oxygen^{18} composition of rain samples varied from -19.8 to -5.2 SMOW.

Creeks vary from the calcium-magnesium-bicarbonate type to the sodium-calcium-sulphate type. Groundwater inflow is the most important component of creek discharge during the spring and early summer months. Oxygen^{18} composition ranges from -19.3 to -8.7 SMOW.

Three chemical groundwater facies occur in the Whitewater Lake Basin: Type I, a calcium-magnesium-bicarbonate-sulphate facies characteristic of the Boissevain Formation and the shallow sand and gravel deposits, Type II, a calcium-magnesium-sulphate facies occurring in a variety of deposits including glacial till and glacial sand, and Type III, a sodium sulphate and sodium chloride facies characteristic of glacial till and the Riding Mountain Formation. Electrolytic conductivity values range from 1000 to 41,000 micromhos.cm.$^{-1}$ at 25°C., with lowest values occurring in the Boissevain Formation and outwash sands and gravels while larger values are characteristic of till waters and the Riding Mountain Formation. Spatial variations in the major-ion chemistry of the groundwater substantiates the groundwater movement interpreted from hydraulic head measurements.

Whitewater Lake is of the sodium-magnesium-sulphate type. Total dissolved solids range from 2000 to 4500 milligrams.liter^{-1} during the open-water season. Evapotranspiration causes seasonal increases in the total dissolved solids, conductivity, major-ion chemistry and pH of the lake. Flushing of the lake occurs under the ice during the winter months. Highly concentrated lake water moves through the bottom sediments and is replaced by inflowing groundwater having a relatively low conductivity. Rapid increase in the oxygen^{18} content of the lake occurs during the open-water season due to high evapotranspiration rates.

Interstitial waters from the lake bottom sediments are chemically similar to lake water. The oxygen^{18} composition of the interstitial water

samples indicate the downward movement of lake water is occurring.

Water budget and chemical balance equations for selected time intervals in 1970 and 1971 indicate that groundwater inflow may vary from 15 to 60 percent of the lake volume and that groundwater outflow through the bottom of the lake varies from 35 to 60 percent of the lake volume. Groundwater flushing is an important factor influencing lake behaviour.

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CHAPTER I

INTRODUCTION

Purpose and Scope of Study

Whitewater Lake is a shallow closed basin lake less than 5 feet deep occupying 25 square miles in an agricultural area of southwestern Manitoba in the Interior Plains region of western Canada. The lake is similar to several other post-glacial lakes in western Canada with regards to physiographic and climatic setting.

This study is an investigation of the geological and hydrological environment of the Whitewater Lake Basin with emphasis on the physical and chemical relationships which occur among the hydrologic components of the lake system. Whitewater Lake is of particular hydrologic interest because it is situated in a high evaporation region, has no surface outflow and yet has relatively low salinity. This is an unusual situation for a closed lake basin in the Interior Plains region.

Whitewater Lake is also a hydrologic phenomenon associated with many practical problems in the area including land use, agricultural land productivity, water resources and wildlife management. This study provides information which could be used to assist in lake management problems.

Geologic, hydrometric, chemical, natural stable isotope and computer techniques were used to investigate various phases of the study. The multi-approach method utilizing physical, chemical and mathematical data was used to achieve a synthesized interpretation of the lake system. This method yields an interpretation which approaches the complex reality of the interrelated elements of the natural environment. A detailed account of the methods of investigation is included in Appendix A, p. 261.

A general description of the area is presented in Chapter I followed by a description of Whitewater Lake. Major features including topography, drainage and lake morphology are discussed.

The geological setting of the basin is defined in Chapter II. General geology based on the literature is presented followed by detailed stratigraphic descriptions from drill hole data. A portion of the preglacial-glacial history of the area and origin of the basin are interpreted from the stratigraphic evidence.

In Chapter III the hydrologic environment of the basin is discussed. Qualitative analysis of the hydrologic components including precipitation, evapotranspiration, surface water, groundwater and lake water is presented.

Chapter IV deals with the hydrochemical environment of the lake basin. Seasonal variations in major-ion chemistry and oxygen^{18} composition related to the hydrologic components are discussed.

A quantitative evaluation of the hydrologic components is presented in Chapter V. Water budgets are used to determine the groundwater flux of Whitewater Lake for the years 1970 and 1971. Groundwater inflow and subsurface outflow to and from Whitewater Lake are estimated using Darcy's Law and these estimates are compared to inflow and outflow quantities calculated from chemical balance equations.

Description of Terrestrial Area

Location and Access

The Whitewater Lake Basin is located in an agricultural area 160 miles (260 km.) southwest of Winnipeg (Fig. 1, p.136). Whitewater Lake occupies about 25 square miles (64 km.^{2}) of area within the Boissevain Till Plain of the Western Upland region of Manitoba (Fig. 2, p. 137). The lake lies at the northern edge of Turtle Mountain (Fig. 3, p. 138).

The area is readily accessible by means of numerous section roads although direct access to Whitewater Lake is limited by a border of surrounding swampland. Some of the local roads are impassable during wet weather.

Topography and Drainage

Throughout the northern portion of the area relief is generally low and the topography is undulating and hummocky. This region is characterized by numerous shallow intermittent potholes and sloughs.

The topography becomes strongly rolling toward the south (Fig. 3, p. 138) and elevations rise from 1,650 feet (540 m.) near Whitewater Lake to above 2,400 feet (785 m.) on Turtle Mountain over a distance of 6 miles (10 km.). Turtle Mountain is an erosional remnant of the "third prairie level" (Fig. 4, p. 139) which at one time extended east from the Missouri Coteau (Bannatyne 1970). There is no great relief on Turtle Mountain except near the western end where the tops of a few hills are 200 to 300 feet (70 to 100 m.) above the general level (Johnston, 1934).

Numerous lakes occupy depressions on Turtle Mountain.

Surface drainage in the area around Whitewater Lake is poorly defined. There are no surface outlets from Whitewater Lake. Intermittant streams on the north slope of Turtle Mountain drain into swampland bordering Whitewater Lake. There are no direct surface inlets entering Whitewater Lake. Streams flowing off the northeast slope of the mountain drain into the Pembina River (Fig. 3 , p. 138). Intermittent streams north and west of Whitewater Lake, principally Elgin Creek and Medora Creek respectively, drain into the Souris River.

Climate

The climate of the area is characteristic of an interior continental region with cold winters and warm summers (Johnston, 1934). Bossenmaier (1953) reports that Whitewater Lake rests on the arbitrary line separating the sub-humid lands in the east from the semi-arid lands to the west and that the region is characterized by variations in precipitation. Table 1, p. 198 is a summary of the monthly and annual precipitation at Boissevain, (Fig. 3, p. 138)for periods up to 19 years as compiled by Bossenmaier (1953). The average annual precipitation for these periods is 18.25 inches (46.35 cm.). Larger amounts of annual precipitation near 25 inches falls on Turtle Mountain. A comparison of the monthly and annual precipitation at Boissevain and Peace Gardens (Fig. 3, p.138) is shown in Table 2, p.198 for the period 1967 to 1970.

Twenty-five percent of the annual precipitation in the vicinity of Whitewater Lake at Boissevain falls as rain during the months of June and July (Table 1, p.198). The precipitation diminishes after July and does not recover until large amounts of snow fall during the winter months.

Rain in the order of 10 inches (20.5 cm.) however may fall locally within a few hours as heavy thunder showers are prevalent during the hot summer months (Mukammal, 1958).

Evaporation from Whitewater Lake during the summer months is probably in the order of 25 to 30 inches (63 to 76 cm.). This estimate is based on studies by McKay (1965) regarding evaporation from reservoirs on the Canadian Prairies. Evaporation data (Table 3, p.199) for the period 1967 to 1970 from Baldur, Manitoba located 50 miles (80 km.) east of Whitewater Lake and generally in the same climatic zone and elevation, indicates and average summer lake evaporation of 21.6 inches (55 cm.). Comparison of the annual precipitation and summer lake evaporation in the area indicates that Whitewater Lake is situated in a region where there is a net moisture deficiency during the summer months. Periodically the area is subject to drought.

The mean monthly temperature of southern Manitoba ranges from a minimum of 0.07°F.(-17.5°C.) in January to a maximum of 67.3°F. (19.6°C.) in July (Bossenmaier, 1953; from Ellis and Shafer, 1940). Bossenmaier (1953) interprets the frostfree period at Whitewater Lake to be 105 days from the end of May to the middle of September. The ground is generally frozen from November to the middle of April when the mean air temperature drops below freezing. The mean daily monthly temperature at Boissevain for the period 1966 to 1970 is shown in Table 4, p. 199.

Vegetation

Vegetation in the Boissevain Till Plain around Whitewater Lake belongs to the "Grasslands Region of the Southern Plains of Manitoba" (Halliday, 1937). These grasslands are characterized by mixed short and tall prairie grasses with associated herbaceous plants.

Vegetation of Turtle Mountain is also of the grassland region but belongs to the "Prairie-Aspen-Grove Section". The prevailing type of vegetation is tall prairie grasses but numerous bluffs of aspen, poplar and oak are common around depressions and along stream channels.

Whitewater Lake is characterized by aquatic vegetation varying from non-emergent species such as sago, bladderwort, pondweed, water crowfoot, water milfoil and chara to emergent species such as reed grass, whitetop and hard-stem bulrush (Bossenmaier, 1953). Wet meadow and semi-aquatic plants many of them saline tolerant halophytes occur between the waters edge and cultivated fields.

Soils

The distribution of soils in the Whitewater Lake area is shown in Fig. 5, p. 140. Distinct variations exist between the soils developed of Turtle Mountain, those developed on the Boissevain Till Plain and the soils of the Whitewater Lake Basin.

Soils developed of Turtle Mountain above 1,900 foot contour are of the "Degrading Black Earth and Grey Wooded Zone " (Ellis, 1938). Saline soils do not occur here as soluable salts are leached downward and carried away in the drainage waters (Pratt and Ellis, 1954).

Soils on ground moraine of the Boissevain Till Plain belong to the "Dark Brown Steppe-Black Earth Transition Zone" (Ellis, 1938). These generally well-drained soils are characterized by a rich organic black to brown finely granular surface horizon, a brown narrow columnar "B" horizon and the presence of a lime carbonate layer 12 to 16 inches (30 to 40 cm.) below the surface. Salinized soils are of common occurrence in poorly drained areas where the dominant ion present in soil solution is sulphate (Pratt and Ellis, 1954). An average analysis of saline soil samples from the Boissevain Till Plain is given in Table 5, p.200 .

Soils developed on the lacustrine clay which surrounds Whitewater Lake are a complex of immature soils showing varying degrees of profile development in the process of a transition from hydromorphic through salinized to well drained soils (Pratt and Ellis, 1954). Sulphate salts of sodium and magnesium are common in soil solutions. An average analysis of saline soil samples from the lacustrine clay plain is shown in Table 5, p. 200. The very high concentrations of sodium sulphate in these soils is in in conformity with soluable salt analyses of water samples from the Tertiary rock formations of Turtle Mountain (Pratt and Ellis, 1954) A recent survey of the soils and soil salinity in the Whitewater Lake Basin has been completed by the Manitoba Soil Survey (Eilers, 1971). Eilers (1971) reports that the soils primarily have carbonated, salinized profiles and are usually inperfectly to poorly drained. Saline soils are shown in Fig. 6, p. 141. Salinity within 2 feet (61 cm.) of the soil surface is relatively severe in the salinized soil areas and a constistently high water table is associated with these soils.

Eilers (1971) states that salt accumulation occurs immediately above the water table suggesting the upward migration of salts from the water table via capillarity. Salt accumulation also occurs at the contact beteeen the lacustrine deposits and glacial till. Conductivities and soluable salt analyses from soil extracts at drill site H(Fig. 6, p. 141) from Eilers (1971) are presented in Table 6, p. 201. These analyses are representative of the results obtained from analysis of other shallow drill sites in the area. The conductivities and individual ion concentrations generally show an increase with depth (Table 6, p. 201). The soil extract analyses correlate closely with soluable salt analyses of groundwater samples obtained from observation wells in the area (Eilers, 1971).

The occurrence and distribution of saline soils in the Whitewater Lake Basin suggest that the area is a groundwater discharge area (Eilers, 1972). The nature and occurrence of salt accumulation in soil profiles suggest the upward migration is salts from the water table via capillarity under the influence of intermediate and local groundwater flow systems (Eilers, 1972). These conclusions are supported by data presented in later sections of this report.

Description of Whitewater Lake

Morphology

WHitewater Lake is roughly rectangular in shape trending in a north-easterly direction with a maximum length of about 8 miles (13 km.) and a maximum width of 4 miles (6.4 km.). The southwest, northwest and western shorelines are controlled by natural aand and gravel ridges 4 to 15 feet (1.3 to 4.8 m.) in height. The position of the eastern shoreline is not well defined and varies according to the intensity and direction of the wind. The lake bed slopes gently and evenly toward the centre of the lake (Fig. 7, p. 142).

Lake levels compiled by Bossenmaier (1953) show that since the year 1900 the lake varied from 6 to 9 feet in maximum depth for 10 years, from 4 to 6 feet for 5 years, from 2 to 4 feet for 13 years and from 0 to 2 feet for 18 years and was dry for the major part of 7 years. In the early 1930's the lake was completely dry.

Vegetation

Whitewater Lake is characterized by wide areas of mudflats, feather-edge and dense broad growths of aquatic and marsh vegetation (Bossenmaier, 1953). The type and distribution of aquatic vegetation recognized by Bossenmaier (1953) in 1950 is given in Table 7a, p. 202. Many of the halophytic species present at Whitewater Lake characterize the saline lakes of Saskatchewan described by Rawson and Moore in 1944 (Bossenmaier *et al*, 1954). Those species occurring at Whitewater Lake are listed in Table 7b, p. 203. On the basis of the reported vegetation (Bossenmaier, 1953) the lake may be classified according to the system of Stewart and

Kantrud (1971) as a permanent lake (Class V) moderately brackish (subclass C) with central expanses of open water surrounded by peripheral bands of emergent cover (cover type 3). The moderately brackish conditions of Stewart and Kantrud (1971) refer to lake waters exhibiting a normal specific conductance range of 2,000 to 5,000 micromhos.cm.$^{-3}$ and and extreme range of 1,600 to 18,000. Fen or alkaline bog zones (Stewart and Kantrud, 1971) also occur in the south-western and eastern marsh areas where they are characterized by species of Phragmites communis and Typha latifolia. Pockets of fen zones are common along the margins of brackish, subsaline and saline ponds and lakes where they are often located on gently sloping terrain with a perceptible flow of groundwater on or near the surface (Stewart and Kantrud, 1971). These fen zones occur in the slightly brackish salinity range. This classification however may not hold true over long periods of time due to variable changes in lake level associated with climatological effects. Variability in the distribution of vegetation over a period of years associated with variability of lake levels has been observed (pers. comm., B. Ransom, 1971). Bossenmaier et al (1954) reported the progressive elimination of huge quantities of emergent hydrophytes during high water levels of the mid 1940's and 1950's. Vegetation at the lake in 1950 is shown in Fig. 8, 143.

Many of the emergent species such as Phragmites communis described by Bossenmaier (1953) are phreatophytes or plants that habitually obtain their water supply from groundwater. The occurrence and growth of phreatophytes are controlled by: climate, depth to the water table or capillary fringe, quality of the groundwater and the character of the soil (Robinson, 1958). During the growing season phreatophytes utilize groundwater through transpiration and cause fluctuations in the level of the water table (Robinson, 1958). Distichlis stricta for example which occurs at Whitewater Lake is a shallow-rooted plant that is found generally in areas where the depth to the water table is less than 8 feet (2.6 m.),(Robinson, 1958). In much of the area of salt grass growth, the capillary fringe extends to the land surface so that groundwater evaporates directly from the soil causing a concentration of alkali salts at or near the surface (Robinson, 1958). *Atriplex hastata* occurs in saline soils, especially around alkaline lakes, in salt marshes and in other water logged soils (Robinson, 1958; from Bidwell and Wooten, 1925). *Suaeda depressa* occurs also on saline or saline-alkali soils where the groundwater is of poor quality for crop growth (Robinson, 1958; from U.S. Dept. of Agriculture, 1954).

Chara sp. and "coontail" occurring as broken bits on Whitewater Lake in 1950 have been recorded (Bossenmaier, 1953; from Colls and Neufeld, 1950). *Chara* has the capability of precipitating calcium carbonate on its stem (Pettijohn, 1957).

The occurrence of aspen, *Populus tremuloides* and poplar, *Populus* sp. along ravines down the north slope of Turtle Mountain and in thin patches throughout the northern portion of the area (Bossenmaier, 1953) suggests that these plants are also phreatophytes in this region. This species prefers a groundwater of good quality although it can tolerate a water of moderate salinity (Robinson, 1958).

Lake Temperature

Whitewater Lake is not thermally stratified during the summer months. High energy wave conditions prevalent on the lake during the summer months tend to keep the lake well mixed. Variations of 1 or 2°C. however were measured among surface waters, bottom waters and areas of intense aquatic vegetation. Very shallow waters over mudflat areas moreover may be heated considerably on hot summer days. Lake temperatures rise quickly during the spring and summer months to a maximum in August after which time the temperature declines. Lake temperature appears to be controlled by air temperature.

Historic Lake Levels

Data on Whitewater Lake levels prior to 1969 are limited to observations of local residents (Bossenmaier, 1953) and a few miscellaneous recorded levels since 1959 (Manitoba Water Resources Branch, 1971). These data are indicative of long-term fluctuations in the level of the lake. A synthetic reconstruction of Whitewater Lake levels for the period 1921 to 1969 based on computed inflow, evaporation and precipitation data (Manitoba Water Resources Branch, 1971) indicates the level of Whitewater Lake has never exceeded the natural spillage level of 1,631 feet (535 m.).

The slight slope of the lake bed and large expanses of open water favour the development of seiches or wind tides on the lake. Seiches are responsible for daily fluctuations in lake level. A 11.5 inch (29.2 cm.) seiche for example was measured on one occasion in the eastern portion of the lake following several hours of 25 to 35 m.p.h. (40 to 56 km.p.h.) west north-west winds (Bossenmaier *et al*, 1954).

CHAPTER II

GEOLOGICAL ENVIRONMENT

General Geology

Surficial Deposits

The distribution of surficial deposits in the study area is shown in Fig. 9, p. 144. The following descriptions are adapted from Elson (1962).

Ground moraine, ridged moraine and end moraine deposits consisting respectively of sandy-silty to silty-sandy till, sandy to silty till and sandy to silty till with minor poorly sorted sand and gravel lenses underlie the area. Ground moraine (lgm) is found throughout the central portion of the area flanked by ridged moraine to the north. Minor ridged moraine (lrm) also occurs south of Whitewater Lake. End moraine (lem) extends south from Whitewater Lake over Turtle Mountain. Ground moraine exhibits relief generally less than 10 feet (3 m.) with the terrain undulating to gently rolling. Closed depressions are abundant and randomly distributed over this deposit. Ridged moraine is characterized by minor moraine ridges 3 to 20 feet (1 to 6 m.) high and about 500 feet (164 m.) apart from crest to crest. The ridges probably formed subglacially near the ice margin. End moraine exhibits a rough topography of closed depressions and knobs with relief from 8 to 60 feet (2.4 to 20 m.). It forms broad ridges and hilly areas and includes some hummocky moraine.

Delta deposits (ldg) of coarse sand and medium to fine-grained pebbly gravel are found southwest of Whitewater below Turtlehead Creek. The deposits also include some outwash material.

Lacustrine deposits (1l) of sand, silt and clay and minor delta and outwash deposits occur around Whitewater Lake. Sands occur southwest of the lake immediately north of the extensive delta deposit off Turtlehead Creek. A small linear sand body occurs about five miles directly east of the lake. Lacustrine silts occur mainly around the northwest end of the lake extending in a southwesterly trending belt. A minor silt deposit occurs on the southeast shore of Whitewater Lake. Clays occur in a southeasterly trending belt off the east shore of the lake.

Alluvium (1a) of sand and gravel occurs on the north slope of Turtle Mountain along creek valleys. These deposits form paired terraces.

Lag concentrate (1wt) (water-worked till) deposits of cobbles and boulders with or without a sandy or gravel matrix occur near Boissevain. These deposits are generally less than 2 feet (0.7 m.) in thickness and generally overlie till, stratified deposits or bedrock.

Silt (3si) less than 4 feet (1.2 m.) thick and probably eolian in origin occurs as a discontinuous mantle over ground moraine north of the lacustrine silt deposits northwest of Whitewater Lake.

Alluvium (4a) of mainly coarse sand and fine gravel occurs in abandoned channels and on river terraces along the Turtlehead Creek valley. These deposits are from 3 to 10 feet (1 to 3 m.) in thickness.

Alluvium deposits (5a) of poorly sorted silt, sand, clay and minor gravels occur southwest and southeast of the lake. These materials are currently being deposited on alluvial fans and floodplains.

Bog and marsh deposits (5m) less than 5 feet (1.5 m.) thick of muck and peat occur in extensive deposits immediately southwest and east of Whitewater Lake. Less extensive deposits occur along the south and northwestern shores of the lake.

Beach ridges 3 to 10 feet (1 to 3 m.) in height and up to 4 miles (6.5 km.) in length occur along the northwest, southwest and north shores of Whitewater Lake and 3 miles (4.8 km.) east of the lake. These ridges are composed mainly of sand and gravel.

Pleistocene Geology

Glacial drift consisting mainly of till overlies bedrock in the area. The upper 20 feet (6 m.) or more of the drift is a greyish buff till with many boulders and lenses of stratified sands and gravels overlying a compact, impervious blue clay till that rests on bedrock (Halstead and Elson, 1949) Klassen and Wyder (1970) report the occurrence of multiple till sheets in the area recognized by the presence of stratified interbeds, buried oxidized zones and differences in colour and hardness. The thickness of the drift on the Boissevain Till Plain is commonly less than 50 feet (15 m.) except in the vicinity of Whitewater Lake where thicknesses are 100 feet (30 m.) or more (Manitoba Water Well Drillers' Reports, 1963-1970). On the Turtle Mountain Upland drift thicknesses up to 500 feet (150 m.) are reported although the drift thickness is variable over this bedrock upland (Klassen and Wyder, 1970).

Bedrock Geology

The entire area is underlain by Upper Cretaceous shales of the Riding Mountain Formation (Fig. 10, p. 145). In the south where Turtle Mountain occurs these shales are overlain by the Boissevain Formation,a

Late Cretaceous-Tertiary sandstone and the Turtle Mountain Formation, an Early Tertiary sequence of sand, sandstones and lignite bearing beds (Fig. 11, p. 146). The bedrock geology of the area has been described by Johnston (1934), Wickenden (1945), Elson and Halstead (1949) and Bannatyne (1970). The following descriptions of the bedrock formations are taken from Bannatyne (1970) unless noted otherwise.

Riding Mountain Formation

The Upper Cretaceous marine Riding Mountain Formation in western Manitoba is estimated to be in the order of 1,100 feet (340 m.) in thickness (Wickenden, 1945). The formation is composed of two main rock types; an upper layer of hard, grey, siliceous Odanah Shale and a lower layer of soft, greenish brown bentonitic Millwood Shale. The Odanah Member underlies the study area. Cuttings from wells in the Turtle Mountain area indicate a 150 to 200 foot (45 to 60 m.) interval of soft shale at the top of the Odanah Member. The Odanah Member occurs mainly as thin fissile beds and as thick massive beds that are brittle and break with conchoidal fracture. The shale is hard, grey, siliceous, non-calcareous and in part soft (Johnston, 1934).

Chemical analyses of three samples of Odanah Shale are listed in Table 8 , p. 204. The major constituent of the shale is silica. The main clay mineral present is an interlayered montmorillonite. Calcium and some magnesium are the exchange cations of the clay (Bannatyne, 1970; from Wicks, 1963).

Boissevain Formation

The Boissevain Formation consists mainly of greenish-grey sand, sandstone and shale. Johnston (1934) places the base of the formation at an elevation near 1,625 feet (495 m.) on the basis of observed outcrops. Bannatyne (1970) reports the top of the Riding Mountain Formation (base of the Boissevain Formation) under Turtle Mountain at 1,601 feet (488 m.). Klassen and Wyder (1970) report the Boissevain Formation occurring as 100 feet (30 m.) of fine to medium-grained "salt and pepper" sandstone with occasional shale interbeds in a borehole on Turtle Mountain. Wickenden (1945) estimated the Boissevain Formation to be 100 feet (30 m.) thick.

The sands are believed to be of continental origin on the basis of carbonized fossil plant fragments (Wickenden, 1945). The sandstones are greenish-grey, kaolinitic, fine to medium-grained, non-calcareous, micaceous and exhibit a "salt and pepper" appearance. The sandstones are composed mainly of quartz and chert grains with minor feldspar grains and lignite fragments. Wickenden (1945) reports that portions of the sandstone may be cemented into a hard rock that occurs as lenses in the formation. The rock of cemented lenses has been quarried as a building stone (Halstead, 1959). Shales are hard, brown, silty, banded, calcareous and may contain ironstone concretions. They may also be kaolinitic.

A chemical analysis of a sample of kaolinitic shale from the Boissevain Formation is shown in Table 9, p. 204.

Turtle Mountain Formation

The Turtle Mountain Formation consists of at least 980 feet (300 m.) of sandstone, shale and lignite bearing beds on the Turtle Mountain Upland. The beds are generally non-marine. Sandstones are mostly fine-grained, feldspathic, micaceous, non-calcareous, white or yellowish and kaolinized. Pyrite and magnetite grains commonly occur in the sandstones and fossil plant remains may also be present. The sandstones exhibit vertical fractures. Shales are silty, dark to light grey, calcareous, kaolinitic and carbonaceous. Thin concretionary layers are also present.

A chemical analysis of shale from the Turtle Mountain Formation reported by Bannatyne (1970) is given in Table 10, p. 204. Quartz constitutes at least 10 percent of the shale. Plagioclase feldspar and minor amounts of pyrite are also present. The dominant clay mineral present is a mixed layer illite-montmorillonite with a large amount of calcium and a smaller amount of magnesium as the exchangeable cations (Bannatyne, 1970; from Wicks, 1963). X-ray analyses also indicate the presence of some kaolinite and/or chlorite.

Structural Geology

The regional dip of the bedrock strata is to the west (Bannatyne, 1970), although the Boissevain Formation may dip slightly toward the southeast along the northwest flank of Turtle Mountain and toward the southwest along the northeast flank of the mountain (J. Bamburak, pers. comm., 1971). This suggests the presence of a broad structural syncline having a northwest-southeast trending axis through Turtle Mountain. The presence of the Late Cretaceous and Early Tertiary deposits in the Turtle Mountain area may be interpreted as an indication of a minor basin of deposition similar to that in which the Whitemud and Ravenscrag Formations occur in south-central Saskatchewan (Wickenden, 1945). A well drilled through Cretaceous formations near Deloraine in 1891-92 indicates the presence of a local bedrock low structure (Wickenden, 1945). Christiansen (1967) describes bedrock low structures in Saskatchewan that appear to have formed by collapse as a result of solution of salt from underlying Devonian evaporite deposits. Similar structures occur in the Yorkton area of Saskatchewan (Cherry and Whitaker, 1969). Kupsch (1958) attributes the origin of surface structures in southern Saskatchewan to deep seated tectonic processes, differential compaction over older structures or collapse resulting from the solution of salt beds in Devonian rock. Detailed analysis of topographical and drainage features in southern Saskatchewan reveals many coincidences between surface relief and mapped structures in the near-surface bedrock (Kupsch, 1958).

Whitewater Lake is located within and along the eastern flank of the Devonian Elk Point evaporite basin (Fig. 12, p. 147), and near the eastern edge of the Mississippian "escarpment". The area is underlain by evaporite deposits of anhydrite, sodium chloride and potassium chloride salt beds (Baillie, 1953). McCabe (1959) states "the rapid thinning of Devonian salt along the eastern flank of the Devonian Elk Point evaporite basin, the coincidence of this thinning with the area of thickening of the lower part of the Mississippian section, and the presence of several areas of known (?) salt collapse probably has played an important role in controlling Mississippian sedimentation in this area". Collapse structures occur south of Whitewater Lake in North Dakota (Anderson and Hunt, 1964) where local thickening of Mississippian strata implies these collapse structures formed prior to or during deposition of the Mississippian beds.

Moreover, Whitewater Lake is underlain by the Mississippian oil fields (McCabe, 1963). Studies by McCabe (1971a) in the Virden area just north of Whitewater Lake suggest that the complex of structural lows bordering the oil fields is due to salt collapse.

Pre-Jurassic erosion features such as cuestas, scarps and re-entrants are recognizable along the edge of the Mississippian subcrop (McCabe, 1971b).

Subsurface Stratigraphy and Geohydrology

Definition of Units

A summary of the geologic material encountered in the drill holes immediately around the lake (Fig. 13, p. 148) is presented in Fig. 14, p. 149. A geologic cross section (B-B') which includes the deposits on the northern slope of Turtle Mountain is shown in Fig. 15, p. 150. West-east cross sections (C-C') and (D-D') along the south and north shores of Whitewater Lake are presented in Fig. 16 and 17 on pages 151 and 152.

Physical descriptions of the various units are based on field logs and laboratory examination of samples. Detailed petrological and petrographical analyses were not conducted on the samples. Grain size descriptions are according to the Wentworth grade scale. Colour descriptions are based on the Munsell colour chart.

Hydrogeologic units were defined mainly on the basis of the stratigraphy. Hydrogeologic properties of the stratigraphic units were interpreted on the basis of the physical appearance of the samples.

Unit 1: Riding Mountain Formation

The hard siliceous beds of the Riding Mountain Formation were not encountered in any of the holes drilled around the lake. Water wells near the lake (Fig. 15, p.150) indicate that the Riding Mountain Formation is about 100 to 150 feet (30 to 45 m.) below Whitewater Lake (Manitoba Water Well Drillers' Records, 1963-1970). The occurrence of the Riding Mountain Formation at an elevation of 1,600 feet (490 m.) under Turtle Mountain in drill hole MNR-1 (Bannatyne, 1970) and at elevations around 1,580 feet (480 m.) near Boissevain (Elson and Halstead, 1949) suggests the presence of an erosional or structural basin under Whitewater Lake. This basin is indicated in Fig. 15, p. 150.

Elson and Halstead (1949) report that wells drilled into the Riding Mountain Shale may reach one of three aquifers: (1) the fractured upper beds, (2) an aquifer at an elevation of about 1,450 feet (440 m.) and (3) one yielding soft water at an elevation of about 1,250 feet (380 m.) above sea level. These aquifers are generally under sufficient hydraulic pressure to allow the water to rise within 20 to 50 feet (6 to 15 m.) of the ground surface. They yield moderate amounts of salty water.

The bedding and fissility of the shale suggest the horizontal component of hydraulic conductivity is greater than the vertical component. Secondary permeability resulting from joint and fracture zones is probably important in increasing the hydraulic conductivity particularly at the contact with overlying deposits. This has been suggested by Halstead (1959) and Schwartz (1970) in these areas.

Unit 2: Boissevain Formation

The Boissevain Formation was encountered in drill holes 17, 41 and 25. Drill hole 17 (Fig. 15, p. 150) penetrated 71 feet (22 m.) of orange-buff to olive brown (2.5Y4/4), locally calcareous, fine to coarse-grained bedded sands underlain by olive grey (5Y4/2) to dark grey (2.5Y3/2) calcareous, very fine-grained bedded sand containing lignite fragments and occasional well rounded grey siliceous shale pebbles. In drill hole 41, 12 feet (3.7 m.) of orange-buff sand was encountered underlain by 47 feet (14 m.) of interbedded fine-grained sand, silt and thin lignite seams. Below this the drill penetrated 11 feet (3.4 m.) of very hard, coarse-grained, laminated, cross-laminated, poorly sorted, calcareous, yellowish grey silty sandstone and conglomeratic sandstone. Much of the sandstone is weathered with yellow and white staining. The sandstone is composed mainly of quartz and chert grains, minor limestone grains and some highly spherical, well-rounded grey siliceous shale granules. Angular coal fragments up to 25 mm. in diameter occur within laminations.

This section is interpreted as being the lower part of the Boissevain Formation on the basis of lithology and stratigraphic position in the area. The poor sorting, cross-bedding and textural features of the sands suggest they are fluviatile in origin. The changes in lithology of the unit may represent a facies change near the base of the formation or there may be at least two different units present here. The lower portion of the formation may represent a distinctive older formation, or a transition zone between the Boissevain Formation and the Riding Mountain Formation. The occurrence of the weathered zone and the conglomeratic sandstone containing pebbles of Riding Mountain Shale suggests the presence of an unconformity.

The possibility of ice-thrusting during the Pleistocene causing the movement of bedrock blocks on the north flank of Turtle Mountain is a mechanism that could have produced stratigraphic complexities in the area. An outcrop near highway 3 in Tp. 3, R. 20, Section 6 exhibits contorted and slumped bedding. Beds of the Turtle Mountain Formation appear to have been thrust southward over beds of the Boissevain Formation with subsequent slumping of the Turtle Mountain Formation beds (Plate I, p. 197). Displacement is less than 10 feet (3 m.). The general distribution of such features in the area is not known. The Boissevain Formation at this locallity consists of 5 feet (1.5 m.) of brown to orange-buff medium to coarse-grained, thinly bedded, cross-bedded sandstone (Plate I, p. 197). The contact with the overlying Turtle Mountain Formation is irregular; a disconformity is apparent and a thin (50 mm.) gravel bed occurs discontinuously near the contact. Much of the sandstone is covered by a thin encrustation of salts (Plate I, p. 197).

A small number of wells drilled into the formation yield moderate to abundant supplies of clear iron-bearing water under artesian pressure (Elson and Halstead, 1949). The fine to coarse sandy texture and unconsolidated nature of the formation probably results in a high porosity and high intergranular permeability. Bedding causes the horizontal component of permeability to be greater than the vertical component. Large amounts of water were encountered during the drilling of the formation.

Unit 3: Turtle Mountain Formation

The Turtle Mountain Formation was not encountered in any of the drill holes near Whitewater Lake. The formation was observed in contact with the Boissevain Formation at the ice-thrust site mentioned above. At this locality 10 feet (3 m.) of interbedded grey shale and orange-buff fine-grained sandstone disconformably overlie the Boissevain Formation. The Turtle Mountain Formation has pronounced vertical fracturing and slumped bedding with beds slumping toward the north.

Wells drilled into the Turtle Mountain Formation yield moderate to abundant supplies of hard clear water on the Turtle Mountain Upland (Elson and Halstead, 1949). The outcrops of the Turtle Mountain beds form an excellent intake area for aquifers in the underlying formations (Halstead, 1959).

Variable texture and bedding planes probably causes the formation to have very heterogeneous permeability. Secondary permeability resulting from joint fracture zones is probably important throughout the formation. The horizontal bedding suggests the horizontal component of hydraulic conductivity is greater than the vertical component. Vertical fracturing would however increase the vertical component of hydraulic conductivity to some extent.

Unit 4: Glacial Till

Hard silty-sandy to sandy oxidized till was encountered in drill holes 30 and 36 at depths of 86 and 90 feet (26 and 27.5 m.) (Fig. 17, p. 152). In hole 30 the upper foot of till is weathered, streaked with carbonate and limonite, highly fractured and mantled by a 2 inch (5 cm.) crust of grey (2.5YN8), calcareous, laminated silty clay. The oxidized till varies from light olive brown (2.5Y5/6) to grey (2.5YN6). Dominant pebbles present are brown, black and tan chert and minor pink quartzite and limestone granules. Pebbles range in size from 6 to 12 mm.

in diameter. In hole 36 the till also contains gypsum crystals up to 4 mm. in diameter. Seive analysis indicates the till is made up of 25 to 40 percent sand and 60 to 75 percent silt and clay.

This till may correlate with the Shell Till recognized by Klassen (1969) near Roblin, Manitoba. The Shell Till was deposited by a west-flowing glacier in Pre-Wisconsin time and it may have a regional distribution (Klassen, 1969). The occurrence of abundant chert pebbles in the till suggests the till was derived from Tertiary deposits south and west of Whitewater Lake. The weathered zone at the top of the unit indicates deposition of the till was followed by an interglacial interval.

The hard compact nature of this deposit suggests that the till is highly impermeable. Fracturing within the weathered zone at the top of this till suggests that secondary permeability may be important in this zone. The limited thickness of this zone probably favours the movement of water horizontally rather than vertically.

Unit 5a: Sand

Laminated very fine-grained sand occurs interbedded with gravel (Unit 5b) and overlies glacial till (Unit 4) as shown in Fig. 17, p. 152. Twenty-five feet (7.6 m.) of sand was penetrated in drill hole 37 where the unit underlies Unit 5b. The sands are light grey (2.5YN4) to dark grey (2.5YN7) and are locally fossiliferous (unidentified calcareous bioclasts 0.5 to 1 mm. in diameter), micaceous and slightly calcareous. Fossil plant fragments and well rounded siliceous shale pebbles are occasionally present.

These sands probably represent an interglacial deposit. The laminated nature of the deposit suggests a lacustrine origin. The deposits may correlate with the Roaring River Clay deposits described by Klassen *et al*, (1967) along the Roaring River in the Duck Mountain Upland. These deposits are generally associated with large buried valleys (Klassen, 1969).

The fine-grained sandy texture of this deposit results in a high porosity but low permeability. The laminated nature of the deposit suggests that the horizontal component of permeability is greater than the vertical component.

Unit 5b: Gravel

A gravel composed mainly of soft fissile shale pebbles was encountered in a number of drill holes (Fig. 17, p. 152). The gravel overlies glacial till (Unit 4) in drill hole 36 and appears to have been deposited contemporaneously with Unit 5a. The gravel is generally dark grey in colour (2.5YN/2) although in drill hole 36 the shale pebbles were oxidized to a brown (2.4Y4/4) colour. Flat, soft, angular, well rounded, waxy shale pebbles occur in a silty or very fine-grained quartz sand matrix or without a matrix. The gravel is well sorted locally and appears bedded. Limestone and pink quartzite granules varying in size from 2 to 12 mm. in diameter occur randomly in the gravel. Minor greenish-white, soft, rounded bentonite particles up to 12 mm. in diameter were found in the unit in drill hole 34 at 55 feet (17 m.) below the surface. Gypsum rosettes up to 12 mm. in diameter and marcasite concretions 3 mm. in diameter were found in the gravel 50 feet (15 m.) below the surface in drill hole 35.

This unit probably represents an interglacial deposit. The distribution and thickness of the deposit along the northern slope of Turtle

Mountain suggests the gravel may have been deposited as alluvial fans (Fig. 17, p. 152). The nature of the shale pebbles and thickening of the gravel toward Turtle Mountain implies the gravel was derived from the interbedded Tertiary sands and shales of the Turtle Mountain and Boissevain Formations. These deposits may also be fluviatile and lacustrine in part. Well rounded shale pebbles and some good sorting suggest water working of the materials.

Intergranular permeability and high porosity are the most important hydraulic properties of this unit although they are probably variable depending on the absence or presence of the matrix of fine sand. Although bedding is not pronounced in the deposit the preferred orientation of the flat shale pebbles would result in a preferred component of permeability. Flat pebbles however would probably exhibit an imbricated fabric thus favouring the vertical movement of water.

Unit 6: Glacial Till

Silty-clayey till overlying Units 5a and 5b is extensively distributed throughout the Whitewater Lake basin (Fig. 14, p. 149). This till does not appear to occur above the 1,700 foot (520 m.) contour on Turtle Mountain. Up to 40 feet (12 m.) of hard, uniform, very dark grey brown (2.5YN3/2) till was encountered during drilling. The till is generally smooth textured, calcareous and clayey with only minor quartz, chert, limestone and shale granules. Faceted pebbles up to 25 mm. in diameter occur locally in gravelly portions of the till. The upper part of the till is well fractured with vertical fractures marked by iron and manganese staining. Small sand pockets of well sorted, clean, quartz and chert sand occur locally near the top of the till. Gypsum rosettes up to 50 mm. in diameter and marcasite concretions were also noted near the top of the till. The contact with the overlying till (Unit 8) is generally sharpe. Contact with underlying Units 5a and 5b appears disrupted and transitional with interbeds of the various materials occurring over a 10 foot (3 m.) interval.

Fracturing and staining near the top of the till suggest that deposition of the till was followed by an interglacial period. On the basis of colour, texture and oxide-stained fractures the till may correlate with the Minnedosa Till described by Klassen (1969) from a locality along the Minnedosa River Valley. The Minnedosa Till appears to have been deposited by a southwesterly flowing glacier during or prior to Early Wisconsin time.

The soft but clayey nature of this unit suggest that the till has a very low permeability. Vertical fracturing at the upper part of the till probably results in a secondary permeability in this zone. The narrowness of this zone would favour the horizontal component of permeability.

Unit 7: Sand

Ten feet (3 m.) of medium to very coarse-grained grey buff to olive brown (2.5Y4/4) quartz sand was encountered in drill hole 30, 25 feet (7.5 m.) below the ground surface overlying glacial till (Unit 6). The sand is thinly bedded and well sorted. Minor well rounded shale pebbles occur bedded in the sands.

The coarse texture, good sorting and limited extent of the deposit suggest it is fluviatile in origin. The deposit may represent an interglacial deposit or it may be contemporaneous with Unit 6. The deposit may mark the position of a buried river valley.

Porosity and permeability are probably relatively high because the deposit is medium to coarse-grained and unconsolidated. The horizontal component of permeability is probably greater than the vertical component because of the bedding.

Unit 8: Glacial Till

Sandy-silty to silty-sandy till is an extensive unit throughout the area (Fig. 14, p. 149). This till overlies clayey till (Unit 6) in the Whitewater Lake Basin and extends over the Turtle Mountain Upland. This unit corresponds to the ground moraine deposits of Elson (1962) shown in Fig. 9, p. 144. The till is generally olive brown (2.5Y4/4) in colour and well oxidized to depths up to 30 feet (9.2 m.) Particles of limestone, granite, chert and shale vary from sand size to 50 mm. in diameter. Coal fragments and disintegrated granitic pebbles are common. The till is very fractured. Gypsum crystals are common along the fracture surfaces.

This upper till may correlate with the Lennard Till described by Klassen (1969) near Lennard, Manitoba. The Lennard Till appears to have been deposited by the last continental glacier that flowed in a south-westerly direction during the Wisconsin advance (Klassen. 1969).

This unit yields small supplies of water within the upper 10 to 15 feet along the north slope of Turtle Mountain in the vicinity of Whitewater Lake (Halstead and Elson, 1949). Vertical fracturing in the unit probably causes the vertical permeability component to be greater than the horizontal component. The permeability of this unit is probably in the range 2×10^{-5} to 7×10^{-9} feet per second. This range was obtained by Hvorselv tests of glacial till in the Wilson Creek Watershed near McCreary, Manitoba by Schwartz (1970) and may be indicative of the tills at Whitewater Lake since the geological settings are similar.

Unit 9a: Sand

Fine, medium, coarse-grained sand and minor gravel overlie glacial till (Unit 8) in the vicinity of Whitewater Lake. These deposits correspond to the lacustrine sand described by Elson (1962) as shown in Fig. 9, p. 144. Water well records indicate the sands form an extensive deposit along the northern slope of Turtle Mountain and around the northeast corner of Whitewater Lake (Fig. 18, p. 153). Two shallow drill holes (Manitoba Water Resources Branch, 1971) indicate that the sands extend under the southwest end of Whitewater Lake. The distribution of the sands around Whitewater Lake suggests that the deposits underlie the southwest, southeast and northeast areas of the lake.

The sands vary in thickness from 1 to 15 feet (0.3 to 4.6 m.) and thicken toward Turtle Mountain (Fig. 19, p. 154). The upper surface of the sands along the northern slope of Turtle Mountain slopes toward Whitewater Lake. Northeast of the lake the sands form a mound. The sands appear continuous in part with the Boissevain Formation south of Whitewater Lake (Fig. 18, p. 153) and alluvium deposits particulary along creek valleys although the connection is not genetic.

The sands vary from dark grey (2.5YN4) to greyish brown (2.5Y5/2) and olive (5Y5/4) in colour. The sands are commonly laminated, well to poorly sorted. They grade laterally and vertically into laminated silt and clay. An average grain size analysis of 4 samples of the unit made by Manitoba Water Resources Branch (1971) indicates the sediment is made up of 72 percent sand, 26 percent silt and clay and 2 percent gravel. Sand ranged from 64 to 81 percent,silt and clay from 18 to 35 percent,gravel from 0 to 6 percent. The deposit is classified as sand according to the texture classification of Shepard (1954). Gypsum crystals commonly occur in the sands near the water table. The sands are saturated and yield moderate amounts of water. The permeability of the sand deposit is variable depending on the silt and clay content.

The laminations in the sands suggest a lacustrine origin. Elson (1958) states that a glacial lake existed in the Whitewater Lake Basin during the period of initial deglaciation of the area. The variable thickness and shape of the sand bodies along the south shore of Whitewater Lake (Fig. 16, p. 151) suggest the sands may be partly fluviatile. The relative position of the sands adjacent to and below the Boissevain Formation suggest the sands were derived from this formation and deposited as outwash fans and stream deposits during deglaciation of the area. Contours on the top surface of the sands (Fig. 18, p. 153) suggest the sands were deposited in stream valleys that flowed northward off the slopes of Turtle Mountain during the last glacial retreat. Present day streams have established themselves in approximately the same location. This implies that base level at that time was at a lower elevation than present base level. Paired terraces along the creeks south of Whitewater Lake (Elson, 1962) are evidence that these creeks occupy ancestral valleys. Quinn (1957) attributes river terracing and alluviation during the Pleistocene to arid-humid climatic cycles associated with glacial advances and retreats rather than tectonic or eustatic changes. Climatic fluctuations from wet and cool to warm and dry have been described for some Pleistocene sediments in southwestern Manitoba by Klassen et al (1967) on the basis of paleontological evidence.

The fine to coarse-grained texture and unconsolidated nature of this deposit results in high porosity and high permeability. The sands are confined, overlain by low permeability lacustrine clays and underlain by low permeability till. This probably causes preferred horizontal movement of water through this unit. Bedding of the sands also tends to favour the horizontal component of permeablity.

Unit 9b: Silt

Laminated, calcareous silt overlies the sand (Unit 9a) and glacial till (Unit 8) throughout the Whitewater Lake Basin (Fig. 14, p. 149). The unit varies from 1 to 10 feet (0.3 to 3 m.) in thickness and grades laterally and vertically into sand and clay. An average grain size analysis of four samples of the deposit indicates that the sediment is made up of 41 percent silt, 35 percent sand and 24 percent clay (Manitoba Water Resources Branch, 1971). Silt ranges from 33-51 percent, sand 27-48 percent and clay 11-40 percent. The deposit is termed a sandy silt according to the textural classification of Shepard (1954). The silts are pale olive (5Y6/3) to olive yellow (5Y6/6) in colour with dark greyish brown (2.5Y3/2) organic-rich laminations. Gastropod shells are common. White salts, gypsum crystals and elliptical calcareous concretions (6 to 12 mm. in diamater) appear concentrated above the water table in the silt unit. A white (2.5Y8/2) carbonate zone generally occurs above the water table in the silt zone.

Fine laminations, fossils, uniform thickness and the extensive distribution of the unit suggest that the deposit is lacustrine. The occurrence of lacustrine deposits at an elevation of 1,700 feet (520 m.) on Turtle Mountain and the distribution of the deposits toward the north imply deposition in a proglacial lake with the ice margin lying west and north of Whitewater Lake.

Unit 9c: Clay

Massive plastic very dark grey (5Y3/1) to olive brown (2.5Y4/4) clay occurs south of Whitewater Lake underlying sand (Unit 9a) and overlying glacial till (Unit 8). The clay breaks with a subconcoidal fracture and has the consistency of "gumbotil". The clay is commonly speckled with gypsum crystals.

The texture and homogeneity of the deposits suggest the clay is lacustrine. The limited distribution of the deposit in channels in the underlying till implies the unit may be partly fluviatile. Deposits of "gumbotil" in glaciated regions are generally developed under processes of chemical weathering which proceeds fastest under humid conditions (Quinn, 1957).

Since Units 9b and 9c are fine-grained and dense, the permeability of these units is probably very low. Local variations in grain size may increase the permeability. The lack of observable fractures excludes the possibiblity of major secondary permeability.

Unit 10: Sand and Gravel

Six feet (1.8 m.) of coarse-grained sand and gravel were encountered near the surface in drill hole 37 (Fig. 17, p. 151). The deposit is bedded and moderately well sorted. Pebbles up to 50 mm. in diameter are composed of quartz, limestone, granite and chert.

The sinuous morphology and variable texture of the deposit suggest it is an esker. These deposits were interpreted as beach ridges by Elson (1962) shown as such in Fig. 9, p. 144.

The sinuous shape of the deposit and limited thickness favour the horizontal movement of water in this unit. Coarse texture results in high porosity and high permeability.

Unit 11: Gravel

Two feet (0.7 m.) of well-sorted gravel was encountered near the surface in drill hole 20. The deposit contains well rounded uniform sized (4 to 6 mm. in diameter) pebbles of chert and limestone.

The deposit is interpreted to be alluvium of Recent age and occurs along an abandoned channel. This unit corresponds to the surface alluvium deposits (5a) of Elson (1962) shown in Fig. 9, p. 144.

The coarse texture and good sorting of this deposit results in high porosity and high permeability. The deposit however is small.

Lake Bottom Sediments

The bottom sediments of Whitewater Lake were examined to provide information on the hydrologic, geologic, biologic and related chemical processes acting on and within the lake. The nature, thickness and distribution of Recent bottom sediments reflect these processes in the lake system and aid the interpretation of the development of the lake since the deposition of the post-glacial lacustrine deposits (Unit 9).

Johnston (1934) described Whitewater Lake to be saline and noted that on evaporation during the dry season an encrustation of white salts is deposited on the shores of the lake and hence the name of the lake. Bossenmaier (1953) described the bottom of Whitewater Lake as consisting of heavy textured sediments, except for local areas of sand, gravel and widely scattered rock. He also noted the occurrence of salt deposits on the surface of wide mudflats in the eastern and western ends of the lake. Bossenmaier (1953); from Colls and Neufeld (1950) reports the encrustation of white salts on drying portions of the shore and on emergent vegetation to be those of calcium and magnesium. White salts were observed on emergent vegetation along the northshore of Whitewater Lake in September 1970 and these were identified by X-ray analysis to be mainly thenardite (anhydrous sodium sulphate; Na_2SO_4) some bloedite (hydrous magnesium sulphate; $MgSO_4.7H_2O$) and minor carbonate minerals.

Surface sampling and shallow cores (Fig. 20, p. 155) obtained of the bottom deposits indicate the Recent sediments have a maximum thickness of 18 inches (46 cm.) near the centre of the lake and are underlain by glacio-lacustrine clay, silt and sand (Unit 9). The Recent sediments are widespread and consist mainly of silty and clayey dark black, soft calcareous muds. During sampling the muds smell strongly of H_2S gas. When dry the sediments are medium grey and exhibit light and dark laminations. A 6 to 25 mm. flocculated, soft and slimy light buff oxidized layer occurs at the sediment-lake water interface. The muds consist mainly of silt and clay sized particles with minor sand and gravel fractions. Grain size analyses performed by the Manitoba Water Resources Branch (1971) on 7 sediment samples indicate silt size particles constitute 32 to 52 percent, clay size particles 34 to 50 percent and sand size 10 to 32 percent. Samples treated with dilute hydrochloric acid gave insoluable residues of 60 to 80 percent, indicative of the high carbonate content of the muds.

Granular (0.5 to 2 mm.) "nutty zones" 2 to 4 inches (50 to 100 mm.) in thickness occur within the muds. These granular particles are composed of well rounded silty shale fragments which resemble the shale gravel (Unit 5b) underlying the lake basin. Granitic and quartz pebbles are occasionally present in the sediments particularly near gravel deposits along the southwest and northwest shores of the lake.

Binocular examination revealed the main mineral constituent to be quartz in the silt and sand size fraction. Quartz grains generally are angular in shape exhibiting sharp edges and conchoidal fractures. Biological clasts observed include gastropod shells of Lymnacea sp. and Gyraulus sp., ostracod carapaces, plant remains (stems, seeds) of Scirpus sp. and Chenopodium sp. and egg cases of Daphnia sp. Substantial quantities of disintegrated calcareous clasts were observed in the finer fraction of the sediments.

Calcium carbonate encrusted pebbles and light grey laminations occur locally in the sediments on mudflats where algae mats are conspicuous. Sediment coatings were also observed on submergent vegetation in the lake. X-ray and Differential Thermal Analysis of the these coatings revealed the presence of a carbonate mineral and quartz.

Deposition of sodium and magnesium sulphate salts in the terrestrial nearshore zone of Whitewater Lake may be due to the evaporation of brackish lake water. The occurrence of these salts on emergent vegetation suggests the salts are derived from the groundwater regime via capillarity. This may be indicative of direct groundwater discharge or movement of lake water into the nearshore zones under the influence of transpiring phreatophytes. The magnesium, sodium and sulphate ions may come from the groundwater or lake water; both of these waters are enriched in these constituents.

The limited thickness and apparent uniform distribution of the sediments suggest that post-glacial deposition has been slow and uniform. The dark colours of the wet muds and the presence of H_2S gas suggest that reducing conditions are prevalent in the sediments. Predominance of silt and clay size fractions suggests deposition in a quiet environment with a limited sediment source. The major sediment source area is Turtle Mountain. Creeks deposit the bulk of their sediment loads as alluvial floodplain deposits south of the lake. Gradual northward expansion of these deposits, reworking by shoreline processes, wave action and incorporation of suspended sediment in the lake and subsequent deposition on settling probably represent the major detrital contributions to the lake bottom. Angular quartz grains suggest a near source which may be local glacial materials reworked by shoreline processes. Granular silty shale fragments in the lake sediments may be derived from the erosion of Unit 5b along the creek valleys to the south of the lake. Pebbles of granite and quartz in the lake sediments suggest the reworking of the shoreline "beach" and esker deposits (Unit 10). Much of the finer fractions may also be aeolian. The laminations of the deposits may reflect seasonal variations in sedimentation rates and availability of sediment. Coarser laminae may be deposited during the early summer under maximum wave conditions while the finer fraction is deposited under the ice during the winter months. Laminations may also reflect seasonal variations in the chemical precipitation of calcium carbonate. Sediment trapping by the muscilagenous thalli of algae and chemical precipitation of calcium carbonate appear to be important processes on mudflat areas and the nearshore zone. Submergent vegetation may also be important in trapping detrital grains stirred up by wave action and the precipitation of calcium carbonate as in the case of Chara sp. which is capable of precipitating calcium carbonate on its stem. Accumulations of calcareous bioclasts and plant fragments is also an important biosedimentological process operating in the lake, The high carbonate content of the bottom sediments may be attributed mainly to the deposition and disintegration of calcareous bioclasts. Organic accumulation and subsequent decomposition and the activity of anaerobic bacteria are probably responsible for the production of H_2S gas and reducing conditions in the muds. Calcium carbonate is also being precipitated from the lake water supersaturated with respect to calcite by non-biological processes. This is diccussed futher in Chapter IV.

Bedrock Topography

An interpretation of the bedrock topography in the area is shown in Fig. 21, p. 156. This interpretation is a modification from Klassen and Wyder (1970) and is based on water well records from Halstead and Elson (1949), Elson and Halstead (1949), Manitoba Water Well Drillers' Reports (1963-1970) and results of the 1971 drilling program at Whitewater Lake. Klassen and Wyder (1970) consider the bedrock topography to be primarily the result of Tertiary erosion and Pleistocene erosion. Kupsch (1964) suggests that bedrock surfaces and preglacial topography reflect bedrock structures in his studies in southern Saskatchewan.

Bedrock topography in the Whitewater Lake area indicates a bedrock upland 1,600 to 2,100 feet (490 to 640 m.) in elevation under most of the Turtle Mountain Upland. The bedrock surface slopes under the Boissevain Till Plain toward the north from 1,600 to 1,300 feet (490 to

400 m.). A trough-like depression underlies Whitewater Lake and extends in a northeasterly trending arc from Deloraine to Elgin Creek. A bedrock high at an elevation of 1,600 feet (490 m.) is located 5 miles (8 km.) north of Whitewater Lake.

A buried valley about 1 mile (1.6 km.) in width runs northward from Turtle Mountain east of Whitewater Lake (Klassen and Wyder, 1970). Elson (1958) mentions that Turtle Mountain was divided near the centre by a small preglacial valley which extended north to Whitewater Lake, east to Killarney and southeast across the International Border. Another buried valley appears to underlie the present position of Turtlehead Creek southwest of Whitewater Lake (Fig. 9, p. 144). These valleys probably join a major buried valley that appears to occupy the bedrock low under Whitewater Lake. This valley does not appear to extend much further west of Deloraine (R. Eilers, pers. comm., 1972). Work by Bamburak (pers. comm., 1972) indicates a major buried valley occuping the present position of Turtlehead Creek on the Turtle Mountain Upland. This large valley may be continuous with the valley through Whitewater Lake and would explain why this valley does not continue west of Deloraine.

Klassen and Wyder (1970) state that "Regional Tertiary drainage in the western Canadian plains was consequent, and flowed east and northeast toward Hudson Bay. Valleys, two to fifteen miles wide with gently sloping walls, formed a dendritic pattern on the underlying generally soft, homogeneous Cretaceous shales (Kupsch, 1964; Christiansen, 1962; and Stalker, 1961)". Preglacial drainage in the Whitewater Lake area appears to follow these patterns.

Preglacial-Glacial History of the Whitewater Lake Area

A portion of the preglacial-glacial history of the Whitewater Lake area is interpreted on the basis of the stratigraphic evidence obtained during the 1971 field season and reports by Elson (1958), Klassen (1969) and Klassen and Wyder (1970). Many of the concepts have been drawn from similar studies in North America such as Kupsch (1964), Meneley *et al*, (1957), Howard (1960) and Christiansen (1967).

During Tertiary-Early Pleistocene time a major preglacial river valley existed north of Turtle Mountain under the present location of Whitewater Lake. This valley was incised in the Cretaceous shales of the Riding Mountain Formation (Fig. 22-1, p. 157). Flow was toward the east and northeast. This valley may have been a southern tributary of the preglacial Pierson Valley or the Medora Valley described by Klassen and Wyder (1970). Smaller valleys tributary to this valley existed on Turtle Mountain and on the bedrock high to the northwest. Preglacial river valleys in western Canada generally had widths up to 6 miles (9.6 km.) and relatively gradual sloping sides (Klassen and Wyder, 1970)

The first record of glaciation appears to be during Pre-Wiconsinan time when glacial till (Unit 4) was deposited by a west-flowing glacier. Much of the till (Fig. 22-2, p. 157) was deeply weathered and removed by erosion during a subsequent interglacial interval.

A glacial lake formed in the area during the advance of the next continental glacier (Fig. 22-3, p.157). Gravels and sands derived from bedrock materials on Turtle Mountain and transported by streams were deposited in the fluviatile-lacustrine environment.

Glacial till (Unit 6) was then deposited throughout the area by a southwesterly flowing glacier during or prior to Early Wisconsinan time

(Fig. 22-4, p. 158). Deposition of the till was probably followed by an interglacial period. Sand deposits probably of fluviatile origin were deposited during the interglacial interval or contemporaneously with the recession of the glacier (Fig. 22-5, p. 158). The till may have been subject to erosion during this interglacial interval.

Glacial till (Unit 8) was deposited by the last continental glacier that flowed in a southwesterly direction during Wisconsinan time (Fig. 22-6, p. 158). After glaciation river valleys originating on the Turtle Mountain Upland incised the till along the north slope of the mountain. Deposits of clay and sand (Unit 9) were deposited along the river valleys. Later a small glacial lake formed in the Whitewater Lake Basin and discharged eastward past Killarney through the Pembina River (Elson, 1958). Extensive outwash deposits of sand and gravel were deposited along the north slope of the mountain. Further withdrawl of the ice margin caused Lake Souris then in existence in North Dakota (Elson, 1958); from Lemke, 1951) to expand into Manitoba west of Turtle Mountain and opened lower western outlets for the small glacial lake (Elson, 1958). The eastern outlet of this small lake was abandoned (Elson, 1958). Extensive deposits of lacustrine silt and clay were probably deposited during this stage of the glacial lake. Then as the ice receeded further north the small glacial lake became a non-glacial feature (Elson, 1958)

It appears that during part of the glacial and particularly during the interglacial intervals, rivers flowed off the northern slope of Turtle Mountain. These rivers supplied most of the sediment to the basin during interglacial intervals. Evidently glaciation only tended to modify the existing topography along the upland as river valleys established themselves in approximately the same locations as the ancestral valleys. Figure 23, p.159 , is a diagramatic east-west cross section showing the stratigraphy of a valley along the north slope of Turtle Mountain. This schematic section shows the probable relationship that exists between the bedrock geology and Pleistocene deposits across a valley near Whitewater Lake. Undoubtedly erosion during the interglacial intervals removed many of the units along these valleys. This is seen in Fig. 16, p. 151, where glacial till Units 6 and 8 are missing in drill hole 4.

Origin of the Whitewater Lake Basin

The Whitewater Lake Basin is underlain by a bedrock low which probably represents a collapse feature caused by solution of salt from the Devonian evaporite deposits and/or to a Pre-Jurassic erosion feature on the Mississippian "escarpment". Bedrock strata in the area suggest the collapse structure formed prior to or during deposition of the Mississippian beds. The collapse mechanism is however a continuous process and the solution of salt by groundwater is undoubtedly happening at the present time (Christiansen,1967). Brine springs high in sodium chloride, flowing from Devonian beds where they outcrop in eastern Manitoba suggest that the removal of salt by solution is still an active process (Baillie, 1953; van Everdingen, 1971).

Prior to glaciation a major river valley existed in the Whitewater Lake area. The position of this valley was probably controlled to some extent by the bedrock low.

Glaciation only modified the existing topography and the area became a site for thick accumulations of glacial till and stratified Pleistocene sediments. The drift thickness and topography of the surficial deposits in the area reflect the bedrock low. The presence of glacial lake sediments in the Whitewater Lake Basin implies the collapse structure formed prior to or during glaciation. Glacial loading probably increased the stress on the underlying bedrock formations. The increased stress may have accelerated the solution and migration of salts at depth. In this way the collapse mechanism was probably accelerated during the Pleistocene.

A combination of glacial and fluviatile processes resulted in the formation of the glacial lake stage of Whitewater Lake during Wisconsinan time. During deglaciation the lake became a non-glacial feature. Water inflow and sediment input were reduced, the outlet was abandoned and Whitewater Lake became a closed basin lake.

CHAPTER III

HYDROLOGIC ENVIRONMENT

Hydrologic Cycle

The idealized hydrologic cycle in the Whitewater Lake Basin is depicted diagrammatically in Fig. 24, p. 160. Major inflow components to Whitewater Lake are precipitation, surface water and groundwater seepage. There are no surface outlets from Whitewater Lake and the outflow components therefore include; evaporation, transpiration and groundwater seepage. An important part of the hydrologic cycle is the geochemical cycle. In the hydrologic cycle water undergoes definite chemical changes due to the geologic materials it comes into contact with, biological activity and climatic effects. The chemical composition and seasonal variations in the chemistry of Whitewater Lake are products of the chemistry of the inflow components, the outflow components and the effects of the geologic, biologic and climatic processes acting on the lake.

Hydrologic Components

Precipitation

A comparison of the seasonal precipitation (1971) at four meteorological stations near Whitewater Lake is given in Table 11, p. 205. Location of the stations is shown in Fig. 25, p. 161. Seasonal precipitation values from two stations on the west side of the lake are within 3 percent of their mean value. Values from two stations on the east side of the lake are within 18 percent of their mean value. The mean seasonal value for the stations west of the lake is 9 percent greater than the mean value for the stations east of the lake.

The 3 percent difference between the individual station values on the west side of the lake may be attributed to the location of the rain gauges with respect to windbreaks. Furguson and Storr (1969) report that the principle cause of undercatch is turbulence of the air stream over the guage oriface. From a study in the Streeter Basin of southern Alberta, Ferguson and Storr (1969) report that a standard rain guage measured 3 percent less rainfall than a pit guage at the same location. The 18 percent difference between the seasonal values on the east side of the lake may be attributied to local variability in rainfall. Preliminary results (Ferguson and Storr, 1969) from a flat prairie regime in the Bad Lake Basin in south central Saskatchewan indicate gradients of one-half inch per mile over a 3 month total rainfall period with an average of 3.62 inches (9.2 cm.). Measured amounts varied from 3.19 inches (8.1 cm.) to 4.19 inches (10.6 cm.) or up to 16 percent from the mean over an area of 8 square miles (20.4 km.^{2}) with 48 rain gauges on a square grid with a spacing of 1 mile (1.6 km.). Most of the 9 percent difference between stations east of the lake and those west of the lake is attributed to local variability in rainfall.

Variations in annual precipitation means on the Canadian prairies are relatively small. McKay reports that mean annual isohyets indicate that variations of more than 1 inch (2.5 cm.) per 100 miles (160 km.) are relatively uncommon (Ferguson and Storr, 1969; from McKay, 1965).

Precipitation records at Deloraine and Boissevain are both representative of the seasonal rainfall in the Whitewater Lake area (Fig. 26, p. 162). Although the region is subject to local variability in rainfall, precipitation is generally widespread and falls locally only when convective storms occur during the summer months. The major portion of the annual precipitation falls during the period April to August. Precipitation diminishes after July; August is usually a particularly dry month.

Evaporation

Although several methods are available for measuring evaporation (Kazmann, 1965; McKay and Stichling, 1961) the Class "A" pan was chosen because of its simplicity and because the increase in accuracy which could be estimated using more complex methods is not known. McKay and Stichling (1961) report that the Canadian prairies are climatologically dissimilar to the regions for which most evaporation equations and pan relationships have developed. Evaporation studies by McKay and Stichling (1961) in eastern Saskatchewan indicate that the various methods of determining evaporation show widely diverging results and that some methods are preferable to others. Adjusted Class "A" evaporation observations according to the methods of Kohler *et al* (1955) for example were 27 percent less than a water budget value (≃ true evaporation) for a reservoir in Saskatchewan (McKay and Stichling, 1961). Annual pan evaporation multiplied by a coefficient of between 0.7 and 0.8 will generally yield a reasonable first approximation of the evaporation from a nearby lake (Kazmann, 1965). These coefficients however vary from year to year, monthly and geographically, the variance depending largely on the length of the observation interval (McKay and Stichling, 1961). Many other variables affect evaporation from a lake including the manner and variation of the wind with height, temperature, and size of the lake, the roughness of the water surface, atmospheric stability, barometric pressure and the density and kinematic viscosity of the air. It is believed that Class "A" evaporation pans placed at reasonable proximity to Whitewater Lake are representative of lake evaporation within a seasonal error of ±30 percent. Larger errors would be expected for monthly evaporation values. Kazmann (1965) suggests the inherent error in an evaporation analog-prototype suudy is probably not less than 20 percent for large bodies of water. Ferguson *et al* (1970) report that pan data corrected in the standard method for energy transfer through the sides and bottom of the pan are probably representative of the monthly evaporation to within 15 to 20 percent. The pan method of estimating lake evaporation is largely dependent on the assumption that the lake is sufficiently shallow to enable heat storage effects to be neglected. Whitewater Lake has a maximum water depth of 4 to 5 feet (1.2 to 1.5 m.) and therefore is well suited for application of the pan estimation method.

Daily and monthly Class "A" pan evaporation at stations 1 and 2 are shown in Fig. 27, p. 163. A comparison of the pan evaporation at these two stations is given in Table 12, p. 206. Figure 27 indicates a general increase in pan evaporation from May through to the middle of September.

After September pan evaporation declines steadily. Maximum evaporation is observed during August. This behaviour appears to be controlled primarily by available energy. Seasonal evaporation at Whitewater Lake generally follows the evaporation trends outlined by Ferguson *et al* (1970) for the Prairie (Zone 4) climatic zone. This zone is characterized by a strong rise in evaporation from April to May, a leveling off and then a strong rise from June to a well-marked maximum in July, falling steadily thereafter. The drop in evaporation during June is attributed to the well-marked period of cloudiness and precipitation which occurs over the prairies in June. Kazmann (1965) reports that cyclical variability of annual evaporation can cause difficulties in model-prototype correlation. The annual seasonal change has one influence on the exposed evaporation pan and another on the nearby lake at the same time. The water surface temperature of a lake generally lags further behind that of the air as the depth of a lake increases and mean temperatures of deep prairie lakes tend to become equal to the mean air temperature in June, after which time the average temperature of the lake surface exceeds that of the air until freeze-up (McKay and Stichling, 1961). Evaporation losses from a large lake are probably greater than small reservoirs after June because of the difference in the vapor pressure deficit which is greater for large lakes (McKay and Stichling, 1961). They do point out however, that "if there is no energy advected into or out of a lake, and the mean water temperature exceeds that of the air because of the way in which energy is stored in the water, then a lake will lose more energy through radiation than if its temperature regime were identical to that of the air. It follows then that less energy is available for dissipation as sensible heat and evaporation, and that evaporation under these circumstances may be less". Although Whitewater Lake is shallow it is quite large and storage effects may affect evaporation during the fall. The net effect is that lake evaporation is probably somewhat higher than the corrected pan evaporation during the fall. Apart from this, lake evaporation during the summer months probably behaves similarly to the observed pan evaporation.

Generally pan evaporation on the east side of Whitewater Lake is higher than evaporation on the west side. This difference is as high as 25 percent for monthly intervals (Table 12, p. 206). The seasonal difference is only about 4 percent. Difference up to 25 percent may be attributed to variations in pan exposure with respect to Whitewater Lake. Mukammal (1961) reports that variations in pan exposure with respect to open water evaporation such as from a lake greatly affect the true pan coefficient, since wind has an appreciable effect on pan evaporation, and vapor potential differences are greatly influenced by the movement of air over moist land or open water surfaces. Since west winds are prevalent in the Whitewater Lake area evaporation at station 1 should be greater than station 2. Since this is not the case the difference is probably due to the proximity of the pans to the lake. Station 1 is located less than one-half mile (0.8 km.) from the lake while station 2 is about 3 miles (4.8 km.) east of the lake. Pan evaporation from station 1 being much closer to the lake is perhaps more indicative of the actual lake evaporation.

Using pan coefficients of 0.70 and 0.80, the apparent evaporation from Whitewater Lake during 1971 is 19.5 and 22.0 inches (49 to 56 cm.) respectively. The true evaporation value is very likely within this range. Compared to the seasonal precipitation mean of 15.9 inches this indicates a moisture deficit of 3.6 to 6.1 inches (9.2 to 15.5 cm.). These values are probably low and evaporation may be as much as 30 percent higher on the basis of results obtained from other prairie reservoirs. Mean monthly and annual lake evaporation maps prepared by the Department of Transport, Meteorological Branch (1971) based on Class "A" pan data from 1957 to 1966 and supplemented by other climatological data indicate that Whitewater Lake is situated in a region where the long term mean annual lake evaporation is in the order of 30 inches (76 cm.). The discrepancy between the 1971 evaporation figures compared to the long term mean may be due to an underestimate of pan coefficient for the 1971 period. Calculated pan coefficients greater than 0.80 may have been used in compilation of the long term mean value. The close proximity of the pan to the lake may also be responsible for the lower figures of 1971.

Transpiration

Extensive areas of emergent vegetation at Whitewater Lake can transpire large quantities of water. The hydrologic effects of these hydrophytes on a water body is twofold since hydrophytes also reduce evaporation by sheltering and shading effects (Eisenlohr, 1966). Transpiration varies with meteorological factors and occurs at different rates throughout the growing season, depending on the stage of growth. Since hydrophytes on the prairies are herbaceous plants they stop transpiring some time in the fall (Eisenlohr, 1966). On the basis of his studies on the effects on hydrophytes in prairie potholes in North Dakota, Eisenlohr (1966) concluded that the presence of hydrophytes reduces evaporation significantly and that the reduction may be offset by transpiration. The total water loss from a vegetation-filled pothole is generally about 10 percent more than a clear pothole (Eisenlohr, 1969)

Emergent vegetation at Whitewater Lake (1970-1971) was primarily distributed around the circumference of the lake. Submergent vegetation is distributed throughout the lake and this growth tends to reduce wave activity on the lake. In this way evaporation losses are probably reduced on windy days. The distribution of vegetation is not the same on an annual basis and appears to be related to water level fluctuations. Aerial photographs of the lake taken over a period of years show considerable difference in lake levels and the distribution of aquatic vegetation (B.Ransom, per. comm., 1971).

Since emergent vegetation occurs primarily around the sides of Whitewater Lake the plants probably transpire large quantities of water in the nearshore zone and their sheltering effect on the water body is minimal.

The approximations of lake evaporation in 1971 based on pan evaporation are minimum values in consideration of transpiration effects. A conservative estimate of seasonal evapotranspiration at Whitewater Lake may be about 10 percent higher. Coupled with other factors a seasonal evapotranspiration value 40 percent higher than corrected pan evaporation values is probably not unreasonable. An approximation of the 1971 seasonal evapotranspiration from Whitewater Lake may therefore be 27.3 to 30.8 inches (69.5 to 78.2 cm.) using pan coefficients between 0.70 and 0.80. Compared to the seasonal precipitation mean of 15.9 inches (40.4 cm.) this indicates a moisture deficit of 11.4 to 14.9 inches (29.0 to 39.8 cm.). Seasonal evaporation values of 27.3 to 30.8 inches compare favourably with the annual lake evaporation maps prepared by the Department of Transport (1970), although the maps do not include the effect of transpiration.

Surface Water

Surface inflow to Whitewater Lake is limited to numerous intermittent creeks which flow periodically off the north slope of Turtle Mountain. Generally these creeks do not flow directly into the lake but drain into swampland bordering the lake. Many of these streams have well developed valleys originating on the upper slopes of Turtle Mountain (Fig. 3, p. 138) while others appear to originate near the base of Turtle Mountain near elevations of 1,750 (535 m.). Bossenmaier (1953) reports that eight major creeks transport water from melting snows and heavy spring rains to the lake and that the creeks are dry by early summer. Occasionally the creeks may run until early fall or during the fall after being dry much of the summer (Bossenmaier, 1953). The basin lacks a surface outlet, except perhaps during times of extremely high water levels (Bossenmaier *et al*, 1954).

Hydrographs of Turtlehead Creek (Fig. 28, p.164) based on staff gauge measurements taken below the Deloraine reservoir may be indicative of streamflow conditions in many of the creeks south of Whitewater Lake. Hydrographs taken below the reservoir generally coincide,but are larger in magnitude, with hydrographs taken above the reservoir where natural flow conditions exist (Fig. 28, p.164).

The hydrographs of the daily discharge of Turtlehead Creek for the period 1969 through 1971 generally exhibit the same features. In 1969 high rates of flow during April occurred when precipitation was small (Fig. 26, p. 162). Streamflow diminished during May and June although large amounts of precipitation fell during this period. A slight flow peak then occurred during July corresponding with high rainfall. In 1970 a small flow peak occurred during April prior to any substantial rainfall that month. In late April flow quickly increased to over 100 c.f.s. (28 c.m.s.) in a few days and then gradually declined over a period of one month. By the end of June the creek had stopped flowing. In 1971 peak flow occurred during the first week in April although the first spring rainfalls occurred in late April and May. Streamflow then decreased during May when substantial amounts of rain fell and then peaked again during June and July. The latter peak occurred during a period of high rainfall.

During 1971 the creeks east of Turtlehead Creek flowed from early April until the middle of July and from late September until freeze-up. Turtlehead Creek was the major discharging creek although the creeks east of Turtlehead were observed to be flowing one week after Turtlehead Creek had stopped flowing in July. Peak flows of these creeks are probably similar to Turtlehead Creek (100-200 c.f.s.).

It appears that high flow rates on Turtlehead Creek during the period of April and May was related to spring snow melt and fall storage in the watershed rather than rainfall. Flow peaks during the summer and fall months are related to rainfall during those months. Reduced flow during periods of significant precipitation appears anomalous. High evaporation rates during these periods or reduced flow from the Deloraine reservoir may be responsible. Comparison of the 1971 hydrographs above the reservoir and below the reservoir indicates that flow below the reservoir was slightly higher than flow above the reservoir during May and July suggesting the reservoir did not reduce flow below the reservoir during that period. Flow below the reservoir during September and October was less than the flow above the reservoir suggesting the reservoir was responsible for reduced flow at that time. The effect of channel evaporation on flow rates is probably not significant.

A substantial portion of the streamflow during April and May may be due to base-flow. Reduced flow rates during periods of high precipitation may reflect reduced rates of base-flow contributions to the streams during these intervals. High base-flow peaks could lag behind periods of precipitation which would explain the out of phase relationship between streamflow and precipitation.

Springs occur at many places around the base of Turtle Mountain

(Johnston, 1934). Elson and Halstead (1949) report springs along a ravine where the Boissevain sandstone outcrops in Twp. 2, R.19, Section 35. Springs and seepages were observed along creek valleys near Whitewater Lake (Fig.13, p. 148) during the field work in 1971. Flow from these springs was small although base-flow to the creeks during the early spring months may be substantial. Springs occur near elevations of 1750 feet (535 m.) on the north slope of Turtle Mountain (R. Eilers, pers. comm., 1971). This is the same elevation where many of the smaller creeks appear to originate. Boissevain sandstone also underlies the Turtle Mountain Upland at this elevation (Fig. 10, p. 145). Springs probably result from lateral discharge of groundwater from the Boissevain Formation. Stratigraphy along the creek valleys indicates geological conditions are favourable for high levels of base-flow.

Groundwater

Water Table Observation Wells

Seasonal fluctuations of the water table in the vicinity of Whitewater Lake are shown in Fig. 29, p. 165 for the period 1969-1971. Water table levels are also shown in Table 13, p. 207. Generally the wells tend to behave in a similar manner throughout the year. A complete record available for wells 20, 21, 22, 24 and 25 during the period from February 1969 to May 1970 indicates the water table rose quickly in the early spring during March and April. After April the water table fell until the middle of June and then rose quickly until the middle of July. From July to March the water table fell slowly but steadily with only minor upward fluctuations during late September and October. The wells were not monitored during May 1970 to July 1971. During late 1971 the water table dropped over the period of August and September but rose during late September and October of that year. The water table at well 25 did exhibit some exceptions to the general trend; rising slowly during February to July 1969 and then dropping slowly until March 1970.

The similar behaviour of the observation wells shows that each of the wells may be indicative of the relative regional water table fluctuations in the area. Wells 20, 21, 22 and 24 located wast and southwest of Whitewater Lake indicate the water table follows the topographic slope from the Turtle Mountain Upland toward Whitewater Lake in this region. This indicates that groundwater generally flows from Turtle Mountain toward Whitewater Lake. The water table at well 39 north of Whitewater Lake reflects the topography in that area with inferred groundwater movement from the north toward Whitewater Lake.

A general rise in the water table during the months of March and April may reflect infiltrating contributions of snow melt, spring rains and delayed contributions of previous autumn rains to the water table. Comparison of water table levels and seasonal precipitation (Fig. 26, p. 162) indicates the drop in the water table during May and June is anomalous as large amounts of rain fell during those months. A rise in the water table during late June and July appears to coincide with large amounts of rainfall at that time. The decrease in water levels from late July to March 1970 corresponds to decreased precipitation during that interval while minor upward fluctuations in September and October reflect fall rains. Well 25 tends to reflect the fluctuations in seasonal precipitation more closely than the other wells; the water table rising from March to July during a time of increased precipitation and then falling from late July to March as precipitation declined. Generally the water table would be expected to lag behind in response to seasonal precipitation and water table fluctuations will not correlate precisely with rainfall and moreover, the same quantitiy of rain will not always produce the same change in water level (Kazmann, 1965). A time lag could explain the lowering of the water table during May and June when precipitation occurred. The initial rise in water levels in the spring may then reflect moisture storage from the previous year's autumn rains and snow melt reaching the water table. Spring rains in May and June may not recharge the water table until late June and July or later. The slow lowering of the water table after July may be due to natural groundwater discharge and evapotranspiration processes during a period of small amounts of precipitation. Seasonal fluctuations of well 25 are not as pronounced as the other wells suggesting the water table at this locality is maintained by discharging groundwater conditions. Well 25 is located in glacial sand (Unit 9a) while wells 20, 21 and 22 are located in glacial till (Unit 8). The high permeability of the glacial sand would make the well more sensitive to water table fluctuations caused by precipitation or discharging groundwater flow conditions. The time lag between rainfall and water table response would be relatively shorter and discharging groundwater flow conditions would result in a relatively constant water table.

A comparison of water table fluctuations and the discharge hydrograph of Turtlehead Creek during 1969 (Fig. 28, p. 164) indicates a similar behaviour. A rising water table in the early spring corresponds to increased creek discharge. Decline in the water table during late April to June coincides with a decrease in stream discharge at that time and a small peak in the creek discharge at the same time.

At least four processes could explain the seasonal corresponding behaviour of the creek hydrographs and the water table: (1) both fluctuations are caused by short-term seasonal precipitation effects, (2) the creeks are influent streams which tend to recharge the water table during periods of runoff, (3) the creeks are effluent streams which discharge during periods of a rising water table, (4) both fluctuations are caused by natural groundwater flow conditions related to long-term precipitation trends and geohydrological and topographical controls. An evaluation of these relationships is discussed later under the section dealing with creek chemistry in Chapter IV.

Piezometers

Piezometer levels in the Whitewater Lake Basin in 1971 are shown in Table 14, p. 211. Piezometer hydrographs (Fig. 30, p. 166) generally indicate the same relative response after installation. Piezometer levels dropped after installation until September after which time they rose. Apart from evident lowering after bailing and sampling most of the piezometers had reached equilibrium within 2 months after installation. Piezometers which did not follow the general trend were: piezometer 28 which was dry for at least 3 months after installation but showed some response by November, piezometer 7 and 8 which dropped drastically during October but regained in November and piezometers 26 and 27 which dropped steadily during the season. No attempt has been made to explain the natural seasonal fluctuations in piezometer levels. Eilers (1972) employing piezometers of the same design in the Deloraine area has noted seasonal fluctuations in piezometer levels over a period of 2 years. The potentiometric data obtained in the Whitewater Lake area during the period of July to December 1971 is therefore not representative of the long-term hydrologic conditions. The data may be indicative of general groundwater movement in the area during the monitoring period.

Piezometer nests (7,8), (12,13), (17,18,19), (20,21,22),((28,29) and (40,41) exhibited recharging groundwater conditions characterized by downward increasing hydraulic gradients. Discharging groundwater conditions characterized by upward increasing hydraulic gradients were prevalent at nest (30,31) and (37,38). Nests (14,15,16) and (25,26,27) exhibited slight upward gradients below the 30 foot (9.8 m.) depth and downward gradients above this depth. Nest (10,11) exhibited slight discharging conditions during the period July and August and then recharging conditions until November.

Flow Patterns

Hydraulic head measurements obtained on August 13, were plotted on the north-south cross section B-B' to delineate the groundwater flow system south of Whitewater Lake (Fig. 31, p. 167). Piezometer data obtained September 9 were plotted on the west-east stratigraphic cross sections C-C' (Fig. 32, p. 168) and D-D' (Fig. 33, p. 169) north and south of Whitewater Lake respectively. Data obtained on these dates were used because of completeness and because the observations were representative of the hydrologic conditions during the period August to November. All the hydrostratigraphic units were considered to be isotropic and equipotential lines were constructed to fit piezometer data and to be consistent with relative changes in permeability of the units. Groundwater flow directions were adjusted according to the procedure outlined by van Everdingen (1963) for the effect of vertical exaggeration in the cross sections.

The groundwater flow pattern shown in Fig. 31, p. 167 is highly generalized due to the lack of piezometer control at site 24 and at depths below 90 feet (30 m.). The pattern serves as a general indication of the groundwater movement normal to the water table gradient within the upper 50 feet (17 m.) of the deposits south of Whitewater Lake. The flow patterns shown in Figs. 32 and 33 on pages 168 and 169 show generalized lateral and vertical groundwater movement in the upper 70 feet (23 m.) of the deposits north and south of the lake respectively. Complex stratigraphic relationships and anisotropy of the geohydrologic units allow for only a generalized concept of the groundwater movement in the area.

The groundwater flow pattern shown in the north-south cross section B-B' indicates a downward and lateral movement in water through the system from the Turtle Mountain Upland toward Whitewater Lake. Recharge occurs on the Turtle Mountain Upland and water moves downward and laterally through the Boissevain Formation. At the contact between the Boissevain Formation and the overlapping deposits to the north the change in permeability from a relative high range to a lower range results in the vertical dispersal of water at this locality. Groundwater discharge probably occurs in this zone. Saline soils occurring at the surface in this area (Eilers, 1972) suggest the upward movement of water and removal of water from the system by evaporation and transpiration processes. Outwash sand and gravel deposits (Unit 9a) continuous with and downslope from the Boissevain Formation may channel water away from the formation into shallow deposits around and under Whitewater Lake. The wedging and thinning of these deposits toward the lake probably result in the upward and downward movement of water from these sands into overlying lacustrine clay deposits (Unit 9b) and underlying glacial till (Unit 8) respectively. This local stratigraphic control appears to be one of the principle causes of the formation of saline soils in the area (Eilers, 1972). Water may also be channeled downslope along the fractured contact between glacial till Units 6 and 8. Highly permeable glacial sand (Unit 7) also occurs locally between these two till units. Paleotopographic features in the form of subsurface irregularities along this contact zone may cause the upward movement of water resulting in groundwater discharge areas. Water movement in glacial till Units 8 and 6 appears to be downward and laterally toward the north. The apparent wedging of gravel Unit 5b downslope from the Boissevain Formation and thinning of the unit under Whitewater Lake may result in channeling water away from the Boissevain Formation toward the north. Rapid thinning and the imbricated fabric of the deposit may result in the upward and downward movement of water from the highly permeable portions of the unit into the overlying glacial till and underlying deposits. Water movement in the shale of the Riding Mountain Formation was not interpreted due to the lack of piezometer data.

The groundwater flow pattern in the west-east cross section C-C' south of Whitewater Lake indicates a general downward movement of water through the system with flow concentrated toward regions where the glacial deposits are the thickest. These areas correspond with the positions of the buried valleys on Turtle Mountain. Stratigraphy exercises important control on groundwater movement as equipotential lines tend to parallel geologic contacts. Groundwater movement in individual units is only inferred due to the lack of piezometric control.

The groundwater flow pattern on the east-west cross section D-D' north of Whitewater Lake indicates the general downward movement of water in the upper 30 to 40 feet (9 to 12 m.) of the deposits. Upward flow appears to be prevalent below 30 to 40 feet. The zone of demarcation corresponds to the contact between glacial tills Units 8 and 6. In drill hole 30, 10 feet (3 m.) of highly permeable glacial sand occurs between the two tills. Upward flow in this region may be due to the presence of gravel Unit 5a which underlies the area. The high permeability of this unit, its continuity with the Boissevain Formation and its confined nature between glacial tills Units 6 and 4 allows this unit to channel water from the Boissevain Formation. Rapid thinning of this unit under Whitewater Lake probably results in the upward and downward movement of water in this region. Upward flow does not appear to extend into the glacial till Unit 8 but is probably dissipated as lateral flow along the contact zone between Units 8 and 6. Fracturing and the occurrence of highly permeable sands locally along this contact would favour the lateral movement of water along this zone.

Piezometric Surfaces

Piezometeric surface maps were prepared for arbitrary depth ranges to indicate the areal movement of groundwater in the Whitewater Lake Basin. Three depth ranges were chosen, 15-30 feet, 30-45 feet and 50-80 feet, on the basis of available piezometric data obtained September 9, 1971. Hydraulic head values in these depth ranges probably do not vary graatly and are representative within the overall stratigraphy of the deposits overlying bedrock. Piezometer surfaces for these depth ranges are shown in Fig. 34, p. 170.

The piezometeric surfaces for the three depth ranges considered are very similar indicating that the hydraulic head does not vary greatly with depth and the regional piezometric surface dips under Whitewater Lake. Although there is no piezometric data available under the lake the distribution of hydraulic head around the lake suggests the lake is underlain by a piezometric low rather than a piezometric mound. Areally groundwater flow is directed toward the centre of the lake basin from the Turtle Mountain Upland and the region northeast of the lake.

The piezometric low under Whitewater Lake is probably the result of hydrological conditions related to the low bedrock surface under the lake and the permeablity of the deposits overlying bedrock in this area. If bedrock topography and stratigraphy of the overlying deposits are controlling factors of groundwater flow then the major areas of groundwater inflow are probably southwest and southeast of the lake (Fig. 35, p. 171). These regions are underlain at shallow depth by highly permeable sands and gravel (Unit 9) which are in part continuous with the Boissevain Formation. These deposits may channel water away from the Boissevain Formation downslope along buried stream valleys and buried outwash fans. Similarly the region northeast of the lake may be a major outlet as this area lies in the thalweg of a buried valley and is underlain by highly permeable sands 25 feet (7.5 m.) below the ground surface. The shallow deposits in this region appear to be more important in directing groundwater toward the centre of the basin since the deposits slope toward the lake (Fig. 18, p. 153). However, the distribution of the deposits toward the west may be such that these sands are channeling water away from the lake toward the north.

Recharge and Discharge Areas

Analysis of shallow groundwater potentiometric data indicates recharging conditions are prevalent throughout the region. The major recharge area appears to be the Turtle Mountain Upland. The only discharge area monitored occurs under the northwest portion of the lake associated with the thinning of the shale gravel deposit (Unit 5b).

Geohydrologic conditions suggest discharge areas may also occur in zones marked by the subcrop of the Boissevain Formation, the Riding Mountain Formation and glacial sand and gravel deposits (Unit 9). Complex stratigraphic relationships including subsurface irregularities may result in additional discharge areas. These conditions contribute to the formation of saline soils in the Whitewater Lake area (Eilers, 1972). Saline soil conditions (Eilers, 1972) are perhaps the best indication of the extent of these discharge areas.

The occurrence of gypsum rosettes and marcasite concretions in the shale gravel (Unit 5b) at depths of 50 feet (15.0 m.) and near the top of glacial till Unit 6 suggests discharging groundwater conditions have characterized the basin in the past. Paleotopography and geologic conditions during the interglacial intervals were probably favourable for groundwater discharge in the basin.

Lake Water

Lake Levels

Lake levels obtained from staff gauge measurements at Whitewater Lake in 1970 and 1971 are shown in Table 15, p. 213. Daily water levels obtained from a recording gauge in 1970 and 1971 are shown in Table 16 and 17, pp 214 and 215. Lake level hydrographs for 1970 to 1971 are shown in Fig. 36, p. 172.

In 1971 lake level rose steadily after spring breakup to maxiumum levels in late July and then dropped steadily until the end of August.

After August lake level remained steady with slight fluctuations until freeze-up in early November. The maximum seasonal change in lake level during the period of no surface runoff was -1.1 feet (-33.8 cm.). In 1971 lake level exhibited a steady rise after breakup until late June and then a steady lowering to the end of August. After August the lake level remained relatively constant with minor fluctuations showing a slight upward trend during October until freeze up in late October. Maximum seasonal change in lake level in 1971 during the period of negligible surface runoff was -0.8 feet (-24.3 cm.).

The lake hydrographs of 1970 and 1971 generally have the same seasonal fluctuations. The rise in lake levels during May and June corre responds with flow from the creeks south of the lake (Fig. 28, p. 164). There appears to be no obvious direct correlation between periods of rainfall and rising lake levels. This may be due to the high evaporation rates during the spring. The steady lowering of lake levels in July and August appears to be related to the high evaporation rates, low precipitation and no surface runoff from the creeks during this time. Flow from creeks during July 1971 does not appear to affect lake level appreciably. The constant lake level prior to freeze up is probably due to decreased rates of evaporation, increased precipitation and small amounts of surface runoff. For the period June to October 1970, with no active surface runoff, lake level dropped about 1.0 feet (30.5 cm.) while lake evaporation less rainfall was 2.0 feet (61.0 cm.). In 1971 during the period of no active surface runoff from July to November, lake level dropped about 0.5 feet (15.3 cm.) while lake evaporation less rainfall was 0.7 feet (21.6 cm.).

Lake evaporation figures for 1970 and 1971 were determined from Class "A" evaporation pan data and represent minimum losses considering probable errors in determining lake evaporation and since the total evapotranspiration was not computed. The discrepancy between lake level changes and minimum evaporation losses implies that additional quantities of water must have been entering the lake to maintain lake levels. The most reasonable source of additional quantities of water would be groundwater inflow. This is discussed further in Chapters IV and V.

CHAPTER IV

HYDROCHEMICAL ENVIRONMENT

Chemical Composition of Precipitation

Major-ion Chemistry

Precipitation samples collected in 1971 contained both wet and dry fallout and are only a general indication of the ionic levels present in the precipitation. These are shown in Table 18, p. 216. The samples are a good indication of the total atmospheric input to Whitewater Lake. Table 19, p. 220 is a summary of the chemical analyses of the rain samples. Samples exhibiting low conductivities (Fig. 37, p. 173) probably contain a smaller component of dry fallout than the samples having higher conductivities. Moreover the samples having low conductivity values may be more representative of the composition of the wet fall component. Electrolytic conductivity values of the rain samples ranged from 6.6 to 388 micromhos.cm.$^{-1}$ (Table 19, p. 220). Mean conductivity of the samples collected at stations 1 and 2 was 25.7 and 62.6 micromhos.cm.$^{-1}$ respectively.

Table 19, p.220 indicates that calcium is the dominant cation present in the rain samples followed by sodium, magnesium and potassium (mg./liter). Sodium is the dominant cation in the snow sample (Table 18, p. 216) followed by magnesium, calcium and potassium. Schwartz (1970) reported maximum values of 2.46 Na$^+$, 1.5 Ca^{2+}, 1.49 K$^+$ and 0.45 Mg^{2+} in mg./liter, with total dissolved solids less than 15 mg./liter for three rain samples collected in the Wilson Creek watershed of western Manitoba. Armstrong and Schindler (1971) have reported average analyses of rain and snow samples collected in the "Experimental Lakes Area" of northwestern Ontario during 1968-70. They report an average analysis of 2 rain samples as 0.22 Na^+, 0.10 Mg^{2+}, <0.10 Ca^{2+}, 0.09 K^+ and an average analysis of 8 snow samples as 0.26 Ca^{2+}, 0.20 Na^{2+}, 0.10 K^+ and 0.04 Mg^{2+} in mg./liter. Rutherford (1967) observed somewhat higher values of sodium in snow samples as compared to rain samples in southeastern Ontario. Mean values in mg./liter of chemical analyses of precipitation in southeastern Ontario (Rutherford, 1967) indicate that the rain is composed of SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+} and K^+ in order of abundance while snow is composed of HCO_3^-, SO_2^{2-}, Ca^{2+}, Na^+ and Mg^{2+}. Zverev (1963) reports that the mean chemical composition of rain falling in the Medvenka Basin, USSR., as being composed of HCO_3^-, SO_4^{2-}, Ca^{2+}, Mg^{2+} and Na^+ in order of abundance. Zverev (1963) reports precipitation falling in the form of rain being a sulphate-bicarbonate-magnesium type while that falling in the form of snow is the bicarbonate-sulphate-sodium type. Considerable variability in the relative cation abundances of precipitation samples collected from the localities mentioned above suggests the major cation composition of precipitation is controlled by local conditions. Precipitation near Whitewater Lake appears to contain a higher proportion of Na^+ in the rain samples as compared to the localities in Ontario and the USSR. Rutherford considered the Na^+ values in the rainfall in southeastern Ontario to be rather high and concluded that contributing factors other than sea water must be sought.

Rain samples were divided into three arbitrary groups according to their conductivities which are a direct indication of the total dissolved solids present in each sample. The percentage of each cation in each sample was plotted in Fig. 37, p. 173 using the sum of the cations in equivalents per million as the 100 percent base.

Figure 37, p. 173 indicates that the samples of low conductivity at Whitewater Lake differ very little from the samples of higher conductivity in their chemical character. Mg^{2+} ion for example consistently constitutes between 20 and 40 percent of the total cations. Na^+ and K^+ appear widespread in all the samples and Ca^{2+} shows considerable variability although Ca^{2+} does appear limited within 20 and 40 percent on the samples exhibiting highest conductivity values. Very low sodium concentrations appear associated with the samples having low conductivities.

The distribution of the cations in the rain samples from the Whitewater Lake area suggests that wet fallout is composed of Ca^{2+}, Mg^{2+}, Na^+ and K^+ in order of abundance in mg./liter. Dry fallout tends to enrich the samples in Na^+ and samples containing a substantial dry fallout component are composed of Na^+, Ca^{2+}, Mg^{2+} and K^+ in order of abundance. Consistent values of Mg^{2+} and particularly Ca^{2+} in the higher conductivity samples suggest that these ions are the contributions of the dry fallout component.

Soil dust is probably the principle cause of the observed sodium, calcium and magnesium concentrations although minor amounts of these ions are undoubtedly of celestial origin. Potassium may be of celestial origin as samples exhibiting low conductivities contain higher proportions of K^+ ions (Table 18, p. 216). Strong winds, aridity and lack of protective vegetation in the region probably results in much of the precipitation constituents being derived from soil dust. The celestial components appear to be masked by the dry fallout components. Rutherford (1967) attributed the observed concentrations of Ca^{2+} and K^+ in the rain samples of southeastern Ontario to terrestrial origin. He also reported the geographical uniformity for values of dissolved magnesium and attributed the origin to soil dust.

Sulphate concentrations appear consistent except for periodic high values associated with high conductivity values. The SO_4^{2-} content of the snow sample is somewhat high relative to rain samples exhibiting the same concuctivity. Higher sulphate values in snow samples are reported by Rutherford (1967). Rutherford (1967); from Gambell and Fisher (1966) reports that sulphate may be derived from SO_2 by oxidation and that long periods of atmospheric stagnation during the winter months causes significant concentrations of SO_2 to accumulate. Rutherford (1967) suggests that the high sulphate content in snow in southeastern Ontario may be caused by the increased use of fuel oil furnaces in winter for heating homes and factories, during a time of year when atmospheric conditions are relatively quiet. High concentrations of SO_4^{2-} at Whitewater Lake correspond with high concentrations of Na^+ and probably owe their origin to soil dust. Sodium sulphate salts are present and widespread in the saline soils of southwestern Manitoba (Pratt and Ellis, 1954). Witkind (1959) reports that sodium sulphate salts derived from deposits near saline lakes in Montana and North Dakota are dispersed over the environs by wind.

Although HCO_3^- and Cl^- ions were not analyzed, the balance of the sum of the cations against the sum of the anions for each sample indicates that these ions constitute about 50 percent of the anion concentrations. HCO_3^- concentrations are probably in the order of magnitude of the SO_4^{2-} while Cl^- is less important. Molar concentrations therefore indicate that rain samples near Whitewater Lake are of the calcium-magnesium-bicarbonate type. The one snow sample analyzed is of the sodium-magnesium-sulphate type.

pH

The pH of a number of rain samples varied from 5.36 to 6.94 (Table 18, p. 216). Although pH of the samples was determined up to 6 days after sampling the values are probably representative. Zverev (1963) reports pH values of 5.5 to 6.0 for summer rains in the Medvenka River Basin, USSR. A pH of 5.7 would be expected at 25°C. under equilibrium conditions between rain water and the carbon dioxide pressure of the atmosphere (Barrett and Brodin 1955; Carroll, 1970). Samples exhibiting pH values much greater than 5.6 appear enriched in Ca^{2+} and Mg^{2+} probably due to the dissolution of carbonate minerals. Dissolution of carbonate minerals would result in an increase in the pH of the waters. These samples also exhibit higher conductivity values (Table 18, p. 216) which would be expected.

Seasonal Variations

Although precipitation samples are only a general indication of the ionic levels present they may be used for comparison purposes. Seasonal variations in the chemistry of the rain samples at stations 1 and 2 are shown in Fig. 38, p. 174. Samples obtained during the month of September at station 1 were not analyzed.

Electolytic conductivities of samples from station 2 are generally higher than the samples from station 1. Samples obtained at each of the stations on the same day behave similarly with high conductivity values at station 1 corresponding to high values at station 2. Cation concentrations at the stations behave in the same manner with minor exceptions. There also appears to be a general decrease in the cation concentrations during the summer although K^+ does not appear to follow this trend.

Similarities in electrolytic conductivity and cation concentrations at both stations indicate there is little regional variation in the composition of the precipitation. Higher concentrations on the east side of the lake suggest local conditions are responsible. Rain showers generally move from west to east under the influence of prevailing west winds. As showers move over Whitewater Lake evaporation from the lake may contribute small amounts of ionic constituents to the atmosphere. Tarasov (1967) reports salt losses from Lake Balkash via mechanical evaporation and subsequent high salinity values, up to 400 mg./liter, of precipitation in the Balkash area. Higher concentrations east of Whitewater Lake suggest salts and moisture are probably attained locally through evaporation and deposited locally through precipitation. This also implies that Whitewater Lake is responsible for local climatological variations in the area. Higher levels of dust contamination or contamination through handling of rain samples at station 2 may be contributing factors but are probably not responsible for the seasonal trend. The general decrease in the cation concentrations during the summer may be attributed to an increase in protective vegetation, a moderation of winds and the subsequent reduction of dry fallout from the soil dust. Zverev (1963) reports that the chemical content and mineralization of atmospheric precipitation in the Medvenka Basin, USSR. depends on the season of the year and on the physical state of the precipitation. The high values reported in early spring rains at Whitewater Lake may be attributed to strong spring winds, lack of protective vegetation and cultivation of farmland. High values in late August and early September may reflect harvesting operations in the area and the subsequent increase of soil dust to the atmosphere. The consistent trend of potassium through the summer may indicate that potassium is of celestial origin.

Oxygen^{18} Composition of Precipitation

The snow sample taken in March 1971 and rain samples taken in 1971 (Table 20, p. 221) exhibit a wide range of δO^{18} values from -5.2 to -19.8 SMOW. Rain samples generally exhibit decreasing δO^{18} values during the summer. The snow sample is isotropically light, enriched in the lighter isotope O^{16}.

The δO^{18} values compare with values characteristic of rain and snow reported by Epstein and Maydeda (1953). The O^{18}/O^{16} ratio of rain and snow can acquire a wide range of values (Dansgaard, 1953). Snow samples would be expected to be more negative than rain samples although this condition may be variable depending upon climatological factors. Epstein (1957) observed that variations in O^{18}/ O^{16} of rain and snow closely parallel variations in atmospheric temperature with precipitation being isotropically lighter during the colder months. The apparent decrease in δO^{18} values during the summer months ar Whitewater Lake suggests atmospheric temperature is not the controlling factor since an increase in δO^{18} would be expected with increasing temperatures. Other factors such as source of the moisture and conditions of precipitation formation (Dincer, 1968) must be important.

Chemical Composition of Surface Water

Major-ion Chemistry

Chemical analyses of creek samples collected near Whitewater Lake in 1971 are shown in Table 21, p. 222. A summary of the chemical analyses is shown in Table 22, p. 227.

The summary of chemical analyses of creek samples from selected sites in 1971 indicates that the average composition of individual creeks differs. Average creek chemistry ranges from the magnesium-clacium to calcium-magnesium-bicarbonate type (site 1), the magnesium- calcium or clacium-magnesium-sulphate type (Sites 2, 4 and 8) to the sodium-magnesium or sodium-calcium-sulphate type (sites 3, 6 and 5). Average creek conductivities range from 720 to 1660 micromhos.cm.$^{-1}$.

A representative selection of creek samples were plotted on a Piper trilinear diagram (Fig. 39, p. 175) to show the chemical characteristics of the creek samples according to the relative concentrations of the constituents. Cations and anions were plotted as a percentage of their individual totals in equivalents per million.

The Piper trilinear diagram (Fig. 39, p. 175) indicates that the creek samples generally exhibit a consistent chemical composition within certain limits. Ca^{2+}, Mg^{2+} and Na^{+} constitute from 20 to 60 percent of the cations and plot in a distinctive triangular field. HCO_3^- and SO_4^{2-} exhibit a wide range and vary from 10 to 70 and 35 to 90 percent of the anions respectively. Cl^- is consistently low, less than 3 percent of the anions. The distribution of the creek samples in the Piper trilinear diagram indicates that many of the samples may be mixtures of two chemically distinct waters; a calcium bicarbonate type and a sodium sulphate type.

High electrolytic conductivity values up to 2860 micromhos.$cm.^{-1}$ of the creek samples implies that surface runoff resulting from rain and snowmelt would have to acquire substantial quantities of dissolved solids very quickly to account for the high chemical concentrations. An average chemical analysis of 10 samples from site 3 for example indicates ionic concentrations of 227 Na^+, 143 Ca^{2+}, 89.5 Mg^{2+}, 12.5 K^+, 888 SO_4^{2-}, 316 HCO_3^- and 12.9 Cl^- in mg./liter., with average conductivity of 1659 micromhos.$cm.^{-1}$. Rain with a pH near 5.7 falling on the region is capable of dissolving small quantities of carbonate minerals very quickly. Under equilibrium conditions with atmospheric CO_2 at $1\times10^{-3.5}$ atm. and 5°C. the dissolution of calcite in water results in concentrations of 30 mg./1. of Ca^{2+} and 90 mg./1. of HCO_3^- while dolomite dissolution produces 125 mg./1. of HCO_3^-, 21 mg./1. of Ca^{2+} and 12 mg./1. of Mg^{2+} (Cherry *et al*, 1971). Greater quantities of these ions may be dissolved in the soil zone when infiltrating waters attain equilibrium with carbonate minerals at higher CO_2 pressures. Elevated CO_2 pressures in the soil zone may be produced by decaying organic matter and root respiration (Baver, 1963). Soils on the north slope of Turtle Mountain are well leached, well drained and not salinized. They probably contribute substantial amounts of Ca^{2+}, Mg^{2+} and HCO_3^- to infiltrating precipitation. Infiltration and quick interflow to the creeks would explain the observed Ca^{2+} and HCO_3^- concentrations in the creek samples but would not account for high concentrations of the other ions particularly Na^+ and SO_4^{2-} as soluable sodium sulphate salts do not occur in appreciable amounts in the soils on Turtle Mountain. However, relatively high concentrations of Na^+, Mg^{2+} and SO_4^{2-} are reported to be characteristic of the groundwaters in the region (Johnston, 1934; Halstead and Elson, 1949; Halstead, 1959 and Eilers, 1972). This is also discussed later in this chapter in the section dealing with groundwater chemistry. A large groundwater component could therefore explain the relatively high ion concentrations of the creeks.

pH

Creek pH values determined in the field varied from 8.00 to 8.46. Laboratory pH values exhibited a range of values from 7.45 to 8.62. A comparison of field and laboratory pH values for the same samples indicates that the laboratory values are probably within 0.5 pH units of the field values.

Ca^{2+}, Mg^{2+}, HCO_3^- and field pH data were plotted on calcite and dolomite dissolution diagrams (Fig.40, p. 176) based on Langmuir's (1971) equilibrium constants. The equilibrium diagrams are those constructed by Cherry (1971) for the dissolution of pure calcite, pure dolomite and sequential dissolution based on the assumption that calcite dissolves to equilibrium before dolomite is introduced to the system at $5^{\circ}C$. Areas above the equilibrium lines indicate supersaturation while areas below the lines indicate undersaturation.

Creek samples plotted in Fig. 40, p. 176 indicate that all the samples were supersaturated with respect to calcite and dolomite. Although the field pH values were determined at creek temperatures above $5^{\circ}C$. the corrected effect of temperature in the diagrams would be a lowering of the equilibrium lines, the samples would still be supersaturated in all cases.

Ca^{2+}/Mg^{2+} close to 1.00 (Table 22, p. 227) suggest the quantities of Ca^{2+} and Mg^{2+} in the creeks are derived from the dissolution of dolomite. Under atmospheric CO_2 pressures, surface runoff derived mainly from precipitation would not be supersaturated with respect to calcite and dolomite if these minerals were readily available for dissolution. Supersaturation suggests relatively large quantities of calcite were dissolved at elevated CO_2 pressures in the soil zone and that these quantities are entering the creeks via quick interflow and groundwater flow. Shallow groundwaters in the area are supersaturated with respect to calcite and dolomite and base-flow therefore could represent a large component of the creek discharge during the spring months. This is discussed later in this chapter in the section dealing with groundwater chemistry.

Seasonal Variations

Seasonal variations in the major-ion chemistry and conductivity of five selected creek sites south of Whitewater Lake are shown in Fig. 41, p. 177. Although individual creeks differ in conductivity values at an one time, conductivity values of all the creeks fluctuate during the season in the same manner. Creek conductivities were approximately 300 micromhos.cm.$^{-1}$ during the period of flow in early April. Conductivities then increased during the period of active flow to a maximum near 2900 micromhos.cm.$^{-1}$ in late May although creek discharge had peaked about the middle of April. During June, creek conductivities dropped steadily to a relative low in late June. Creek discharge exhibited another peak during this period. By the middle of July the creeks exhibited conductivities in the range 800 to 1200 micromhos.cm.$^{-1}$ at a time when streamflow had stopped.

The consistent behaviour of the creek conductivities suggests these creeks are under the influence of the same controlling factors. Low conductivities in April are probably indicative of large snowmelt contributions to the creeks. The rapid increase in conductivities during April must be due to a substantial brackish groundwater component as large amounts of precipitation were not recorded during this interval.

Continued increase in the creek conductivities during periods of high rainfall in May probably indicated that the groundwater component was still important as the source of high concentrations of dissolved solids. Rainfall during this period did not dilute the creeks appreciably even though creek flow had declined during this time. Low conductivity values in June and July suggest that the brackish groundwater component during this period was reduced. Chemically there appears to be two types of groundwater inflow occurring; a shallow interflow component and a deeper more saline base-flow component. The chemical dilution during this period may be attributed to contributions of direct runoff, channel precipitation, quick return flow and a reduction in the proportional contributions of groundwater. Schwartz (1970) noted this effect during periods of rainfall in the Wilson Creek watershed of Manitoba.

The seasonal variations in creek conductivities indicates that base-flow and interflow are the most substantial components in the discharge of the creeks during the early spring. Large amounts of interflow and base-flow during this period may be due to fall storage in the watershed and the subsequent delayed interflow, direct groundwater discharge through base-flow and/or springs, a delayed groundwater discharge pulse that is contained to some extent during the winter months and released during the early spring or a combination of the above components. A possible explanation for the large amounts of groundwater flow to the creeks in the spring may be accumulated bank storage. Groundwater flow percolating toward the creeks during the winter months is accumulated as bank storage along the creeks when the ground surface is frozen. As the ground thaws during the spring, bank storage is released and streamflow increases. Once this storage is dissipated the groundwater component to the creek decreases. Groundwater flow would tend to increase again after periods of heavy precipitation which would raise the water table increasing the hydraulic gradient toward the stream. This effect would exhibit a time lag after the precipitation had occurred. Creek discharge during the summer months however appears to be directly related to the seasonal rainfall, and streamflow contains contributions of direct runoff, channel precipitation and quick return flow. Quick return flow here refers to the subsurface streamflow contributions which occur during and immediately after a storm and which are composed of interflow and transient shallow groundwater inflow.

Individual cations and anions generally behave similarly with seasonal variations in the concentrations of ions paralleling the creek conductivities. Na^+, Mg^{2+}, K^+, SO_4^{2-} and Cl^- concentrations behave in a similar manner while Ca^{2+} and HCO_3^- concentrations behave differently from the other ions. Since Na^+,Mg^{2+},K^+ and Cl^- concentrations parallel conductivities it would appear that the major source of these ions must come from groundwater components. Interflow or shallow groundwater which has passed through a soil zone with high CO_2 partial pressures would contain substantial concentrations of Ca^{2+}, Mg^{2+} and HCO_3^- but very little Na^+, SO_4^{2-} and Cl^- because of the slow solution rates of silicate minerals, the short contact times involved and the general unavailability of the soluable sodium, sulphate and chloride salts on the ground surface of recharge areas and in the leached upper soil horizons (Schwartz, 1970). High concentrations of Na^+, Mg^{2+}, K^+, SO_4^{2-} and Cl^- are therefore probably characteristic of a long-term or deeper groundwater contribution. The long-term groundwater component appears important during the early spring when large amounts of Na^+, Mg^{2+}, K^+, SO_4^{2-} and Cl^- are added to the creeks. Ca^{2+} and HCO_3^- concentrations show a relative increase during the summer month suggesting that direct precipitation and quick return flow are probably more important at that time. Individual creeks do show some variation in major-ion chemistry which probably is a result of the relative proportions of the streamflow components at any particular time. Chemical hydrographs from site 1 of the magnesium-calcium or calcium-magnesium bicarbonate type incicate that the long-term groundwater and shallow groundwater components probably exist in the same relative proportions throughout the flow period. Site 3 of the sodium-magnesium or sodium-calcium sulphate type has however a strong long-term component during the early spring while the shallow groundwater component appears to be decreasing. This is shown by the relative increase in Na^+, Mg^{2+}, K^+, SO_4^{2-} and Cl^- while Ca^{2+} and HCO_3^- exhibit a marked decrease. These effects not only depend on the quantity of each component but also upon the total concentration of each component. Very small additions of the long-term groundwater component at very high concentrations for example may produce the same net effect on the creek chemisty as large amounts of the component at lower concentrations.

Seasonal variations in the major-ion chemistry of the creeks indicate that groundwater is the most important component in the creek discharge during the spring and early summer. Moreover, the increase in the concentration of individual ions during periods of active flow implies the creeks are effluent streams. The simultaneous increase of the water table and stream discharge suggests that both fluctuations are controlled by a groundwater discharge pulse. This appears related to long-term precipitation trends and delayed flow.

Oxygen^{18} Composition of Surface Water

Creek samples taken in 1971 exhibit a wide range of δO^{18} values from -8.7 to -29.5 SMOW., (Table 23, p. 228). Generally the creeks exhibit a relative increase in O^{18} content during the season.

Low δO^{18} values during April may reflect the effect of a substantial snowmelt contribution to the creeks at that time. An increase in the δO^{18} value during the summer months may reflect the effects of precipitation, open-surface processes or subsurface processes in the basin. Precipitation tends to be more positive than snow and would increase the O^{18} content of the creeks after the initial snowmelt period. However precipitation tends to become more negative (Table 20, p. 221) during the summer months and this would not explain the higher δO^{18} values of the creeks at that time. Above-surface stages of the recharge process, namely interception by vegetation, water retention in surface depressions and puddles, overland flow and stream flow are essentially similar as the isotope balance is concerned in that they increase the contact time between the water and the open atmosphere under optimum conditions for isotope change (Gat and Tzur, 1967). This increased contact time would result in enrichment of O^{18} content of the creeks. Groundwaters probably exhibit isotope ratios similar to precipitation and it may be difficult to separate these components if they occur simultaneously. Subsurface processes such as direct evaporation from soil pores or by water uptake through root systems and subsequent evapotranspiration (Gat and Tzur, 1967) may increase the O^{18} content of groundwaters relative to precipitation. If subsurface processes are important then substantial quantities of groundwater inflow could explain the increase in the O^{18} content of the creeks. The rather low δO^{18} value (-29.5) of creek 4 on May 6 appears anomalous and may be due to analytical errors.

Chemical Composition of Groundwater

Major-ion Chemistry

Piezometer samples have a wide range of major cation concentrations with SO_4^{2-} and HCO_3^- the dominant anions (Table 24, p. 229). Chloride is generally low, less than 20 percent while SO_4^{2-} varies from 50-98 percent and HCO_3^- ranges from less than 5 to 55 percent of the anions. Sulphate type waters are predominant in the area.

Samples obtained from the piezometers and wells were plotted on Piper trilinear diagrams (Figs. 42 and 43, pp 178 - 179) to show the chemical characteristics of groundwater samples obtained from the various hydrostratigraphic units in the region. Cations and anions were plotted as a percentage of their individual totals in equivalents per million.

Three chemical types of groundwater were delineated in the Whitewater Lake area on the basis of arbitrary boundaries shown in Fig. 42, p. 178. These boundaries were drawn by consideration of the distribution and grouping of points in the cation and anion fields. There is a definite separation in the anion field at the 20 percent HCO_3^- isogram. Cations appeared to be grouped between $Na^+ + K^+$ isograms 20-40, 40-60 and 60-80 percent. The 60 percent $Na^+ + K^+$ isogram was chosen for convenience to define three chemical facies of groundwater. Type I water, a calcium-magnesium-bicarbonate sulphate facies is characteristic of the Boissevain Formation and glacial sand and gravel deposits (Unit 9a). Type II water, a calcium-magnesium-sulphate facies occurs in a variety of deposits including glacial sand and gravel (Unit 9a), glacial till (Units 6 and 8) and shale gravel (Unit 5a). The hydrochemical facies are not confined to particular geohydrologic units.

Samples obtained from observation wells of the Manitoba Soil Survey shown in Table 25, p. 282 do not vary appreciably in their chemical make-up as evidenced by samples obtained from wells 22 and 25 in 1970 and 1971. Wells sampled in August 1970 exhibit the same chemistry as the wells sampled in August 1971. Well samples plotted on a Piper trilinear diagram designated with the three chemical facies defined from the piezometer plots are shown in Fig. 43, p. 179. The water bearing units encountered in the wells sampled are also shown. Well samples have a wide range of major cation concentrations while anion concentrations generally range from 60-98 percent SO_4^{2-} and less than 5 to 40 percent HCO_3^-. Chloride is generally low, less than 10 percent except for samples from the Riding Mountain Formation which are as high as 90 percent Cl^-. Well samples characteristic of geohydrologic units tend to plot in the same fields as the respective piezometer samples. Samples obtained from glacial sand (Unit 9a) plot in facies Type I and II. Samples from glacial till (Unit 8) plot in facies Type II and III while samples from sand and shale (possibly Units 5a,5b) plot in Type III facies. Samples obtained from the Riding Mountain Shale are of the sodium chloride type and they plot in facies Type III.

A summary of the chemistry of the major hydrostratigraphic units in the Whitewater Lake area is given in Table 26, p. 235. Conductivity values indicative of the total dissolved solids present have a wide range of values from 1,000to 41,000 micromhos $cm.^{-1}$, (Tables 27, 28, pp 236, 238). Values are lowest in the Boissevain Formation and glacial sand and gravel deposits (Unit 9a). These two units also exhibit a similar chemistry. Hydrochemical similarity is also shown between glacial tills

(Units 6 and 8) and sand and gravel deposits (Unit 5). The chemistry and higher conductivity values of the glacial till units may reflect discharge from Units 5a and 5b. If the sand and gravel deposits (Unit 5) are channeling water from the Boissevain Formation this water must be undergoing a progressive change in chemical composition by dissolution processes or mixing processes in the unit. Upward movement of water from the Riding Mountain Formation may also be modifying the chemistry of the shallow groundwaters. Higher Cl^- values in the shallow groundwater would be expected in these areas.

A comparison of the major-ion chemistry of the groundwaters (Fig. 42, p. 178) and the major-ion chemistry of the creek samples (Fig. 39, p. 175) indicates that many of the creek samples fall in the Type I and II groundwater facies corresponding with the distribution of samples obtained from the Boissevain Formation and glacial sand and gravel deposits (Unit 9a). The remainder of the creek samples are richer in HCO_3^-. This suggests that the long-term groundwater inflow to the creeks comes from the Boissevain Formation. Relatively high HCO_3^- concentrations of the creeks are probably indicative of contributions from direct precipitation, snowmelt and shallow groundwaters.

pH and Carbonate Equilibria

Ca^{2+}, Mg^{2+}, HCO_3^- and field pH data obtained from piezometer sites were plotted on calcite and dolomite dissolution diagrams (Fig. 44, p. 180) based on Langmuir's (1971) equilibrium constants. Cherry (1971) has demonstrated the use of carbonate equilibrium diagrams in assessing the effect of the dissolution of carbonate minerals in groundwater chemistry and in determining the chemical evolution of groundwaters.

The pH and HCO_3^- data plotted on carbonate equilibrium diagrams tend to plot into two groups, one group in the pH range 7.0 to 7.5 and the other group in the 8.5 to 10.0 range. Samples in the upper range group are well scattered above the equilibrium lines. The low pH group falls along the equilibrium lines. Ca^{2+} and Mg^{2+} data plot well above the equilibrium lines and exhibit considerable scatter.

The pH and HCO_3^- relationships generally indicate that the observed concentrations in the groundwaters may be attributed to the dissolution of calcite and dolomite. These minerals are readily available in the drift of the region. Many of the samples however, particularly those having high pH values contain HCO_3^- in excess of that obtained by the simple dissolution of the carbonate minerals. The pH values of these samples may be affected by redox reactions which raise the pH. The corresponding HCO_3^- concentrations meanwhile are low compared to the other samples. It should be noted that the high pH samples are distributed in the groundwaters north and east of Whitewater Lake except for sites 3 and 20 which are south of the lake. The samples north of the lake may reflect discharging groundwaters from the Riding Mountain Formation which are low in HCO_3^- concentrations. Eilers (1972) also reports relatively low HCO_3^- concentrations from the waters of the Riding Mountain Formation compared to the shallow groundwaters of the drift. Site 3 is a deep piezometer while site 20 is located in shale gravel Unit 5b. These sites may also be under the influence of discharging groundwaters from the Riding Mountain Formation.

Excess concentrations of Ca^{2+} and Mg^{2+} indicate that the observed values are not related solely to the simple dissolution of calcite and dolomite. Those samples which do plot nearest the equilibrium lines are obtained from the Boissevain Formation and glacial sand Unit 9a. Since groundwater flow appears to be toward the north away from the Boissevain Formation it appears the groundwaters must be accumulating excess quantities of Ca^{2+} and Mg^{2+} in the glacial deposits near Whitewater Lake. Bedrock waters from the Riding Mountain Formation are very low in Ca^{2+} and Mg^{2+} but high in Na^+ and Cl^-. Although discharging waters from the Riding Mountain Formation are not the source of excess quantities of Ca^{2+} and Mg^{2+} they may be responsible for the release and transport of these ions within the glacial deposits. Highly concentrated NaCl rich groundwaters moving upward from the Riding Mountain Formation could cause the release of Mg^{2+} and Ca^{2+} cations from montmorillonite clay minerals in the overlying drift. This process may be comparable to the regeneration process of water softening materials by passing concentrated NaCl solution through the material (Linsley and Franzini, 1972). Mg^{2+} would be released preferentially to Ca^{2+} since Ca^{2+} is absorbed by the clay in preference to Mg^{2+} (Wiklander, 1964). In this manner the resulting shallow groundwaters would be enriched in Na^+, Cl^-, Mg^{2+} and to a lesser amount in Ca^{2+}. This is particularly evident in the shallow deposits east and northeast of Whitewater Lake and is discussed in the following section.

Spacial Variations in Groundwater Chemistry

Spacial variations in groundwater chemistry are useful in interpreting groundwater flow directions and particularly the chemical evolution of groundwater in the area. Groundwaters rend to increase in concentration along the flow direction as the dissolution of minerals progresses (Schoeller, 1959). The upward movement of water particularly in arid regions in conjunction with evaporation will also result in the progressive concentrations of discharging groundwaters.

Individual ion concentrations, conductivity and pH values for samples obtained from the piezometer sites on August 13 and September 9, were plotted on north-south (B-B') cross sections (Figs. 45, 46, pp 181, 182) and west-east (C-C', D-D') cross sections (Figs. 47-51, pp183-187), to show vertical and lateral variations in the groundwater chemistry. Total dissolved solids were plotted for various depth ranges (Fig. 52, p. 189) to indicate areal variations in chemistry.

Cross sections B-B' show a downward and lateral increase northward in the conductivity of the shallow groundwaters. Values of the total dissolved solids also indicate this trend. These values are lowest and consistent in the Boissevain Formation while higher and more variable in the other deposits. Site 37 shows a slight upward increase in conductivity and total dissolved solids. Na^+ and SO_4^{2-} values follow the same trend as the majority of conductivity values. Mg^{2+} values increase downward and laterally toward the north in the Boissevain Formation but tend to increase upward in the glacial deposits. Low values occur at site 39. Ca^{2+} exhibits consistent values throughout the system except for rather low values at site 39 and the shallow piezometer at site 37. K^+ has low values with lateral increase toward the north. Cl^- shows an upward increase in the Boissevain Formation and lateral increase toward the north. Relatively high Cl^- values occur at site 20 with the concentration increasing downward. HCO_3^- and CO_3^{2-} values are generally consistent throughout the system with highest values occurring in the Boissevain Formation and anomalous low values occurring at sites 39 and 37. Low HCO_3^- values correspond with low Ca^{2+} and Mg^{2+} values except at site 37 where high Mg^{2+} values occur with low Ca^{2+} and HCO_3^- values. Field pH values appear to correspond with variations in Ca^{2+} and HCO_3^- values. High pH values are associated with low Ca^{2+} and HCO_3^- values. High Mg^{2+} values however are associated with high pH values.

Cross sections C-C' show a downward increase in conductivity values, total dissolved solids, Na^+, SO_4^{2-}, K^+ and Cl^- except for site 12 which shows the reverse trend. Ca^{2+} generally exhibits consistent values in a narrow range throughout the system with slight downward increasing trends except for site 12. Mg^{2+} shows a downward increase in values except for the high values at site 12 and rather low values at site 3 and the deep piezometer at site 20. HCO_3^- has consitstent values increasing downward in the system although site 12 is high and site 3 is low. Field pH values tend to reflect Ca^{2+}, Mg^{2+} and HCO_3^- values with low pH values corresponding to high concentrations of the other ions and conversely.

Cross sections D-D' generally show an upward increase in values of conductivity, total dissolved solids, Na^+, Mg^{2+}, K^+ and SO_4^{2-}. These concentrations however increase slightly downward at site 30. Ca^{2+} and Cl^- generally have consistent values throughout the system. HCO_3^- values are relatively high west of site 37 and conspicuously lower east of site 37. Within these zones the values are generally consistent. Field pH values correspond with observed HCO_3^- values with low pH values west of site 37 and high pH values to the east. The pH values also correspond with Ca^{2+} values but not with the Mg^{2+} values.

The areal distribution of total dissolved solids at depths 15-30 feet (Fig. 52, p. 189) indicates an increase in values from the Turtle Mountain Upland toward the north. The values northeast of the lake are relatively low compared to values west and east of the lake. For depths 30-45 feet the total dissolved solids increase toward the north and east. Highest values occur east of the lake. For depths 50-80 feet the total dissolved solids increase inward toward the centre of the basin and toward the east.

Highest values occur under the south and southeast shores of the lake.

The distribution of conductivity, total dissolved solids, Na^{+} and SO_4^{2-} values in cross sections B-B' indicate the downward and lateral movement of the groundwater from the Turtle Mountain Upland toward the north. These chemical parameters substantiate the groundwater movement interpreted from the hydraulic head measurements. The relatively low magnitude of total dissolved solids at site 37 compared with shallow piezometers to the south suggests flow is being channeled directly from the Boissevain Formation along Unit 5b with only slight concentration and modification of the chemical constituents along the flow path. The distribution of Mg^{2+}, Cl^{-} and K^{+} suggests upward movement of groundwater through the glacial deposits north of the Boissevain Formation. Relatively high Cl^{-} values at site 20 may incicate discharge from the Riding Mountain Formation into the overlying deposits. The upward increase in Cl^{-} values in the Boissevain Formation also reflects the upward movement of water from the Boissevain Formation. High pH values associated with low Ca^{2+} and HCO_3^{-} values suggest the concentration of these ions is related to the dissolution of calcite and dolomite. High Mg^{2+} associated with high pH suggest the concentrations of Mg^{2+} are not related solely to the dissolution of dolomite but to other processes such as the dissolution of magnesium sulphate salts or ion exchange processes. Anomalous low values of Ca^{2+} and Mg^{2+} at sites 39 and 37 however may reflect ion exchange with clay minerals in the drift. Both these piezometers are located in Unit 5b which is shale gravel. This shale gravel is derived from the shales of the Turtle Mountain Formation which are composed mainly of illite-montmorillonite clays with large amounts of calcium and smaller amounts of magnesium as the exchangeable cations. Exchange of Ca^{2+} and Mg^{2+} from the groundwaters with Na^{+} in the shale gravel could explain the low Ca^{2+} and Mg^{2+} values at this site.

The distribution of conductivity, total dissolved solids, Na^+, SO_4^{2-}, K^+ and Cl^- apart from site 12 in cross sections C-C' indicates the downward movement of shallow groundwaters. These chemical parameters substantiate the groundwater movement interpreted from hydraulic head measurements. The anomalous behaviour of site 12 suggests discharging groundwaters are responsible for the observed chemistry. Site 12 is located in glacial sand 9a and has a chemistry similar to waters of the Boissevain Formation although more highly concentrated. Channeling of water from the Boissevain Formation through Unit 9a, upward discharge, subsequent dissolution processes, stagnation and evaporation could result in the observed chemistry at site 12. High values of Ca^{2+}, Mg^{2+} and HCO_3^- at site 12 also suggest the upward movement of water. The apparent interrelationship of field pH, Ca^{2+} and Mg^{2+} values suggests the concentration of these ions is controlled by dissolution of calcite and dolomite. A low Mg^{2+} value at site 20 in shale gravel Unit 5b corresponding with a low pH may be the result of ion exchange processes. Relatively high Ca^{2+} value at site 3 appears anomalous and may be due to contamination from Portland cement used in construction of the piezometer.

The distribution of conductivity, total dissolved solids, Na^+, Mg^{2+}, K^+ and SO_4^{2-} in cross sections D-D' indicates the upward movement of shallow groundwater through the system. These chemical parameters substantiate the groundwater movement interpreted from hydraulic head measurements below 30 feet (9.8 m.). Apart from site 30 the chemical data do not indicate the downward movement of groundwater interpreted from the hydraulic head measurements in the upper 30 to 40 feet of the deposits. Site 30 is underlain by 10 feet (3 m.) of highly permeable sand 25 feet below the surface and is situated in the thalweg of a buried valley. These conditions are probably responsible for channeling water downward and laterally in this zone. The apparent interrelationship of field pH and Ca^{2+} values suggests the concentration of these ions is controlled by the dissolution of calcite. Consistent values of Cl^{-} throughout the system suggest the upward movement of chloride waters from the Riding Mountain Formation north of the lake is occurring. Groundwaters east of site 37 exhibiting high conductivity values, high pH, and low Ca^{2+} and HCO_3^{-} concentrations probably reflect discharge from the Riding Mountain Formation. Mg^{2+} values probably are not related directly to pH values and carbonate equilibria but are probably due to the dissolution of magnesium salts and ion exchange processes.

The areal distribution of total dissolved solids at the depth ranges considered substantiate the hydraulic head data. Groundwater flow is directed inward to the basin from the Turtle Mountain Upland and the region north of the lake. Relatively low values northeast of the lake may be due to groundwater outflow and flushing. Lateral movement through this zone toward the north probably prevents the concentration of mineral constituents through groundwater discharge in this region. Groundwater movement east and west of the lake is predominantly inward and upward. Long-term duration of waters in this zone, stagnation and evaporation probably results in the high concentration of chemical constituents in these areas.

Oxygen^{18} Composition of Groundwater

The samples obtained from the glacial till are distinctly higher in O^{18} content than the samples from the shales of the Riding Mountain Formation (Table 29, p. 241). Glacial till samples exhibit δO^{18} values from -17.2 to -11.2 while samples from the shale exhibit values from -18.0 to -14.4. Samples from the glacial deposits near Whitewater Lake exhibit comparitively high values of δO^{18} between -15.0 and -2.0.

Higher δO^{18} values in the glacial till waters compared to the shale bedrock waters are probably indicative of evaporation processes. The isotope composition of oxygen in natural waters is mainly controlled by processes of evaporation and condensation (Epstein and Mayeda, 1953). Although processes of diffusion, reaction kinetics and organic matter (Epstein, 1957) as well as fractionation by shale micropore systems (Graf *et al*, 1965) may also contribute to isotope variations in natural waters their effect on shallow groundwaters is probably not important. Evaporation processes combined with the following hydrologic conditions could explain the higher concentrations of O^{18} in the glacial deposits: (1) the progressive evaporation of discharging groundwaters from the bedrock shales, (2) the progressive evaporation of discharging groundwaters in the glacial deposits, (3) variations in the isotopic composition of precipitation, (4) above-surface processes of evaporation and shallow subsurface processes as evapotranspiration in recharge areas. The progressive evaporation of discharging groundwaters from the bedrock shales is probably not an important factor controlling the O^{18} content of the shallow groundwaters. There is a distinct difference between the samples collected from the glacial deposits compared to the shale samples. Moreover this difference is not a simple function of depth. Distinctive differences in the major-ion chemistry of the waters from these units and total dissolved solids of the shale samples being much greater than the shallow water samples imply that the shallow groundwaters are not evaporative products of the shale bedrock waters. Variations in the isotopic composition of precipitation parallel variations in atmospheric temperature with precipitation being isotopically lighter during the colder months as compared with the warmer months(Epstein, 1957). Geographical and meteorological controls also cause variations in the isotopic composition of precipitation. The fractionation factors associated with these controls are generally quite small and would not account for the difference in O^{18} content between the till samples and the shale samples without being coupled with groundwater flow conditions. Above-surface processes of evaporation and shallow subsurface processes such as evapotranspiration in recharge areas of the glacial deposits and evaporation of discharging groundwaters are perhaps the best explanations. The comparatively high δO^{18} value of -2.0 at well 24 implies this well is located in a discharge area. A consistently high water table 1 to 5 feet below the ground surface during the summer months, high groundwater conductivities and high soil salinity values at this site substantiate this interpretation. Relatively high δO^{18} values of -11.8 for example at depths of 20 feet may not necessarily indicate discharging conditions but may reflect evaporation and evapotranspiration during recharge. It should be noted that some of the shallow sites in the shale bedrock have relatively high δO^{18} values compared to deeper sites in the shale. These differences may also be due to partial evaporation of recharging groundwaters. The major-ion chemistry of these recharging waters may not alter the major-ion chemistry of the shale waters but could have a major isotopic influence.

A comparision of the oxygen^{18} values of groundwater samples and those of creek samples (Table 23, p. 228) indicates the creek samples correspond with the groundwater samples from the shallow glacial deposits. The increase in O^{18} content of the creek samples from April to May could be explained by increased groundwater contributions from the shallow deposits. In the early spring during snowmelt the creeks would be isotopically lighter due to the low O^{18} content of snow. As the snowmelt component decreased and the groundwater component increased the creeks would show an increase in O^{18} content. The relatively low δO^{18} value of site 4 on May 6 is probably indicative of minor groundwater contributions and a high precipitation component.

Chemical Composition of Lake Water

Major-ion Chemistry

Chemical analyses of Whitewater Lake samples prior to 1970 are shown in Table 30, p. 242. Chemical analyses of lake samples in 1970 and 1971 are shown in Tables 31 and 32, pp 243 and 245. pH readings of Whitewater Lake obtained in 1971 are shown in Table 33, p. 249.

Chemical analyses obtained in 1970 and 1971 were plotted on a Piper trilinear diagram (Fig. 53, p. 189) to show the chemical character of the lake water and to compare the lake water chemistry with the groundwater and the creek chemistry. Conductivity, total dissolved solids, lake temperature, lake level and major-ion chemistry values for 1970-71 were plotted (Fig. 54, p. 190) to show the seasonal variation of these parameters. pH values obtained for selected sites in 1971 were also plotted in Fig. 54, p. 190.

The trilinear plot of the surface water samples taken from Whitewater Lake during 1970 and 1971 indicates the lake water had a consistent chemistry during those years. The lake water was characterized by a high Na^+ (60 percent of cations), Mg^{2+} (35 percent of the cations) and SO_4^{2-} (90 percent of anions) content. These relative percentages varied within narrow limits of about 5 percent during the years 1970 and 1971. The one sample taken under the ice in March 1971 was more enriched in Mg^{2+} and SO_4^{2-} compared to the ice-free lake water. A comparison of the distribution of lake water samples on the Piper plot with the distribution of groundwater samples (Fig. 53, p. 189) indicates the lake water samples plot at the intersection of the three main groundwater types present in the basin. The lake water however does not appear to correspond with any particular groundwater type characteristic of a geohydrologic unit although it closely resembles groundwater from glacial till and glacial sand Unit 9. The lake water has a lower proportion of Ca^{2+}, Na^+ and SO_4^{2-} and a higher proportion of Mg^{2+}. A comparison of lake water and creek water (Fig. 39, p. 175) indicates the lake water corresponds with a minor number of creek samples. The lake water however is much higher in Mg^{2+}, Na^+, Cl^- and SO_4^{2-} and lower in Ca^{2+} compared with the majority of the creek samples.

Seasonal Variations

Seasonal variations in the chemistry of Whitewater Lake during 1970 and 1971 indicate that elecrolytic conductivity and total dissolved solid values (Fig. 36, p. 172) behaved in a corresponding manner. Total dissolved solids were within 80 percent of the electrolytic conductivity values. In May 1970 conductivity values were near 2,500 $micromhos.cm.^{-1}$ and then increased steadily with minor downward fluctuations to a maximum near 4,500 micromhos.cm.$^{-1}$ by late October. Values continued to increase under the ice during the winter months with values of 5,600 to 14,150 reported in November and 34,000 reported in March 1971. In April 1971 conductivity values were low again near 2,000 micromhos.cm.$^{-1}$. These values then increased during the open water season with minor fluctuations to a maximum value near 4,000 micromhos.cm.$^{-1}$ in October. Overall, the seasonal values observed in 1971 were slightly lower than the 1970 values. Major-ion chemistry (Fig. 54, p. 190) exhibited the same general trends as the conductivity values with some minor exceptions. In 1970 Na^+, K^+, Mg^{2+}, Cl^- and SO_4^{2-} increased correspondingly with minor downward fluctuations during the season. Ca^{2+} however behaved irratically with no apparent net increase during the season. HCO_3^- increased over the season but behaved differently from the other ions during the spring months. Decrease in HCO_3^- concentration for example occurred when the other ions were increasing. The rate of change of Na^+ and SO_4^{2-} was greater than the other ions. In 1971 Na^+, Mg^{2+} and SO_4^{2-} fluctuated in the same manner during the season. Cl^- and K^+ also increased and fluctuated together in the same manner but slightly differently from the other ions. HCO_3^- and Ca^{2+} also increased with minor fluctuations although apparent increases in Ca^{2+} corresponded with decreases in HCO_3^-. pH values obtained in 1971 increased from May to September and then decreased. The value obtained on a sample from under the ice in March 1971 was quite low at 7.5. Maximum values reached in late August were near 9.4. pH values obtained along the southern and western shores were consistently lower than values obtained along the north shore the same day.

Chemical data available for the years 1968 and 1969 (Table 30, p. 242) indicate lake chemistry at that time was very similar to the chemistry observed in 1970 and 1971. Conductivity and major-ion chemistry values in 1969 varied within the ranges observed in 1970 and 1971. Relative molar concentrations were about the same. A sample obtained in very shallow water of 0.2 feet (5.2 cm.) in 1968 had a rather high conductivity value of 13,500 micromhos.cm.$^{-1}$ although the molar concentrations were similar to lake chemistry observed in 1968 and 1969.

The relative molar concentrations of Whitewater Lake did not vary considerably during the years 1968 to 1972 although seasonal variations in total dissolved solids, electrolyic conductivity, major-ion values and pH occurred. A slight decreasing trend in total dissolved solids has occurred during these years. Annual constancy in the relative ionic composition of the lake suggests the total ion input and loss tend to balance. Losses due to outflow and precipitation of minerals appears to be occurring. The major-ion chemistry of the lake corresponds closely with groundwaters from shallow deposits of glacial sand and glacial till and with surface waters from streams south of the lake. This suggests that the lake water is a mixture of shallow groundwater and creek water. A higher proportion of Na^+, Mg^{2+}, SO_4^{2-} and Cl^- and lower proportion of Ca^{2+} in the lake water compared with the creek samples and the fact that much of the creek flow is derived from groundwater discharge indicates that the lake contains a large groundwater component. Seasonal increase in the total dissolved solids, conductivity, major-ion chemistry and pH is controlled by evaporation. Seasonal rainfall does not affect the major-ion chemistry greatly although minor fluctuations occur during periods of rain. Evaporation decreases after September and this would not explain the continued increase in lake conductivity at this time of year. Another factor which could explain this increase would be the influx of saline groundwater. The only source of this water would be from the glacial till or the Riding Mountain Formation. Hydraulic head data and shallow groundwater chemistry along the northshore of Whitewater Lake suggest this is possible. Groundwater discharge in this area would have to be constant to explain the chemical behaviour of the lake water. High conductivity values under the ice in November and March are probably due to the ice-forming process with concentration of the residual waters under the ice. Low conductivity under the ice in April 1971 however suggests flushing of the system must occur probably through shallow groundwater movement. This implies downward seepage or lateral movement of the highly concentrated lake water and replacement with lower conductivity groundwater. The only source of low conductivity groundwater would be from the shallow glacial sand which underliespart of the lake basin. This concept contradicts the possible discharge of saline groundwater from till or the Riding Mountain Formation. It may be that both processes are occurring in separate parts of the lake and that seasonal fluctuations in the rates of groundwater discharge from these sources is occurring.

The effect of evaporation would be expected to result in the seasonal increase and corresponding behaviour of all the major ions if chemical reactions and biological activity were not taking place in the lake. The evaporation effect is reflected to some extent by all the major ions. Na^+ and SO_4^{2-} however increase more rapidly than the other ions. This may be due to high inputs of sodium sulphate groundwater from the glacial till or other factors. The removal of $CaCO_3$, $MgCO_3$ and $MgSO_4$ from solution in the nearshore zone and their deposition as a capillary encrustation on the shore flats could also explain this phenomenon (written comm., D. Delorme, 1971). Evaporation of the lake waters in this manner would concentrate the next most soluable salt mainly Na_2SO_4 in the solution. Delorme suggests that water movement is from the lake to the shore and not vice versa with movement likely by capillary action in the non-saturated zone. Similarly the concentrations of K^+ and Cl^- would be expected to increase relative to the other ions since KCl is also a highly soluable salt. The corresponding behaviour of K^+ and Cl^- may also be due to groundwater discharge from the Riding Mountain Formation which is enriched in these ions. The seasonal behaviour of Ca^{2+} and HCO_3^- is controlled by factors other than evaporation. Creek discharge during periods of active surface runoff and carbonate equilibria in the lake are probably controlling factors. Ca^{2+} and HCO_3^- are important constituents in the creek samples and may be important contributions to the lake in the early spring. There was no obvious increase in Ca^{2+} and HCO_3^- content of the lake waters however during the period of active surface runoff.

Carbonate Equilibria and pH

Irregular behaviour of Ca^{2+} and HCO_3^- in the lake water during the season could be explained by carbonate equilibria. A plot of Ca^{2+}, Mg^{2+} and HCO_3^- concentrations versus field pH values (Fig. 55, p. 191) indicates the lake samples are supersaturated with respect to calcite and dolomite. Although field pH values were determined at lake temperatures above $5^oC.$, the corrected effect of temperature in the diagrams would be a lowering of the equilibrium lines; the samples would still be super-saturated in all cases. The sample obtained under the ice in March 1971 was saturated with respect to calcite and supersaturated with respect to dolomite. A rise in temperature, agitation by waves, evaporation and subsequent decrease in the solubility of CO_2 gas and increase in pH (Garrels and Christ,

1965) would favour the chemical precipitation of calcium carbonate from solution during the summer months. The erratic behaviour of Ca^{2+} and HCO_3^- in the lake water suggests that the precipitation of calcium carbonate is taking place. The biological precipitation of calcium carbonate has been noted previously and this may account for the behaviour of Ca^{2+} and HCO_3^-. Removal of dissolved CO_2 gas from the lake water by transpiring plants would also favour the chemical precipitation of clacium carbonate. There is no evidence suggesting the precipitation of dolomite is taking place. Mg^{2+} fluctuates in the same manner as Na^+ and SO_4^{2-} during the season suggesting dolomite is not being precipitated in major quantities in the lake.

Variations in pH during 1971 corresponded closely with variations in lake temperature and the rate of evaporation. Noticeable lowering of pH occurred after periods of heavy rain suggesting climatological factors are the most important controls on pH in the lake. Rains having pH values in the range 5.4 to 6.9 would be expected to lower the pH of the lake which is normally above 8.0 during the summer months. Evaporation and increase in temperature tend to decrease the solubility of dissolved CO_2 gas in the lake water and subsequently the pH which is controlled by the partial pressure of dissolved CO_2. Plant transpiration during the growing season would also reduce CO_2 pressure in the water. Since herbaceous plants stop transpiring in the fall this could explain the lowering of pH at that time. Lower pH values noted along the south and western shores of the lake probably reflect areas of groundwater discharge. These regions are underlain by glacial sand at shallow depth and are in major groundwater flow regions. Groundwater having pH values near 7.5 could be responsible for lowering pH of the lake water in these areas. Streams south of the lake have pH values near 8.2 and they would have a minimal effect on the pH of the lake. Since these creeks were not active during June and July of 1971 they were not responsible for the lower pH values along the southern and western shores of the lake at that time.

Oxygen^{18} Composition of Lake Water

The oxygen^{18} values of Whitewater Lake samples in 1970 and 1971 are shown in Table 34, p. 251. Seasonal variations are shown in Fig. 36, p. 172.

During 1970 the O^{18} of the lake water increased rapidly during the spring and summer months from a relatively low δO^{18} value of -10.5 to a maximum value of -2.7 by the middle of September (Fig. 36, p. 172). Values were down somewhat during the period May 26 to June 1 after an initial May 19 value of -8.7. After September the O^{18} content decreased slightly. Samples obtained from the surface and near the bottom of the lake on September 7 had values in the range -4.3 to -3.4. Samples obtained during a north to south traverse across the lake on September 27 showed values in the range -6.2 to -4.2 with largest values recorded nearest the shores and lower values recorded toward the southern shore of the lake. The δO^{18} value obtained from a sample taken under the ice in March 1971 was -10.9. During 1971 the O^{18} content of the lake increased from a low -8.8 in April to a relative maximum of -5.0 by late August. Values were down somewhat during the period of late April and early May.

Rapid increase in the δO^{18} values during the open water season in 1970 suggests the lake was highly evaporative. The slight drop in O^{18} during late May and early June was probably due to an influx of isotopically light groundwater since precipitation and streamflow during that period was negligible. Little variation in the O^{18} content of surface samples and bottom samples on September 7 suggests the lake was well mixed vertically. Lateral variations obtained on September 27 indicate differences up to -2.0 δO^{18} units may occur. Lower δO^{18} values toward the south shore probably result from the influx of isotopically light groundwater or surface runoff in this area. The drop in O^{18} after reaching a maximum in September was probably due to decrease in the evaporation rate, and groundwater inflow since precipitation and streamflow during that time was negligible. Lake level during this period was relatively constant. The relatively low δO^{18} value recorded for the sample obtained under the ice in March 1971 may indicate the presence of groundwater flow under the ice in the winter. Formation of the ice would be expected to cause concentration of O^{18} in the residual water below the ice. The low δO^{18} value recorded however suggests the concentrated residual waters were flushed, probably through downward seepage and the influx of isotopically lighter groundwater. Rapid increase in δO^{18} values during 1971 again indicated that a highly evaporative regime occurred during the summer months. Slight dilution of O^{18} content during late April and early May was probably due to surface runoff, direct precipitation and groundwater inflow which occurred during this time. Since these components have similar δO^{18} values their contributions could not be separated.

Chemical Composition of Interstitial Waters of Lake Sediments

Interstitial water samples from the lake bottom sediments (Table 36, p. 252) exhibit electrolytic conductivity values in the range 4,000 to 12,300 micromhos.cm.$^{-1}$. A comparison of conductivity values and total dissolved solids indicates the total dissolved solids can be much greater, particularly for the highly mineralized samples. Each of the cores showed a continuous increase in conductivity and major-ion chemistry with depth. A Piper trilinear plot (Fig. 56, p. 192) indicates the interstitial water samples are very similar to the lake samples and are composed mainly of Na^+ (50-60 percent cations), Mg^{2+} (40-50 percent cations) and SO_4^{2-} (75-85 percent anions). The interstitial waters however are slightly more enriched in HCO_3^- and less enriched in Cl^-. A comparison of interstitial waters with groundwater samples (Fig. 42, p. 178) indicates the interstitial samples plot at the intersection of the three main types of groundwater present in the basin. The interstitial samples however do not correspond closely with any particular groundwater type. Field pH values of the interstitial samples were lower than the lake water and were consistently near 7.5. Eh values of the samples obtained from the bottom muds were negative at -0.2 volts while a sample from sand underlying the muds was positive at +0.4 volts. Eh of the lake water obtained at the same time was positive at +0.4 volts. Variations of pH and Eh in the bottom muds and lake water are shown in Fig. 57, p. 193.

The increase in the conductivity and major-ion contents with depth in the bottom sediments suggests that mineralized groundwater is diffusing upward through the bottom sediments and mixing with the lake water. The interstitial water samples however do not compare closely to any particular groundwater type present in the basin but to a possible mixture of all three types of groundwater in the basin. It is unlikely that the groundwaters should mix within the bottom sediments Modification of upward moving groundwater in the thin mantle of bottom sediments also appears unlikely. An increase in the interstitial ionic concentrations with depth could only be explained by the concentration of lake water through downward seepage. The chemical similarity between the lake water and the interstitial waters suggest this is taking place. Negative Eh values in the bottom muds imply reducing conditions are prevalent. Under these conditions quantities of dissolved CO_2 gas may be produced by decaying plants and by bacteria. This process would explain the lower pH values in the bottom muds and the higher proportion of HCO_3^- concentrations compared to the lake water. Increased partial pressures of CO_2 would increase the carbonic acid activity of the interstitial waters and subsequently its capacity for dissolving carbonate minerals. A plot of the interstitial samples on carbonate equilibrium diagrams (Fig. 55, p. 191) indicates the samples are saturated with respect to dolomite but only saturated and somewhat undersaturated in one case with respect to calcite. Downward seepage of lake water, lowering of pH due to reducing conditions and the availability of carbonate minerals in the form of bioclasts could explain the observed levels of Ca^{2+} and HCO_3^- in the interstitial waters. In addition quantities of sodium and magnesium sulphate salts would have to be available in the bottom sediments to explain the observed levels of Na^+, Mg^{2+} and SO_4^{2-}. This implies that the chemical precipitation of these salts is taking place in the lake. The solubility of these salts is quite high and it is doubtful that they were being precipitated in the main part of the lake during the summers of 1970 and 1971. This does not rule out the possibility that precipitation of these salts did not occur in the past during times of low water levels or complete dryness. Chemical precipitation of these salts may occur under the ice during the winter months from highly saline residual water. In this way quantities of these salts could be deposited in the bottom sediments. Warmer temperatures and relatively dilute lake waters during the summer months would favour the dissolution of these salts in the bottom sediments and result in the seasonal concentration of the lake water. This effect has been described by Strakov (1970) for closed saline lakes in the USSR. This effect however is probably not as important as the evaporative process. A somewhat lower proportion of Cl^- in the interstitial waters compared with the lake water appears anomalous. Highly soluable chloride salts are probably not present in the bottom sediments to the extent of the lesser soluable sulphate salts.

The downward movement of the lake water through the bottom sediments does not necessarily imply groundwaters are not entering the lake. Relatively constant lake levels and chemistry of the lake water suggest groundwater discharge is an important phenomenon. It appears however that this discharge is restricted to specific areas in the lake and is not occurring as diffuse seepage through the bottom sediments.

Oxygen^{18} Composition of Interstitial Waters

The two samples of interstitial waters analyzed have relatively high δO^{18} values of -5.7 and -7.4 (Table 35, p. 251). The δO^{18} values also decrease downward in the core examined.

Relatively high δO^{18} values indicate the interstitial waters have been subject to evaporation. They probably represent former lake water which has moved downward into the bottom sediments. The downward decrease in δO^{18} may be due to the influence of isotopically lighter groundwater below the bottom sediments. It is unlikely that the fractionation of groundwaters is taking place in the bottom sediments. The samples are probably indicative of a zone in which mixing of the lake water and groundwater is occurring.

CHAPTER V

HYDROLOGIC AND CHEMICAL BUDGETS

A quantitative analysis of the hydrologic components in the Whitewater Lake system is determined through consideration of the water budget and hydrochemical budget of the lake. Changes in storage and major-ion chemistry of the lake during any period are a result of the net effect of water inflow and outflow, and major-ion input and loss to and from the lake. These budgets are useful in evaluating the groundwater component of the system since this component cannot be measured directly.

Water Budget

The water budget of Whitewater Lake for any time interval t during the open water season may be expressed:

$$V_F - V_I = V_{TI} - V_{TO} \qquad (1)$$

where V_F = final lake volume, V_I = initial lake volume, V_{TI} = volume of total gain and V_{TO} = volume of total loss. Inflow components are precipitation V_P, groundwater inflow V_{GI} and surface runoff V_{SI}. Outflow components are evaporation and transpiration V_{EP}, groundwater outflow V_{GO} and surface outflow V_{SO}. Expanding equation 1 then:

$$V_F - V_I = V_P + V_{GI} + V_{SI} - V_{EP} - V_{GO} - V_{SO}. \qquad (2)$$

Since the lake has no surface outlet $V_{SO} = 0$. If an interval is chosen when surface runoff is negligible and $V_{SI} = 0$, then equation 2 may be written:

$$V_F - V_I = V_P + V_{GI} - V_{EP} - V_{GO} \tag{3}$$

The net groundwater component is:

$$V_{GI} - V_{GO} = V_F - V_I - V_P + V_{EP} \tag{4}$$

Since the components of the right hand side of the equation may be approximated from direct measurements this leaves an equation with two unknowns which may be written:

$$V_{GI} - V_{GO} = X . \tag{5}$$

Equation 5 is an expression of the net groundwater flux in the lake for the time interval considered.

Results of water budget calculations of Whitewater Lake for two periods of no surface inflow from July 6 to August 31, 1970 and July 15 to August 31, 1971 are shown in Fig. 58, p. 194. Data used in calculations are presented in Table 37, p. 254.

A negative groundwater flux with groundwater outflow exceeding inflow was calculated for the period in 1970. In 1971 a positive groundwater flux occurred with inflow exceeding outflow. Since the water budget calculations only provide a measure of the groundwater flux a quantitative evaluation of the probable groundwater movement through the pertinent geohydrologic units underlying the lake was undertaken to define the quantities which could be entering and leaving the lake.

Groundwater Inflow

A major source of groundwater inflow is through the shallow glacial sand and gravel Unit 9 which channels water downslope from the Boissevain Formation south of Whitewater Lake (Fig. 18, p. 153). These deposits also occur north of the lake where they are recharged locally. A seepage segment 5 miles (8km.) in length was estimated for the deposits south of the lake and average thicknesses of 5 and 10 feet (1.7 and 3.0 m.) were assigned. The area north of the lake was assigned a segment length of 3 miles (4.8 km.) and an average thickness of 5 feet (1.7 m.). A range of hydraulic gradient values were estimated from Fig. 18, p. 153 and a range of permeability values were assigned. Probable discharge from these deposits over a period of 45 days was calculated using Darcy's Law in the form:

$$Q = KA(\text{grad } h)T \tag{6}$$

where Q is the total discharge in ft.^3, K is the average permeability in ft.sec.^{-1}, grad h is the average hydraulic gradient and T is the time in seconds. Results of these calculations shown in Table 38, p.255 indicate that the total groundwater discharge from glacial sand and gravel Unit 9 under optimum conditions could be as much as $1,200 \times 10^6$ ft.^3 (28,000 acre-feet) over a period of 45 days. Using an average permeability value of 5×10^{-2} ft.sec.^{-1} which is not unlikely for sand and gravel and average hydraulic gradient values from 5×10^{-3} to 1×10^{-2} gives a total discharge in the range 300 to 575×10^6 ft.^3 (7500 to 13,000 acre-feet). Discharge from sand and gravel Unit 5 was not calculated since the areal extent of the deposits under the lake is not known and because the deposits are mantled by glacial till having a very low permeability. Undoubtedly some discharge from the unit is occurring particularly along the creek channels south of the lake. Major quantities of seepage from the unit however are probably not entering the lake.

Subsurface Outflow

Subsurface outflow from Whitewater Lake is probably taking place as downward seepage through the bottom sediments and glacial till underlying the lake. Seepage areas of 10 and 20 square miles were estimated and average hydraulic gradients of 0.5 and 1.0 were assigned. Average permeability values were assigned and seepage quantities over a period of 45 days were calculated using Darcy's Law. Results of these calculations shown in Table 39, p. 256 indicate that seepage through the bottom sediments and glacial till could be as much as 1,100 × 10^6 ft.^{3} (25,000 acre-feet) over a 45 day period. Using an average permeability of 5 × 10^{-7} for the glacial till and a hydraulic gradient of 1, probable seepage quantities for areas from 10 to 20 square miles would range from 300 to 500 × 10^6ft.^{3} (7,000 to 11,000 acre-feet) over a 45 day period.

Hydrochemical Budget

The hydrochemical budget of Whitewater Lake for any particular time t during the open-water season may be expressed as;

$$C_F V_F - C_I V_I = C_{TI} V_{TI} - C_{TO} V_{TO} \tag{7}$$

where C_F = final concentration of a major-ion, conductivity or total dissolved solids, in the lake,

C_I = initial concentration in the lake,

C_{TI} = total concentration of the inflow components,

C_{TO} = total concentration of the outflow components.

This equation however does not include the effects of evapotranspiration or chemical processes acting in the lake. The effect of these factors is applied to the initial lake concentration and equation 7 may be rewritten:

$$C_F V_F - K(C_I V_I) = C_{TI} V_{TI} - C_{TO} V_{TO} \qquad (8)$$

where K is the coefficient to account for the effect of evapotranspiration, carbonate precipitation, precipitation of salts along the shores, mechanical loss of salts through evaporation, and other factors. Although these factors act throughout the interval chosen their effect only on the initial concentration was examined to simplify the calculations. The error involved is probably insignificant. Since evapotranspiration is probably the major factor acting to increase the concentration of the lake and the other factors cause dilution, K is always greater than 1. The value of K may be determined from the relationship:

$$K = \frac{V_I}{V_I - V_{EP}} \qquad (9)$$

assuming evapotranspiration is the main factor. Equation 8 may be expanded in consideration of equation 3 to:

$$C_F V_F - K(C_I V_I) = C_P V_P + C_{GI} V_{GI} - C_{GO} V_{GO} \qquad (10)$$

where C_P = concentration of precipitation, C_{GI} = concentration of inflowing groundwater and C_{GO} = concentration of outflowing groundwater. The concentration of outflowing groundwater in this case would be the average lake water concentration during the interval examined and would be expressed:

$$C_{GO} = \frac{C_I + C_F}{2} . \qquad (11)$$

Rearranging equation 10:

$$C_F V_F = K(C_I V_I) + C_P V_P + C_{GI} V_{GI} - C_{GO} V_{GO} \qquad (12)$$

and using equation 5 substituting the value of V_{GI} from equation 12 gives:

$$C_F V_F = K(C_I V_I) + C_P V_P + C_{GI}(X + V_{GO}) - C_{GO} V_{GO} \ . \qquad (13)$$

Expanding and collecting terms of V_{GO}:

$$V_{GO} = \frac{C_F V_F - K(C_I V_I) - C_P V_P - C_{GI} X}{C_{GI} - C_{GO}} \ . \qquad (14)$$

Once V_{GO} is determined the value may be substituted into equation 5 to solve for V_{GI}.

Computer Analysis

Since the concentrations of the groundwaters in the basin exhibit a wide range of values, the solution of equations 14 and 5 require a range of values to be considered for the concentration of the inflowing groundwater C_{GI}. Conductivity values for example range 1,000 to 30,000 micromhos. cm.$^{-1}$. Consideration of a range of C_{GI} values consequently results in a range of values for V_{GI} and V_{GO} being determined. These calculations are best handled by computer analysis whereby the range of values can be determined quickly.

A computer program was developed to solve hydrochemical budget equations of Whitewater Lake for periods in 1970 and 1971. The program was run on an IBM-360 computer at the University of Manitoba. Two time periods were examined; one during the 1970 season and the other during

1971 on the basis of available data from intervals when surface runoff was negligible. Maximum time periods were chosen to reduce errors in the measurement of the parameters. A linear change was assumed for all the parameters during the periods.

Changes in conductivity, total dissolved solids, Na^+ concentration and Cl^- concentration were utilized providing 4 solutions for each period investigated. Na^+ and Cl^- were chosen because these ions are probably not involved to a major extent in chemical reactions in the lake. Ca^{2+}, Mg^{2+} and HCO_3^- were not used because they are probably precipitated as carbonate minerals or are affected by biological processes. The analytical error incurred in the determination of SO_4^{2-} was too high to warrant the use of this ion as a sensitive parameter. Data obtained for two periods of no surface inflow from July 6 to August 31, 1970 and July 15 to August 31, 1971, are shown in Table 37, p. 254. Lake volumes were determined from planimeter measurements on the contour map of the lake after the method of Hutchinson (1957). Precipitation values for 1970 were obtained from monthly meteorological records (Department of Transport, 1970) for the station at Boissevain. Evaporation data in 1970 was obtained from records at Baldur, Manitoba. Precipitation and evaporation data for 1971 was obtained from station 2 established east of Whitewater Lake. Corrected Class "A" pan evaporation data for both years was increased by 40 percent to account for the probable effects of transpiration and other errors in the estimates of lake evaporation. Calculations of related volume changes due to evaporation and precipitation were based on lake areas corresponding to the initial lake levels considered. Concentrations of Na^+ and Cl^- in the rainfall were estimated as 1.00 and 0.60 ppm. respectively. Conductivity and total dissolved solids of the rainfall were given values of 25.0 micromhos.cm.$^{-1}$ and 25.0 ppm respectively. Results of the computer analysis of the two periods are shown in Tables 40-43, pp 257-260.

Results of the hydrochemical budgets based on conductivity values (Table 40, p. 257) indicate that the conductivity of inflowing groundwater was less than 3,800 micromhos.cm.$^{-1}$ in 1970 and less than 3,400 micromhos. cm.$^{-1}$ in 1971. Conductivity values greater than these figures gave negative values of inflow and outflow. Groundwater inflow in 1970 was slightly less than outflow while the reverse was true in 1971. Somewhat greater inflow and outflow occurred in 1971 compared to 1970. Hydrochemical budgets based on total dissolved solids (Table 41, p. 258) show the same trends as the budgets based on conductivity. The hydrochemical budgets based on Na^+ (Table 42, p. 259) indicate inflowing groundwater in 1970 contained less than 575 ppm. Na^+ and less than 625 ppm. in 1971. On the basis of Na^+ more groundwater flow occurred in 1971 while groundwater outflow exceeded inflow in 1970 and inflow exceeded outflow in 1971. Hydrochemical budgets based on Cl^- (Table 43, p. 260) indicate groundwater flow in 1970 contained less than 82 ppm. Cl^- and less than 74 ppm. Cl^- in 1971. On this basis greater groundwater flow occurred in 1971 while outflow exceeded inflow in 1970 and vice versa in 1971.

The hydrochemical budgets in 1970 and 1971 indicate groundwater inflow for periods of about 45 days was from 90 to 40,000 × 10^6 ft.^{3} (2,000 to 920,000 acre-feet) and 260 to 28,000 × 10^6 ft.^{3} (6,000 to 640,000 acre-feet) respectively. Groundwater outflow for these periods was in the range 125 to 40,000 × 10^6 ft.^{3} (2,900 to 920,000 acre-feet) for 1970 and 490 to 28,000 × 10^6 ft.^{3} (11,300 to 640,000 acre-feet) in 1971.

The hydrochemical budgets of 1970 and 1971 indicate a similarity in the conductivity,total dissolved solids, Na^+ and Cl^- content of the inflowing groundwater. The chemistry of a major groundwater input would not be expected to vary greatly from year to year. Conductivity values less than 3,800 micromhos.cm.$^{-1}$, Na$^+$ concentrations less than 625 ppm. and Cl$^-$ concentrations less than 82 ppm. would be characteristic of groundwater from sand and gravel Units 5 and 9 and the Boissevain Formation. Major groundwater inflow to the lake would probably be via Units 5 and 9 which channel water away from the Boissevain Formation. A major influx of saline groundwater is not occurring. Inflowing groundwaters dilute the lake offsetting the effects of evapotranspiration. Groundwater inflow is generally balanced by groundwater outflow. This relationship might be expected in the lake system since increased inflow would raise lake levels and subsequently the rate of seepage. The larger quantities of inflow and outflow in 1971 compared to 1970 appear reasonable since average lake chemistry was lower in 1971 and lake levels were higher.

Values of groundwater inflow in the range 90 to 40,000 × 10^6 ft.^{3} and outflow in the range 125 to 40,000 × 10^6 ft.^{3} for periods of 50 and 45 days represent minimum and maximum quantities of each component. Since lake volume at an elevation of 1,628.0 feet is only about 2,000 × 10^6 ft.^{3} (47,000 acre-feet) it seem improbable that the lake would be replaced by groundwater more than once during a period of 45 days. Inflow and outflow values greater than 2,000 × 10^6 ft.^{3} are therefore probably unreasonable. This assumption then limits the net conductivity of inflowing groundwater to a maximum of 3,000 micromhos.cm.$^{-1}$, total dissolved solids to 2,500 ppm., Na$^+$ to 500 ppm. and Cl- to 70 ppm.

Comparison of Groundwater Inflow and Outflow Quantities Calculated from Hydrochemical Budgets and Darcy's Law

Ranges of groundwater inflow and outflow for the 50 and 45 day periods in 1970 and 1971 calculated from the hydrochemical budgets and Darcy's Law are shown in Figs. 59 and 60, pp 195 - 196 . An upper limit for groundwater inflow and outflow was set using the maximum inflow and outflow quantities calculated from Darcy's Law.

From Figs.59 and 60, pp 195 - 196 it was evident that results from the hydrochemical budgets based on conductivity and total dissolved solids values gave minimum inflow and outflow values near the maximum limits calculated from Darcy's Law. This suggested that the values of conductivity and total dissolved solids were not reliable chemical parameters for use in the hydrochemical equations. Dilution effects caused by the precipitation of carbonates, precipitation of salts along the shores of the lake and mechanical loss of salt through evaporation were probably significant processes occurring in the lake. These effects would result in a lowering of the conductivity and total dissolved solids of the lake water. In order to satisfy the hydrochemical equations utilizing conductivity and total dissolved solids data larger quantities of inflowing groundwater, shown in Fig. 59 p. 195, with a relatively low conductivity and total dissolved solids would be generated to explain this phenomenon. Na^+ and Cl^- are probably not involved to a major extent in these processes. Hydrochemical results based on Na^+ and Cl^- concentrations show considerable overlap with the inflow and outflow quantities calculated from Darcy's Law. Na^+ and Cl^- concentrations therefore are better indicators for use in the hydrochemical equations. Cl^- concentrations set the lower limits (Figs. 59 and 60, pp 195 - 196) for groundwater inflow and outflow on the assumption that the Cl^- concentration in inflowing groundwater was greater than 14 pp. Cl^- concentrations greater than 14 ppm. correspond with groundwater having total dissolved solids greater than 1,000 ppm. These lower limits are within the ranges based on Na^+.

Using the established upper and lower limits, groundwater inflow for the 50 day period in 1970 was in the range 260 to 1,200 × 10^6 $ft.^3$. In 1971 groundwater inflow was in the range 700 to 1,200 × 10^6 $ft.^3$. Net concentrations of Na^+ and Cl^- in 1970 of the inflowing groundwater were in the range 350 to 500 ppm. Na^+ and 14 to 66 ppm. Cl^-. In 1971 Na^+ concentrations were in the range 73 to 290 ppm. and Cl^- concentrations from 14 to 30 ppm. These values were obtained from Tables 40-43, pp 257 to 260. Na^+ and Cl^- concentrations in these ranges correspond with groundwater from the Boissevain Formation and sand and gravel Unit 9a. Subsurface outflow was from 290 to 1,100 × 10^6 $ft.^3$ in 1970 and from 710 to 1,100 × 10^6 $ft.^3$ in 1971.

Groundwater inflow for a 50 day period in 1970 was a quantitiy of water equal to 15 to 60 percent of the initial lake volume. Subsurface outflow in 1970 was equal to 15 to 60 percent of the initial lake volume. In 1971 for a 45 day period groundwater inflow was equal to 35 to 60 percent of the initial lake volume. Subsurface outflow in 1971 was from 35 to 60 percent of the initial lake volume.

CHAPTER VI

SUMMARY OF CONCLUSIONS

Physical Parameters

Whitewater Lake is characterized by frequent seiches and long-term annual fluctuations in lake level. The lake is not thermally stratified. Whitewater Lake is classified as a permanent lake, moderately brackish with central expanses of open water surrounded by peripheral bands of emmergent vegetation. The occurrence and distribution of phreatophytic vegetation around the lake indicates groundwater conditions are an eminent factor in the basin. The distribution of saline soils around the lake suggests the area is a groundwater discharge area.

Whitewater Lake is situated in the central portion of a Pleistocene glacio-lacustrine basin within the Boissevain Till Plain. The basin is underlain by Cretaceous shales of the Riding Mountain Formation. A Late Cretaceous-Tertiary outlier of Boissevain Formation sandstone overlain by sandstones and shales of the Turtle Mountain Formation occurs on the Turtle Mountain Upland immediately south of the lake. Subsurface stratigraphy of the basin, structural evidence, bedrock topography and drift thickness indicate the origin of the basin is due to a collapse feature caused by the solution of salt from Devonian evaporite deposits below the area and/or to a Pre-Jurassic erosion feature on the Mississippian "escarpment" underlying the basin. During Tertiary-Early Pleistocene time a major preglacial river flowed from the Turtle Mountain Upland toward the northeast under the present location of Whitewater Lake. During the Pleistocene three till sheets were deposited in the basin separated by two interglacial deposits of sand and gravel. During final deglaciation of the area a glacial lake formed in the basin, extensive outwash deposits of sand and gravel were deposited on the north slope of Turtle Mountain and silt, sand and clay were deposited in the lake. Recent bottom sediments, up to 18 inches (46 cm.) in thickness, indicate that post-glacial deposition has been slow and uniform. Source areas of sediment are creeks south of the lake. Gradual northward expansion of alluvial floodplain deposits, reworking by shoreline processes, wave action and incorporation of suspended sediment in the lake and subsequent deposition on settling represent the major detrital contributions to the lake bottom. Laminated bottom sediments indicate seasonal variations in sedimentation rates, availability of sediment and the precipitation of calcium carbonate. Algae are important in trapping and precipitating calcium carbonate in mudflat areas and in the nearshore zone. Submergent vegetation is important in trapping detrital grains stirred up by wave action. The accumulation of calcareous bioclasts and plant fragments is an important bio-sedimentological process operating in the lake.

Although the region is subject to local variability in rainfall, precipitation is generally widespread and falls locally only when occur during the summer months. The major portion of the annual precipitation falls during the period April to August. Precipitation diminishes after July and August is usually a dry month. The annual precipitation measured near Whitewater Lake in 1970 was 17.2 inches (43.8 cm.). In 1971 for the period May to November the mean seasonal precipitation at Whitewater Lake was 15.9 inches (40.2 cm.).

Evaporation at Whitewater Lake increases during the summer months and is primarily controlled by the mean air temperature. After September evaporation declines steadily until the lake freezes in November. Maximum evaporation occurs in August. Lake evaporation estimated from Class "A" pan evaporation records for the period June to October 1970 was 21.7 inches (55.1 cm.). The mean seasonal lake evaporation determined from Class "A" evaporation pans located near the lake for the period May to November 1971 was from 19.5 to 22.0 inches (49.5 to 56.0 cm.).

Extensive areas of emergent vegetation at Whitewater Lake transpire large quantities of water in the nearshore zone and reduce wave conditions on the lake. The summer seasonal evapotranspiration in 1971 coupled with probable evaporation errors in determining lake evaporation was estimated to be from 27.3 to 30.8 inches (69.5 to 78.3 cm.). Compared to the summer seasonal precipitation mean of 1971 this indicated a moisture defecit of 11.4 to 14.9 inches (29.0 to 37.9 cm.).

Surface inflow to Whitewater Lake is limited to eight intermittent creeks which flow periodically off the north slope of Turtle Mountain. The lake lacks a surface outlet. Location of the creeks is controlled by the stratigraphy of the Pleistocene deposits and the bedrock geology. Many of the creeks have established themselves in the location of Pleistocene and/or Tertiary ancestral valleys. Peak flow rates from 100 to 200 cubic feet per second occur during the period of spring snow melt. The creeks flow during the spring months but gernerally become dry by early summer occasionally flowing again in the fall. Flow peaks do not correlate consistently with periods of rainfall. Springs occur at many places around the northern base of Turtle Mountain particularly along creek valleys south of Whitewater Lake. Stratigraphy along the creek valleys indicates that the geologic conditions favour high levels of base-flow to the creeks.

Water-table observation wells in the vicinity of Whitewater Lake indicate the water table slopes from the Turtle Mountain Upland toward the lake in coincidence with the topography. The water-table gradient indicates that groundwater movement is away from Turtle Mountain toward the lake. The water table rises during the months of March and April reflecting moisture storage from previous fall rains and snowmelt contributions to the water table. Generally this is followed by a decline in the water table during the summer months due to natural groundwater discharge and evapotranspiration during periods of low rainfall. Wells located in shallow sand and gravel deposits south of the lake exhibit moderate water table fluctuations suggesting the water table south of the lake is maintained by natural groundwater discharge. A comparison of water table fluctuations and creek hydrographs indicates that a rising water table during the early spring months corresponds with increased creek discharge. Decline in the water table during June and July meanwhile corresponds with decreased flow in the creeks.

The distribution of hydraulic head data around the lake suggests the lake is underlain by a piezometric low rather than a piezometric mound. Areally, groundwater flow is directed toward the centre of the lake basin from Turtle Mountain and the region north of the lake. Groundwater recharge occurs on the Turtle Mountain Upland with shallow groundwater moving downward and laterally through the Boissevain Formation and into outwash sand and gravel deposits to the north. Abrupt changes in permeability result in the upward movement of groundwater south of Whitewater Lake. This phenomenon is responsible for the occurrence of springs and formation of saline soils south of Whitewater Lake. Outwash sand and gravel deposits continuous and downslope from the Boissevain Formation channel groundwater laterally from the Boissevain Formation into shallow deposits around and under Whitewater Lake. Seepage from these deposits southwest and southeast of the lake is a major source of water for the lake. Wedging and thinning of these deposits toward the lake result in the upward movement of water into overlying lacustrine deposits and the downward movement into underlying glacial till units. Groundwater is also channeled downslope along the fractured contact between the upper glacial till units or through highly permeable glacial sand which occurs locally between these tills. Subsurface irregularities along this contact zone may also cause the upward movement of groundwater resulting in localized discharge areas and the formation of saline soils.

Groundwater movement within the glacial till units south of the lake is downward and laterally toward the north. Flow is concentrated toward regions where the glacial deposits are thickest. Stratigraphy exercises important control in groundwater movement as equipotential lines tend to parallel geologic contacts in the drift.

Groundwater movement within the shallow deposits under the north shore of Whitewater Lake is downward. Upward flow however is prevalent below 30 feet. The zone of demarcation corresponds to the contact between the upper glacial till units. Interglacial gravel deposits lying below the middle till unit are probably responsible for upward flow in this region. This lower gravel unit is continuous in part with the Boissevain Formation and its confined nature between two till units allows this unit to channel water downslope from the Boissevain Formation in a similar manner to the upper glacial sand units. Rapid thinning of the lower gravel unit under Whitewater Lake results in the upward movement of groundwater north of the lake. The upward flow is dissipated as lateral flow along the contact zone between the two upper till units.

A major groundwater outlet area for the basin occurs northeast of the lake. The region northeast of the lake lies within the thalweg of a buried valley and is underlain by highly permeable sands 25 feet (8.2 m.) below the ground surface. The shallow sand and gravel deposits northeast of the lake are probably more important in directing shallow groundwater toward the centre of the basin.

Lake levels examined in 1970 and 1971 exhibited the same seasonal fluctuations. A rise in the lake levels during May and June corresponded with flow from creeks south of the lake. Progressive lowering of lake levels during July and August was related to high evapotranspiration rates, small amounts of rainfall and no surface runoff. Steady lake levels prior to freeze-up was due to decreased rates of evaporation, increased amounts of precipitation and small amounts of surface runoff during the fall. No direct correlation between periods of rainfall and rising lake levels was observed. For the period June to October 1970 of no active surface runoff lake level dropped 1.0 feet (30.5 cm.) while lake evaporation less rainfall was 2.0 feet (61.0 cm.). In 1971 during the period of no active surface runoff from July to November lake level dropped 0.5 feet (15.3 cm.) while lake evaporation less rainfall was 0.7 feet (21.6 cm.). Lake evaporation figures for 1970 and 1971 were determined from Class "A" evaporation pan data and represent minimum losses considering probable errors in determining lake evaporation and since the total evapotranspiration was not considered. The discrepancy between the lake level changes and minimum evapotranspiration losses was attributed to the fact that additional quantities of water entered the lake via the groundwater regime to maintain lake levels.

Chemical Parameters

Calcium was the dominant cation present in rain plus dry fallout samples collected near Whitewater Lake in 1971 followed by sodium, magnesium and potassium in order of abundance expressed in terms of weight per unit volume. Sodium was the dominant cation present in a snow sample followed by magnesium, calcium and potassium. Molar concentrations indicated the rain samples were of the calcium-magnesium-bicarbonate type while the snow sample was the sodium-magnesium-sulphate type. Electrolytic conductivity values of the precipitation samples ranged from 6.6 to 388 micromhos.cm.$^{-1}$ at 25°C. pH ranged from 5.4 to 6.9. The wet fallout component of the rain samples was composed of calcium, magnesium, sodium and potassium cations in order of abundance expressed in terms of weight per unit volume while the dry fallout component enriched the samples in Na^+. Consistent values of Mg^{2+} and Ca^{2+} in the higher conductivity rain samples suggested that these cations were also a major contribution of the dry fallout component. Soil dust in the atmosphere resulting from strong winds, aridity and lack of protective vegetation in the region was attributed as the main source of the relatively high amounts of Ca^{2+}, Na^+ and Mg^{2+} in the rain samples. Relatively high concentrations of SO_4^{2-} corresponding with high Na^+ concentrations was attributed to soil dust as sodium sulphate salts are present and widespread in the saline soils of southwestern Manitoba. Seasonal variations in the chemistry of rain samples at stations west and east of Whitewater Lake showed higher concentrations of major ions occurring on the east side of the lake. Higher concentrations on the east side suggest salts and moisture are picked up locally under the influence of westerly winds through evaporation and deposited locally with precipitation . A general decrease in cation concentration during the summer was attributed to an increase in protective vegetation during the growing season, a moderation of winds and subsequent reduction of soil dust to the atmosphere. High cation concentration reported in early spring were due to strong spring winds, lack of protective vegetation and the cultivation of farmlands. High cation concentrations in late August and September probably reflected harvesting operations in the area with an increase of soil dust to the atmosphere. The oxygen^{18} composition of rain samples varied from -19.8 to -5.2 SMOW., with values decreasing slightly during the summer months.

Molar concentrations of creek samples collected in 1971 indicated the creeks ranged from the calcium-magnesium-bicarbonate type to the sodium-calcium-sulphate type. Many of the creeks appear to be a mixture of two chemically distinct waters; a calcium bicarbonate type and a sodium sulphate type. Average creek conductivities ranged from 722 to 1659 micromhos.cm.$^{-1}$ at 25°C. pH ranged from 8.0 to 8.5. Creek samples were supersaturated with respect to calcite and dolomite. Relatively large conductivity values up to 2800 micromhos.cm.$^{-1}$ indicated significant groundwater inflow to the creeks. Rapid increase in creek conductivities during the early spring indicated groundwater inflow was the most important component in the creek discharge. The simultaneous increase of the water table and creek discharge suggests these conditions are controlled by natural groundwater discharge conditions related to long-term precipitation trends and delayed flow. The oxygen^{18} composition of the creek samples ranged from -19.3 to -8.7 SMOW., with the O^{18} content of the creeks increasing during the season.

Three chemical types of groundwater were deliniated in the Whitewater Lake Basin: Type I, a calcium-magnesium-bicarbonate-sulphate facies characteristic of the Boissevain Formation and the shallow sand and gravel deposits, Type II, a calcium-magnesium-sulphate facies occurring in a variety of deposits including glacial till and glacial sand, and Type III, a sodium sulphate and sodium chloride facies characteristic of glacial till and the Riding Mountain Formation. Electrolytic conductivity values ranged from 1000 to 41,000 micromhos.cm.$^{-1}$ at 25°C., with lowest values occurring in the Boissevain Formation and shallow outwash sand and gravel deposits while larger values were characteristic of till waters and waters from the Riding Mountain Formation. Spacial variations in the major-ion chemistry of the groundwater generally substantiates the groundwater movement interpreted from the hydraulic head measurements. Major-ion chemistry moreover suggested upward movement of groundwater through the Boissevain Formation,and upward movement of sodium chloride waters from the Riding Mountain Formation under the northeastern portion of the basin. pH and HCO_3^- relationships in the shallow groundwater indicated that the observed concentrations of these components was from the dissolution of calcite and dolomite. Excess concentrations of Ca^{2+} and Mg^{2+} could not be related to the simple dissolution of calcite and dolomite and were attributed to cation exchange processes in the glacial deposits under Whitewater Lake. Upward moving sodium chloride groundwater from the Riding Mountain Formation may cause the release of Mg^{2+} and Ca^{2+} from montmorillonite clay minerals in the glacial deposits in exchange for Na^+. The oxygen^{18} composition of groundwater samples ranged from -18.0 to -2.0 SMOW. Higher values of O^{18} occurred in the shallow deposits indicating above-surface processes of evaporation and subsurface processes such as evapotranspiration in recharge areas of the glacial deposits and evaporation of discharging groundwater are significant processes near the lake. A comparison of the oxygen^{18} values exhibited by the groundwater samples with those exhibited by the creek samples indicated the creek samples corresponded with the groundwater samples from the shallow glacial deposits. Increasing amounts of groundwater inflow to the creeks during periods of active flow would explain the increase in the O^{18} content of the creeks during these periods.

Whitewater Lake was characterized by a consistent molar chemistry of the sodium-magnesium-sulphate type during the years 1968 through 1971, although seasonal variations in total dissolved solids, electrolytic conductivity, major-ion concentrations and pH occurred. A slight decreasing trend in total dissolved solids has occurred during these years. Annual constancy in the relative ionic composition of the lake suggests ion input to and loss from the lake has been a constant process and that some controlling factor operates,minimizing major changes in ion input or loss. The major-ion chemistry of the lake corresponded closely with groundwater from the shallow deposits of glacial sand and glacial till and with some of the surface waters from streams south of the lake. Seasonal increase in the total dissolved solids, conductivity, major-ion chemistry and pH of the lake was controlled mainly by evaporation. Lake pH was also affected by inflowing groundwater along the south shore of the lake. Seasonal rainfall did not affect the major-ion chemistry of the lake greatly although minor downward fluctuations occurred during periods of rainfall. Flushing of the lake occurred during the winter through shallow groundwater movement. Highly concentrated lake water moved downward or laterally through the bottom sediments and was replaced by inflowing groundwater having a relatively low conductivity. The evaporation effect during the summer months caused increases in all the major ions although Na^+ and SO_4^{2-} increased more rapidly than the other ions. This was due to high inputs of sodium sulphate groundwater from the glacial deposits and also the precipitation of $CaCO_3$, $MgCO_3$ and $MgSO_4$ salts along the shore flats. Frequent fluctuations in the concentrations of Ca^{2+} and HCO_3^- in the lake water during the season was attributed to the precipitation of calcium carbonate from the water column both chemically and biologically.

Rapid increase in the O^{18} content of the lake during the open-water season of 1970 and 1971 occurred due to high evapotranspiration rates. Lower δO^{18} values occurring near the southern shore of the lake were caused by the influx of isotopically lighter groundwater and/or surface runoff. Low δO^{18} values for the samples obtained under the ice substantiated the concept of lake flushing through downward seepage and the influx of groundwater.

Interstitial water samples from the lake bottom sediments were chemically similar to the lake water samples with slight modification indicating that downward movement of lake water is occurring. Relatively high δO^{18} values of the interstitial water samples indicate they represent former lake waters which have moved downward into the bottom sediments.

Hydrologic and Chemical Budgets

Groundwater inflow to Whitewater Lake for a 45 day period was calculated using Darcy's Law. Total discharge from glacial sand and gravel Unit 9 could be as much as 1200 x 10^6 $ft.^3$ (28,000 acre-feet) in 45 days. Subsurface outflow through the bottom of the lake could be as much as 1100 x 10^6 $ft.^3$ (25,000 acre-feet) in 45 days.

Results of hydrochemical budgets indicate groundwater inflow in 1970 and 1971 contained less than 2500 total dissolved solids, less than 500 $mg.liter^{-1}$ Na^+ and less than 70 $mg.liter^{-1}$ Cl^-. A major influx of saline groundwater did not occur. Values of conductivity and total dissolved solids were not reliable chemical parameters for use in the hydrochemical equations. Dilution effects caused by the precipitation of carbonates, precipitation of salts along the shores of the lake and mechanical loss of salt through evaporation were significant processes operating in the lake. Na^+ and Cl^- were better indicators for use in the hydrochemical budget equations.

Groundwater inflow for a 50 day period in 1970 was a quantity of water equal to 15 to 60 percent of the initial lake volume. Subsurface outflow in 1970 was equal to 15 to 60 percent of the initial lake volume. In 1971 for a 45 day period groundwater inflow was equal to 35 to 60 percent of the initial lake volume. Subsurface outflow in 1971 was from 35 to 60 percent of the initial lake volume.

Groundwater inflow is an important factor in the lake. Inflowing groundwater maintains lake levels in spite of losses due to evapotranspiration and subsurface seepage . While continuously contributing quantities of dissolved solids inflowing groundwater also dilutes the lake which is being concentrated by evapotranspiration. Subsurface outflow continuously removes brackish water from the lake and is a major loss and dilution factor. The formation of ice during the winter and flushing of concentrated lake water under the ice are important factors which prevent the progressive annual accumulation of major ions in the lake water and maintain the relative "freshness" of the lake.

CHAPTER VII

REFERENCES CITED

Anderson,S.B. and Hunt,J.B. (1964)- Devonian salt solution in north central North Dakota; Third International Williston Basin Symposium, pp. 93-104.

Armstrong,F.A.J. and Schindler, D.W. (1971)- Preliminary Chemical Characterization of Waters in the Experimental Lakes Area, Northwestern Ontario; Jour. Fish. Res. Board of Can., Vol.28, No.2.

Baille,A.D. (1953)- Devonian system of the Williston Basin area, Manitoba; Manitoba Mines Br. Publ. 67-1.

Barnes,I. (1964)- Field measurement of alkalinity and pH; U.S. Geol. Surv., Water Supply Paper 1535 - H.

Baver, L.D. (1963)- Soil physics; 3rd Edition, Wiley and Sons, New york.

Bossenmaier, E.F. (1953)- Field feeding of waterfowl in the Whitewater Lake district of southwestern Manitoba; M.Sc. thesis, Univ. of Minnesota.

______________Olson, T.A. and Marshall. W.H. (1954)- Some field and laboratory aspects of duck sickness at Whitewater Lake, Manitoba; Transactions of the Nineteenth North American Wildlife Conference, Wildlife Management Institute, Washington., pp 163-175.

Brodin, G. and Barrett, C. (1955)- The acidity of Scandinavian precipitation; Tellus VII, 2., p. 252.

Carroll, D. (1970)- Rock weathering; Plenum Press, New york.

Cherry, J.A. (1971)- Geochemical processes in shallow groundwater flow systems in five areas in southern Manitoba, Canada; *submitted for publication in*: Proceedings, XXIV International Geological Congress, Montreal.

__________and Whitaker, SH. (1969)- Geology and Groundwater resources of the Yorkton area (62-M,N) Saskatchewan; Saskatchewan Research Council.

__________Beswick, B.T., Clister, W.E. and Lutchman, M. (1971)- Flow patterns and hydrochemistry of two shallow groundwater regimes in the Lake Agassiz Basin, southern Manitoba; *in* Geoscience studies in Manitoba, Geol. Assoc. of Can., Spec. Paper No. 9, pp 321-332.

Christiansen, E.A. (1962)- Hydrogeology of surficial and bedrock valley aquifers in southern Saskatchewan; *in* Proceedings of Hydrology Symposium No. 3, National Res. Council Can. Publ., pp 49-71.

Christiansen (1967)- Collapse structures near Saskatoon, Saskatchewan, Canada; Can. J. Earth Sci. Vol.4, No. 5, pp 757-768.

Craig, H. (1957)- Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide; Geochim et Cosmochim. Acta, Vol. 12, p. 133.

Dansgaard, W. (1953)- The abundance of ^{18}O in atmospheric water and water vapour; Tellus 5, pp 461-469.

Degens, E.T. and Chilingar, C.V. (1967)- Diagenesis of subsurface waters;*in*: Developments of Sedimentology, No. 8., Diagenesis in sediments, Elsevier Pub. Co.

Department of Energy Mines and Resources(1967)- Map N.T.S. 62.

Department of Transport (1966 - 1970)- Records of monthly meteorological observations; Meteorological Branch, Ottawa.

______________________ (1970)- Monthly and annual maps of lake evaporation; Climatic Map Ser. 8, Toronto.

Dincer, T. (1968)- The use of oxygen 18 and deuterium concentrations in the water balance of lakes; Water Resources Research, Vol. 4, No. 6, pp 1289-1306.

Eilers, R.G. (1971)- General report on soils, groundwater and salinity for the Whitewater Lake Basin area; unpublished report, Manitoba Soil Survey.

___________ (1972)- Influence of hydrogeologic factors in genetic soil distribution in the Turtle Mountain area, Manitoba; M.Sc. thesis, Dept. of Soil Science, Univ. Manitoba (in preparation).

Eisenlohr, W.S. Jr. (1966)- Water loss from a natural pond through transpiration by hydrophytes; Water Resources Research, Vol. 2, No. 3, pp 443-453.

____________________(1969)- Hydrology of small water areas in the prairie pothole region; Saskatoon Wetlands Seminar, Can. Wildlife Service Report Ser. No. 6, Dept. of Indian Affairs and Northern Development, part II, pp 35-39.

Ellis, J.H. (1938)- The soils of Manitoba; Economic Survey Board of Manitoba.

__________ and Shafer, W.H. (1940)- Reconnaisance soil survey southwestern Manitoba; Soils report No. 3, Manitoba Dept. of Agriculture.

Elson, J.A. (1958)- Pleistocene history of southwestern Manitoba; *in*: Guidebook Ninth Annual Field Conference, Mid-Western Friends of Pleistocene, North Dakota Geol. Surv., Misc. Ser. No. 10, pp 62-73.

__________ (1962)- Virden area, Manitoba and Saskatchewan (Surficial Deposits); Geol. Surv., Canada, P.S. Map 39-1961.

__________ and Halstead, E.C. (1949)- Groundwater resources of Townships 1 to 6, Ranges 18 to 21, Manitoba (Boissevain Area); Geol. Surv. Canada, Water Supply Paper No. 301.

Epstein, S. (1957)- Nuclear processes in geologic settings; Nat. Academy Sci., U.S. Res. Council, Publ. 400.

__________ and Mayeda, T. (1953)- Variations of O^{18} content of waters from natural sources; Geochim et Cosmochim. Acta., No. 4, pp 213-224.

Ferguson, H.L., O'Neill, A.D.J. and Cork, H.F. (1970)- Mean evaporation over Canada; Water Resources Research, Vol. 6, No. 6, pp 1618-1633.

______________ and Storr, D. (1969)- Some current studies of local precipitation variability over western Canada;*in*: Water Balance in North America, American Water Resources Assoc., Proceedings Ser. No. 7, pp 80-101.

Fishman, M.J. and Downs, C. Sanford (1966)- Methods for analysis of selected metals in waters by atomic absorption; U.S. Geol. Surv. Water Supply Paper 1540-C.

Freeze, R.A. (1963)- Groundwater probability, Virden east half, Manitoba Map 1137A, Geol. Surv. of Canada.

Friedman, I. (1953)- Deuterium content of natural waters and other substances; Geochim. et Cosmochim. Acta. No. 4, pp 89-103.

Garrels, R.M. and Christ, C.L. (1965)- Solutions, minerals and equilibria; Harper and Row, New York.

Gat, J.R. and Tzur, Y.T. (1967)- Modification of the isotopic composition of rainwater by processes which occur before groundwater recharge; *in*: Isotopes in hydrology; International Atomic Energy Agency, Vienna.

Graf, D.L., Friedman, I. and Munts, W.F. (1965)- The origin of Saline formation waters: Part II, Isotopic fractionation by shale micropore systems; Illinois State Geol. Surv. Circ. 393.

Halliday, W.E.D. (1937)- A forest classification for Canada; Forest Series, Bull. No. 89, Ottawa.

Halstead, E.C. (1959)- Groundwater resources of the Brandon Map area, Manitoba; Geol. Surv. Canada, Memoir 300.

____________ and Elson, J.A. (1949)- Groundwater resources of the Deloraine area, Manitoba; Geol. Surv. Can. Water Supply Paper No. 300.

Howard, A.D. (1960)- Cenozoic history of northeastern Montana and northwestern North Dakota with emphasis on the Pleistocene: U.S. Geol. Surv. Prof. Paper 326.

Hutchinson, G.E. (1957)- A treatise on limnology Vol. I. John Wiley, New York.

Johnston, W. (1934)- Surface deposits and groundwater supply of Winnipeg Map area, Manitoba; Geol. Surv. Can., Memoir 174.

Kazmann, R.G. (1965)- Modern hydrology; Harper and Row, New York.

Klassen, R.W. (1969)- Quaternary stratigraphy and radiocarbon chronology in southwestern Manitoba; Geol. Surv., Paper 69-27.

____________Delorme, L.D. and Mott. R.J. (1967)- Geology and paleontology of Pleistocene deposits in southwestern Manitoba; Can. J. Earth Sci., Vol. 4, pp 433-447.

____________ and Wyder, J.E. (1970)- Bedrock topography, buried valleys and nature of the drift, Virden map area, Manitoba; Geol. Surv. Can., Paper 70-56.

Kohler, M.A., Nordenson, I.J. and Fox, W.E. (1955)- Evaporation from pans and lakes; U.S. Dept. of Commerce Weather Bureau, Wash., Res. Paper 38.

Kupsch, W.O. (1958)- Surface structures in southern Saskatchewan; Second Williston Basin symposium, Sask. Geol. Soc. and North Dakota Geol. Soc.

____________ (1964)- Bedrock surface and preglacial topography of the Regina-Wynyard region, southern Saskatchewan; *in*: Third International Williston Basin Symposium.

Langmuir, D. (1971)- The geochemistry of some carbonate groundwaters in central Pennsylvania; Geochim. et Cosmochim. Acta. Vol. 35, pp 1023-1045.

Linsley, R.K. and Franzini, J.B. (1972)- Water-resources engineering; 2nd. Edition, McGraw - Hill book Co.

McCabe, H.R. (1959)- Mississippian stratigraphy of Manitoba; Manitoba Mines Br. Publ. 58-1.

___________ (1963)- Mississippian oil fields of southwestern Manitoba; Manitoba Mines Br. Publ. 60-5.

___________ (1971a)- Subsurface stratigraphic studies; *in*:Summary of Field Work, Manitoba Mines Br. Publ.

___________ (1971b)- Stratigraphy of Manitoba, an introduction and review; *in*: Geoscience studies in Manitoba, Geol. Assoc. of Can., Spec. Paper No. 9, pp 321-332.

McKay, G.A. and Stichling, W. (1961)- Evaporation computations for prairie reservoirs; *in*: Proceedings of hydrology symposium No. 2 Evaporation, Dept. of Northern Affairs and Natural Resources, Water resources Br., pp 135-167.

McKay, G.A. (1965)- Evaporation from lakes and reservoirs on the Canadian prairies; Prairie provinces water board, Report No. 5, Supplement A.

Menely, W.A., Christiansen, E,A., and Kupsch, W.O. (1957)- Preglacial Missouri River in Saskatchewan; J. Geol., Vol. 65, pp 441-447.

Mukammal, E.J. (1958)- Study of the Boissevain storm of august 11-12 1957 in Manitoba; Meteorological Br, Department of Transport.

___________ (1961)- Evaporation pans and atometers; *in*: Proceedings of hydrology symposium No. 2, Evaporation, Dept. of Northern Affairs and Natural Resources. Water Resources Br. pp 84-99.

Pettijohn, F.J. (1957)- Sedimentary rocks; 2nd Edition, Harper and Row, New York.

P.F.R.A. (1971)- Report of engineering investivations, Whitewater Lake area; Appendix A, *in*: Report on hydrologic and hydraulic investigations Whitewater Lake area, October, Water Resources Br.

Pratt, L.E. and Ellis, J.H. (1954)- The nature and distribution of saline soils in Manitoba; Manitoba Soil Survey, University of Manitoba.

Quinn, J.H. (1957)- Paired river terraces and Pleistocene glaciation; Jour.Geol. Vol.65, 2, pp 149-166.

Rainwater, F.H, and Thatcher, L.L. (1960)- Methods for collection and analysis of water samples, U.S. Geol. Surv. Water Supply Paper 1454.

Reeburgh, W.S. (1957)- An improved interstitial water sampler; Limnology and Oceanography, Vol. 12, No. I, pp 163-165.

Robinson, T.W. (1958)-Phreatophytes; U.S. Geol. Survey, Water Supply Paper 1423.

Rutherford, G.K. (1967)- A preliminary study of the composition of precipitation in S.E. Ontario; Can. Jour. Earth Sciences, V. 4 pp 1151-1160.

Schoeller, H. (1959)- Recent developments in hydrogeology; Arid Zone Hydrology, Arid Zone Research No. 12 UNESCO.

Schwartz, F.W. (1970)- Geohydrology and hydrochemistry of groundwater: streamflow systems in the Wilson Creek Experimental Watershed, M.Sc. thesis, Dept. of Earth Sciences, Univ. of Man.

Shepard, F.P. (1954)- Nomenclature based on sand-silt-clay ratios; Jour. Sed. Petrol. V. 24, pp 151-158.

Stalker, A.MacS. (1961)- Buried valleys in central and southern Alberta; Geol. Surv. Can. Paper 60-32.

Stwart, R.E and Kantrud, H.A. (1971)- Classification of natural ponds and lakes in the glaciated prairie region; Resource Publ. 92, Bureau of Sport Fisheries and Wildlife, Washington.

Strakhov, N.M. (1970)- Principles of lithogenesis; Vol. 3, Plenum Publ. Co.

Tarasov, M.N. (1967)- Water and salt balance of Lake Balkash during periods of falling and rising levels; *in*: Soviet Hydrology. Issue No. 5.

van Everdingen, R.O. (1963)- Groundwater flow-diagrams in sections with exaggerated vertical scale; Geol. Surv. Can., Paper 64-27.

____________________ (1971)- Surface water composition on southern Manitoba reflecting discharge of saline subsurface waters and subsurface solution of evaporites ; *in*: Geoscience studies in Manitoba, Geol. Assoc. of Can. Special Paper No. 9 pp 343-352.

Manitoba Water Resources Branch (1963-1970)- Manitoba Water Well Drillers' Reports.

________________________________ (1971)- Report on hydrologic and hydraulic investigations Whitewater Lake area; unpublished report.

Wickenden, R.T.D. (1945)- Mesozoic stratigraphy of the eastern plains, Manitoba and Saskatchewan; Geol. Survey of Can., Memoir 239

Witkind, L. (1959)- Quaternary geology of the Smoke Creek-Medicine Lake-Grenora area, Montana and North Dakota; U.S. Geol. Surv. Bull. 1073.

Wiklander, L. (1964)- Cation and anion exchange phenomena; *in*: Chemistry of the soil, 2nd Edition, ACS Monograph, No. 160, pp 163-205.

Zverev, V.P. (1963)- On the question of the part played by the chemical composition of atmospheric precipitation in the formation of groundwater in the Medvenka River Basin; Soviet Hydrology, pp 674-678.

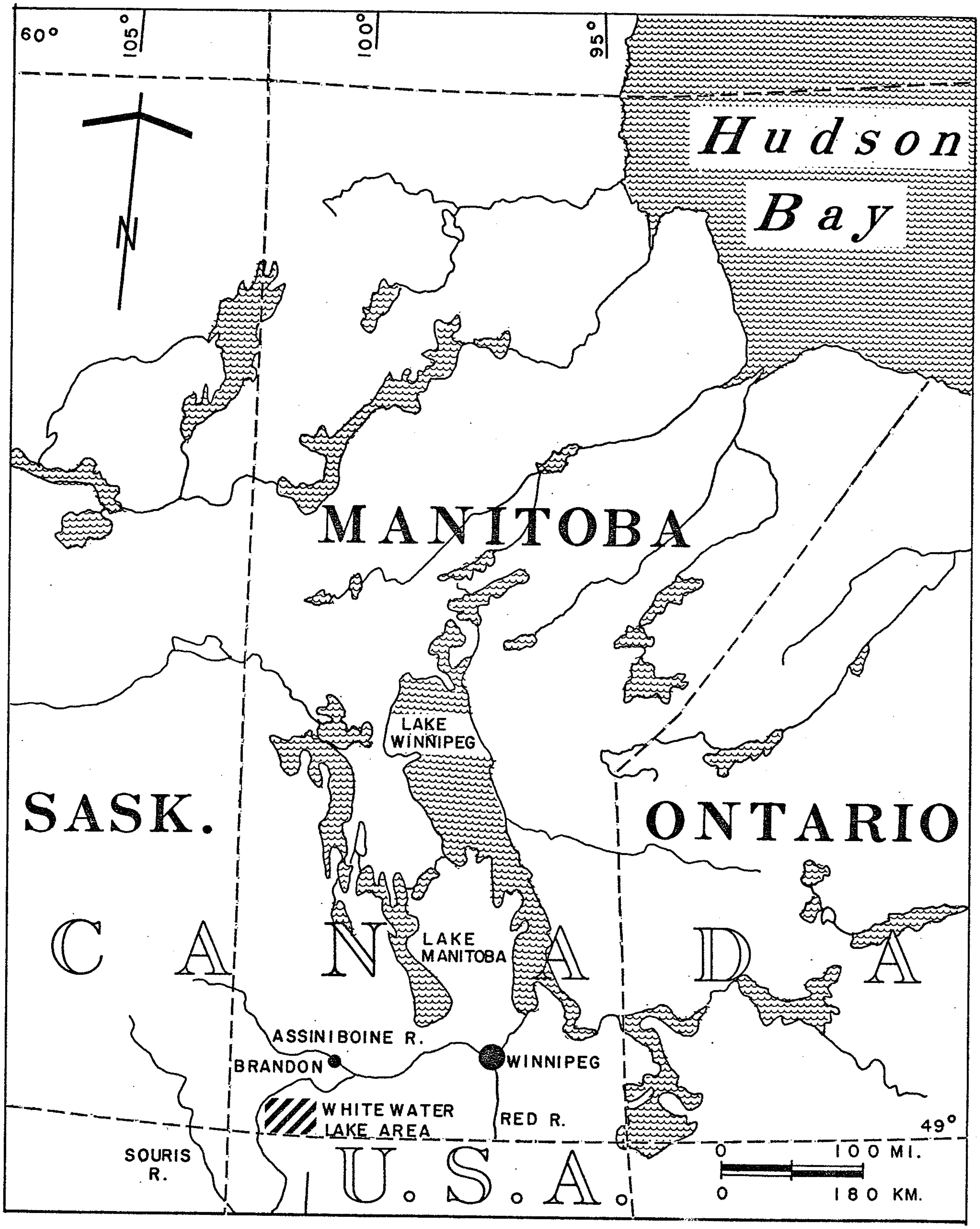


Fig. 1. Location map of the Whitewater Lake area.

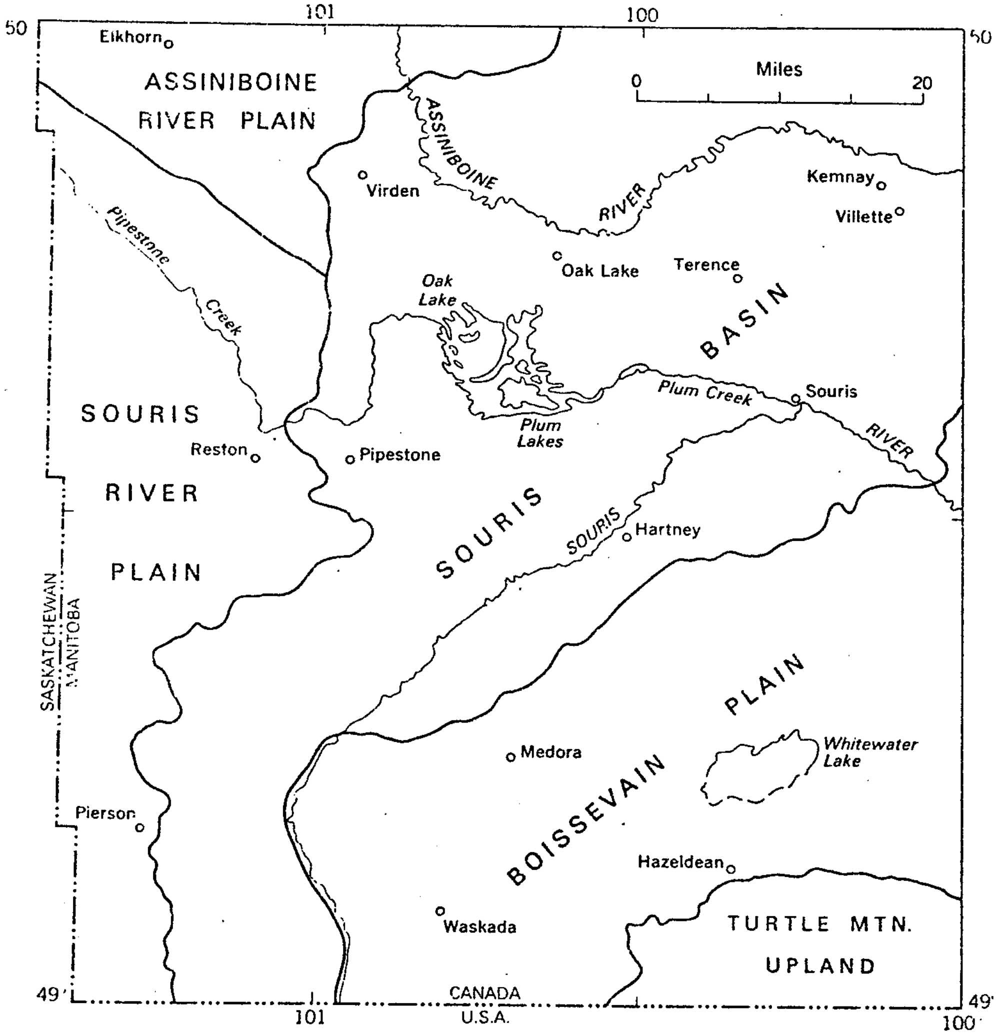


Fig. 2. Physiographic divisions of southwestern Manitoba (from Klassen and Wyder, 1970).

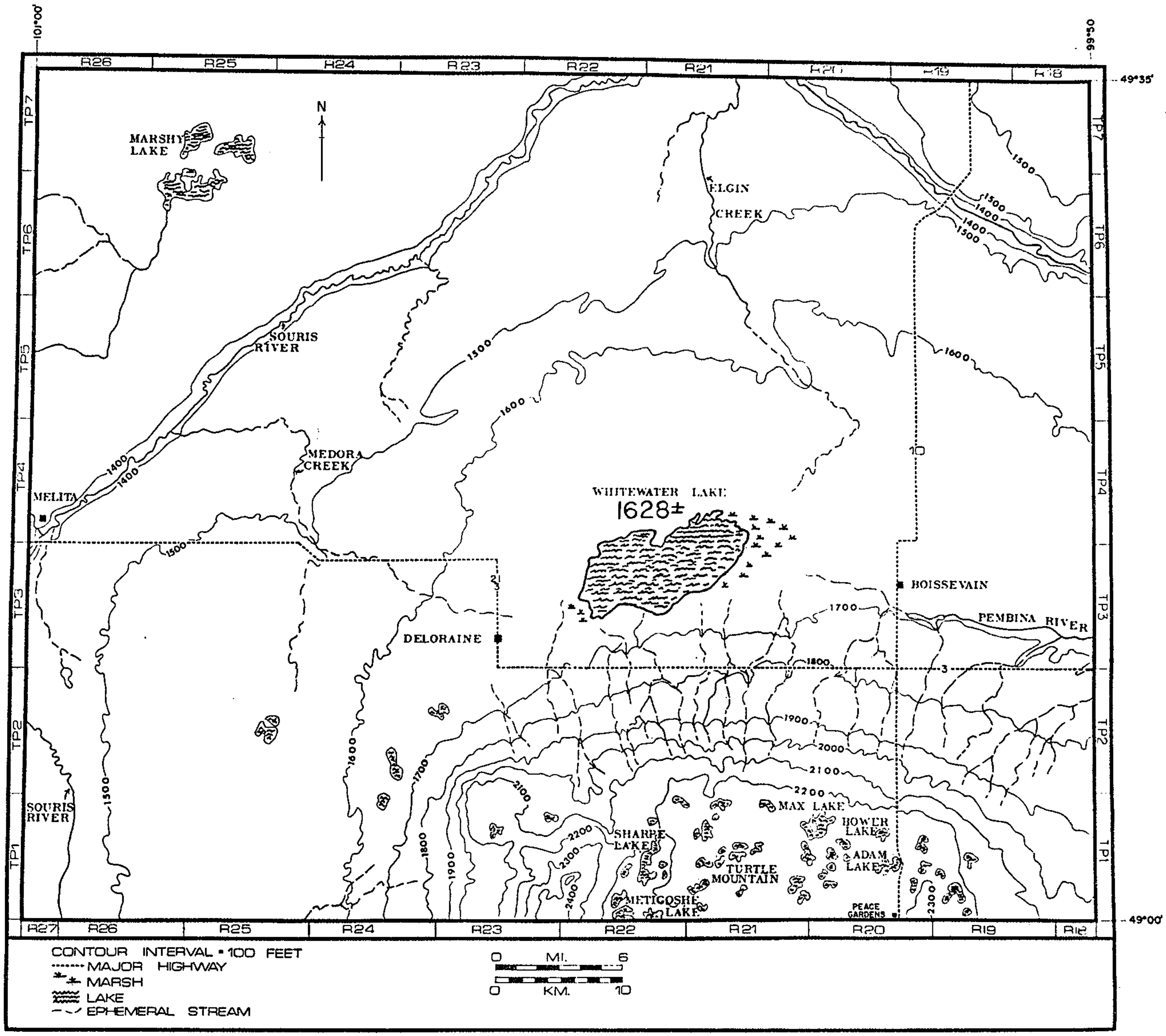


Fig. 3. Topography and drainage.

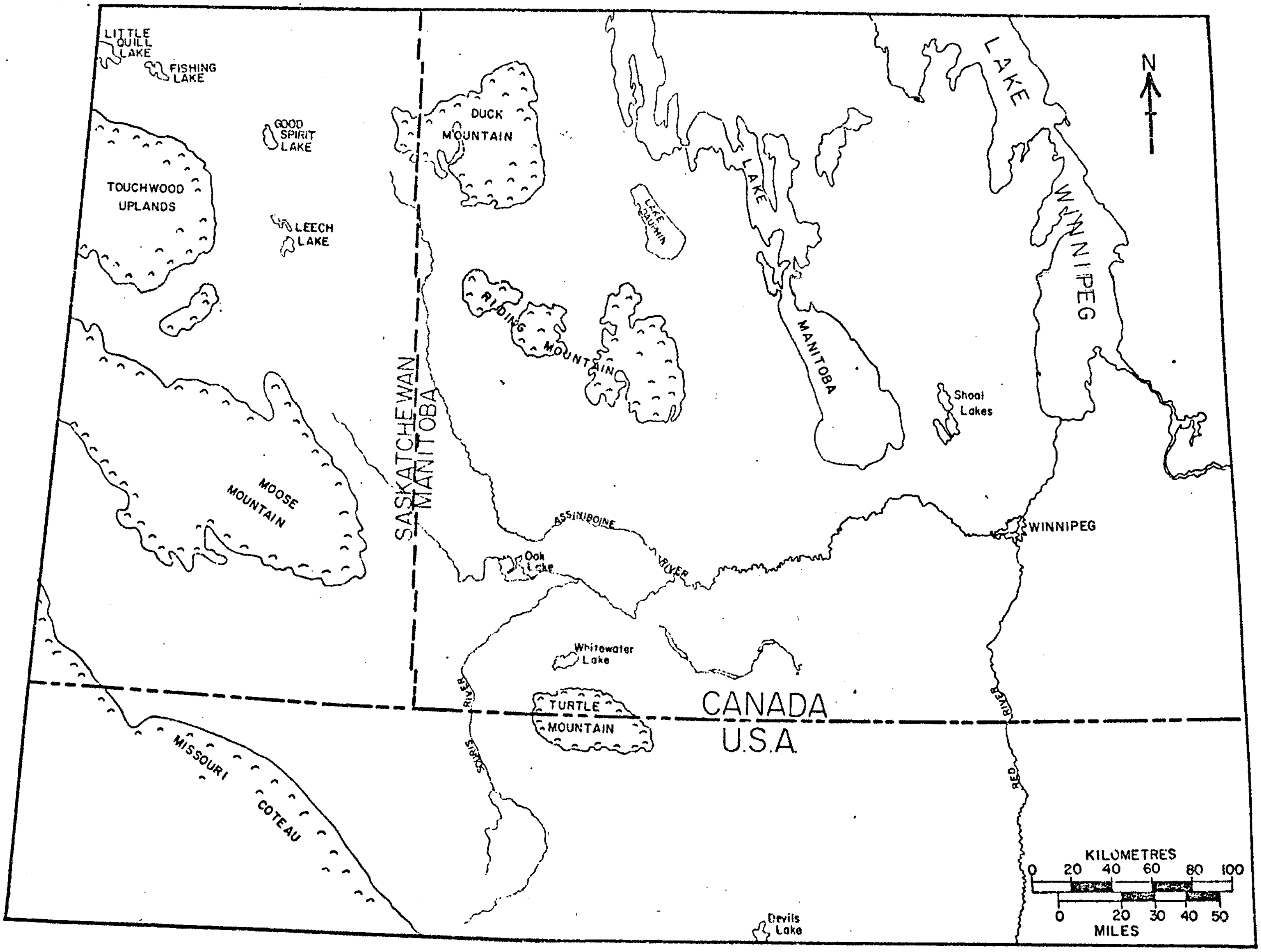


Fig. 4. Upland areas above elevation 2,000 feet in western Manitoba, eastern Saskatchewan and northern United States (modified from Dept. Energy, Mines and Resources, 1967).

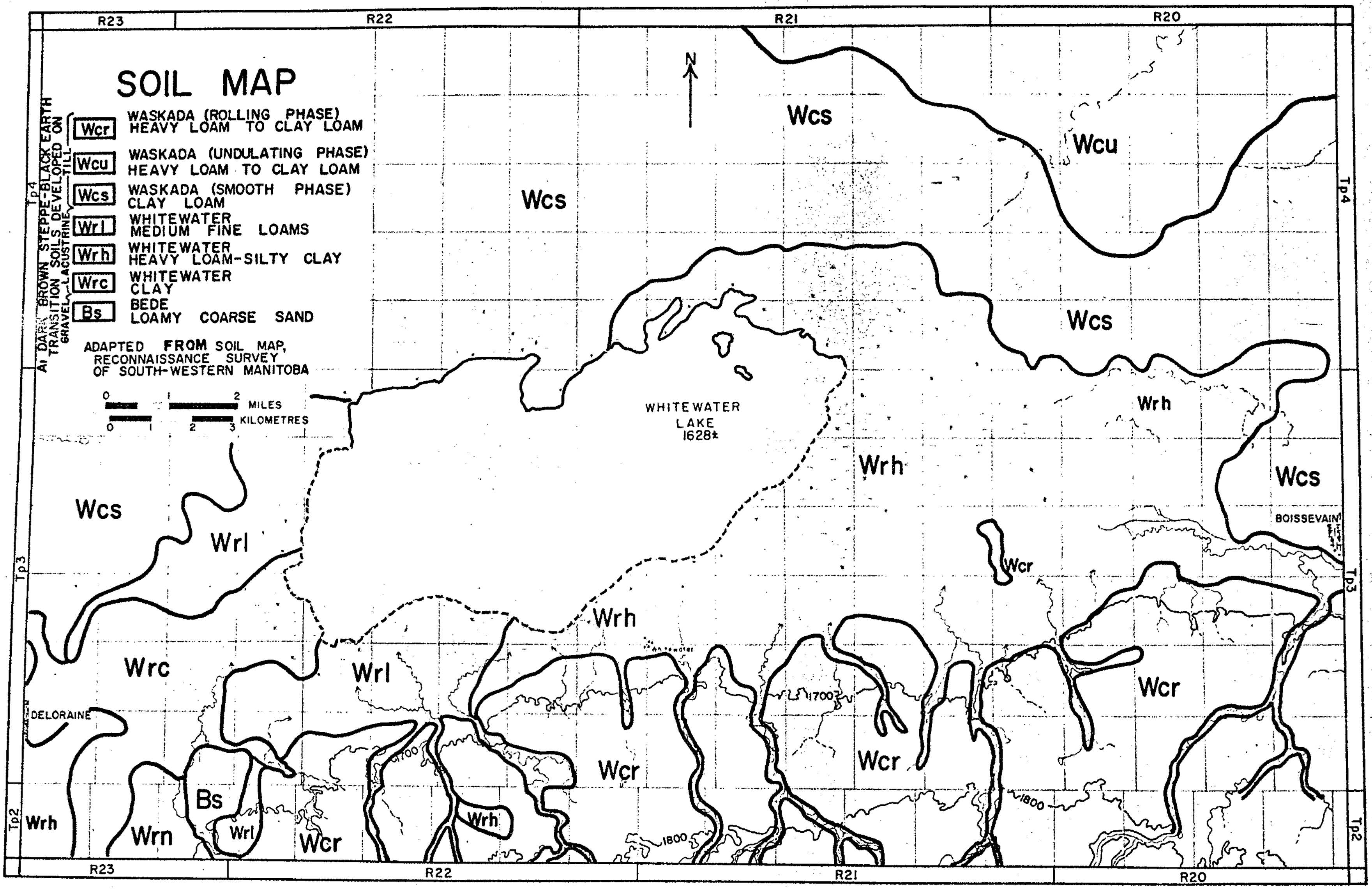
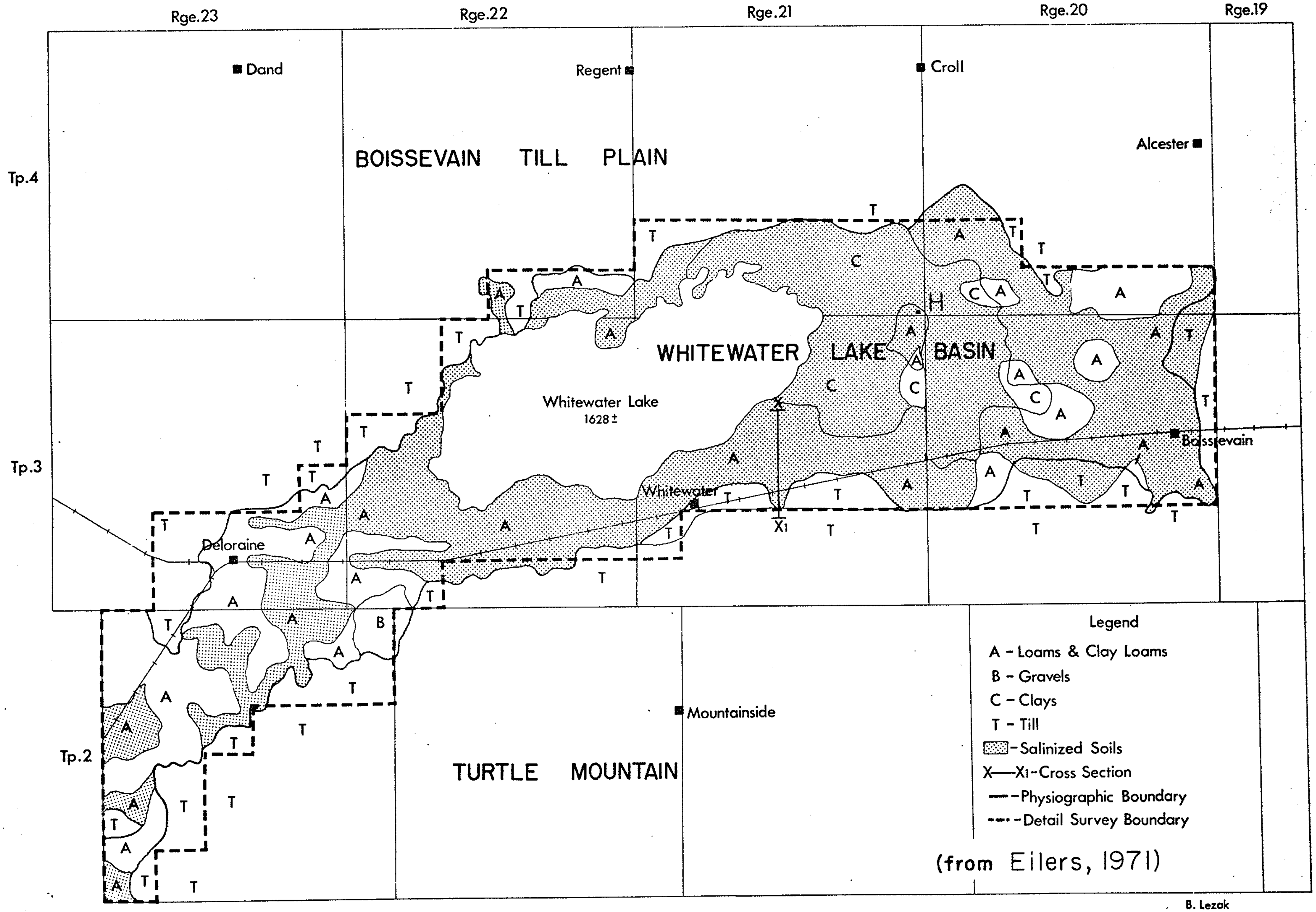


Fig.5. Soil map of Whitewater Lake Basin.



(from Eilers, 1971)

B. Lezak

Fig. 6. Salinized Lacustrine Deposits in the Whitewater Lake Basin.

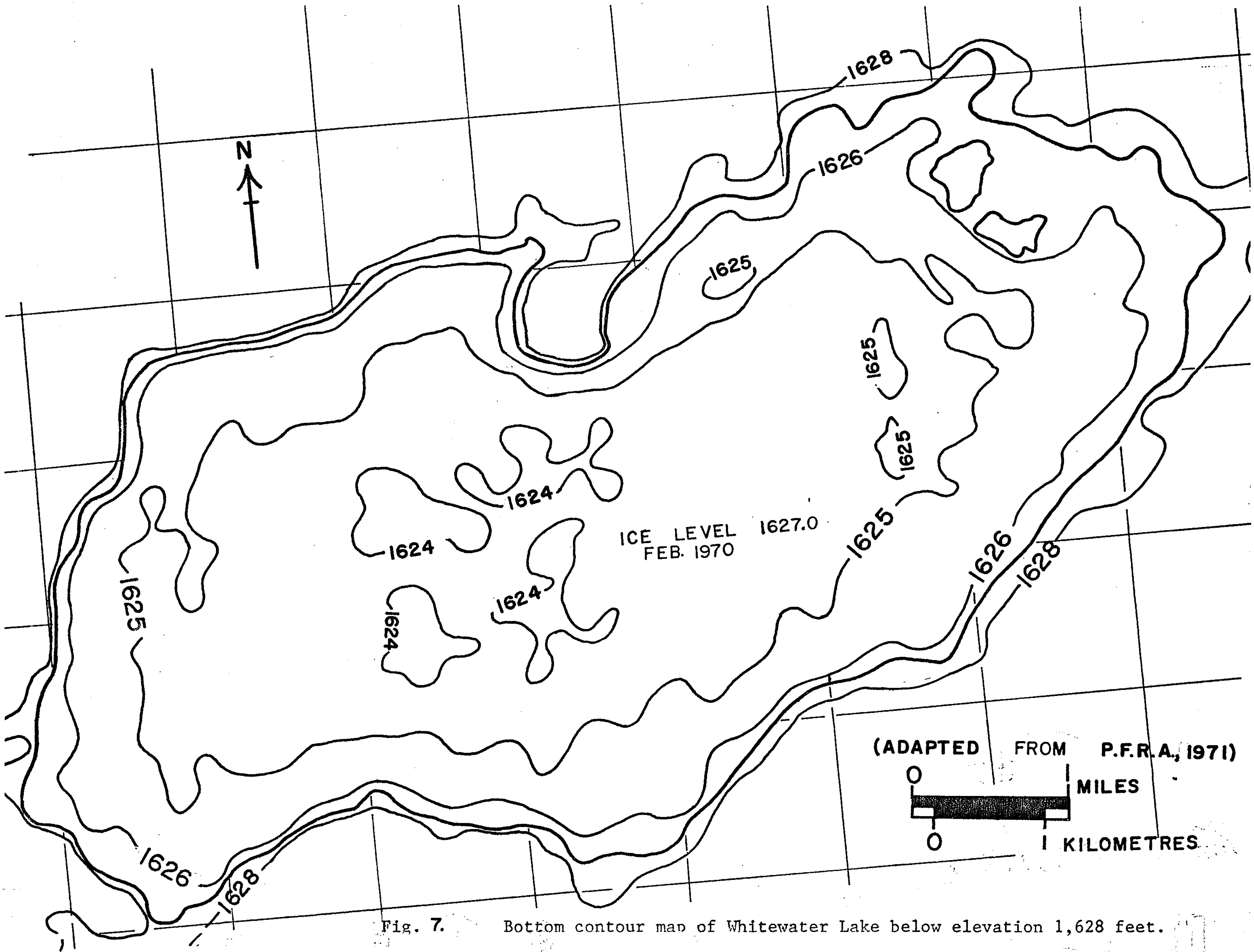
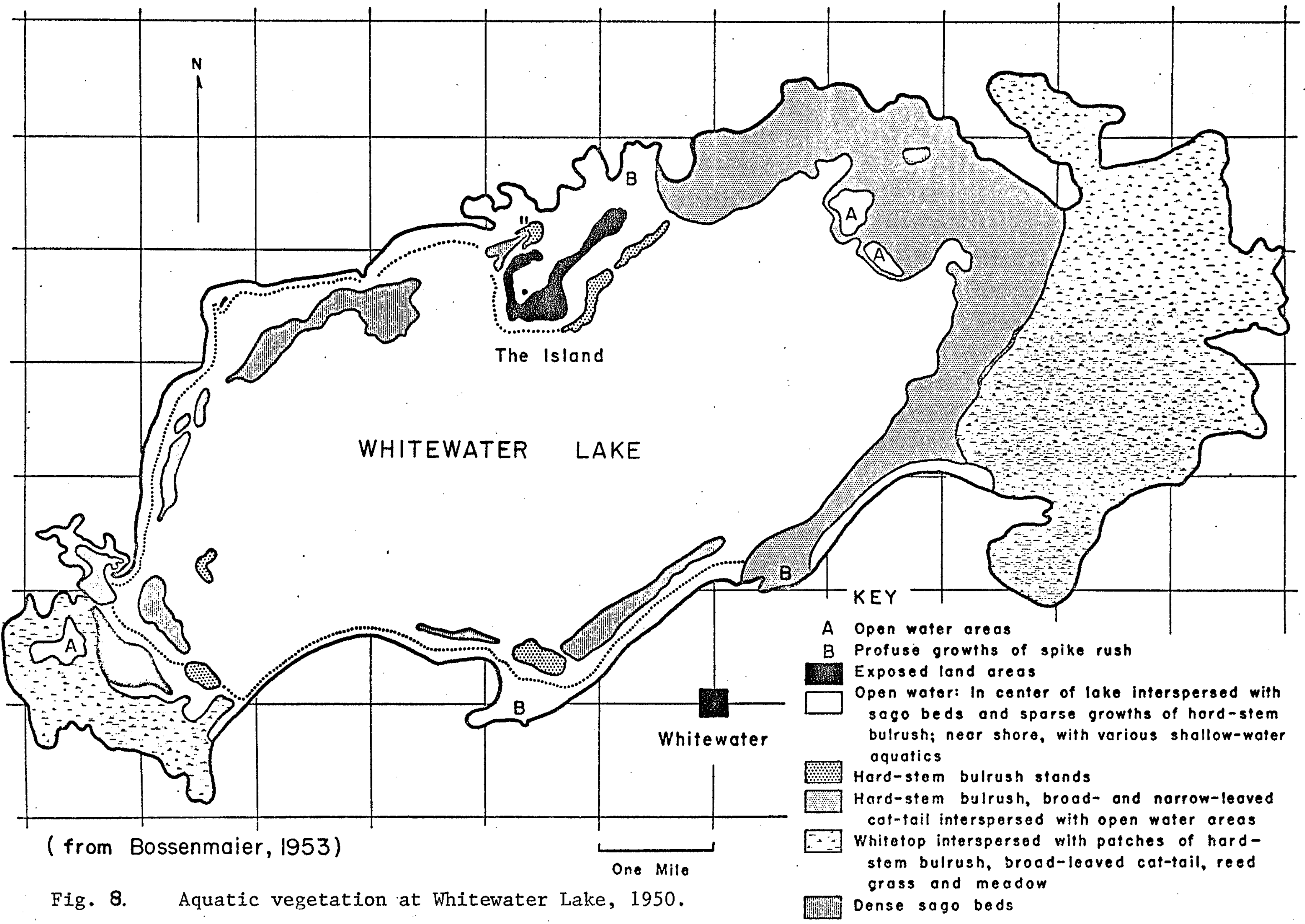


Fig. 7. Bottom contour map of Whitewater Lake below elevation 1,628 feet.



(from Bossenmaier, 1953)

Fig. 8. Aquatic vegetation at Whitewater Lake, 1950.

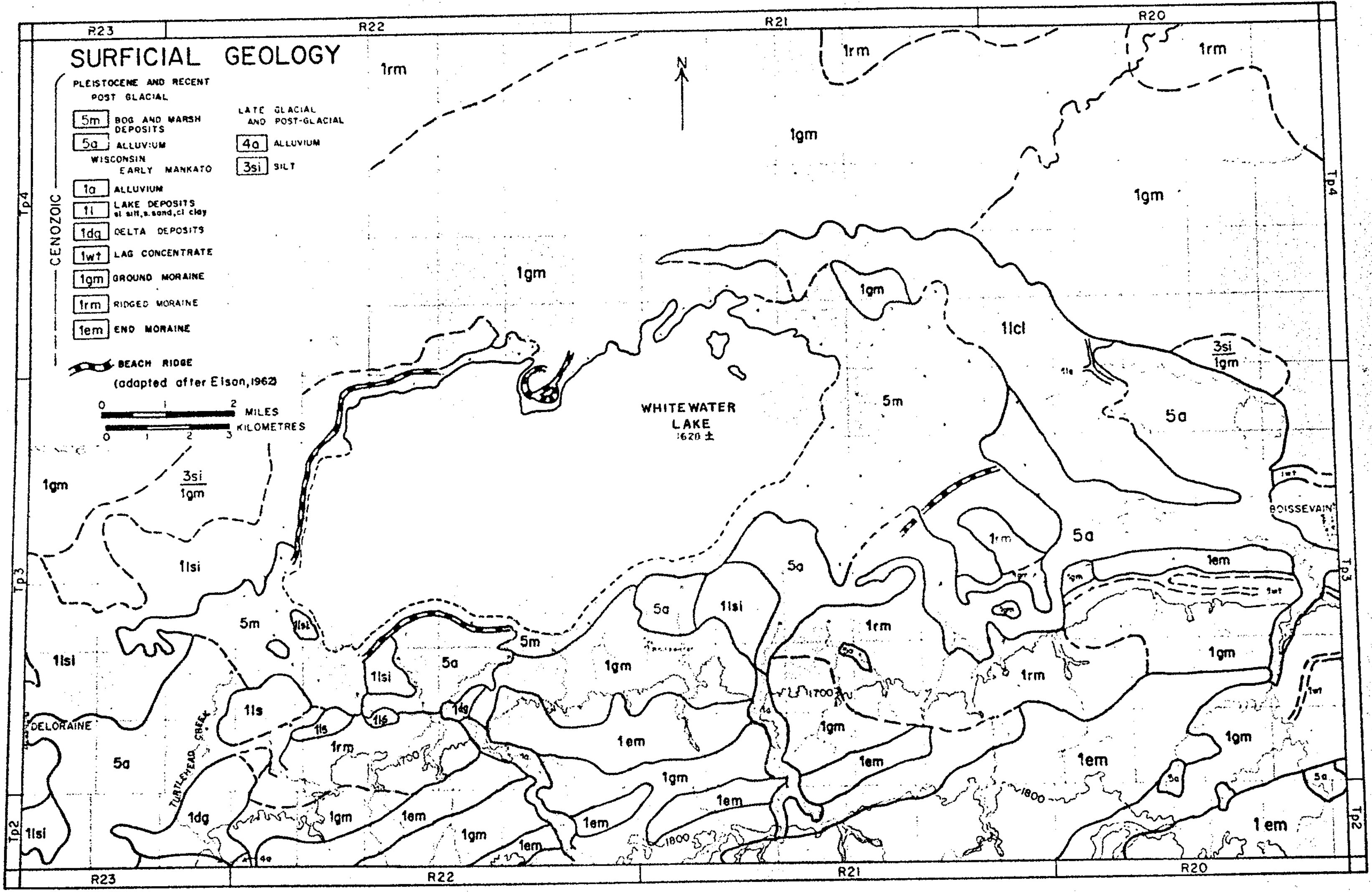


Fig. 9. Surficial geology of the Whitewater Lake Basin.

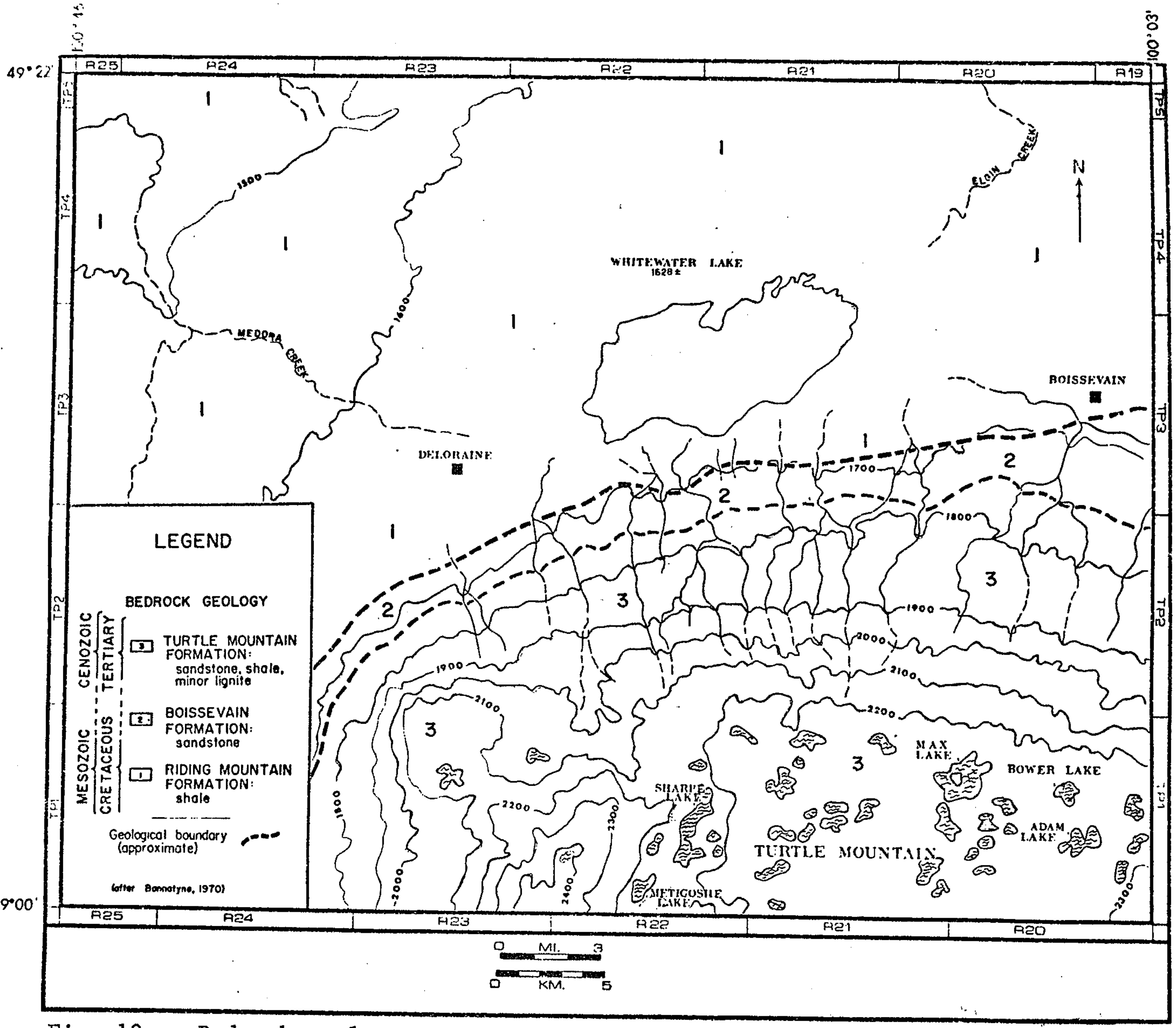


Fig. 10. Bedrock geology.

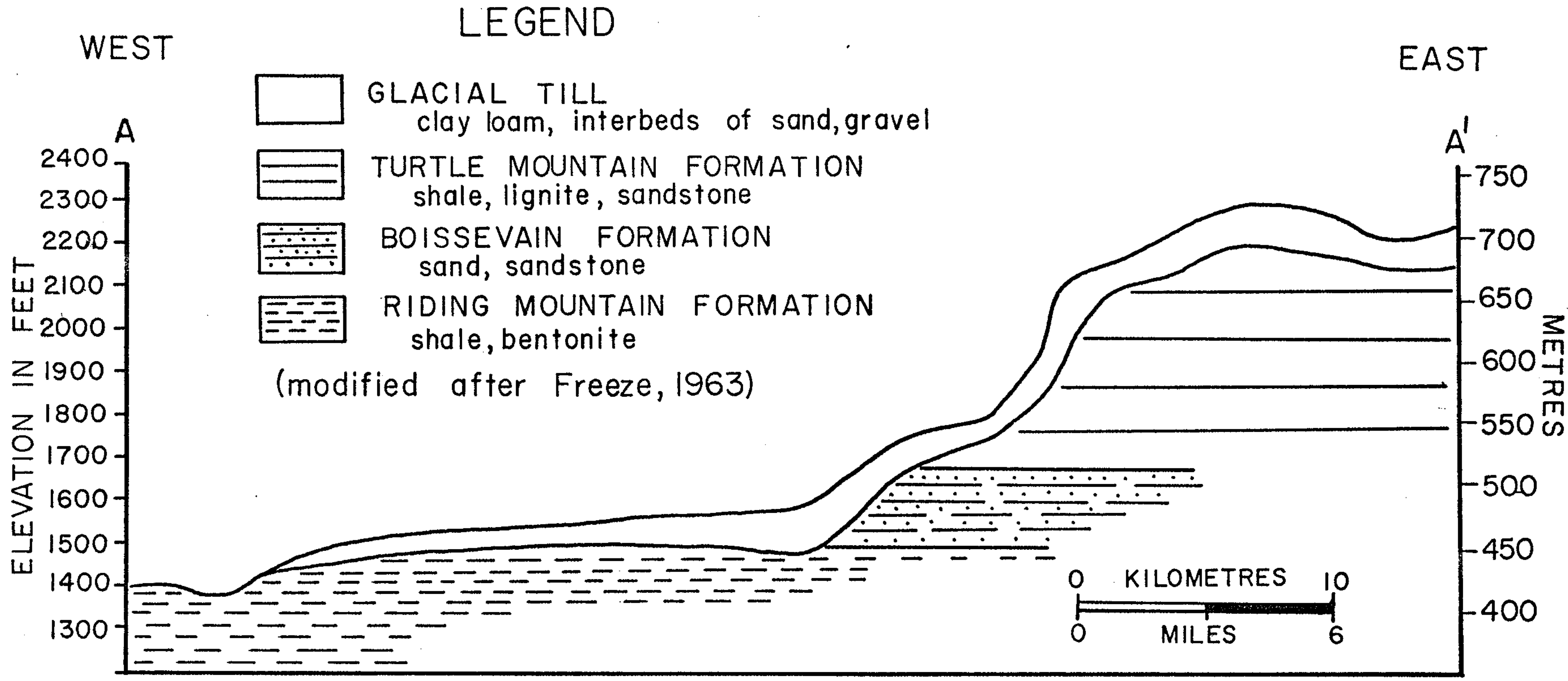


Fig. 11. Geologic cross section looking north along the west flank of Turtle Mountain.

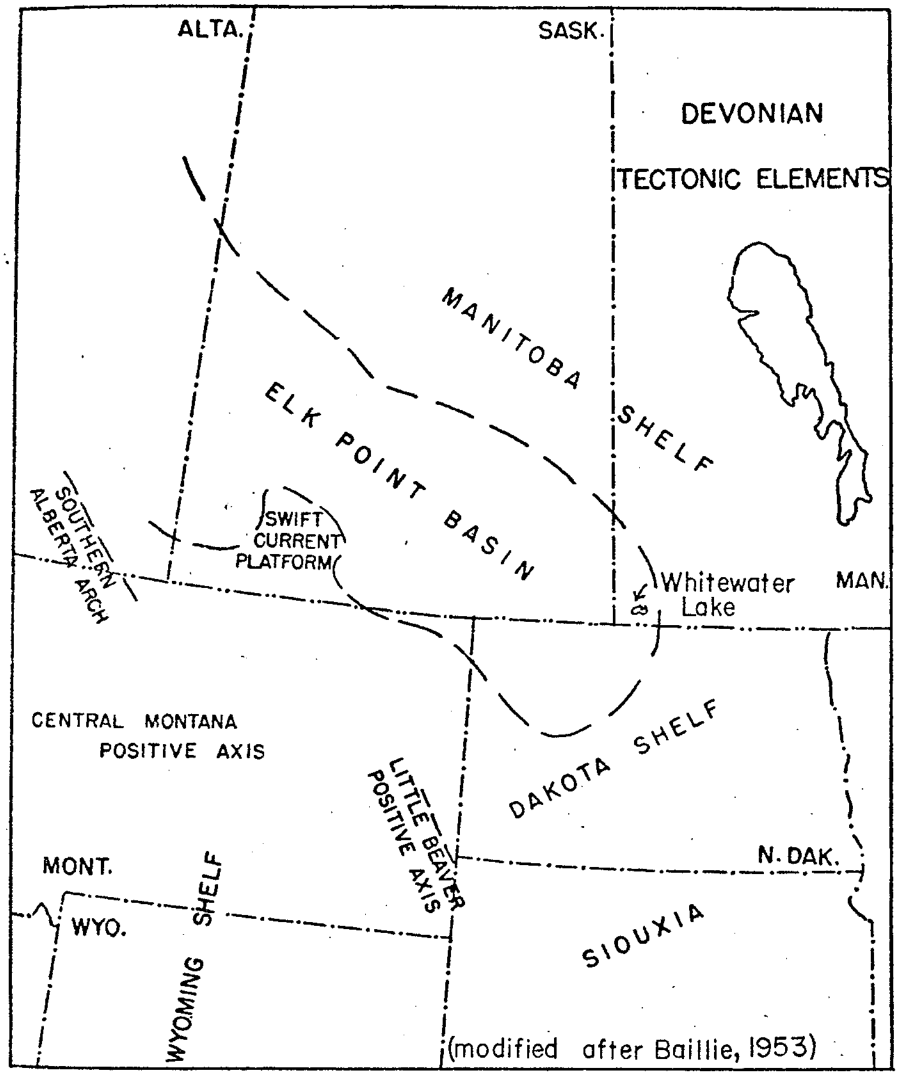


Fig. 12. Diagrammatic map of Devonian tectonic elements.

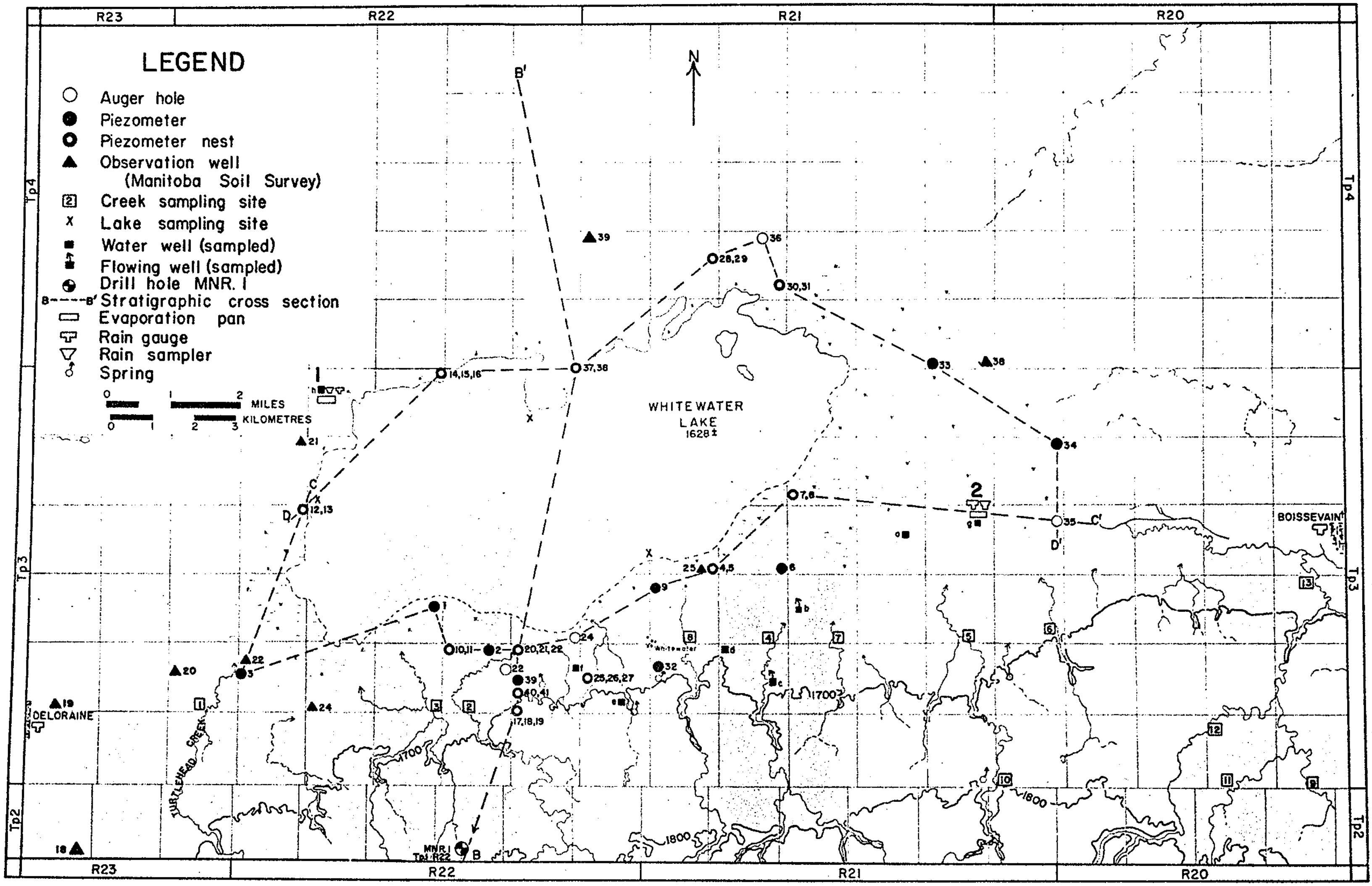


Fig. 13. Location of drill holes and hydrometric sites in the Whitewater Lake Basin.

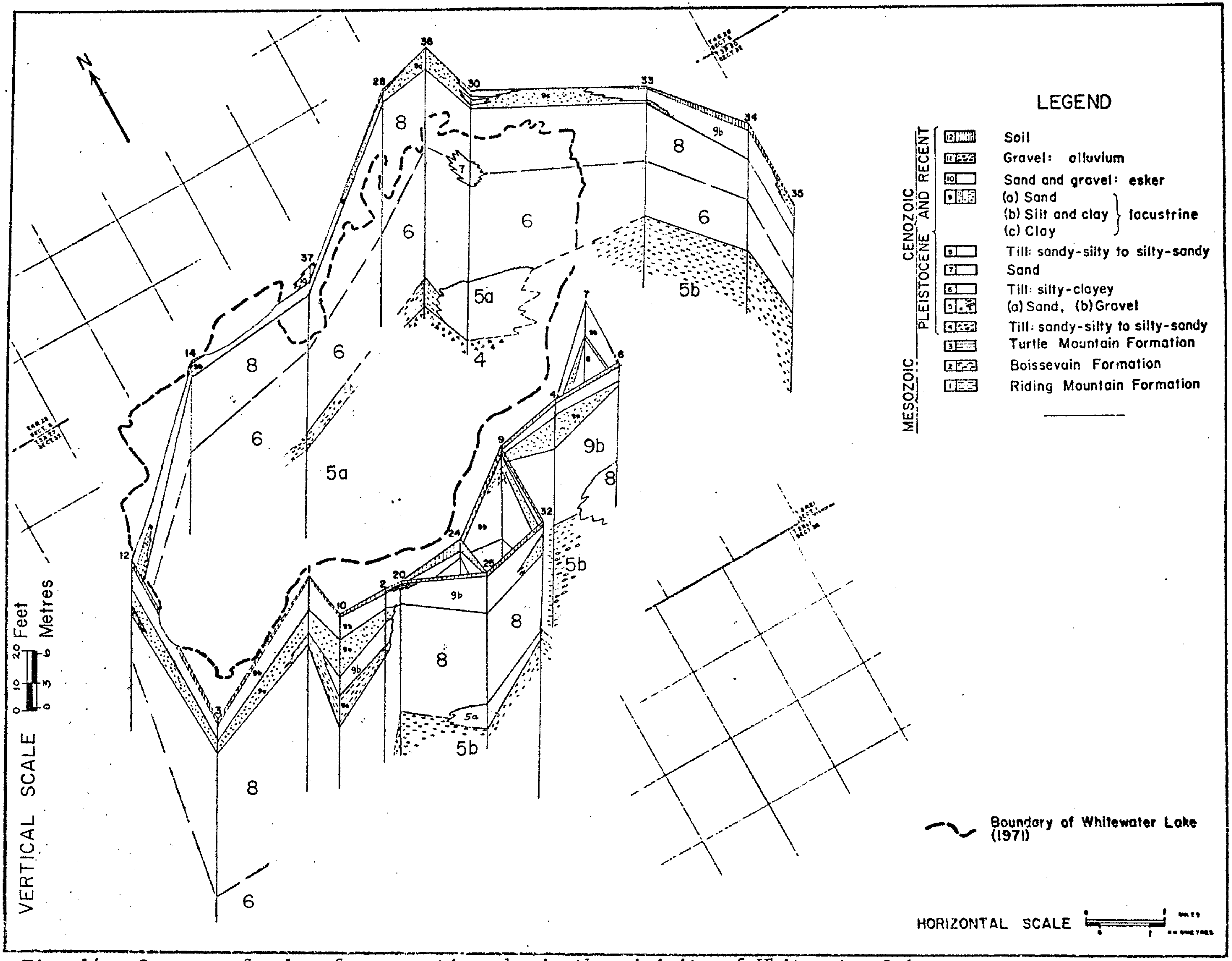


Fig. 14. Summary of subsurface stratigraphy in the vicinity of Whitewater Lake.

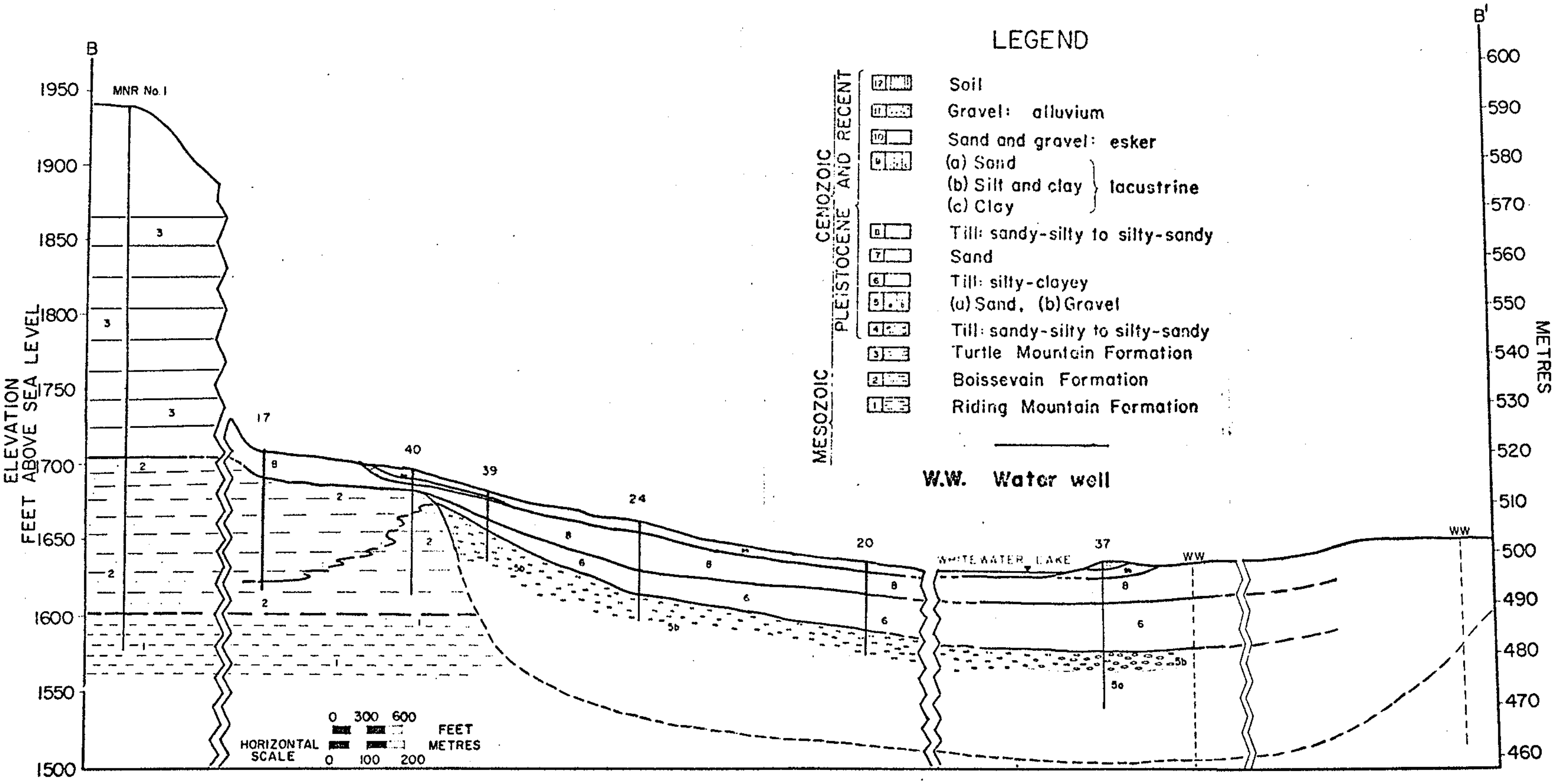


Fig. 15. South-north stratigraphic cross section looking west showing deposits on the north slope of Turtle Mountain and under Whitewater Lake.

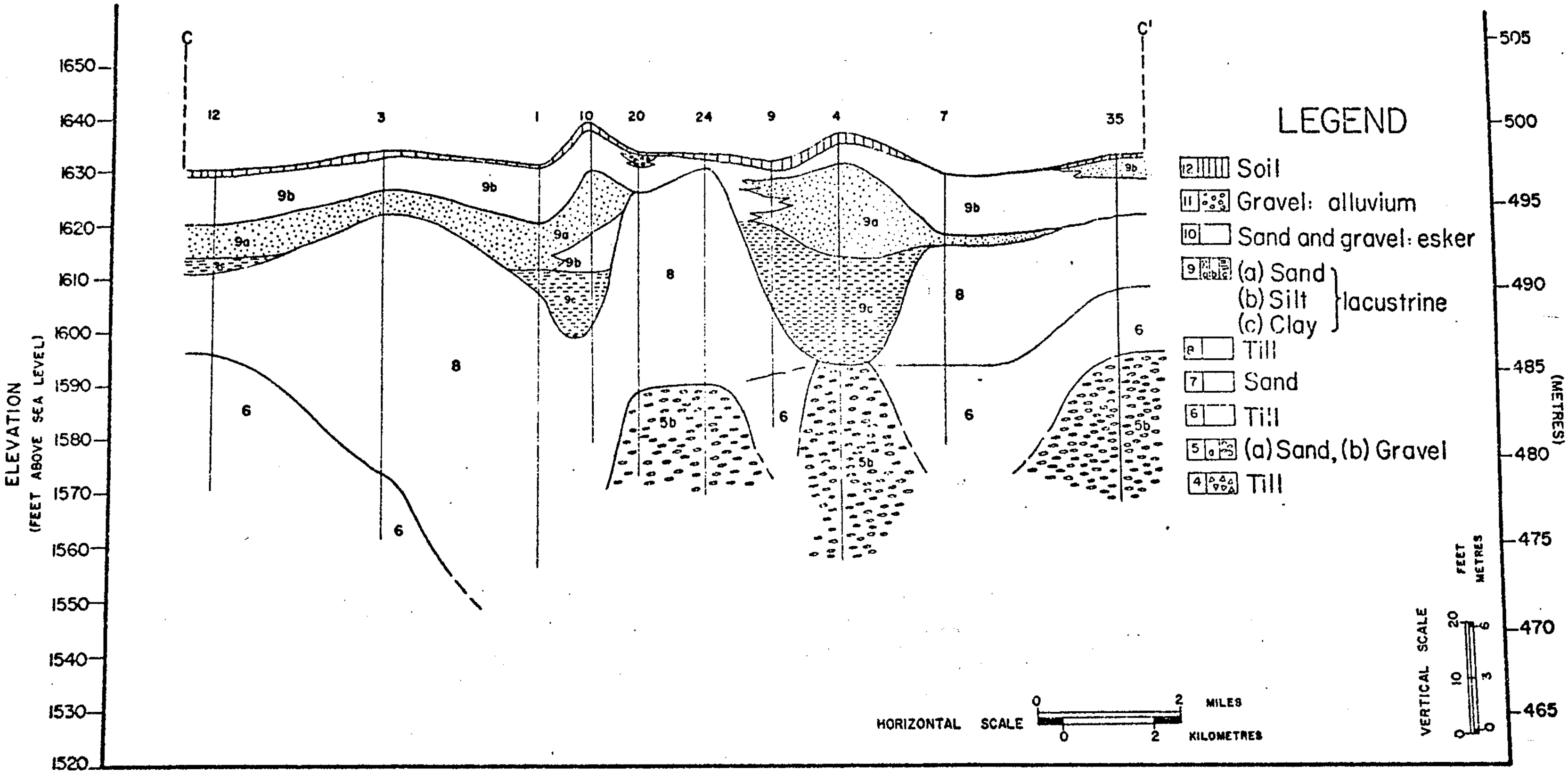


Fig. 16. West-east stratigraphic cross section looking north along the south shore of Whitewater Lake.

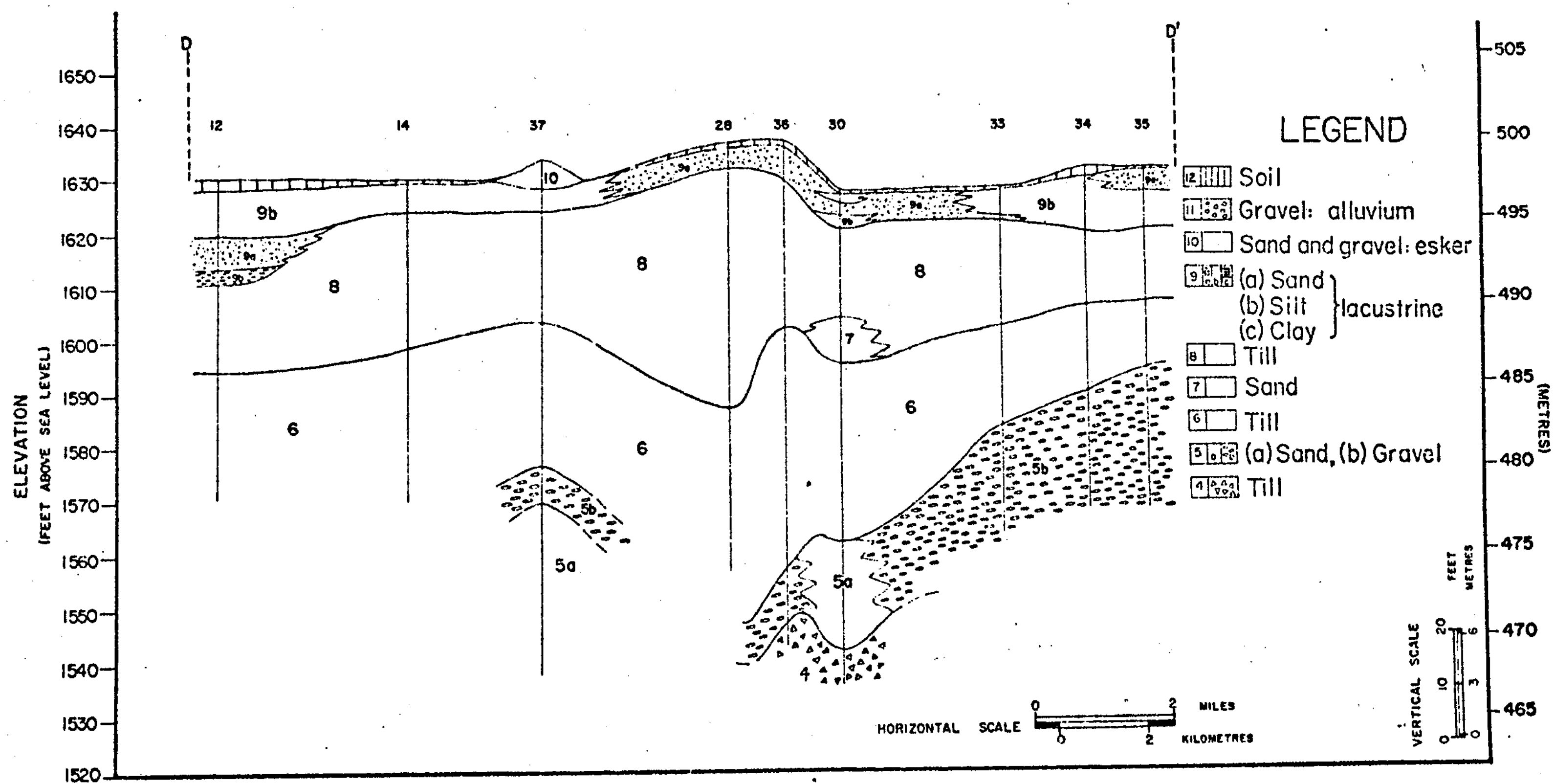


Fig. 17. West-east stratigraphic cross section looking north along the north shore of Whitewater Lake.

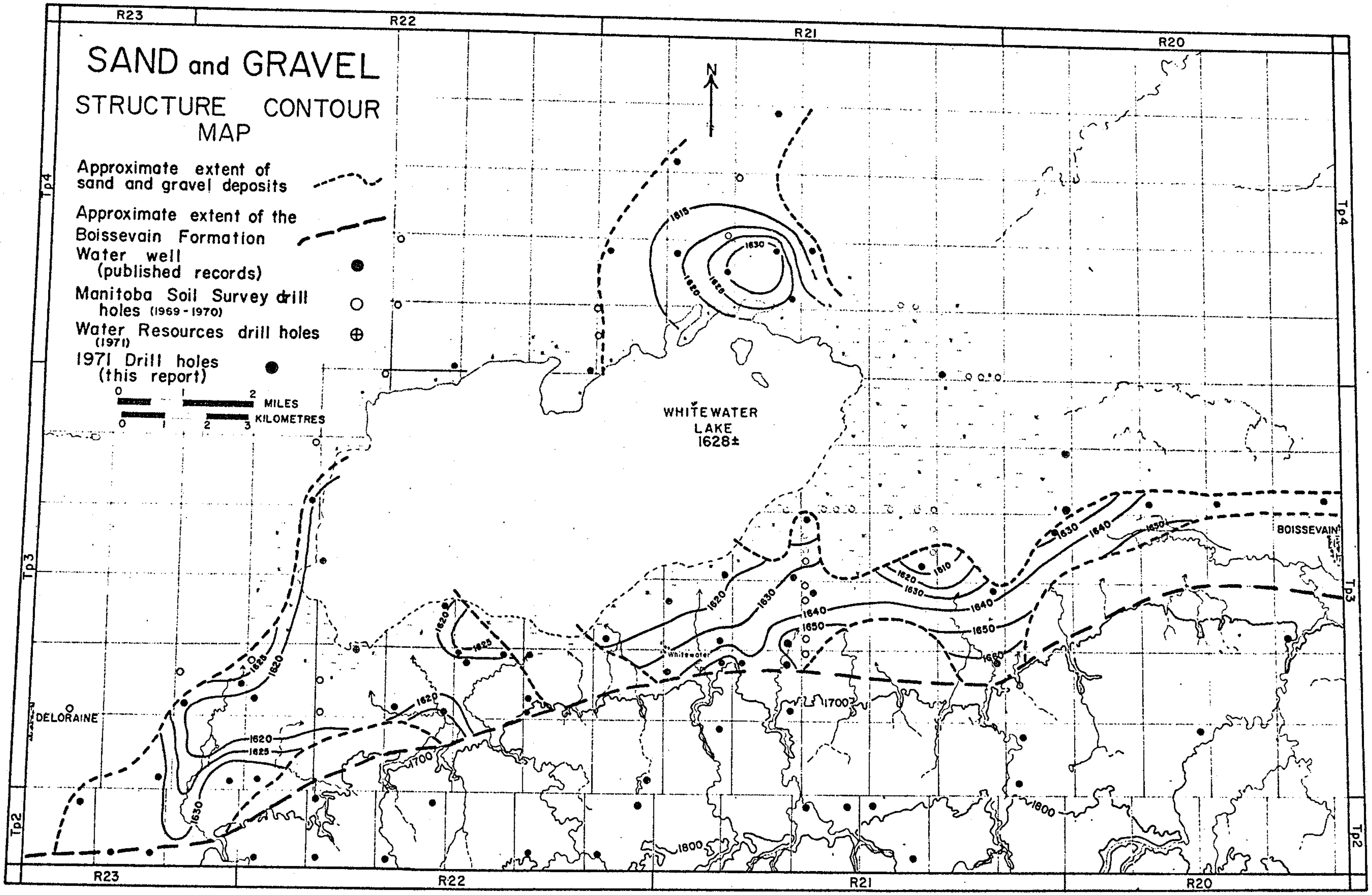
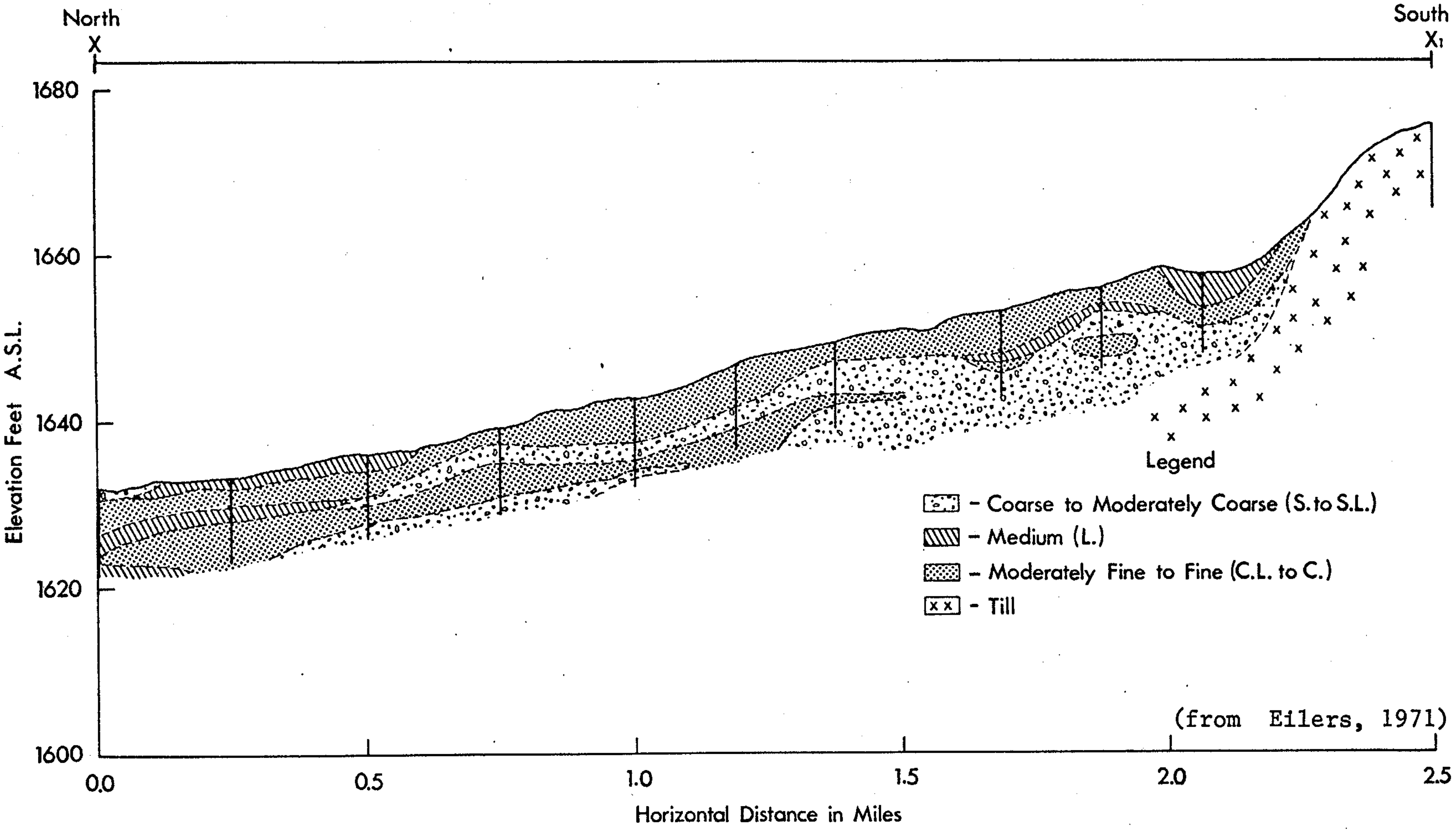


Fig. 18. Structure contour map of glacial sand and gravel deposits (Unit 9). Elevations of upper surface shown in feet above sea level.



(from Eilers, 1971)

Fig. 19. Cross Section X-X₁ (S.W. 27-3-21w - N.W. 10-3-21w) Showing Relief and Stratified Surface Deposits on Southern Edge of Basin.

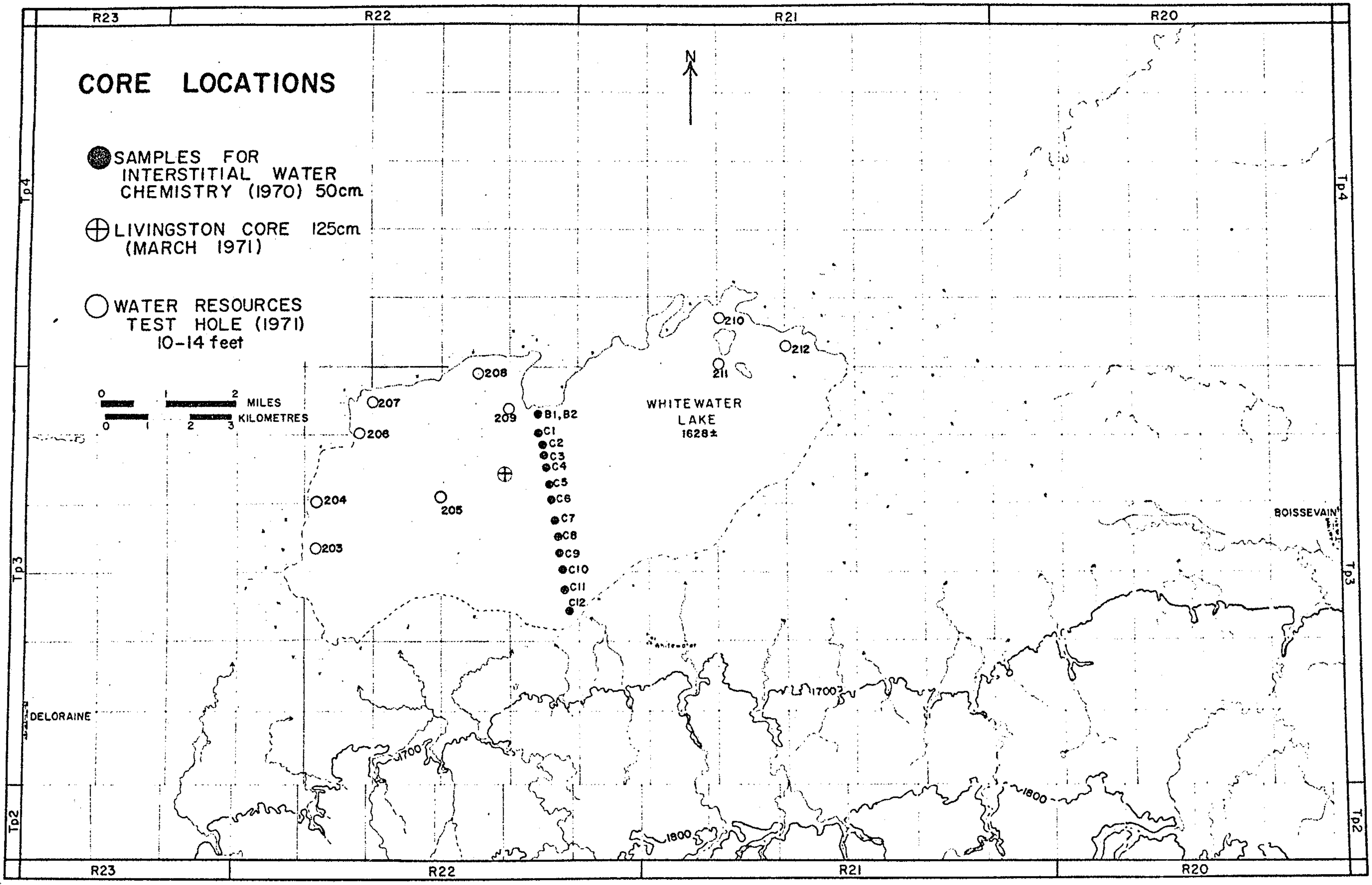


Fig. 20. Location of core samples, Whitewater Lake.

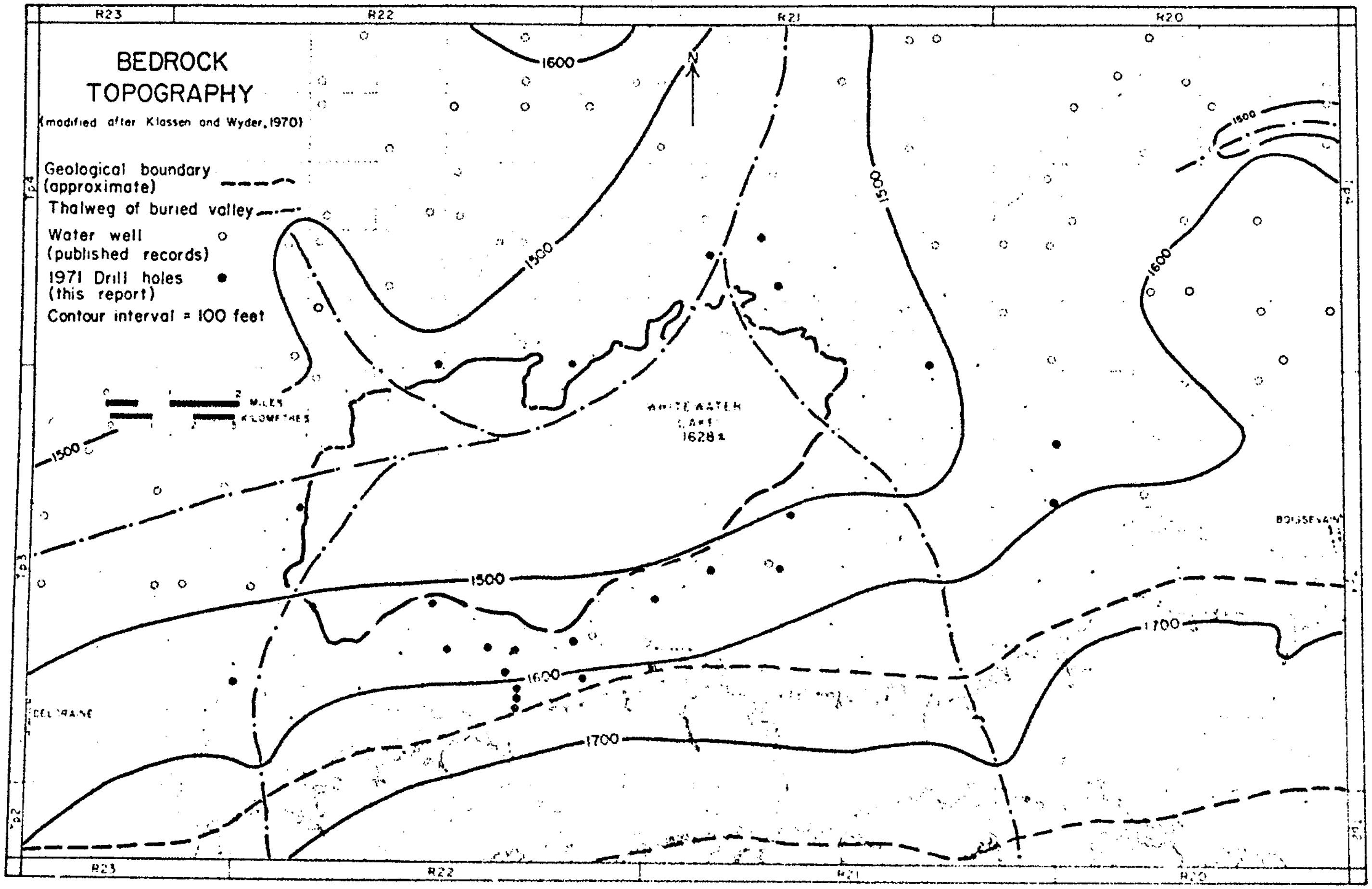


Fig. 21. Bedrock topography of the Whitewater Lake Basin. All drill holes shown did not necessarily encounter bedrock.

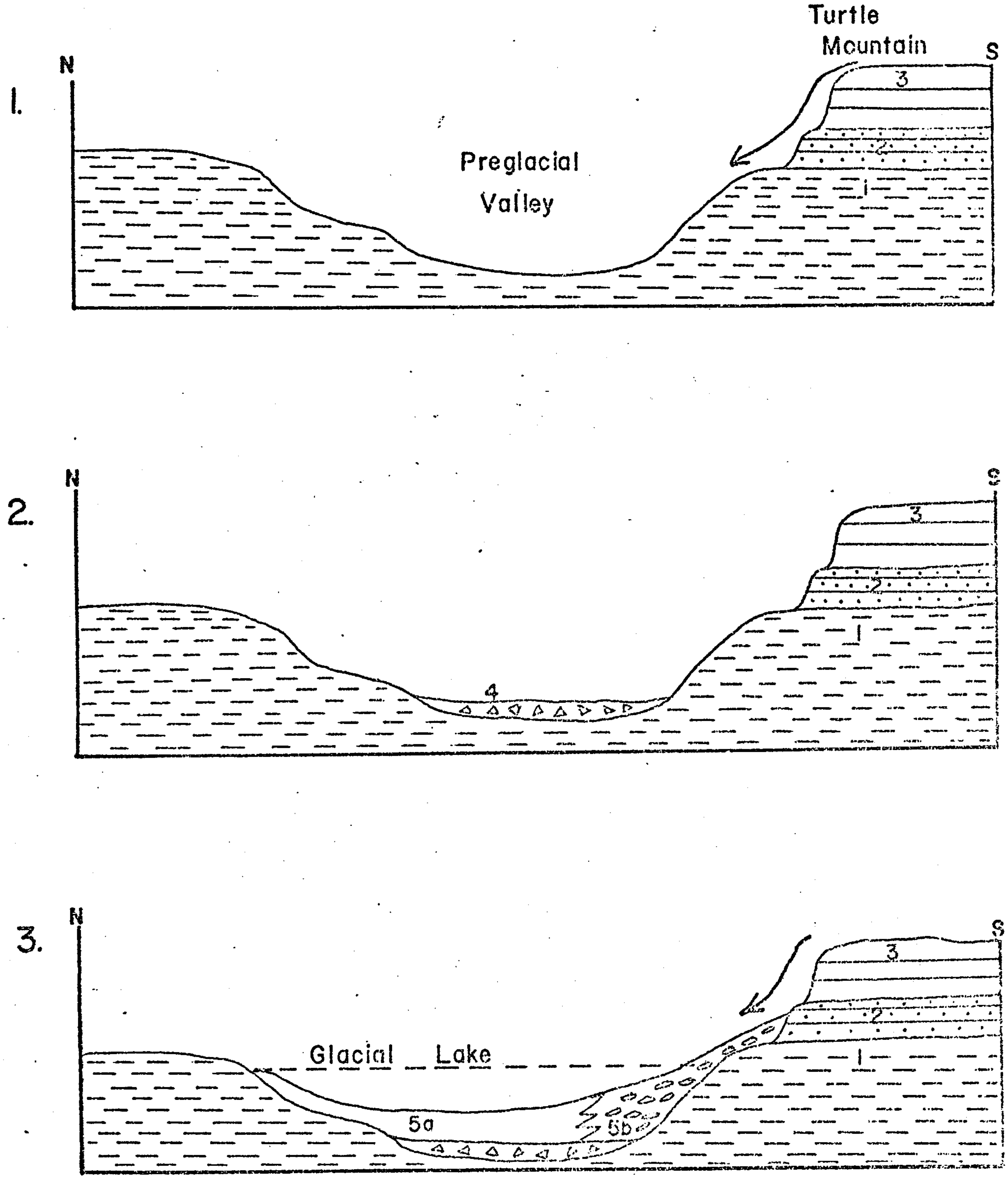


Fig. 22. Tertiary - Pleistocene history of the Whitewater Lake Basin. Diagrammatic cross sections through the basin looking east. 1, Preglacial valley incised in Cretaceous shales (Unit 1). 2, Deposition of glacial till (Unit 4) and erosion. 3, Formation of a glacial lake and deposition of sand and gravel deposits (Unit 5). Arrow indicates source of sediments.

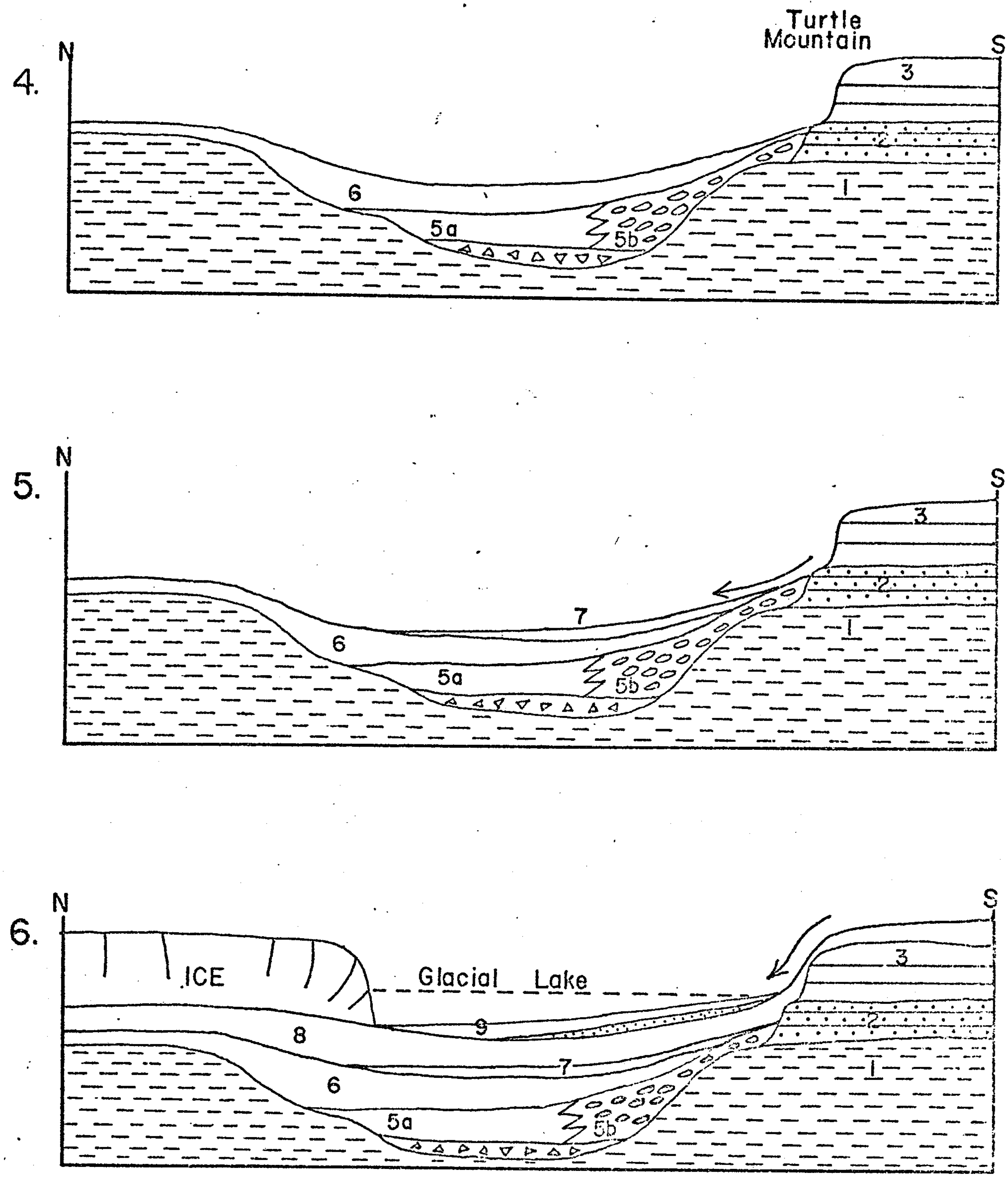


Fig.22.(cont.) Tertiary - Pleistocene history of the Whitewater Lake Basin. Diagrammatic cross sections looking east. 4, Deposition of glacial till (Unit 6). 5, Deposition of glacial sand (Unit 7). 6, Deposition of glacial till (Unit 8); formation of a glacial lake and deposition of fluviatile - lacustrine deposits. Arrow indicates source of sediments.

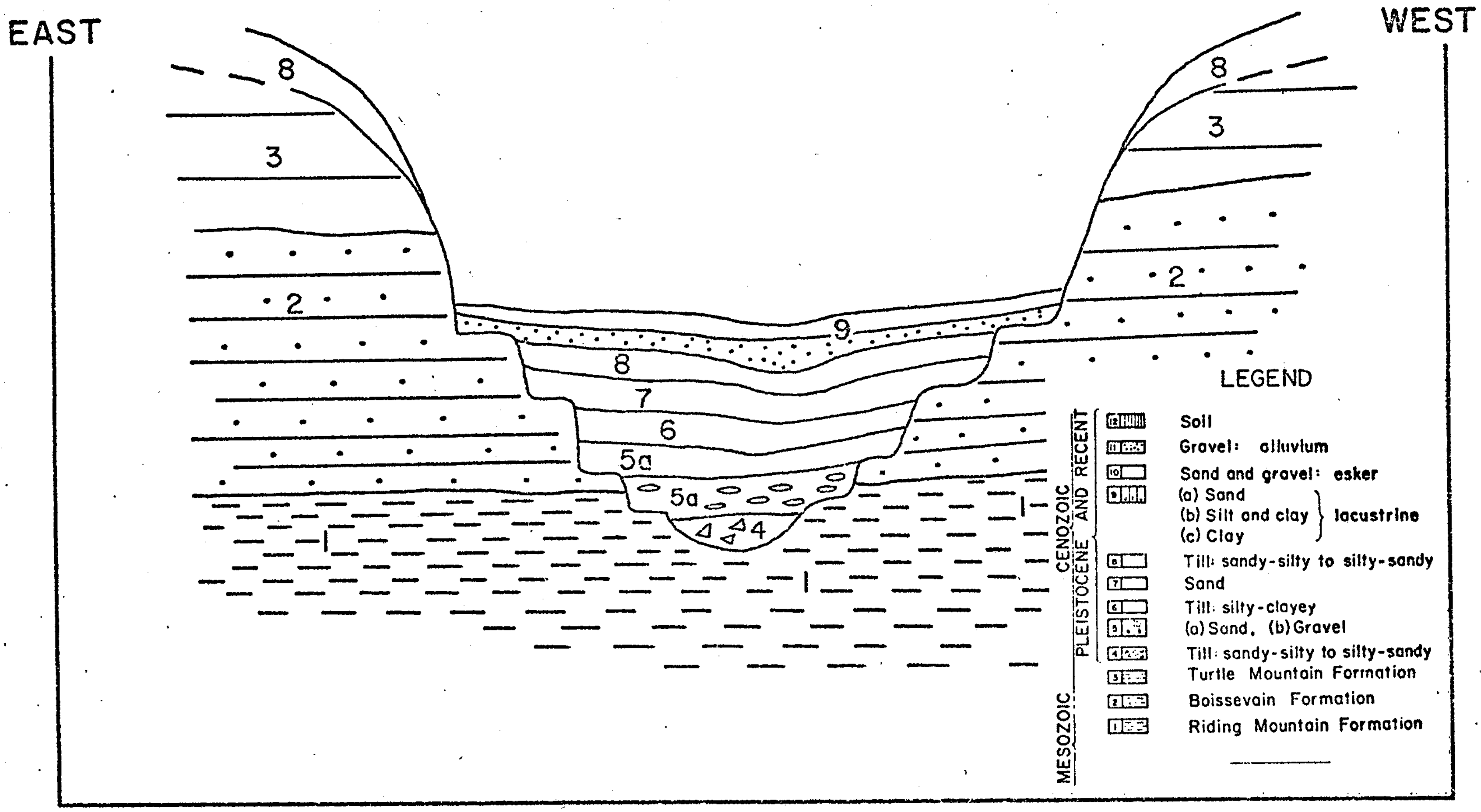


Fig. 23. Interpretive diagrammatic cross section looking south through a stream valley on the north slope of Turtle Mountain.

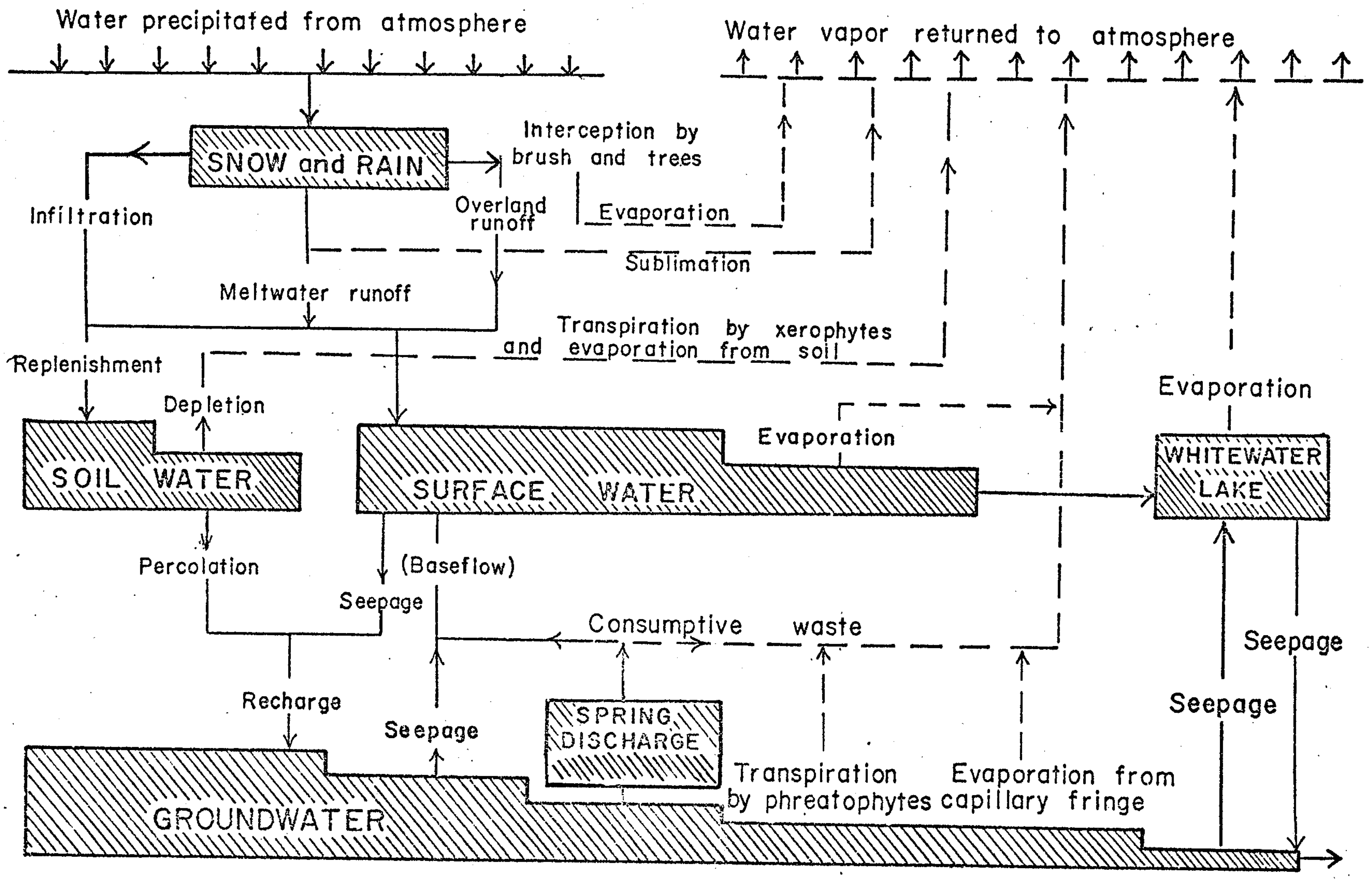


Fig. 24. Idealized hydrologic cycle of the Whitewater Lake Basin (adapted from "the hydrologic cycle of an arid basin", Robinson, 1958).

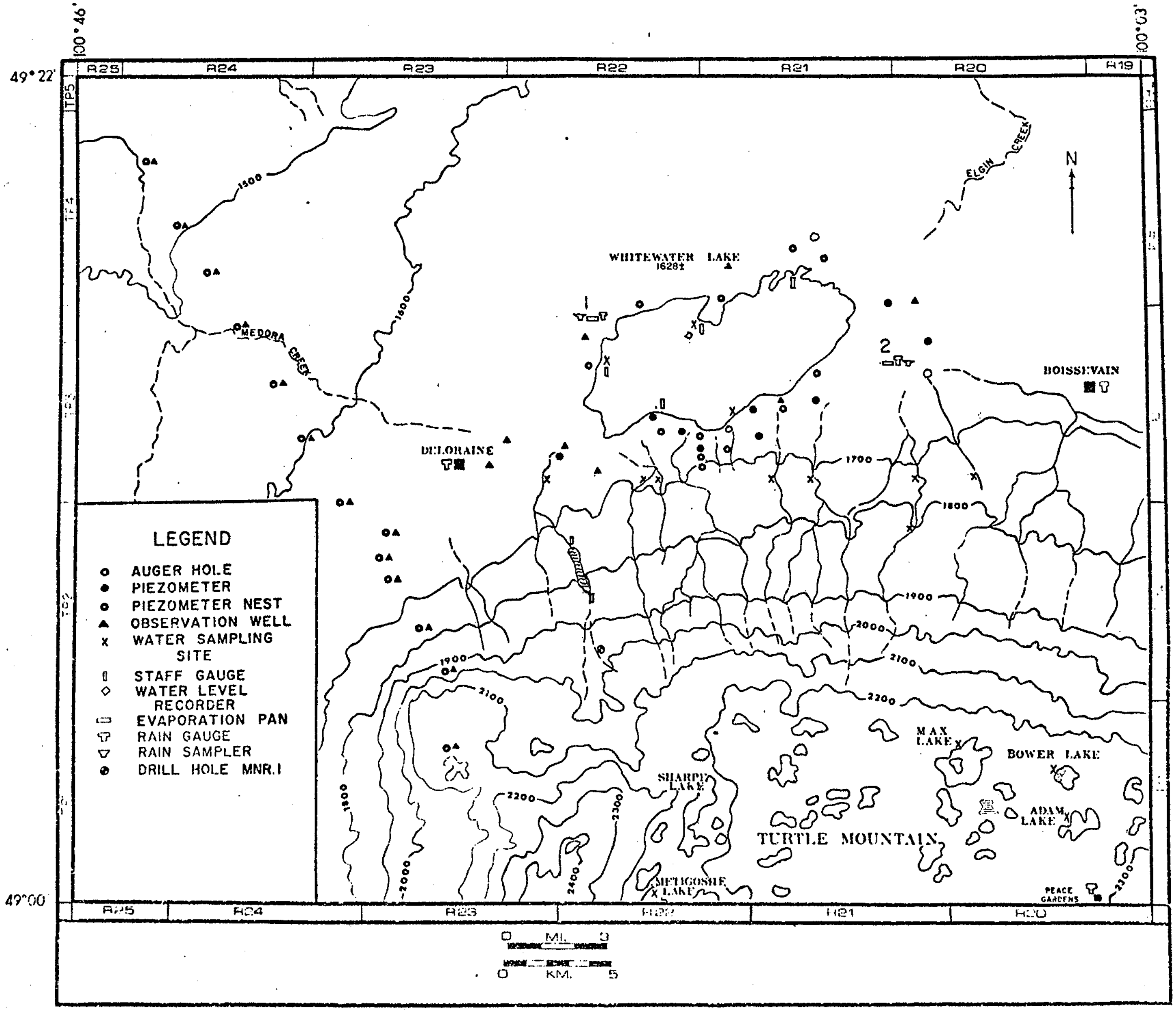


Fig. 25. Hydrometric and meteorological sites in the Whitewater Lake Basin, 1970-1971. Piezometer sites west of Deloraine and all observation wells are those of the Manitoba Soil Survey.

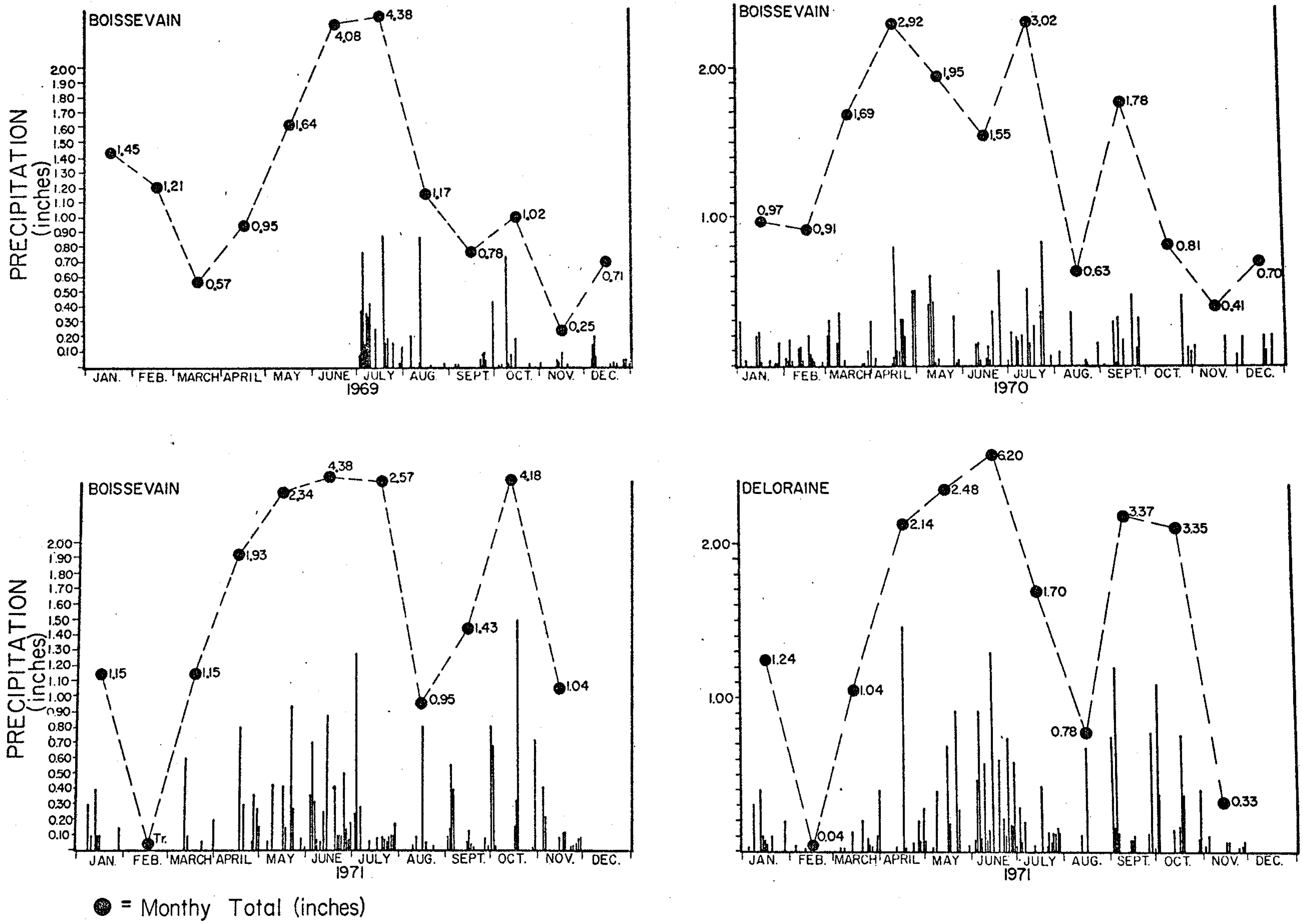


Fig. 26. Daily and monthly precipitation at Boissevain 1969-1971 and Deloraine 1971.

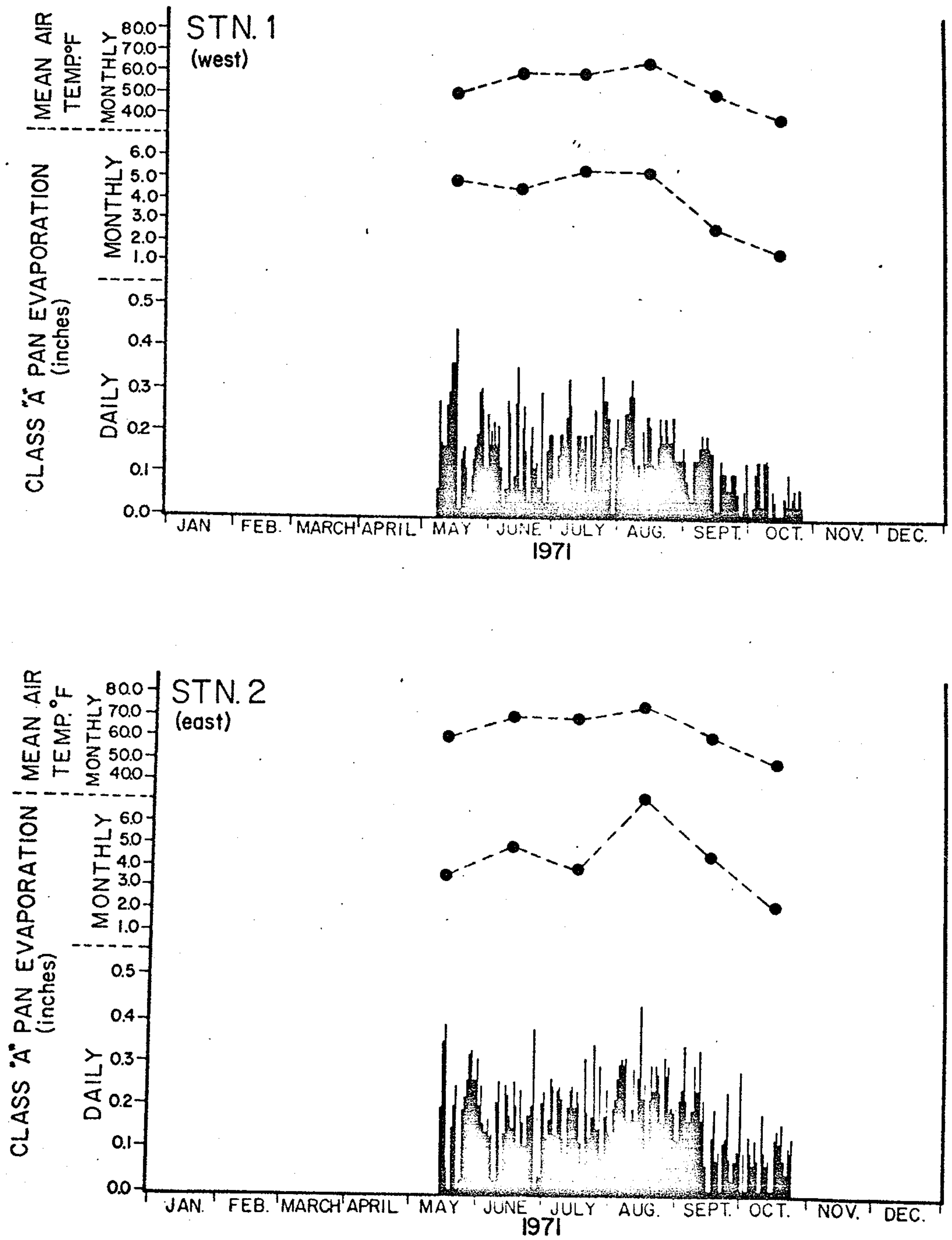


Fig. 27. Daily and monthly Class "A" pan evaporation and mean monthly temperature at Stations 1 and 2 near Whitewater Lake, 1971.

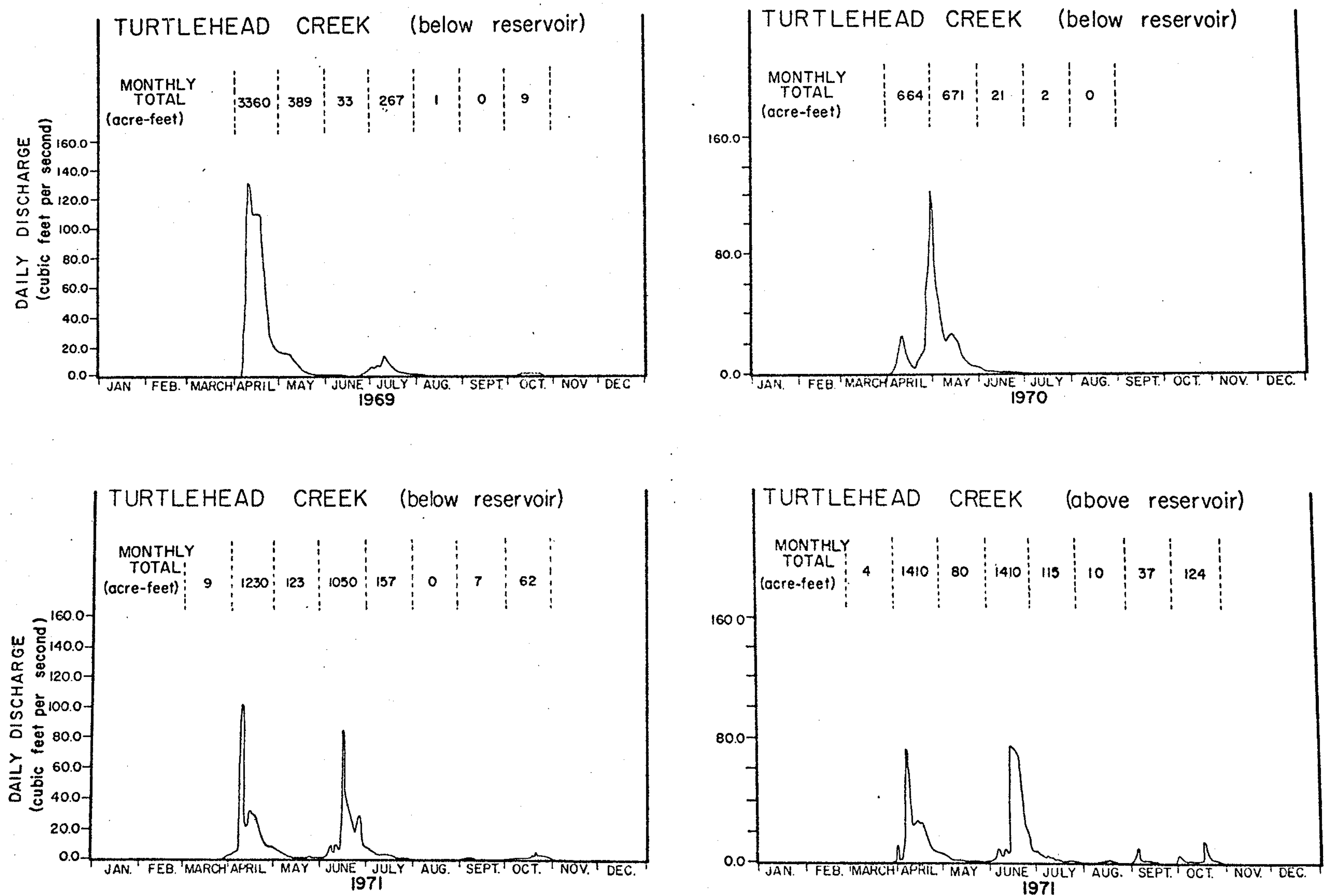


Fig. 28. Daily and monthly discharge hydrographs of Turtlehead Creek 1969-1971.

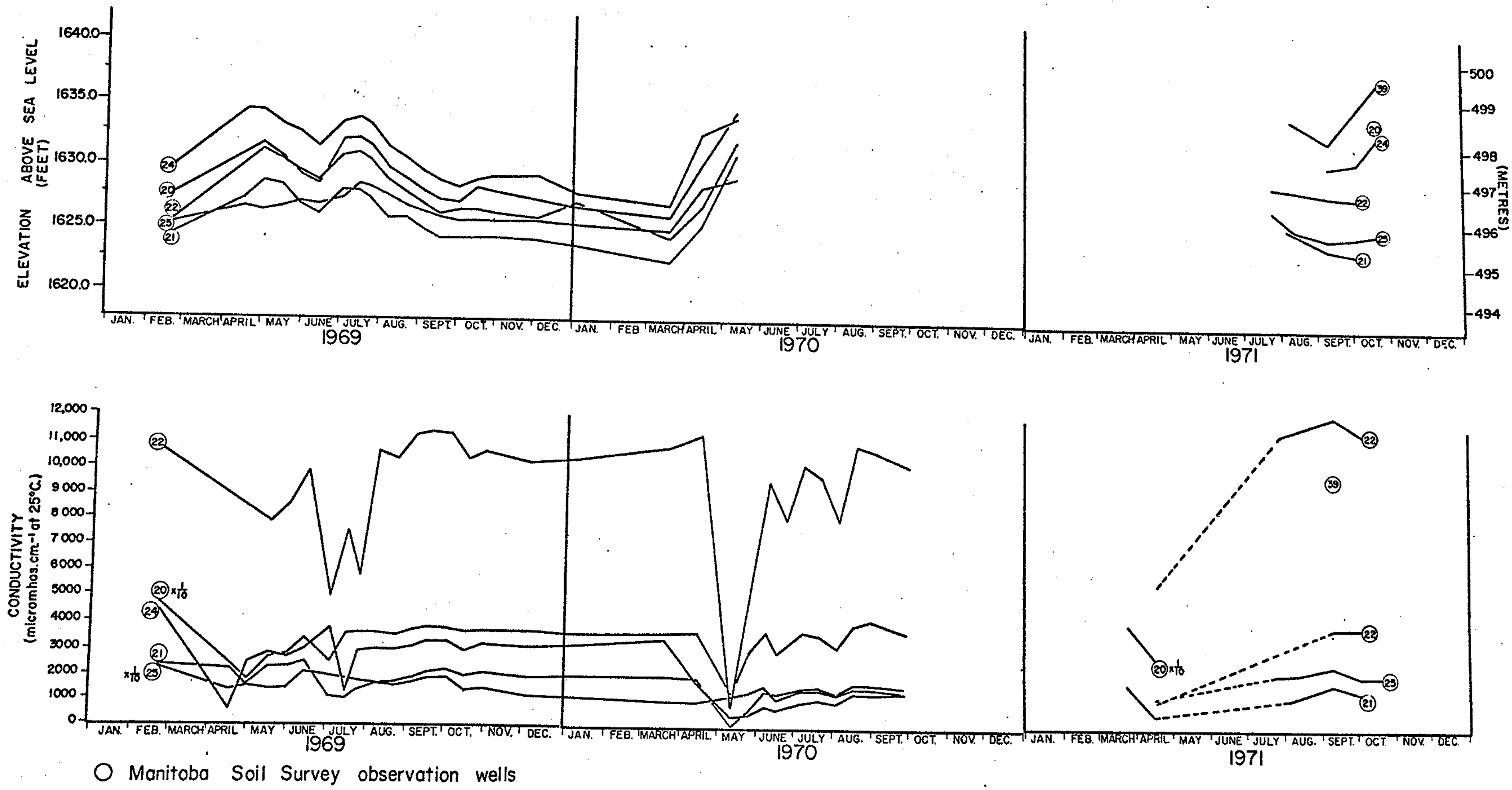


Fig. 29. Seasonal variation in water level and conductivity of observation wells near Whitewater Lake, 1969-1971.

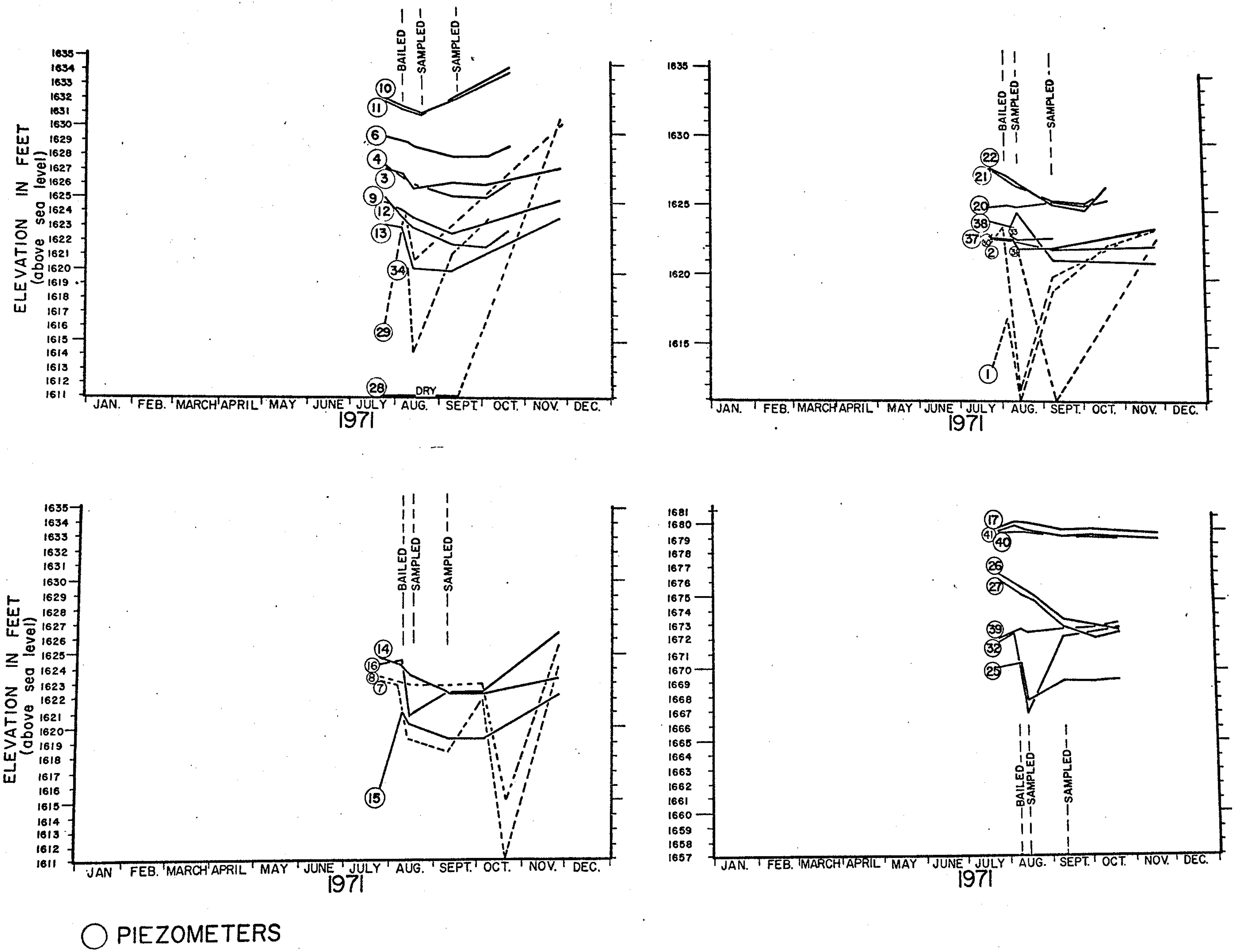


Fig. 30. Seasonal water level response of piezometers near Whitewater Lake, 1971.

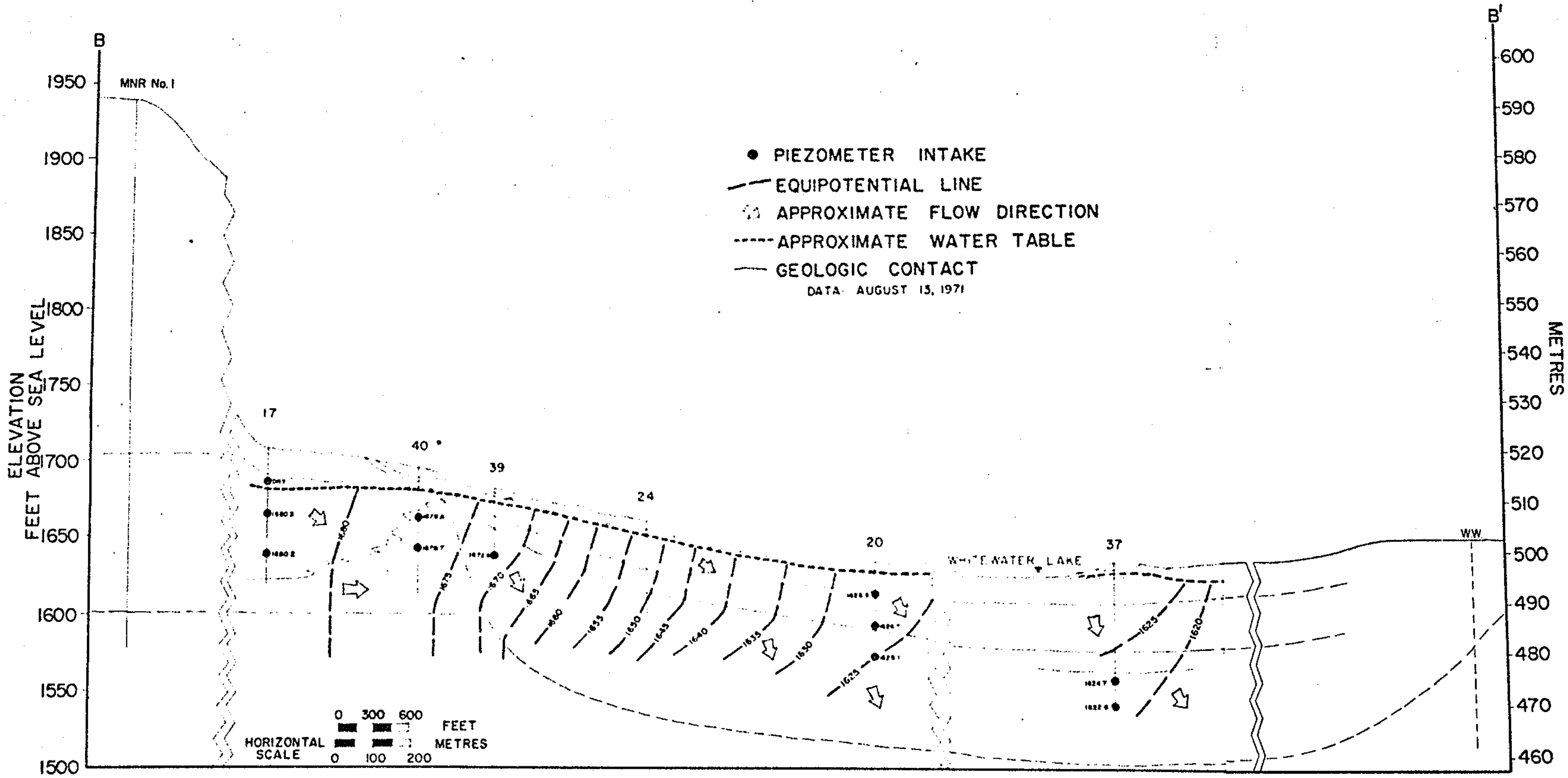


Fig. 31. Groundwater flow pattern along a south-north cross section looking west through shallow deposits on the north slope of Turtle Mountain and under Whitewater Lake.

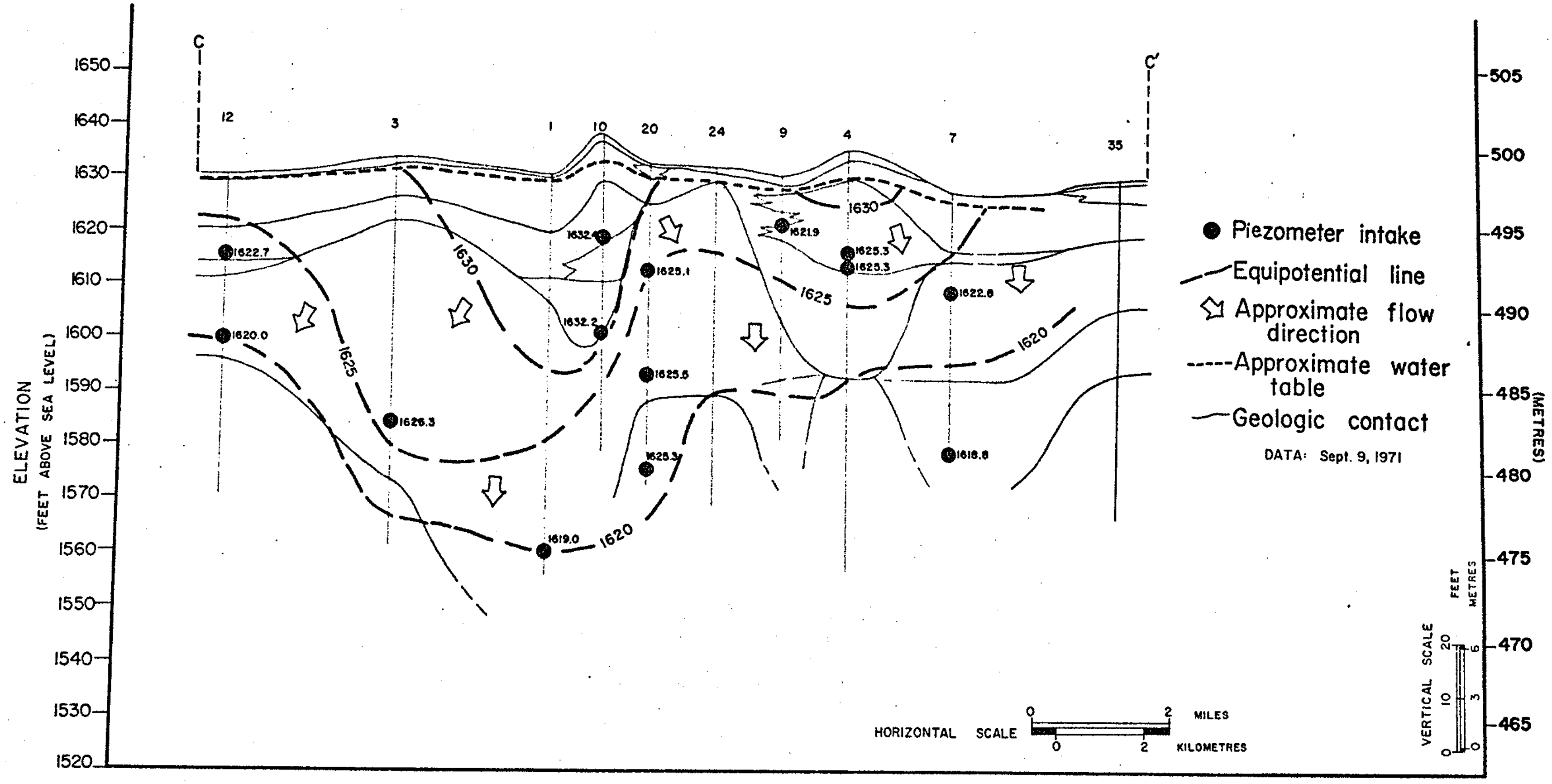


Fig. 32. Groundwater flow pattern along west-east cross section looking north along the south shore of Whitewater Lake.

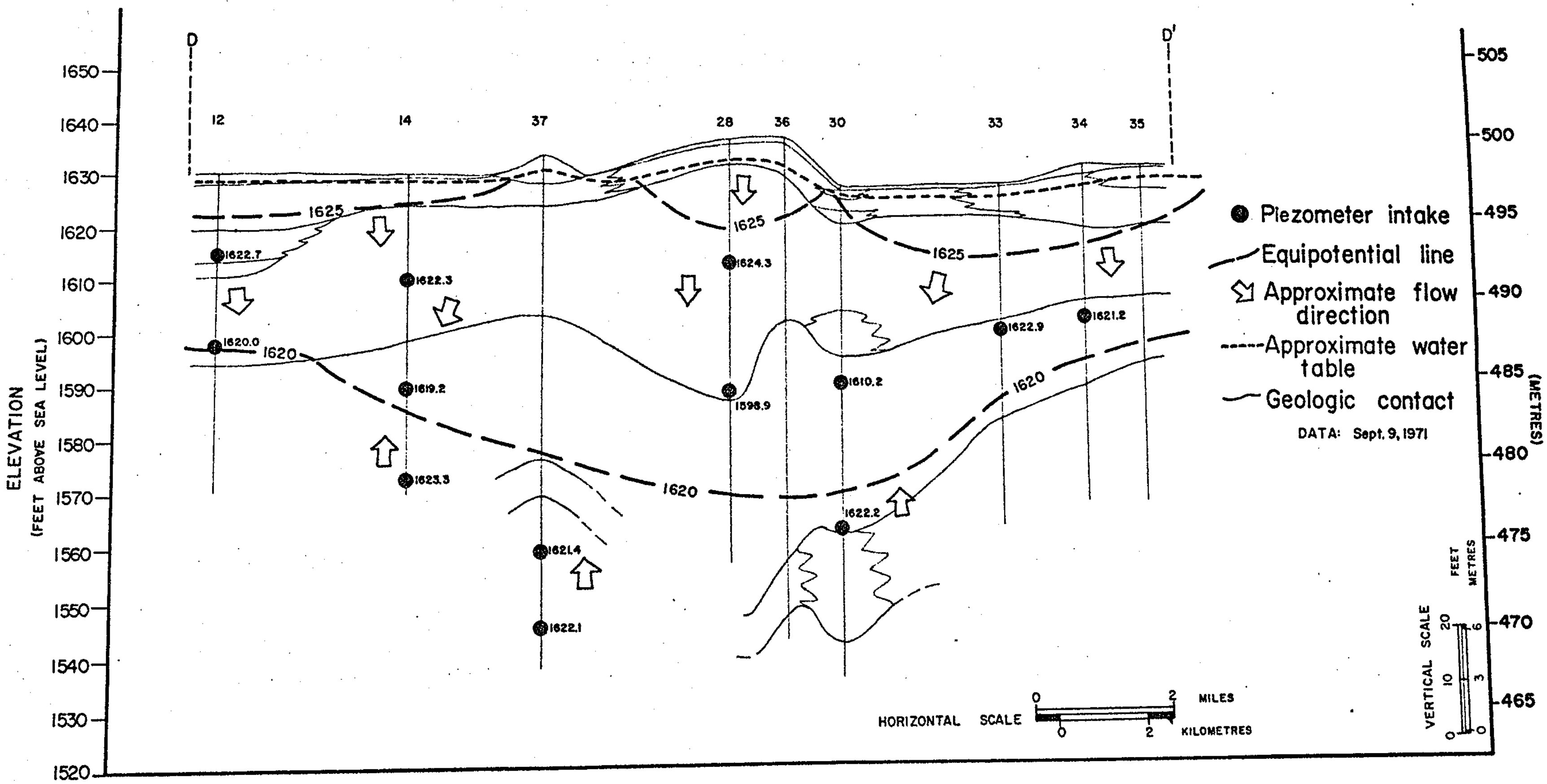


Fig.33. Groundwater flow pattern along west-east cross section looking north along the north shore of Whitewater Lake.

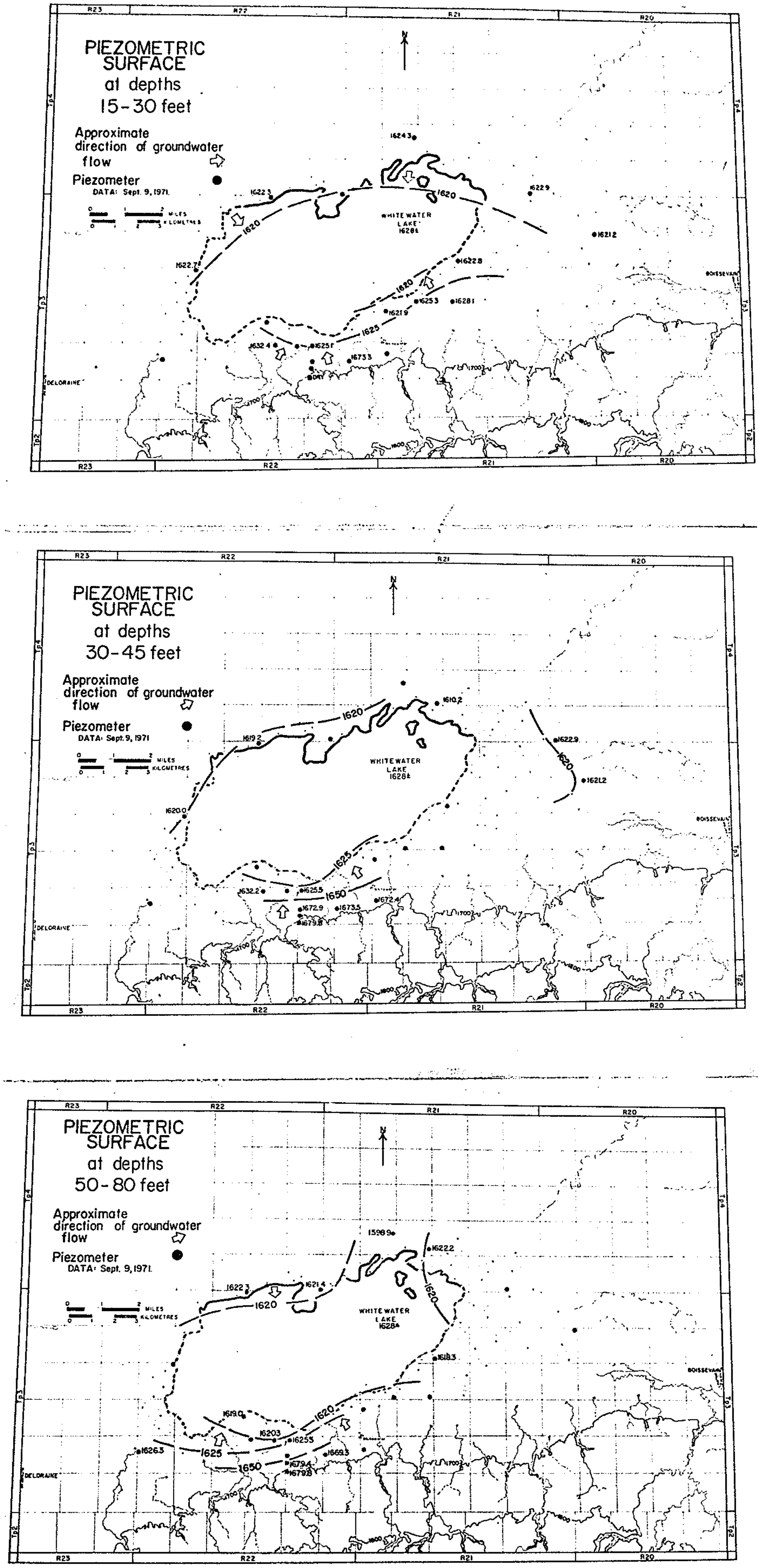


Fig. 34. Piezometric surface maps for various depth ranges in the Whitewater Lake Basin.

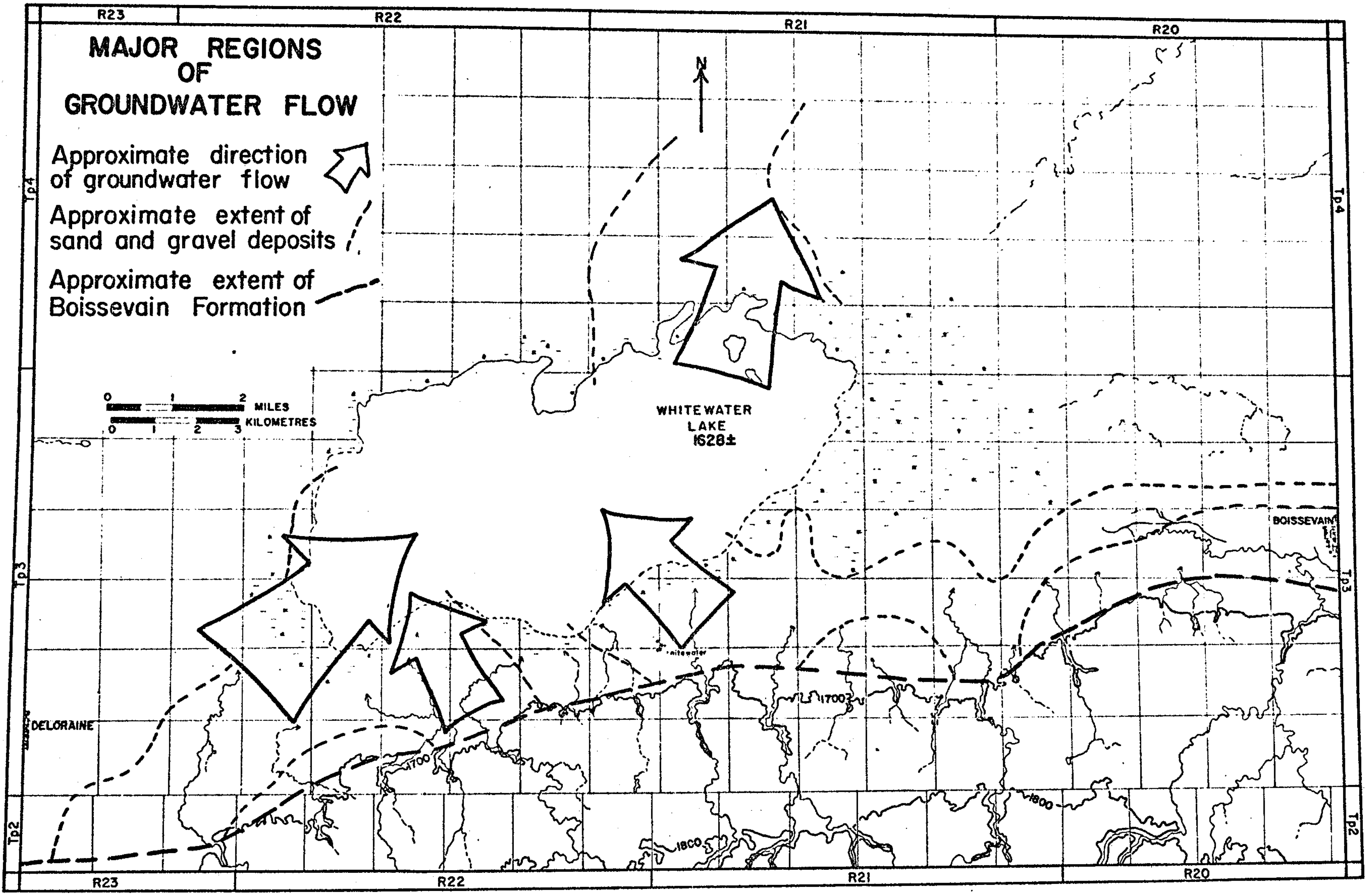


Fig.35. Major regions of groundwater flow in the Whitewater Lake Basin.

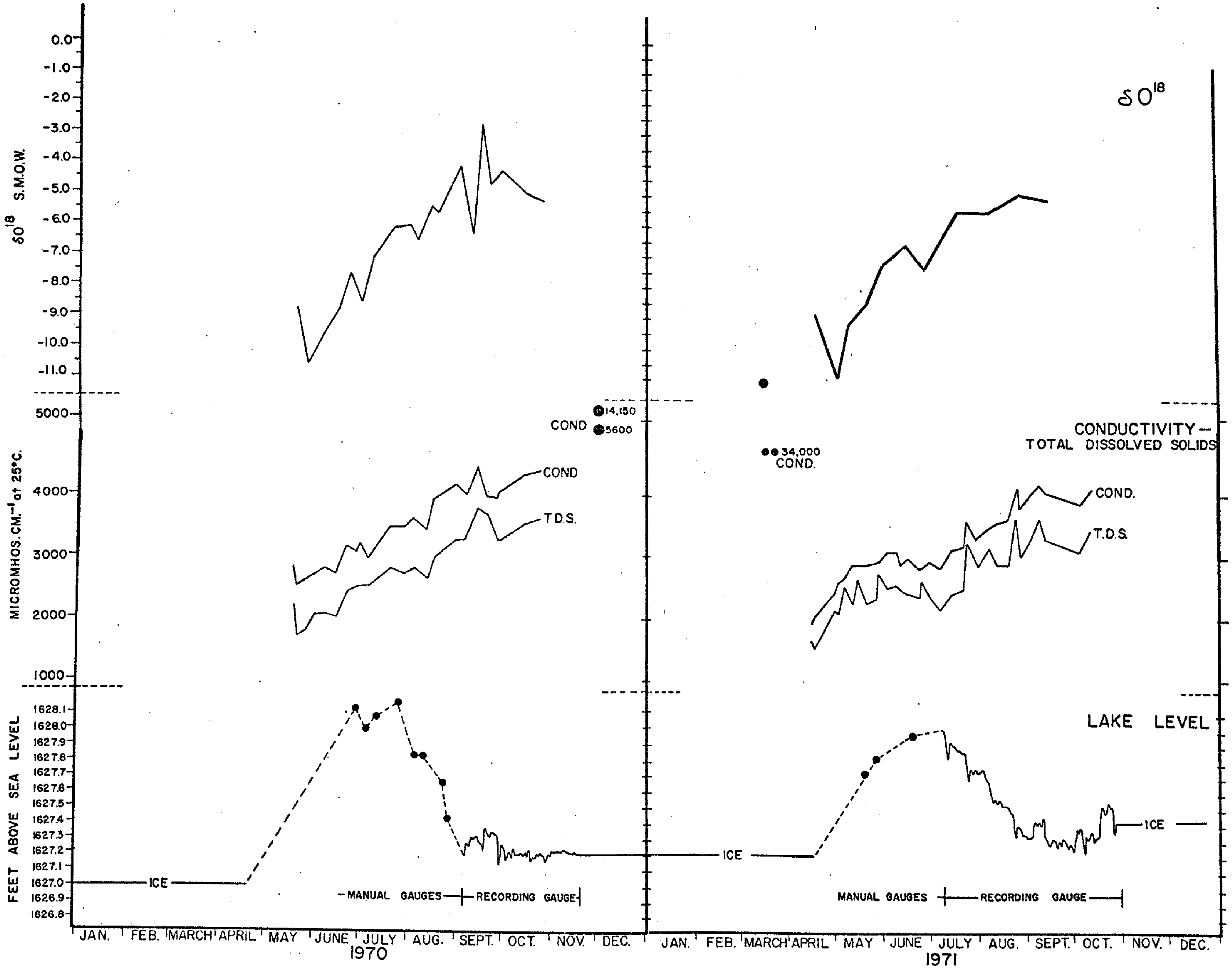


Fig. 36. Seasonal variations in δO^{18}, conductivity, total dissolved solids and lake levels, Whitewater Lake 1970 and 1971.

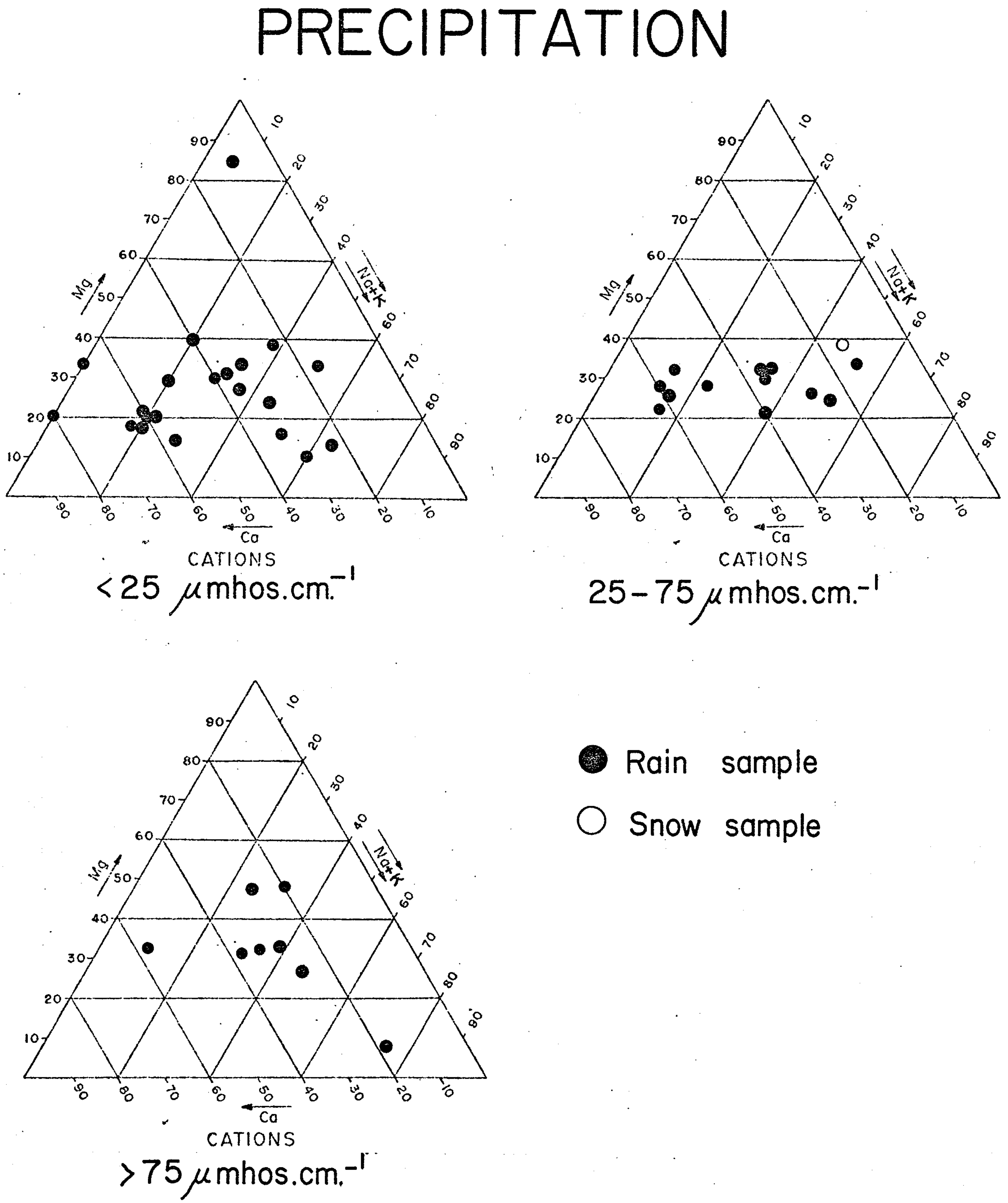


Fig. 37. Triangular cation plots of precipitation samples, 1971.

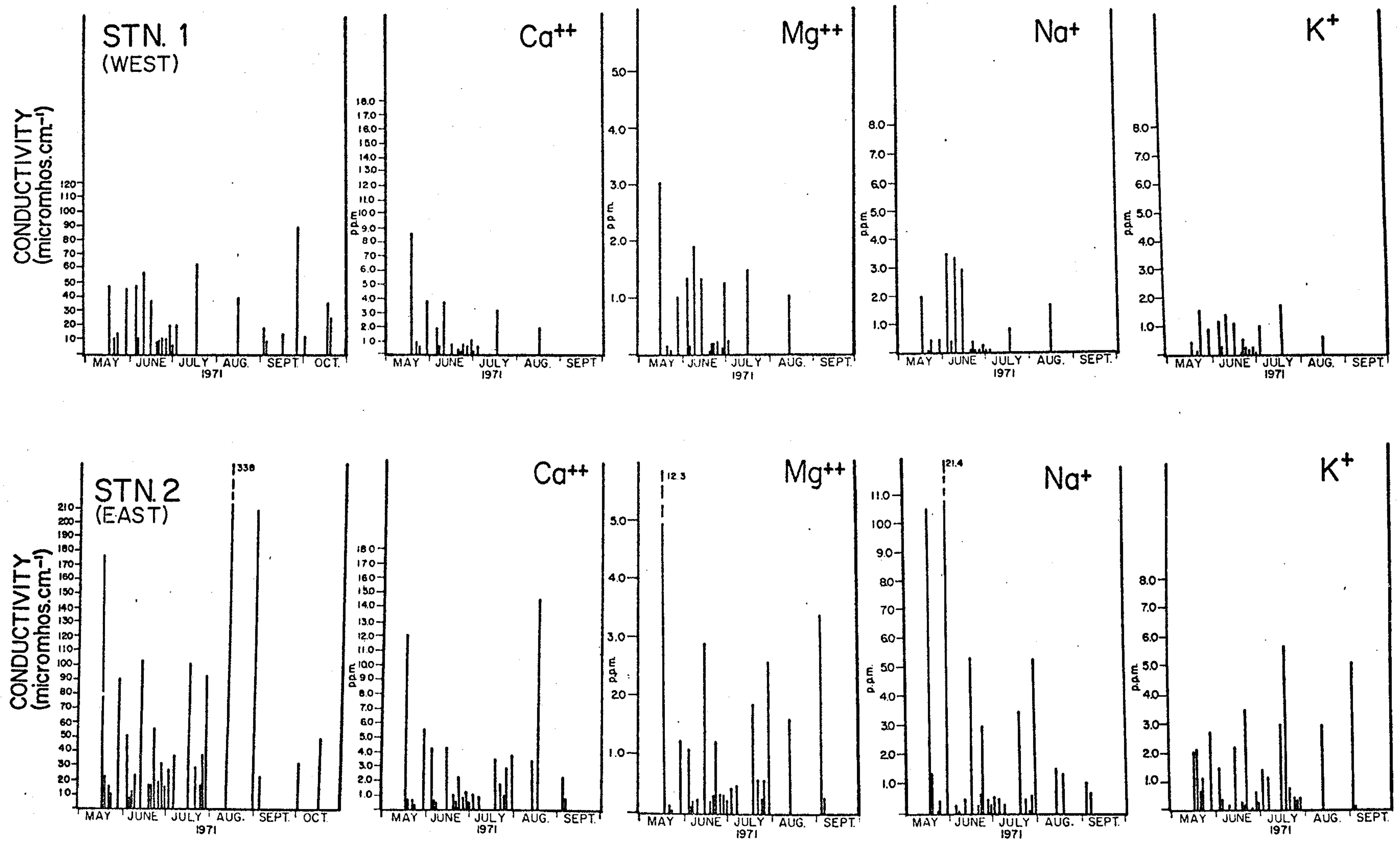


Fig. 38. Seasonal variation of major ions and conductivity of precipitation at stations 1 and 2 near Whitewater Lake, 1971.

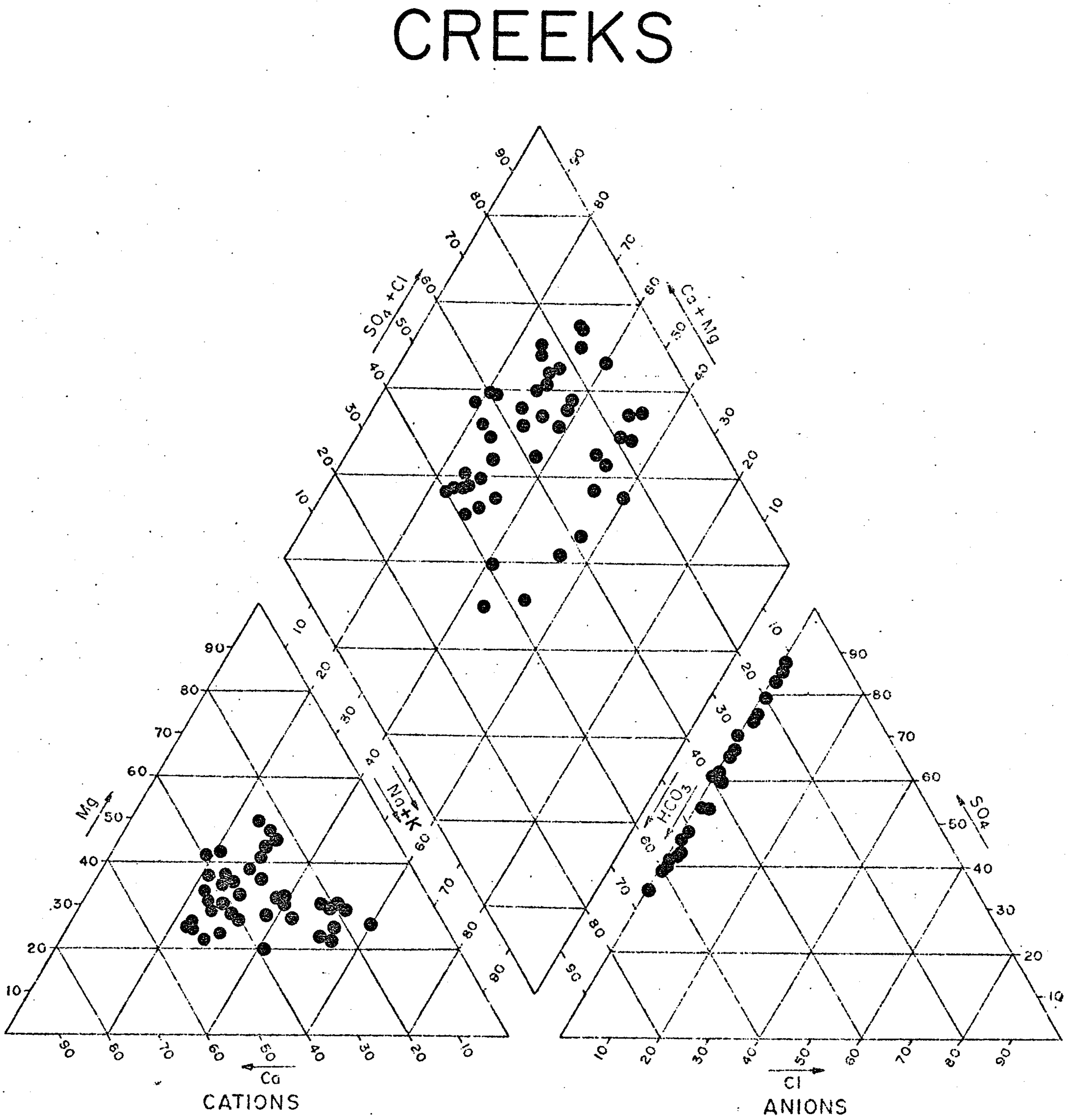


Fig. 39. Piper trilinear diagram showing chemistry of creek samples, 1971.

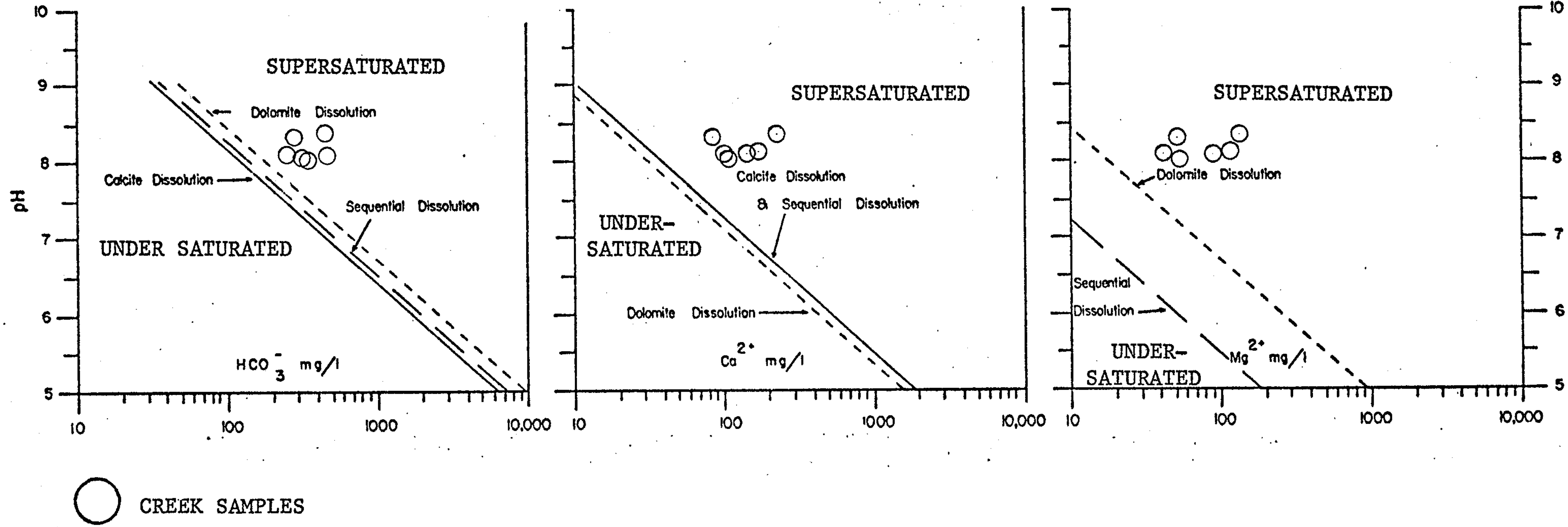


Fig. 40. pH and HCO_3^-, Ca^{2+}, Mg^{2+} concentrations of representative creek samples compared to calcite and dolomite dissolution models based on equilibrium constants at 5°C. from Langmuir (1971). Equilibrium diagrams are from Cherry (1971).

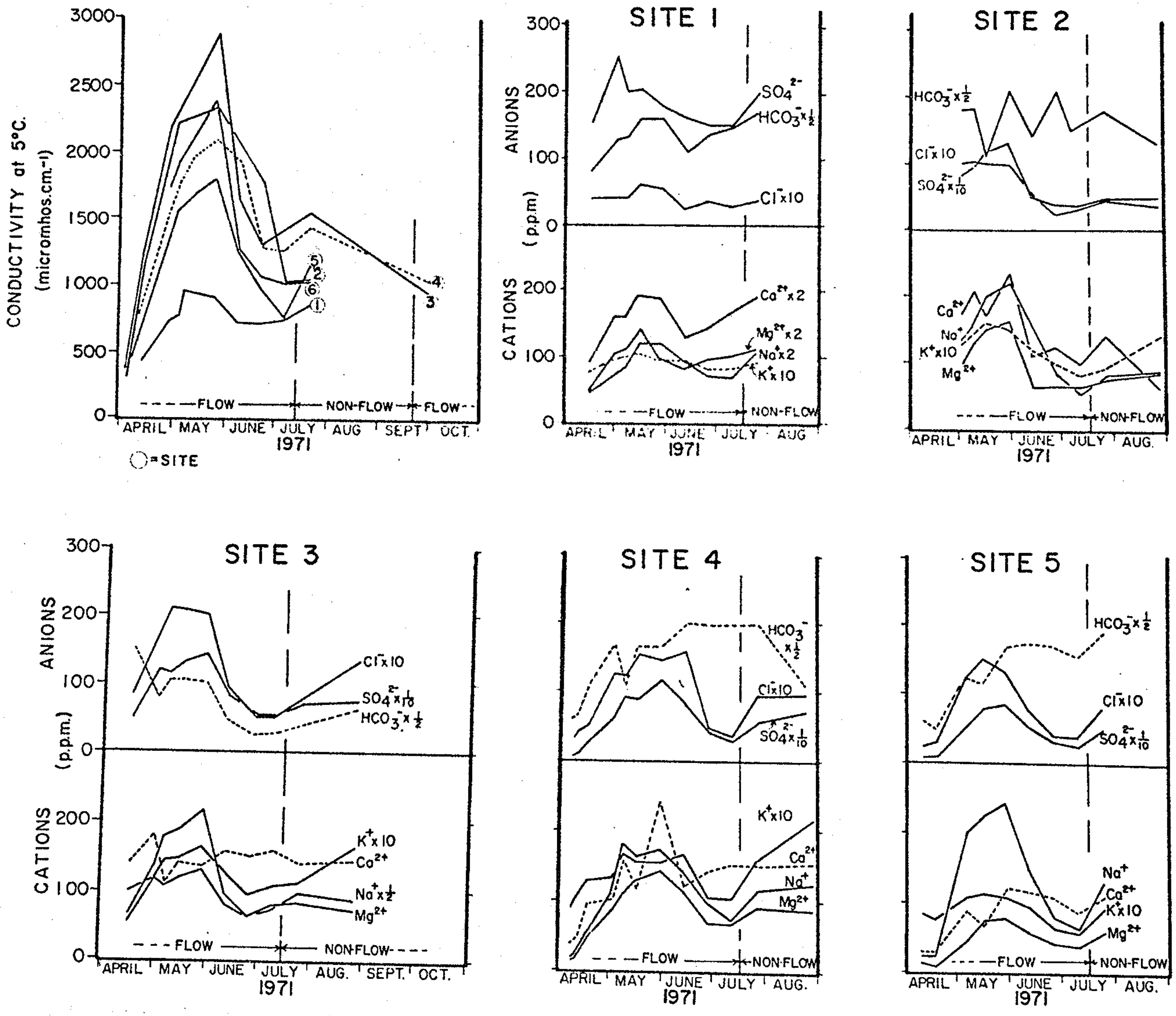
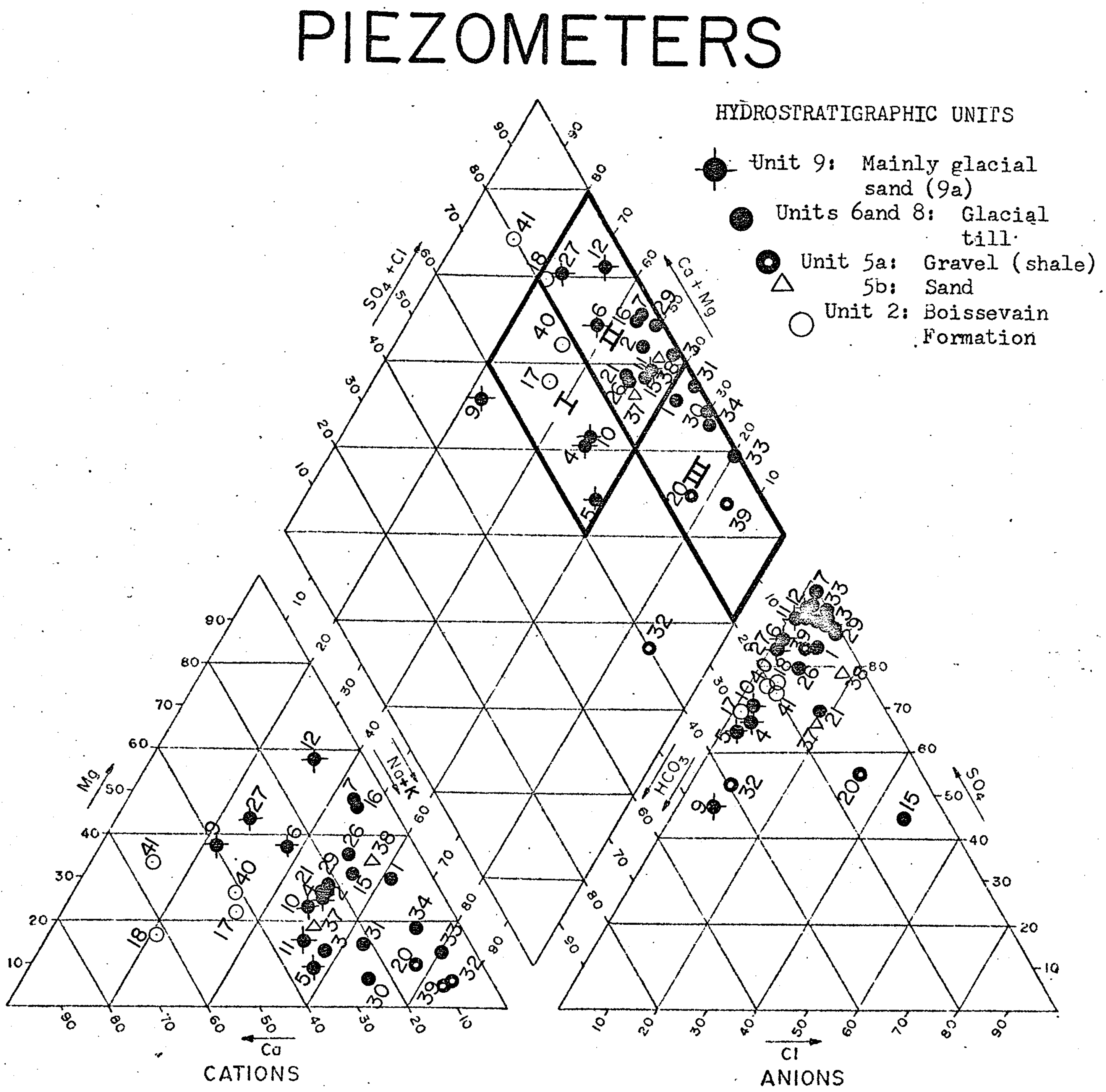
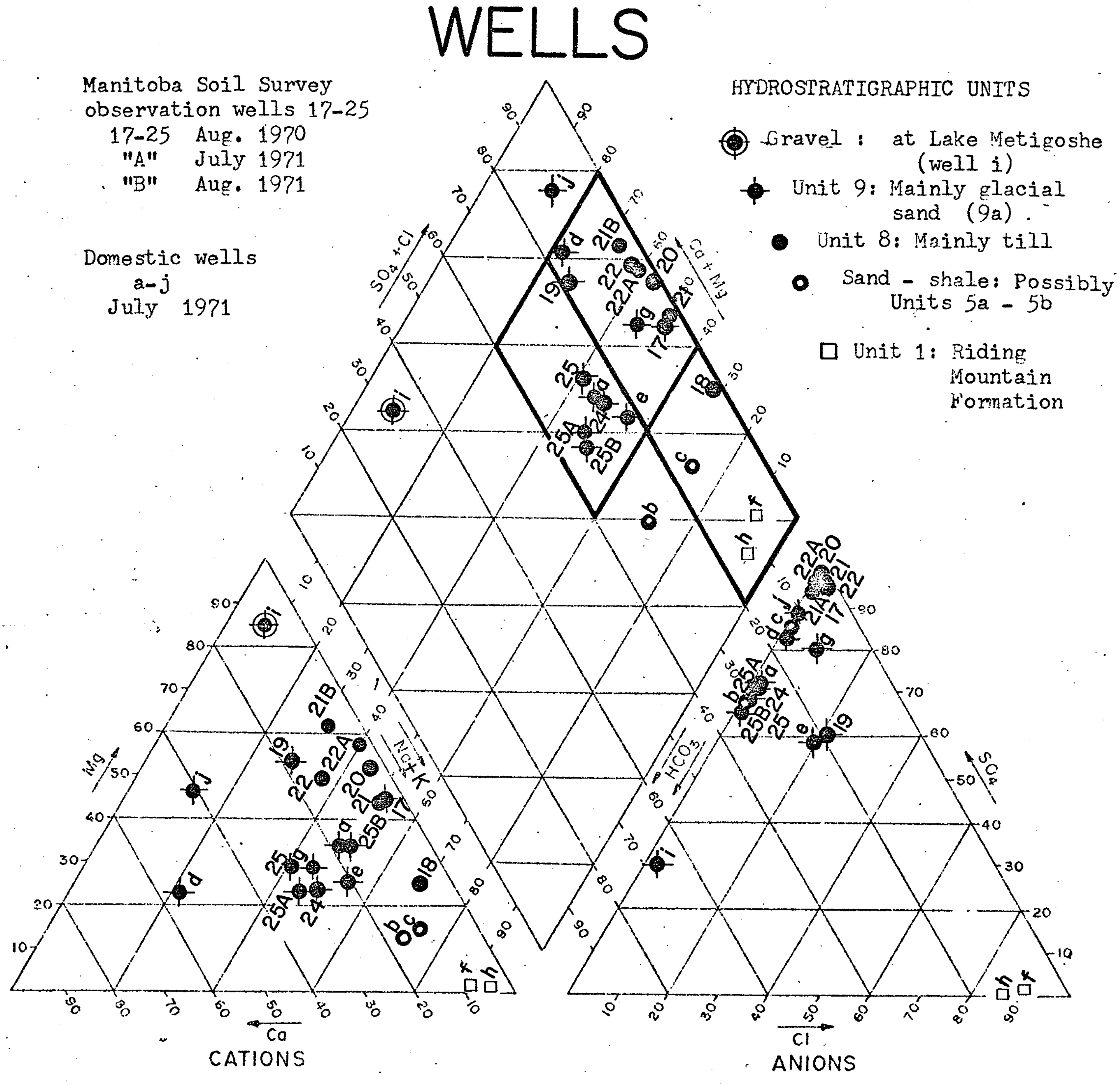


Fig. 41. Seasonal variations in major-ion chemistry and conductivity of creeks south of Whitewater Lake, 1971.



TYPE I	Na:	20-60%	calcium-magnesium-bicarbonate-sulphate
	HCO_3:	20-40%	
TYPE II	Na:	20-60%	calcium-magnesium-sulphate
	HCO_3:	0-20%	
TYPE III	Na:	60-100%	sodium-sulphate and sodium chloride
	HCO_3:	0-20%	

Fig. 42. Piper trilinear diagram showing types of groundwater obtained from piezometers in the Whitewater Lake Basin.



WELLS

Manitoba Soil Survey
observation wells 17-25
17-25 Aug. 1970
"A" July 1971
"B" Aug. 1971

Domestic wells
a-j
July 1971

HYDROSTRATIGRAPHIC UNITS

Gravel : at Lake Metigoshe (well i)

Unit 9: Mainly glacial sand (9a).

Unit 8: Mainly till

Sand - shale: Possibly Units 5a - 5b

☐ Unit 1: Riding Mountain Formation

TYPE I	Na:	20-60%	calcium-magnesium-bicarbonate-sulphate
	HCO_3:	20-40%	
TYPE II	Na:	20-60%	calcium-magnesium-sulphate
	HCO_3:	0-20%	
TYPE III	Na:	60-100%	sodium-sulphate and sodium chloride
	HCO_3:	0-20%	

Fig. 43. Piper trilinear diagram showing types of groundwater obtained from water wells in the Whitewater Lake Basin.

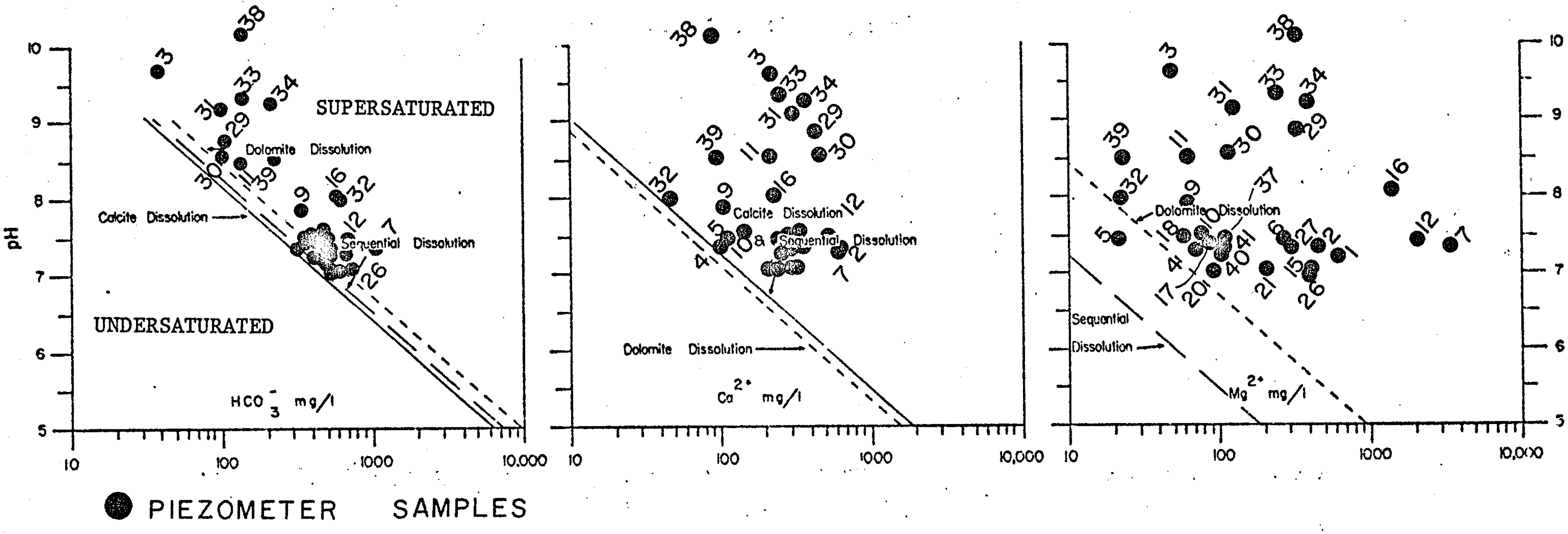


Fig. 44. pH and HCO_3^-, Ca^{2+}, Mg^{2+} concentrations in shallow groundwater in the Whitewater Lake Basin compared to calcite and dolomite dissolution models based on equilibrium constants at 5°C. from Langmuir (1971). Equilibrium diagrams are from Cherry (1971).

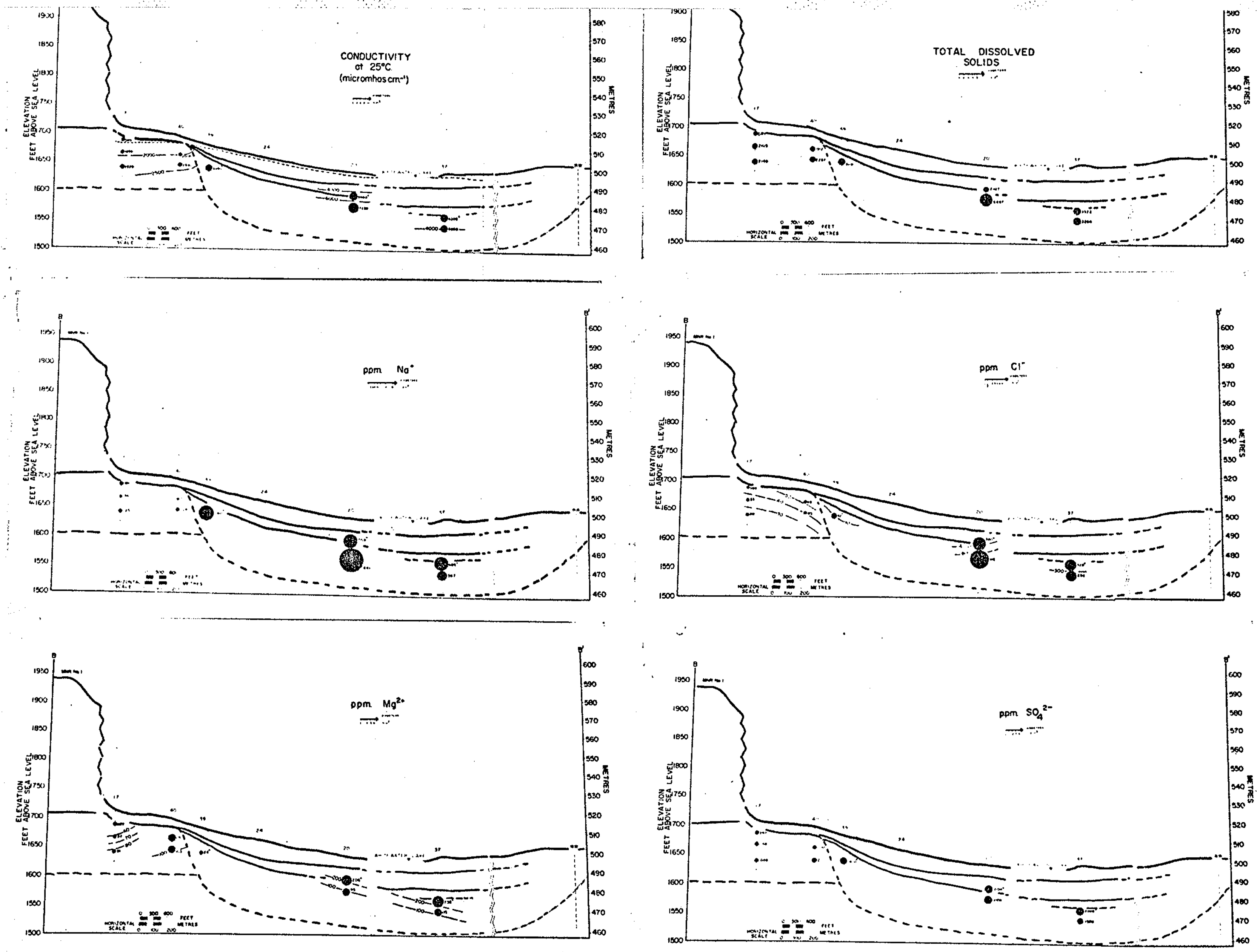


Fig. 45. Distribution of conductivity, total dissolved solids, Na^+, Cl^-, Mg^{2+} and SO_4^{2-} in shallow groundwater along the north slope of Turtle Mountain.

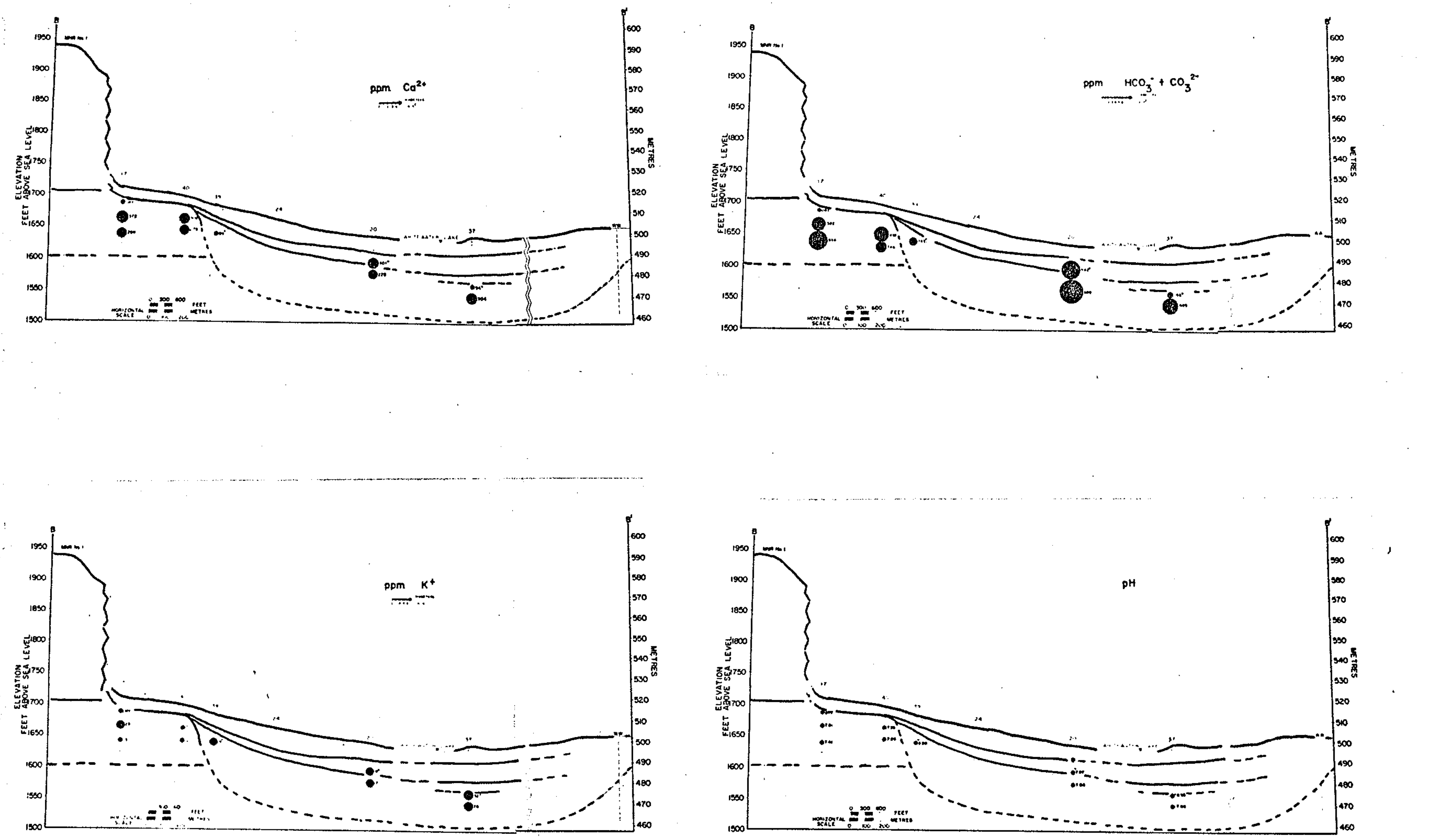


Fig. 46. Distribution of Ca^{2+}, K^{+}, $HCO_3^{-} + CO_3^{2-}$ and pH in shallow groundwater along the north slope of Turtle Mountain.

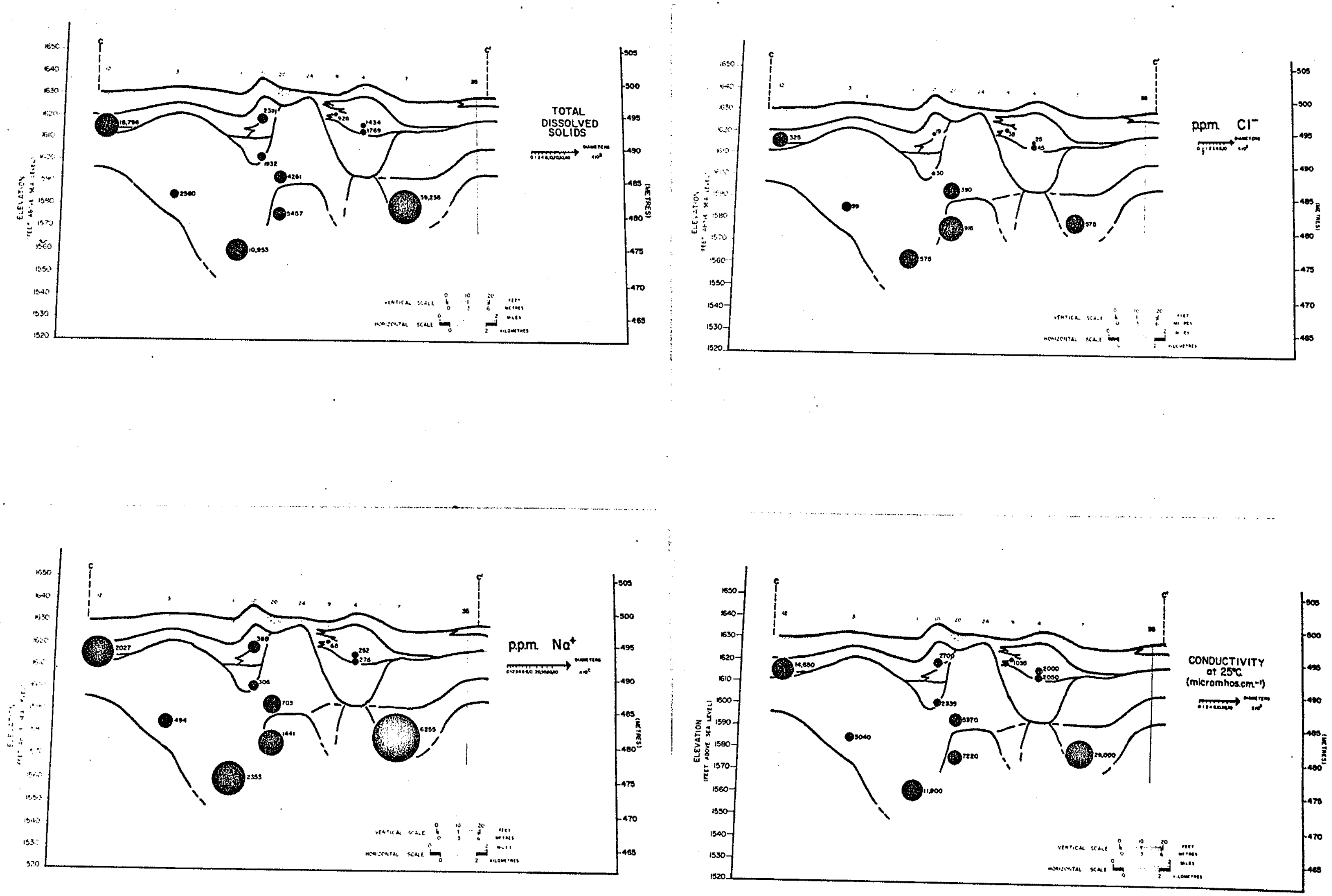


Fig. 47. Distribution of total dissolved solids, conductivity, Na^+ and Cl^- in shallow groundwater along the south shore of Whitewater Lake.

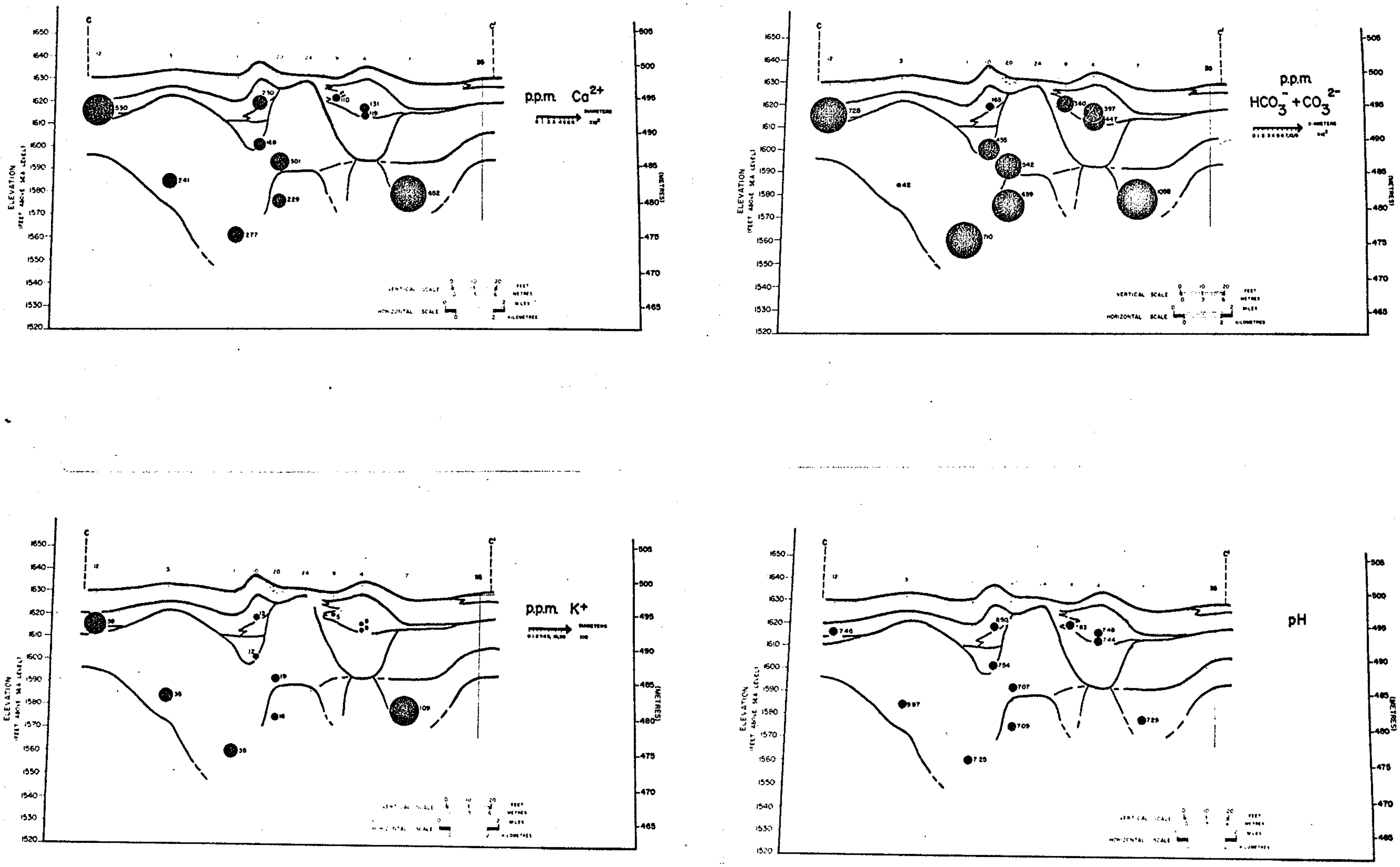


Fig. 48. Distribution of Ca^{2+}, $HCO_3^- + CO_3^{2-}$, K^+ and pH in shallow groundwater along the south shore of Whitewater Lake.

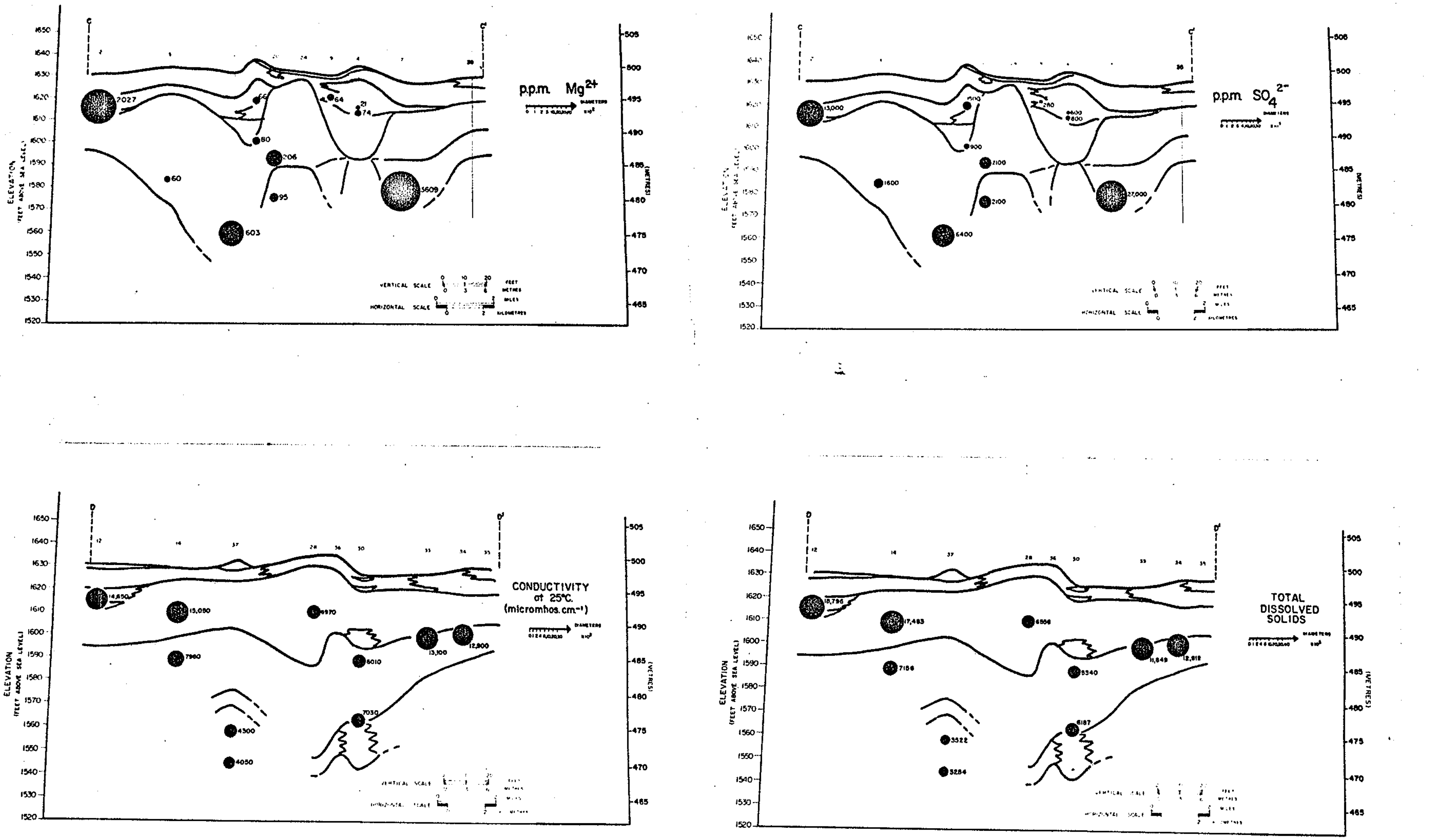


Fig. 49. Distribution of Mg^{2+} and SO_4^{2-} in shallow groundwater along the south shore of Whitewater Lake and the distribution of conductivity and total dissolved solids along the northshore.

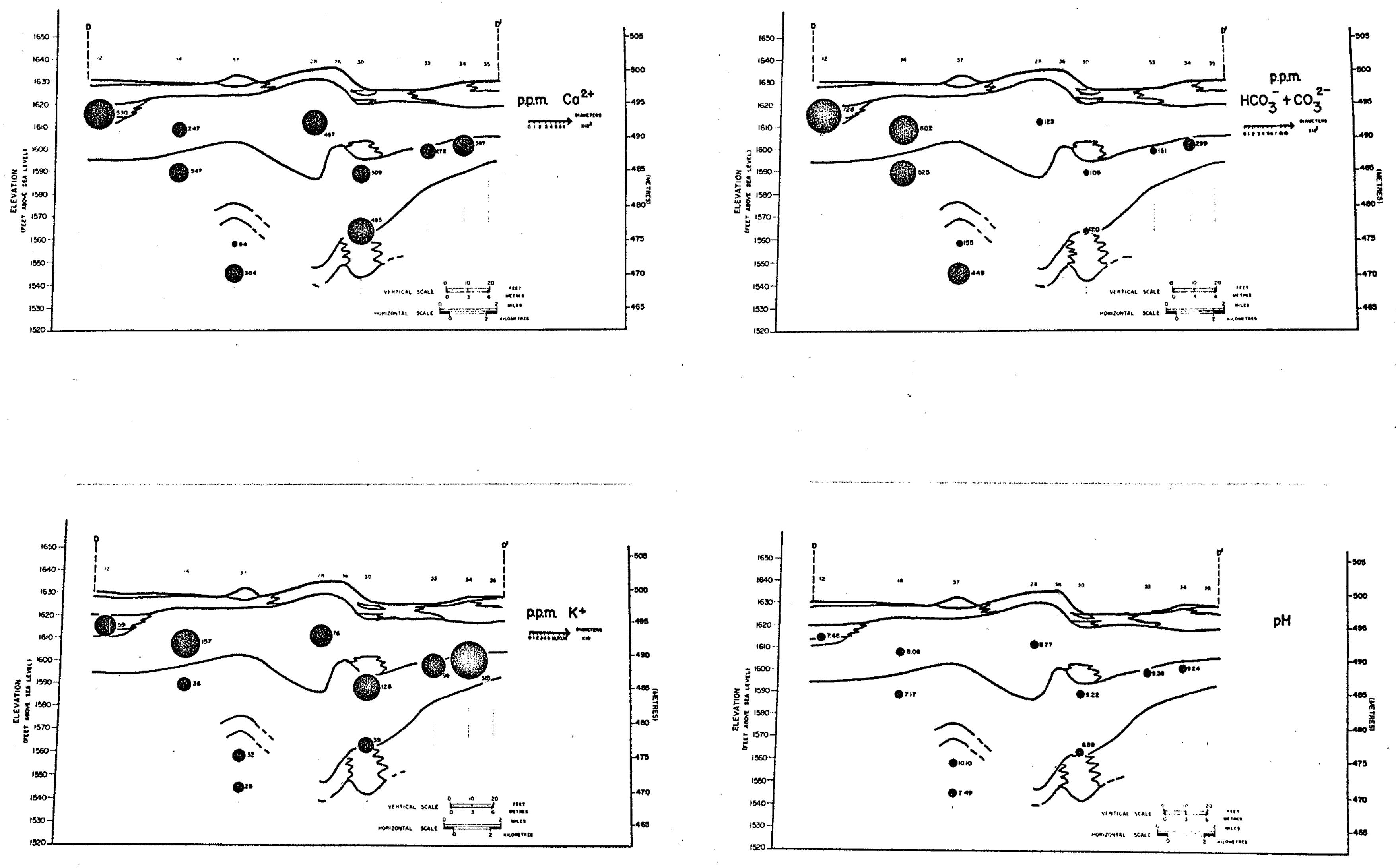


Fig. 50. Distribution of Ca^{2+}, $HCO_3^- + CO_3^{2-}$, K^+ and pH in shallow groundwater along the north shore of Whitewater Lake.

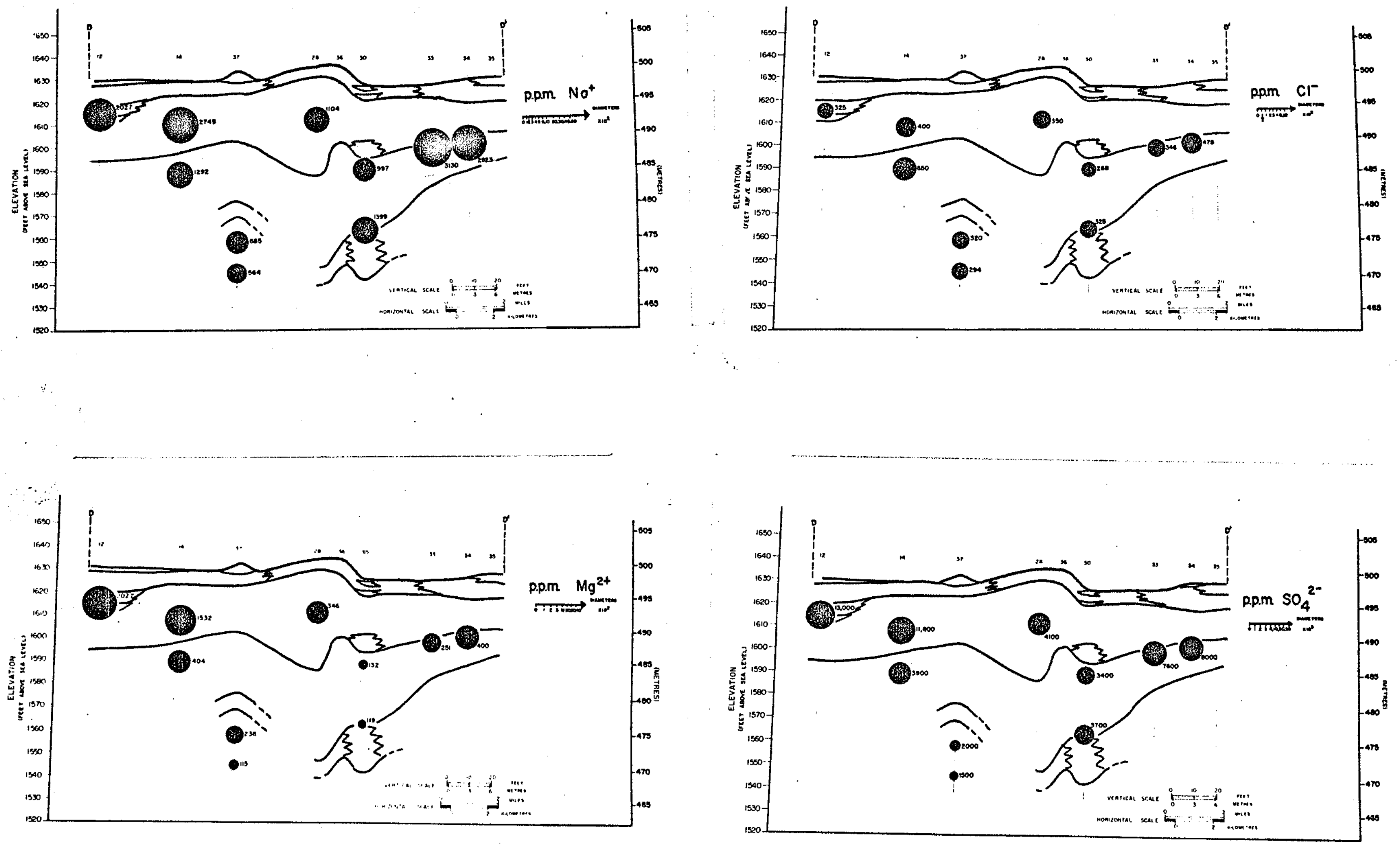


Fig. 51. Distribution of Na^+, Cl^-, Mg^{2+} and SO_4^{2-} in the shallow groundwater along the north shore of Whitewater Lake.

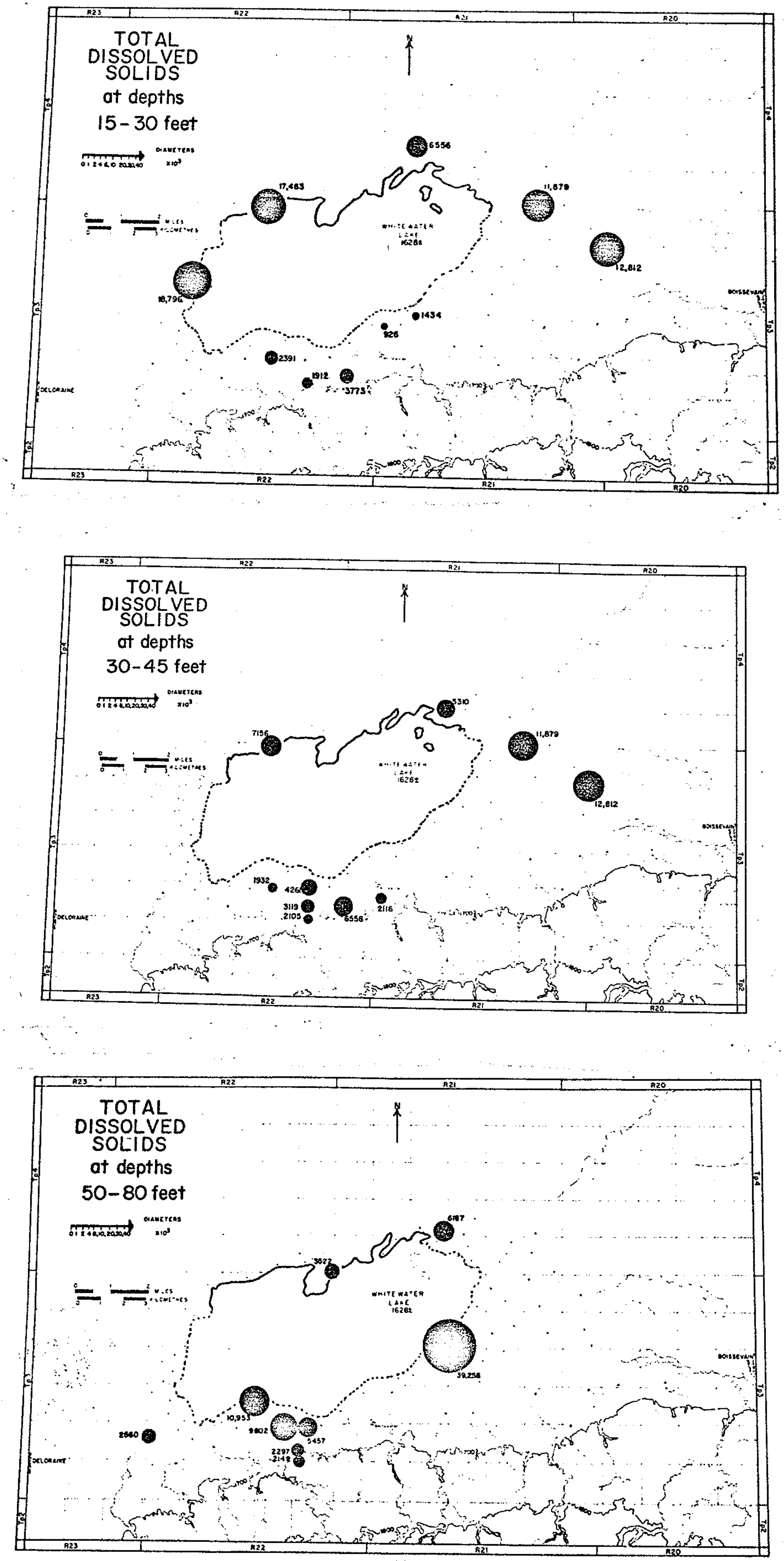


Fig. 52. Distribution of total dissolved solids at various depth ranges in the Whitewater Lake Basin.

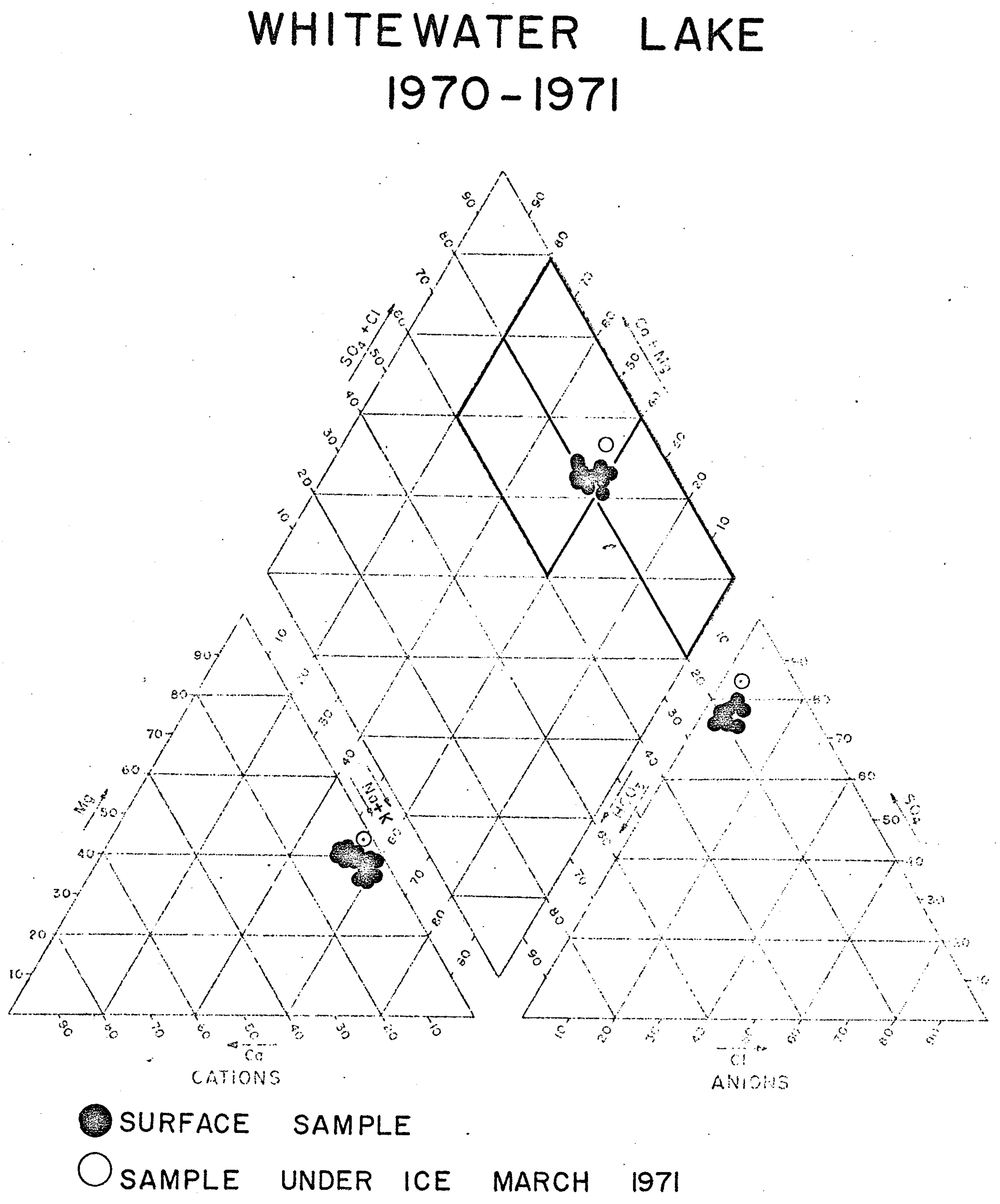


Fig. 53. Piper trilinear diagram showing chemistry of Whitewater Lake samples taken in 1970 and 1971.

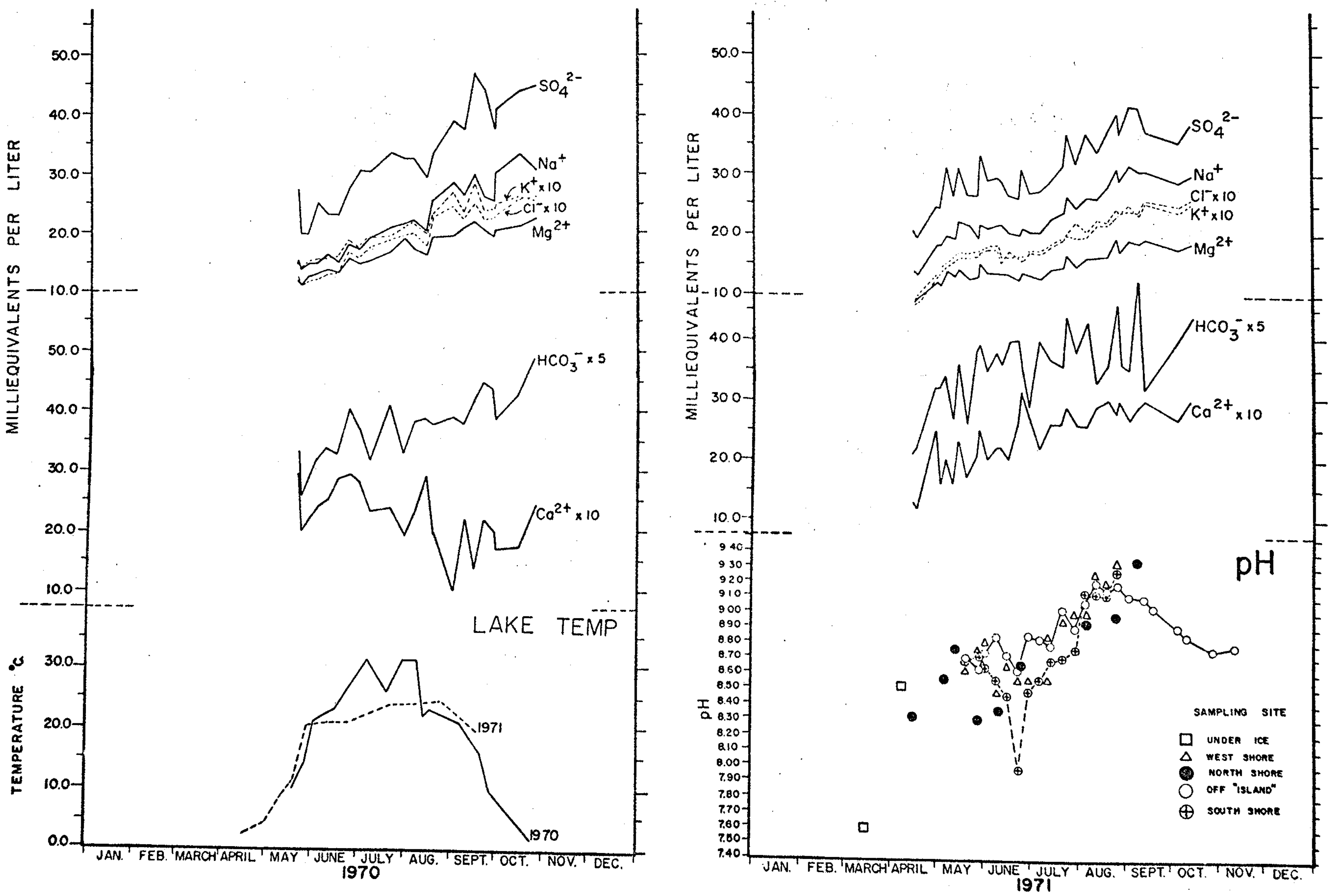


Fig. 54. Seasonal variations in major-ion chemistry, lake temperature and pH at Whitewater Lake, 1970 and 1971.

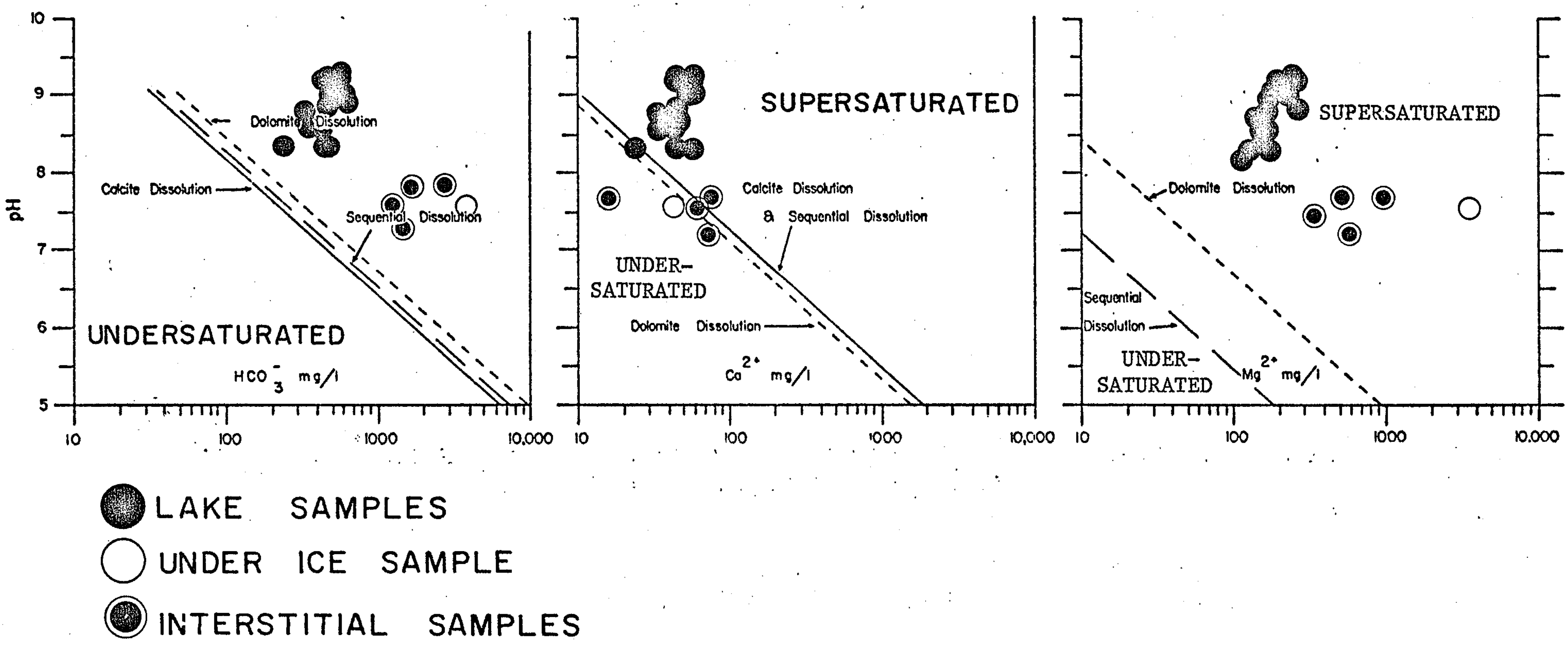


Fig. 55. pH and HCO_3^-, Ca^{2+}, Mg^{2+} concentrations of lake water and interstitial waters compared to calcite and dolomite dissolution models based on equilibrium constants at 5°C. from Langmuir (1971). Equilibrium diagrams are from Cherry (1971).

INTERSTITIAL WATERS OF BOTTOM SEDIMENTS

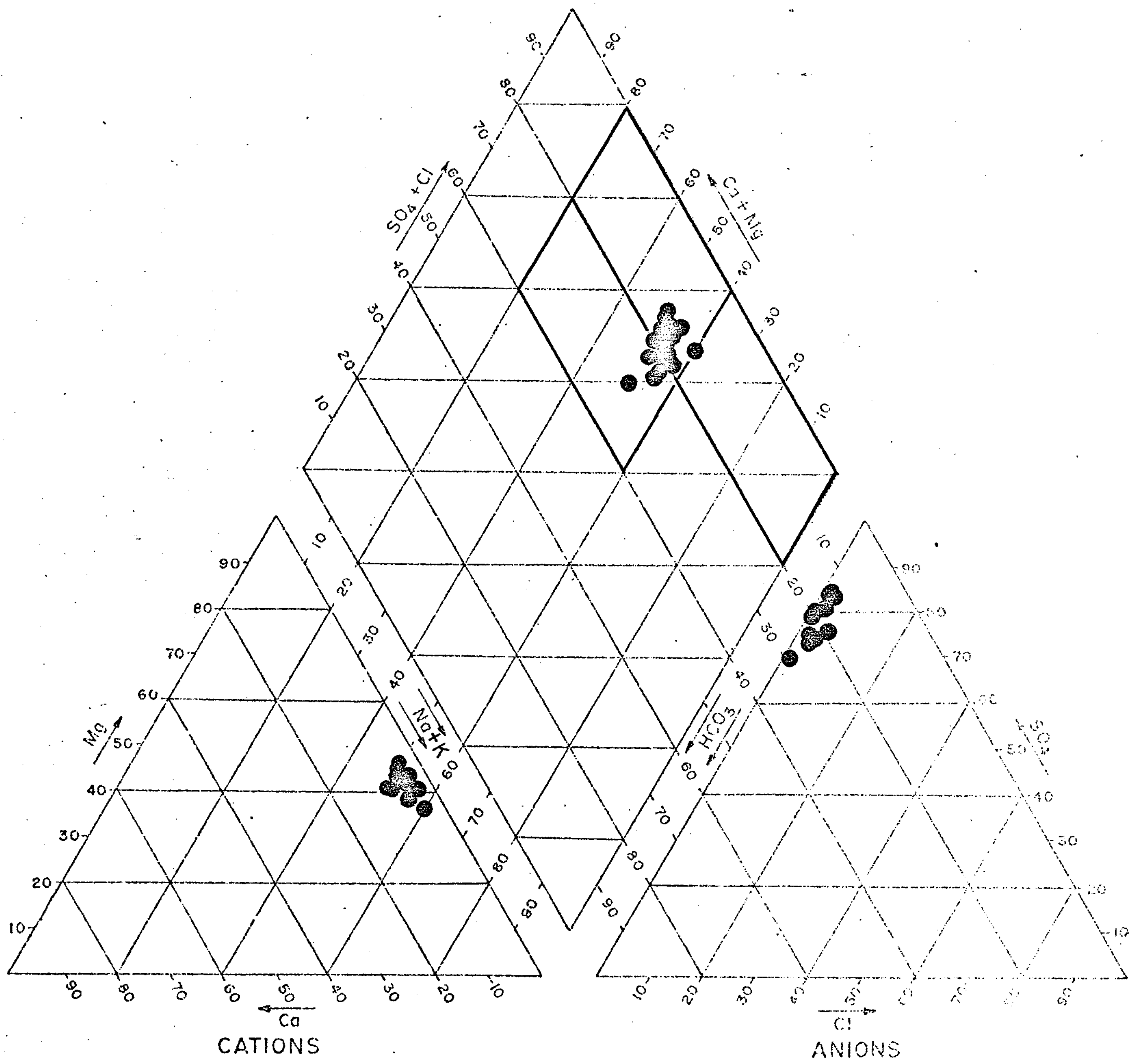


Fig. 56. Piper trilinear diagram showing chemistry of interstitial waters of bottom sediments.

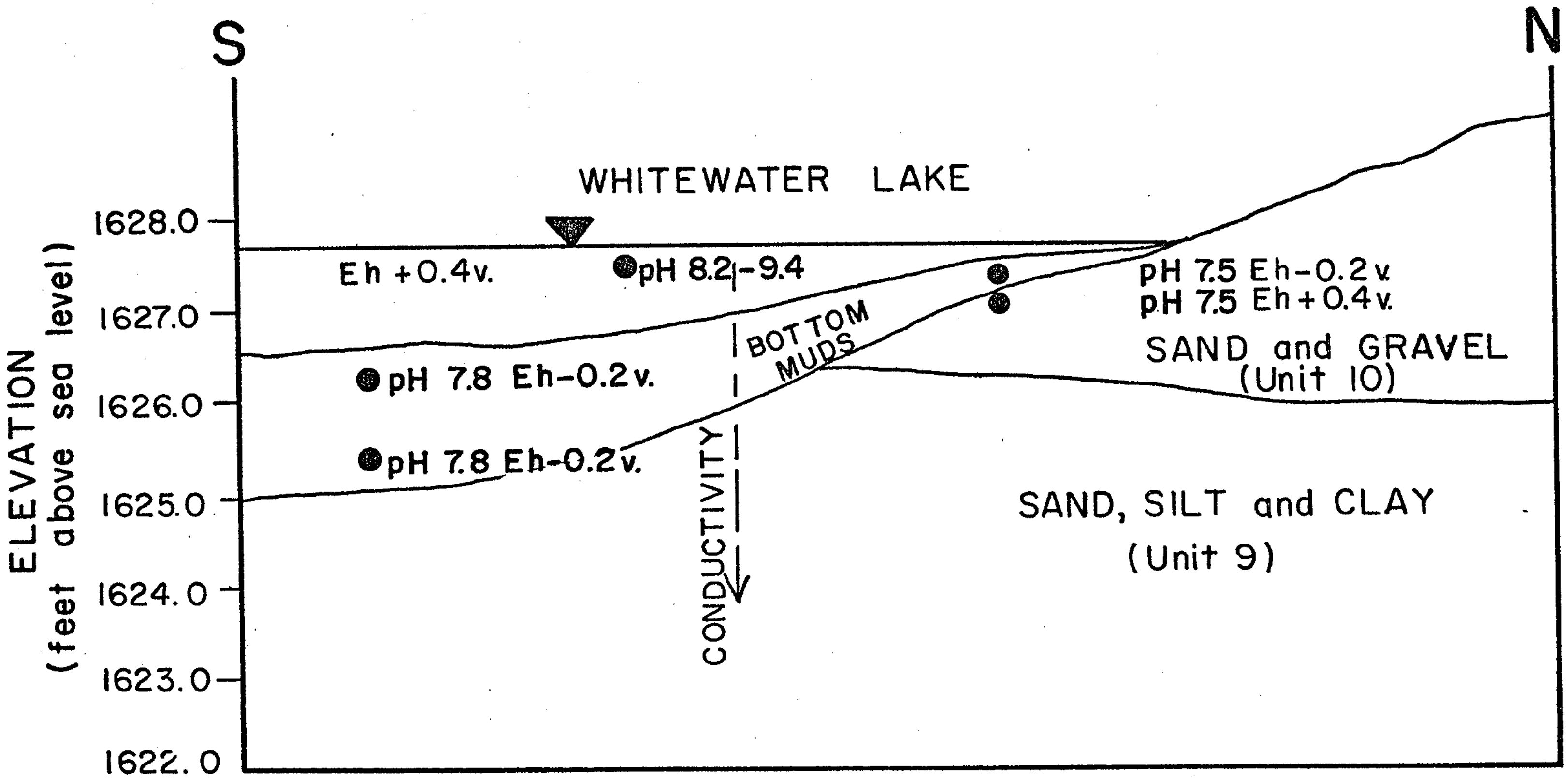


Fig. 57. Variations of Eh and pH in bottom sediments and lake waters, Whitewater Lake. Horizontal scale is representative .

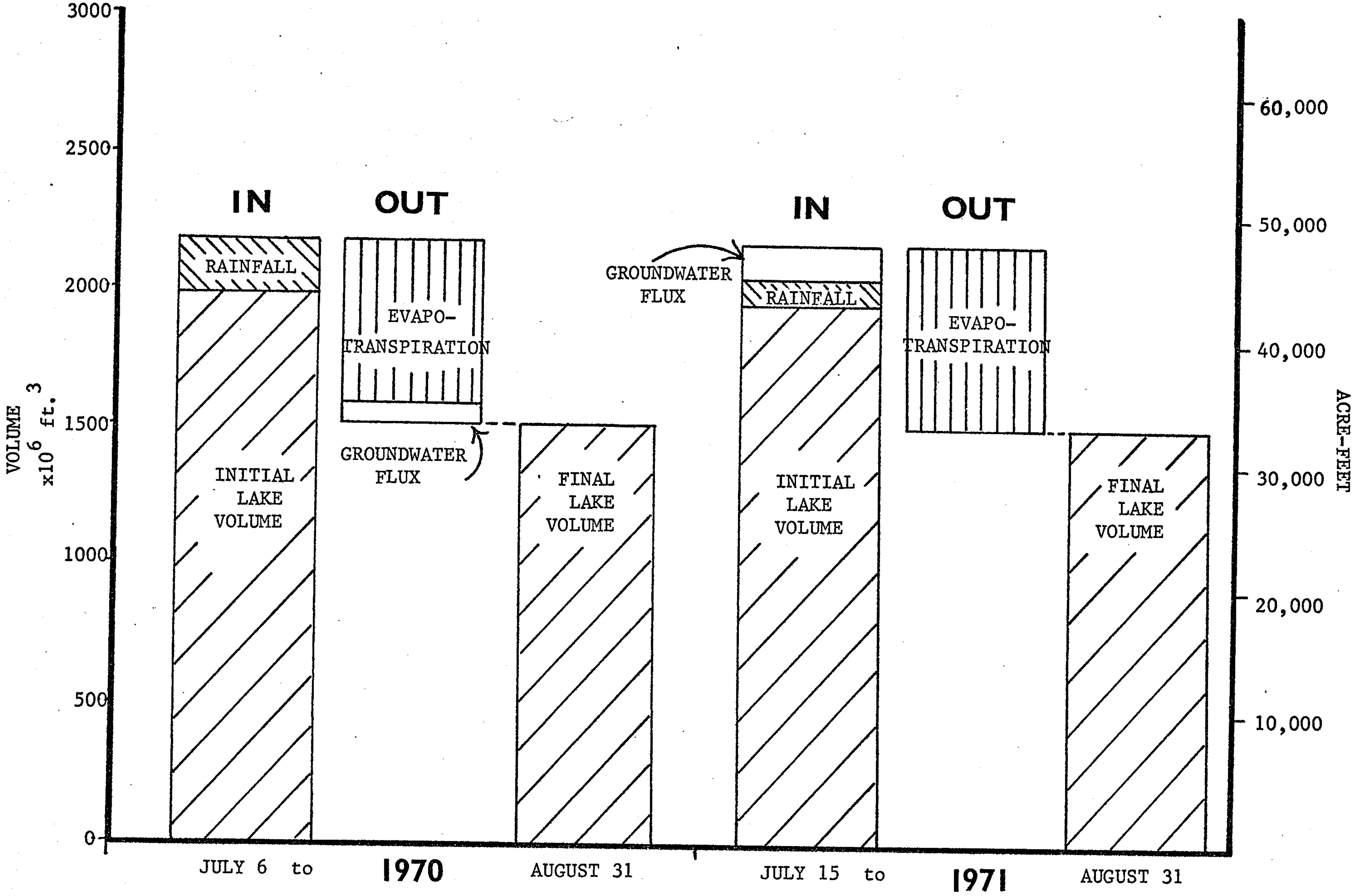


Fig. 58. Results of water budget calculations for Whitewater Lake in 1970 and 1971.

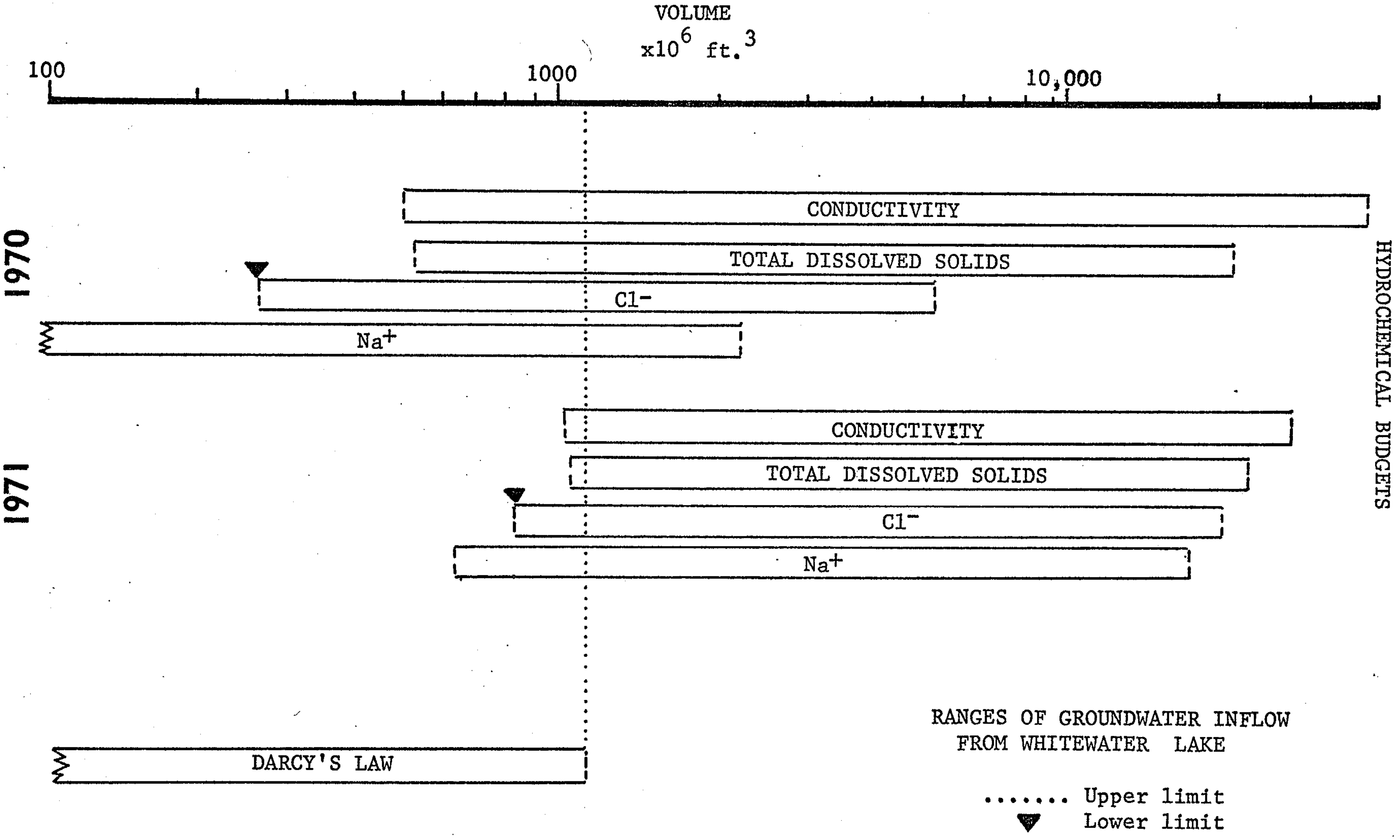


Fig. 59. Comparison of calculated ranges of groundwater inflow based on hydrochemical budgets and Darcy's Law.

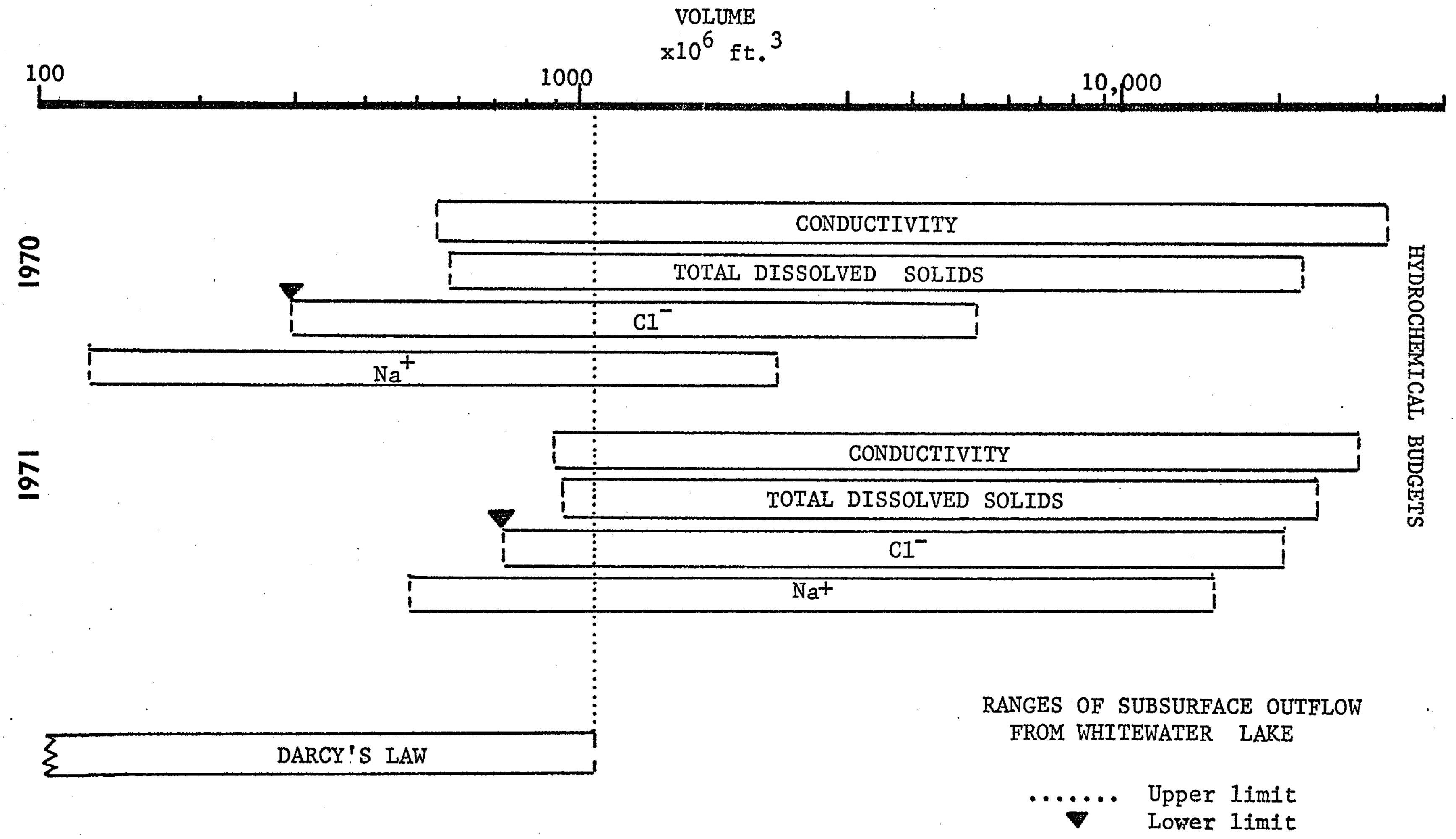


Fig. 60. Comparison of calculated ranges of subsurface outflow based on hydrochemical budgets and Darcy's Law.

1.

2.

PLATE I

Fig. 1. Contact between the Turtle Mountain Formation and Boissevain Formation exposed in creek valley in Sect. 6, Twp.3, R20,W1. Note thrust fault with Turtle Mountain beds overriding beds of the Boissevain Formation. White salts are conspicuous on the surface of the Boissevain Formation.

Fig. 2 Slumping in the Turtle Mountain Formation. Exposure is at the same location mentioned above. Pocket watch indicates scale.

Table 1. Mean monthly precipitation at Boissevain, Manitoba (as compiled by Bossenmaier, 1953).

	Number of years recorded	Inches	Centimeters
January	9	1.03	2.62
February	9	0.78	1.98
March	17	1.09	2.77
April	19	1.05	2.67
May	19	2.09	5.30
June	19	3.55	9.02
July	19	2.52	6.40
August	19	2.48	6.30
September	19	1.33	3.38
October	19	0.66	2.18
November	9	0.85	2.16
December	8	0.62	1.57
Yearly mean		18.25	46.35

Table 2. Monthly and annual precipitation at Boissevain and Peace Gardens, Manitoba for the period 1967 - 1970 (from Department of Transport, Weather Records, 1967 - 1970).

	Boissevain				Peace Gardens			
	1967	1968	1969	1970	1967	1968	1969	1970
January	1.60	0.65	1.45	0.85	--	1.70	3.56	1.25
February	0.60	Tr.	1.21	0.85	--	0.70	1.77	1.30
March	1.00	0.47	0.57	1.70	--	0.65	0.78	2.10
April	2.71	1.48	0.95	2.92	7.67	2.30	1.65	3.75
May	0.44	1.82	1.64	1.95	1.23	3.64	2.29	3.23
June	1.57	1.75	4.08	1.55	2.51	3.20	5.72	2.91
July	0.59	2.49	3.81	3.02	1.87	3.22	3.58	3.42
August	0.59	7.02	1.31	0.63	1.59	11.51	2.51	2.15
September	0.93	2.43	0.73	1.78	1.58	2.39	1.04	1.85
October	2.08	1.10	0.95	0.81	3.25	1.53	1.93	1.25
November	0.56	0.81	0.25	0.41	1.24	2.45	0.40	2.23
December	0.90	0.30	0.70	0.70	2.15	1.03	1.65	1.38
Annual (inches)	13.57	20.32	17.65	17.17	23.09	34.32	26.88	26.82
Annual (centimeters)	34.40	58.80	44.80	43.60	58.70	87.10	68.40	68.20

Table 3. Monthly summer evaporation at Baldur, Manitoba (from Department of Transport, Weather Records 1967 - 1970).

	1967		1968		1969		1970	
	Pan	Lake	Pan	Lake	Pan	Lake	Pan	Lake
May	6.22	4.55	--	--	5.50	4.12	--	--
June	4.83	3.66	9.06	6.69	6.45	4.58	8.34	6.02
July	5.89	4.45	8.16	6.14	6.19	4.50	7.96	5.79
August	7.78	5.57	7.85	5.81	4.80	3.63	7.03	5.01
September	5.74	4.14	4.29	3.11	5.07	3.65	7.19	4.88
Totals (inches)	—	22.37	—	21.75	—	20.48	—	21.70
Totals (centimeters)		56.82		55.25		52.02		55.12

Table 4. Mean daily temperature (^{o}F.) at Boissevain, Manitoba (from Department of Transport, Monthly Weather Records, 1966 - 1970).

	1966	1967	1968	1969	1970
January	-12.1	0.6	-0.4	-7.7	-2.4
February	4.4	1.4	6.6	9.1	6.5
March	26.7	17.8	30.7	14.6	12.9
April	33.2	33.7	41.0	42.5	34.4
May	48.1	47.8	48.2	51.4	47.4
June	61.5	60.4	59.1	54.4	66.9
July	67.1	67.2	64.7	64.9	68.8
August	59.2	64.6	59.1	69.8	66.6
September	57.0	59.4	54.9	54.7	55.2
October	41.7	41.0	41.8	35.9	42.7
November	16.9	25.7	26.3	29.4	23.5
December	9.1	9.2	4.6	15.0	4.0

Table 5. Average analyses of saline soil samples from a specific physiographic area of Manitoba (from Pratt and Ellis, 1954).

Physiographic area	Number of samples	Cations*			Anions†			Total salts (ppm.)	pH
		Ca^{++}	Mg^{++}	Na^{+}	$SO_4^{=}$	Cl^{-}	HCO_3^{-}		
Western Upland Area:									
Forest section									
Till plains	11	16.7	39.9	43.4	90.5	7.4	2.1	12,646	8.3
Lacustrine clay plain	2	7.5	17.5	75.0	97.0	2.0	1.0	26,064	8.6

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* Alkali cations were obtained by difference and expressed as sodium.

† The samples were also analyzed for carbonates and nitrates but no measurable quantities were found to be present.

Cation and anion values are in milli-equivalents expressed as percentages of their totals.

Table 6. Chemical analyses of soil extracts, Whitewater Lake (from Eilers, 1971).

Depth	pH	Conductivity (millimhos cm^{-1})	Na^+ meq/l	Ca^{++} meq/l	Mg^{++} meq/l	Total Cations	$SO_4^=$ meq/l	Cl^- meq/l	HCO_3^- meq/l	Total Anions
0- 9"	7.05	7.74	59.13	13.95	42.59	115.67	113.22	2.75	2.00	117.97
9- 18"	7.25	11.04	88.26	15.62	75.33	179.22	165.79	4.20	7.25	176.24
18- 27"	7.35	11.17	89.56	17.48	75.88	182.92	169.16	3.85	3.75	176.76
27- 36"	7.30	11.04	88.70	15.81	84.25	188.76	176.95	3.90	4.00	184.85
36- 45"	7.30	11.84	96.52	16.74	81.84	195.10	185.16	3.95	4.25	193.36
45- 54"	7.40	11.56	99.13	7.25	76.81	183.19	171.12	4.30	4.25	179.67
54- 63"	7.35	10.80	90.86	9.67	71.79	172.41	161.82	4.75	4.75	171.32
63- 72"	7.45	11.70	98.23	9.30	80.91	188.44	176.70	4.45	5.25	186.40
72- 81"	7.40	11.43	93.04	15.43	80.35	188.82	177.63	4.15	4.50	186.28
81- 90"	7.10	12.14	100.43	17.85	92.44	210.72	189.16	4.45	3.75	197.36
90- 99"	7.60	12.77	106.52	13.76	83.93	214.21	200.69	4.90	5.50	211.09
99-108"	7.60	12.77	99.57	18.60	96.72	214.89	206.27	4.95	4.25	215.47
108-117"	7.40	13.85	109.13	19.34	108.99	237.46	228.87	5.65	5.00	239.52
117-126"	7.40	13.65	106.96	19.71	107.13	233.80	224.03	5.55	3.50	233.08
126-135"	7.20	14.89	115.65	17.29	124.06	257.00	246.63	6.60	4.25	257.48
135-144"	7.30	15.60	130.43	16.36	135.59	282.38	264.95	7.05	6.75	278.75

Table 7 a. Summary of aquatic vegetation at Whitewater Lake 1950 - 1951 (from Bossenmaier, 1953).

A. Species dominant in southwestern and eastern marsh area:

whitetop (*Scolochloa festucacea*)
hard-stem bulrush (*Scirpus acutus*)
broad-leaved cat-tail (*Typha latifolia*)
reed grass (*Phragmites communis*)

B. Emergent species:

hard-stem bulrush (*Scirpus acutus*)
cat-tail (*Typha angustifolia*)
(*Typha latifolia*)
spike rush (*Eleocharis palustris*)
mare's tail (*Hippuris vulgaris*)
water-plantain (*Alisma gramineum*)
alkali bulrush (*Scirpus paludosus*)
three-square bulrush (*Scirpus americanus*)
soft-stem bulrush (*Scirpus validus*)
water parsnip (*Sium suave*)

C. Non-emergent species:

sago (*Potamgeton pectinatus*)
bladderwort (*Utricularia vilgaris*)
pondweed (*Potamogeton pusillus*)
water crowfoot (*Ranunculus trichophyllus*)
water mil-foil (*Myriophyllum exalbescens*)
bur-reed (*Sparganium eurycarpum*)

Chara sp. and "coon-tail" (reported by Colls and Neufeld, 1950)
liverwort (*Fontinalis*)
star-duckweed (*Lemna trisulca*)
lesser duckweed (*Lemna minor*)

Table 7b. Species of aquatic vegetation at Whitewater Lake that also characterize the saline lakes of Saskatchewan (from Bossenmaier et al, 1954).

Triglochin maritima L., seaside arrow-grass

Distichlis stricta (Torr.) Rydb., alkali-grass

Puccinellia Nuttalliana (Schultes) Hitchc., Nuttall's alkali-grass

Eleocharis palustris (L.) R. and S., creeping spike-rush

Scirpus paludosus A. Nels., prairie bulrush

Atriplex hastata L., halberd-leaved atriplex

Chenopodium rubrum L., red goose-foot

Salicornia rubra A. Nels., samphire

Suaeda depressa (Pursh) S. Wats., western sea blite

Halerpestes (Ranunculus) Cymbalaria (Pursh), Greene, seaside crowfoot

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Table 8. Chemical analysis of siliceous shale from the Odanah Member, Riding Mountain Formation (from Bannatyne, 1970).

Hard grey shale NE 1 lsd. 13, sec. 12, tp.5, rge. 8 WPM; Analysts: MacKay and Brown	SiO_2	76.07%	K_2O	1.48%
	Al_2O_3	8.59%	P_2O_5	0.01%
	Fe_2O_3	1.73%	CO_2	nil
	FeO	0.58%	SO_3	n.d.
	TiO_2	0.38%	H_2O	7.92%
	MgO	0.96%	Carbon	0.25%
	CaO	0.60%		
	Na_2O	0.29%		
			Total	98.86%

Table 9. Chemical analysis of kaolinitic shale from the Boissevain Formation (from Bannatyne, 1970).

Representative of a 4 foot (m.) section, SW¼ lsd. 4, sec. 3, tp. 3, rge. 21 WPM. Analysts: MacKay and Brown	SiO_2	72.20%	K_2O	1.98%
	Al_2O_3	13.83%	MnO	nil
	Fe_2O_3	2.47%	P_2O_5	0.06%
	FeO	0.39%	CO_2	0.2%
	TiO_2	0.85%	H_2O	5.51%
	MgO	0.32%	H_2O^-	
	CaO	0.34%	Carbon	0.4%
	Na_2O	0.53%		
			Total	99.08%

Table 10. Chemical analysis of silty shale from the Turtle Mountain Formation (from Bannatyne, 1970).

Light olive grey silty shale from 3.74 foot (m.) section in SE¼ lsd. sec.25,tp.1,rge.24 WPM. Analysts: MacKay and Brown	SiO_2	65.22%	MnO	nil
	Al_2O_3	14.20%	P_2O_5	0.14%
	Fe_2O_3	4.08%	CO_2	nil
	TiO_2	0.62%	H_2O	8.03%
	MgO	1.54%	H_2O^-	
	CaO	1.20%	Carbon	1.3%
	Na_2O	1.24%	Total	99.90%

Table 11. Monthly and seasonal precipitation at stations near Whitewater Lake, 1971.

	West side of lake				East side of lake			
	Deloraine*	Station 1	Mean	Percent Difference	Boissevain*	Station 2	Mean	Percent Difference
		(inches)				(inches)		
May	2.48	2.67	2.57	4%	2.34	1.66	2.00	17%
June	6.20	6.91	6.56	6%	4.38	4.62	4.50	3%
July	1.70	1.77	1.74	2%	2.57	1.25	1.91	15%
August	0.78	0.52	0.65	20%	0.95	0.54	0.75	27%
September	3.37	2.18	2.78	20%	1.43	1.66	1.55	7%
October	3.35	2.81	3.08	9%	4.18	3.09	3.64	15%
Seasonal Total (inches)	17.88	16.86	17.37	3%	15.85	12.82	14.39	18%
Seasonal Total (centimeters)	45.40	42.80	44.10	3%	40.20	32.60	36.40	18%

Seasonal Mean = 15.88 inches (40.20 cm.); Percent difference from mean = 9% (west-east)

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*Data from Department of Transport, unpublished Climatological Station Reports,1971.

Table 12. Monthly and seasonal Class "A" pan evaporation at stations near Whitewater Lake, 1971.

	West side of lake Station 1 (inches)	East side of lake Station 2 (inches)	Mean	Percent Difference
May	5.12	3.78 *	4.45	15%
June	4.75	5.15	4.80	7%
July	5.62	4.23	4.43	5%
August	5.60	7.47	6.54	14%
September	2.90	4.80	3.85	25%
October	1.63	2.46	2.05	20%
Seasonal Total (inches)	25.62	27.89	27.76	4%
Seasonal Total (centimeters)	65.20	70.80	68.00	4%

*Value represents a portion of the month.

Table 13. Water table levels of observation wells near Whitewater Lake.

	1969		1970		1971	
Well and elevation* in feet	Date	Depth in feet	Date	Depth in feet	Date	depth in feet
17	Feb.20	7.6	Jan. 2	7.6		
	April 17	6.0	March 19	8.2		
	May 1	frozen	April 14	7.4		
	May 16	4.7	May 12	2.0		
	May 29	5.1				
	June 13	5.6				
	July 2	5.1				
	July 15	3.9				
	July 24	4.3				
	Aug. 7	5.0				
	Aug. 22	5.9				
	Sept. 5	6.6				
	Sept. 17	7.0				
	Oct. 2	7.1				
	Oct. 16	7.1				
	Oct. 29	8.2				
	Dec. 4	7.4				
18	Feb.20	8.3	Jan. 2	8.8		
	April 17	5.2	March 19	9.6		
	May 1	7.1	April 14	9.8		
	May 16	6.9	May 12	5.4		
	May 29	6.0				
	June 13	7.0				
	July 2	5.9				
	July 15	4.8				
	July 24	4.9				
	Aug. 7	5.8				
	Aug. 22	6.8				
	Sept. 5	7.7				
	Sept. 17	8.1				
	Oct. 2	8.3				
	Oct. 16	8.4				
	Oct. 29	8.3				
	Dec. 4	8.4				
19	Feb. 20	8.1	Jan. 2	7.2		
	April 17	6.0	March 19	8.8		
	May 1	5.8	April 14	7.1		
	May 16	5.3	May 12	3.8		
	May 29	5.6				
	June 13	5.9				
	July 2	4.8				
	July 15	4.0				
	July 24	4.2				
	Aug. 7	5.0				
	Aug. 22	6.4				
	Sept. 5	5.8				

Table 13 . Water table levels of observation wells near Whitewater Lake.

Well and elevation* in feet	1969		1970		1971	
	Date	Depth in feet	Date	Depth in feet	Date	Depth in feet
19(cont)	Sept. 17	6.3	Jan. 2	7.3		
	Oct. 2	6.3	March 19	8.8		
	Oct. 16	6.3	April 14	7.1		
	Oct. 29	6.4	May 12	3.8		
	Dec. 4	6.7				
20	Feb. 20	7.3	Jan. 2	7.8	Oct. 20	1.0
1635.0	April 17	frozen	March 19	8.5		
	May 1	3.2	April 14	4.3		
	May 16	4.3	May 12	0.0		
	May 29	5.6				
	June 13	6.3				
	July 2	2.7				
	July 15	2.6				
	July 24	3.2				
	Aug. 7	5.0				
	Aug. 22	5.8				
	Sept. 5	6.9				
	Sept. 17	7.5				
	Oct. 2	7.7				
	Oct. 16	6.5				
	Oct. 29	6.8				
	Dec. 4	7.4				
21	Feb. 20	7.0	Jan. 2	7.4	Aug. 5	5.2
1631.5	April 17	4.1	March 19	8.6	Sept. 9	6.9
	May 1	2.6	April 14	5.8	Oct. 3	7.3
	May 16	3.0	May 12	0.0		
	May 29	4.4				
	June 13	5.2				
	July 2	3.3				
	July 15	3.3				
	July 24	3.9				
	Aug. 7	5.3				
	Aug. 22	5.9				
	Sept. 5	6.3				
	Sept. 17	6.9				
	Oct. 2	7.0				
	Oct. 16	7.0				
	Oct. 29	7.0				
	Dec. 4	7.1				
22	Feb. 20	6.9	Jan. 2	6.8	July 24	2.7
1632.5	April 17	flooded	March 19	7.9	Aug. 5	2.8
	May 1	1.1	April 14	5.2	Sept. 9	3.5
	May 16	1.8	May 12	0.0	Oct. 3	3.6
	May 29	2.7				
	June 13	3.5				

Table 13 . Water table levels of observation wells near Whitewater Lake.

Well and elevation* in feet	1969		1970		1971	
	Date	Depth	Date	Depth	Date	Depth
22(cont.)	July 2	1.4				
1632.5	July 15	1.2				
	July 24	1.9				
	Aug. 7	3.4				
	Aug. 22	4.4				
	Sept. 5	5.3				
	Sept. 17	6.1				
	Oct. 2	5.7				
	Oct. 16	5.7				
	Oct. 29	5.9				
	Dec. 4	6.3				
24	Feb. 20	5.4	Jan. 2	6.3	Sept. 9	4.0
1635.5	April 17	1.0	March 19	7.2	Oct. 3	3.6
	May 1	1.1	April 14	1.3	Oct. 20	1.6
	May 16	1.9	May 12	0.0		
	May 29	2.9				
	June 13	3.9				
	July 2	1.8				
	July 15	1.3				
	July 24	2.1				
	Aug. 7	3.8				
	Aug. 22	4.7				
	Sept. 5	5.8				
	Sept. 17	6.4				
	Oct. 2	7.0				
	Oct. 16	6.2				
	Oct. 29	6.1				
	Dec. 4	6.0				
25	Feb. 20	9.6	Jan. 2	8.6	July 24	6.7
1635.0	April 17	7.6	March 19	9.3	Aug. 8	7.7
	May 1	8.0	April 14	5.6	Aug. 12	8.3
	May 16	7.6	May 12	5.0	Sept. 9	9.0
	May 29	7.3			Oct. 3	8.9
	June 13	7.4			Oct. 20	8.0
	July 2	7.0				
	July 15	5.7				
	July 24	6.0				
	Aug. 7	6.6				
	Aug. 22	7.4				
	Sept. 5	8.0				
	Sept. 17	8.3				
	Oct. 2	8.6				
	Oct. 16	8.5				
	Oct. 29	8.5				
	Dec. 4	8.4				

Table 13 . Water table levels of observation wells near Whitewater Lake.

Well and elevation* in feet	1969 Date	1969 Depth in feet	1970 Date	1970 Depth in feet	1971 Date	1971 Depth in feet
39 1643.5					Aug. 8	8.2
					Sept. 9	10.0
					Oct. 3	dry
					Oct. 21	4.8

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* Elevations above sea level obtained from P.F.R.A. Topographic Plan of Whitewater Lake (Manitoba Water Resources Branch, 1971).
1969 - 1970 data obtained from R. Eilers, Manitoba Soil Survey.

Table 14 . Piezometer levels in the Whitewater Lake Basin, 1971.

Ground elevation (in feet)	Piezometer and depth (in feet)	July 24	Aug. 5 (bailed)	Aug. 8	Aug. 13 (sampled)	Sept. 9 (sampled)	Oct. 3	Oct. 20	Nov. 25
1631.0	P-1-74	1613.5	1617.0	------	1608.8	1619.0	------	1622.3	1623.6
1636.3	P-2-58	1622.4	1623.8	------	1611.5	1620.3	------	------	------
1634.0	P-3-53	1627.3	1626.8	------	1625.8	1626.3	1626.1	------	1627.4
1635.8	P-4-25	1627.5	------	1626.5	1626.1	1625.3	1625.2	1626.4	------
	P-5-23	1627.4	------	1626.4	1626.2	1625.3	1625.2	1626.4	------
1639.0	P-6-23	1629.5	------	1629.1	1628.8	1628.1	1628.2	1629.0	------
1629.1	P-7-53	1623.1	------	1622.9	1619.2	1618.3	1621.9	1609.5	1624.1
	P-8-21	1623.4	------	1623.0	1622.9	1622.8	1622.9	1615.1	1625.5
1631.8	P-9-14	1625.2	------	1623.4	1623.0	1621.9	1621.7	1622.9	------
1639.7	P-10-41	1632.2	1631.6	------	1631.2	1632.2	------	1634.3	------
	P-11-23	1632.1	1631.5	------	1631.1	1632.4	------	1634.7	------
1630.3	P-12-17	1624.9	1624.2	------	1623.7	1622.7	------	------	1625.1
	P-13-32	1623.3	1623.0	------	1620.1	1620.0	------	------	1623.8
1630.2	P-14-62	1624.7	------	1624.1	1623.3	1622.3	1622.4	------	1626.4
	P-15-43	1615.8	------	1621.0	1620.2	1619.2	1620.2	------	1622.2
	P-16-23	1624.3	------	1624.5	1620.7	1622.3	1622.3	------	1623.2
1706.5	P-17-67	1679.9	1680.4	------	1680.3	1679.8	1679.9	1679.7	------
	P-18-41	1679.9	1680.4	------	1680.2	1679.8	1679.8	1679.8	------
	P-19-22	dry	dry	------	dry	dry	dry	dry	------
1633.6	P-20-60	1625.1	1625.2	------	1625.1	1625.3	1625.3	1625.6	------
	P-21-42	1628.0	1627.2	------	1626.7	1625.5	1625.3	1626.4	------
	P-22-21	1628.0	1627.4	------	1626.9	1625.1	1624.9	1626.6	------

Table 14 (cont). Piezometer levels in the Whitewater Lake Basin, 1971.

Ground elevation (in feet)	Piezometer and depth (in feet)	July 24	Aug.5	Aug.8	Aug.13	Sept.9	Oct.3	Oct.20	Nov.25
			(bailed)		(sampled)	(sampled)			
1683.8	P-25-59	1670.1	------	1670.4	1667.8	1669.3	1669.2	1669.3	------
	P-26-26	1676.7	------	1675.8	1675.2	1673.5	1673.1	1672.7	------
	P-27-16	1676.4	------	1675.3	1674.9	1673.0	1672.2	1672.7	------
1638.0	P-28-50	1588.0	------	dry	dry	1598.9	------	------	1630.9
	P-29-26	1616.1	------	1623.9	1620.8	1624.3	------	------	1630.7
1628.0	P-30-68	1623.0	------	1622.9	1622.1	1622.2	------	------	1623.7
	P-31-40	dry	------	1590.4	1622.1	1610.2	------	------	1623.0
1683.3	P-32-45	1672.0	------	1672.8	1667.1	1672.4	1672.6	1672.9	------
1629.6	P-33-30	------	------	1623.1	1622.8	1622.9	------	------	------
1633.0	P-34-30	------	------	1620.3	1614.2	1621.2	1623.5	------	------
1634.3	P-37-91	1622.9	------	1622.9	1622.6	1622.1	------	------	1622.3
	P-38-77	1624.2	------	1623.7	1624.7	1621.4	------	------	1621.1
1684.2	P-39-38	1672.1	------	1672.8	1672.6	1672.9	1673.0	1673.3	------
1695.1	P-40-51	1679.7	1679.7	------	1679.7	1679.4	1679.4	1679.3	------
	P-41-32	1679.8	1680.1	------	1679.8	1679.4	1679.5	1679.3	------

Table 15 . Lake levels obtained from staff gauge measurements at Whitewater Lake, 1970-1971.

Date:	West Gauge*	North Gauge	East Gauge	South Gauge	Wind (m.p.h.)	Estimated Lake Level	Reliability
1970:							
June 30	1627.56	1627.93	-------	1727.77	w 20-25	1628.1	Fair
July 1	1626.54	-------	-------	-------	w 40	1626.5	Poor
July 6	1627.99	1627.98	-------	1627.97	n 5	1628.0	Good
July 9	-------	-------	1628.18	-------	w 5	1628.2	Good
July 13	1628.14	1628.05	-------	-------	e 5-10	1628.1	Fair
July 20	-------	1627.93	1628.96	-------	s 10-15	1628.0	Poor
July 24	1627.54	1627.65	1628.44	1627.86	nw 15-20	1627.8	Poor
July 27	-------	-------	1628.14	-------	e 2-5	1628.1	Good
July 31	-------	-------	1628.30	-------	nw 10-15	1628.3	Poor
Aug. 7	1627.74	1627.75	1627.98	1627.74	nil	1627.8	Good
Aug.12	-------	-------	1627.90	-------	n 5	1627.9	Good
Aug.13	1627.49	1627.71	-------	1627.50	sw 15-20	1627.7	Fair
Aug.25	-------	-------	1627.63	-------	n 5-10	1627.6	Fair
Aug. 28	1627.39	1627.43	-------	1627.38	sw 0-5	1627.4	Good
Sept.15	-------	-------	1627.54	-------	w	1627.5	Fair
Sept.17	-------	-------	1627.73	-------	sw 10-15	1627.7	Fair
Sept.19	-------	-------	-------	1627.33	nil	1627.3	Good
Sept.21	1626.94	1626.35	1627.88	-------	nw 15-20	1627.4	Fair
Sept.24	1627.35	-------	-------	-------	nil	1627.4	Good
Sept.27	-------	-------	1627.33	-------	e light	1627.3	Good
Sept.29	1627.33	1627.33	-------	1627.33	nil	1627.3	Good
Oct.20	1627.12	1627.19	1627.48	1627.14	w 5-10	1627.2	Good
Dec.13	1627.14	1627.21	-------	1627.26	....	1627.2	...freeze up......
1971:							
May 20	-------	1627.74	-------	-------	se 0-5	1627.7	Good
June 20	-------	1627.98	-------	-------	nil	1628.0	Good

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*Lake levels in feet above sea level, data provided by B.Ransom (Department of Mines, Resources and Environmental Management).

Table 16. Daily water level at Whitewater Lake near Boissevain, Station No. 05NG023, in feet above sea level for 1970 (unpublished data, Water Survey of Canada, 1971).

1970

JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
---	---	---	---	1627.23	1627.17	---	1
---	---	---	---	1627.15	1627.21	---	2
---	---	---	---	1627.27	1627.22	---	3
---	---	---	---	1627.28	1627.21	---	4
---	---	---	---	1627.26	1627.24	---	5
---	---	---	---	1627.17	1627.23	---	6
---	---	---	---	1627.20	1627.24	---	7
---	---	---	---	1627.23	1627.24	---	8
---	---	---	---	1627.22	1627.24	---	9
---	---	---	1627.21	1627.18	1627.24	---	10
---	---	---	1627.28	1627.25	1627.24	---	11
---	---	---	1627.26	1627.21	1627.25	---	12
---	---	---	1627.30	1627.21	1627.24	---	13
---	---	---	1627.32	1627.21	1627.24	---	14
---	---	---	1627.31	1627.22	1627.23	---	15
---	---	---	1627.32	1627.22	1627.23	---	16
---	---	---	1627.33	1627.20	1627.23	---	17
---	---	---	1627.30	1627.22	1627.22	---	18
---	---	---	1627.28	1627.23	1627.23	---	19
---	---	---	1627.28	1627.20	1627.22	---	20
---	---	---	1627.23	1627.24	---	---	21
---	---	---	1627.32	1627.17	---	---	22
---	---	---	1627.38	1627.19	---	---	23
---	---	---	1627.34	1627.20	---	---	24
---	---	---	1627.32	1627.19	---	---	25
---	---	---	1627.33	1627.22	---	---	26
---	---	---	1627.35	1627.22	---	---	27
---	---	---	1627.35	1627.21	---	---	28
---	---	---	1627.34	1627.23	---	---	29
---	---	---	1627.35	1627.21	---	---	30
	---	---		1627.18		---	31

TYPE OF GAUGE - RECORDING
LOCATION - LAT 49 15 26 N
LONG 100 19 29 W

Table 17. Daily water level at Whitewater Lake near Boissevain, Station No. 05NG023, in feet above sea level for 1971 (unpublished data, Water Survey of Canada, 1972).

Provisional data: 1971

JUL	AUG	SEP	OCT	NOV	DEC	DAY
	1627.73	1627.32	1627.23			1
	1627.74	1627.32	1627.30			2
	1627.75	1627.32	1627.33			3
	1627.75	1627.33	1627.38			4
	1627.71	1627.41	1627.35			5
	1627.68	1627.43	1627.39			6
	1627.67	1627.40	1627.28			7
1628.01 A	1627.62	1627.42	1627.21			8
1628.01	1627.58	1627.42	1627.34			9
1628.00	1627.56	1627.38	1627.31			10
1627.92	1627.57	1627.46	1627.32			11
1627.83	1627.56	1627.33	1627.32			12
1627.95	1627.54	1627.32	1627.36			13
1627.93	1627.58	1627.29	1627.29			14
1627.91	1627.57	1627.27	1627.32			15
1627.91	1627.52	1627.28	1627.32			16
1627.90	1627.53	1627.29	1627.32			17
1627.88	1627.53	1627.32	1627.49			18
1627.88	1627.50	1627.30	1627.44			19
1627.88	1627.52	1627.26	1627.52			20
1627.86	1627.49	1627.28	1627.47			21
1627.87	1627.48	1627.30	1627.49			22
1627.87	1627.46	1627.27	1627.54			23
1627.77	1627.33	1627.32	1627.55			24
1627.68	1627.39	1627.32	1627.51			25
1627.77	1627.41	1627.29	1627.51			26
1627.74	1627.40	1627.26	1627.36			27
1627.73	1627.38	1627.26	1627.42			28
1627.76	1627.34	1627.29				29
1627.77	1627.34	1627.27				30
1627.73	1627.34					31

A - Manual Gauge

May 26: 1627.83A

Table 18. Chemical analyses of precipitation samples, 1971.

Sample	Conduct.* 25°C.	pH	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^-	HCO_3^-	CO_3^{2-}	Cl^-		
Stn. 1 May 17	49.3	6.66		2.05	3.06	0.48	8.49	2	--	0	--	0.77	--
				0.09	0.25	0.01	0.42	0.04					
May 21	12.1	5.93		0.05	0.17	0.17	0.81	1	--	0	--	0.05	--
				0.00	0.01	0.00	0.04	0.02					
May 23	14.6	5.36		0.53	0.10	1.58	0.55	<1	--	0	--	0.10	--
				0.02	0.01	0.04	0.03	0.02					
May 29	44.7	6.19		0.54	1.04	0.95	3.80	2	--	0	--	0.32	--
				0.02	0.09	0.02	0.19	0.04					
June 5	49.5	6.04		3.35	1.37	1.20	1.90	8	--	0	--	0.38	--
				0.15	0.11	0.03	0.09	0.17					
June 6	11.8	5.98		0.47	0.16	0.27	0.43	1	--	0	--	0.06	--
				0.02	0.01	0.01	0.02	0.02					
June 10	58.3	6.94		3.43	1.94	1.42	3.75	8	--	0	--	0.54	--
				0.15	0.16	0.04	0.19	0.17					
June 14	38.0	--		3.06	1.36	1.10	0.73	7	--	0	--	0.31	--
				0.13	0.11	0.03	0.04	0.15					
June 19	9.0	--		0.04	0.09	0.07	0.37	≈1	--	0	--	0.03	--
				0.00	0.01	0.00	0.02	0.02					
June 21	10.0	--		0.42	0.21	0.55	0.21	≈1	--	0	--	0.06	--
				0.02	0.02	0.01	0.01	0.02					
June 22	12.0	--		0.16	0.23	0.23	0.65	≈1	--	0	--	0.07	--
				0.01	0.02	0.01	0.03	0.02					
June 26	12.0	--		0.13	0.25	0.20	0.61	<1	--	0	--	0.07	--
				0.01	0.02	0.01	0.03	0.02					
June 28	22.2	--		0.34	0.21	0.33	1.11	<1	--	0	--	0.10	--
				0.01	0.02	0.01	0.06	0.02					

Table 18 (cont). Chemical analyses of precipitation samples ,1971.

Sample	Conduct. 25°C.	pH	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{-}	HCO_3^-	CO_3^{2-}	Cl^-		
Stn.1													
June 30	6.6	--		0.18	1.28	0.09	0.21	≈ 1	--	0	--	0.13	--
				0.01	0.11	0.00	0.01	0.02					
July 13	20.9	--		0.12	0.27	1.08	0.59	2	--	0	--	0.09	--
				0.01	0.02	0.03	0.03	0.04					
July 18	65.6	--		1.91	1.50	1.75	3.08	1	--	0	--	0.39	--
				0.08	0.12	0.04	0.15	0.02					
Aug. 16	41.9	--		1.72	1.05	0.65	1.89	2	--	0	--	0.27	--
				0.07	0.09	0.02	0.09	0.04					
Stn.2													
May 17	177	6.51		10.6	12.3	2.00	12.0	70	--	0	--	2.12	--
				0.46	1.01	0.05	0.60	1.46					
May 18	23.5	5.90		1.14	0.29	2.05	0.73	<1	--	0	--	0.16	--
				0.05	0.02	0.05	0.04	0.02					
May 22	16.2	6.21		0.04	0.16	0.26	0.65	1	--	0	--	0.05	--
				0.00	0.01	0.01	0.03	0.02					
May 23	11.1	5.66		0.49	0.08	1.08	0.24	2	--	0	--	0.07	--
				0.02	0.01	0.03	0.01	0.04					
May 29	91.0	6.31		21.4	1.27	2.62	5.50	8	--	0	--	1.37	--
				0.93	0.10	0.07	0.27	0.17					
June 4	51.7	6.25		0.30	1.13	1.43	4.23	2	--	0	--	0.35	--
				0.01	0.09	0.04	0.21	0.04					
June 5	8.4	5.88		0.04	0.13	0.37	0.55	1	--	0	--	0.05	--
				0.00	0.01	0.01	0.03	0.02					
June 6	12.3	6.19		0.05	0.25	0.26	0.50	1	--	0	--	0.05	--
				0.00	0.02	0.01	0.02	0.02					
June 10	21.1	5.80		0.87	0.42	0.17	1.11	2	--	0	--	0.22	--
				0.04	0.12	0.00	0.06	0.04					
June 14	104	--		5.40	2.97	2.17	4.39	31	--	0	--	0.75	--
				0.23	0.24	0.06	0.22	0.65					

Table 18 (cont.). Chemical analyses of precipitation samples, 1971.

Sample	Conduct. 25°C.	pH	ppm. epm.	Cations				Anions					
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Stn. 2													
June 19	17.0	--		0.33	0.24	0.29	1.23	<1	--	0	--	0.10	--
				0.01	0.02	0.01	0.06	0.02					
June 21	17.0	--		0.70	0.33	0.17	0.60	1	--	0	--	0.09	--
				0.03	0.03	0.00	0.03	0.02					
June 22	55.0	--		3.08	1.29	3.49	2.29	15	--	0	--	0.44	--
				0.13	0.11	0.09	0.11	0.31					
June 26	18.1	--		0.53	0.36	0.07	0.98	1	--	0	--	0.10	--
				0.02	0.03	0.00	0.05	0.02					
June 28	32.0	--		0.37	0.36	0.62	1.39	2	--	0	--	0.14	--
				0.02	0.03	0.02	0.07	0.04					
June 30	15.8	--		0.67	0.27	0.27	0.60	1	--	0	--	0.09	--
				0.03	0.02	0.01	0.03	0.02					
July 3	27.8	--		0.54	0.49	1.33	1.02	1	--	0	--	0.14	--
				0.02	0.04	0.03	0.05	0.02					
July 7	38.8	--		0.31	0.52	1.12	0.90	1	--	0	--	0.12	--
				0.01	0.04	0.03	0.04	0.02					
July 18	101	--		3.56	1.92	5.63	3.49	11	--	0	--	0.62	--
				0.15	0.16	0.14	0.17	0.23					
July 22	28.8	--		0.54	0.63	0.74	1.82	3	--	0	--	0.18	--
				0.02	0.05	0.02	0.09	0.06					
July 25	17.9	--		0.19	0.30	0.42	1.16	1	--	0	--	0.11	--
				0.01	0.02	0.01	0.06	0.02					
July 26	37.3	--		0.70	0.62	0.37	2.93	1	--	0	--	0.24	--
				0.03	0.05	0.01	0.15	0.02					
July 29	92.4	--		5.40	2.64	0.43	3.75	27	--	0	--	0.65	--
				0.23	0.22	0.01	0.19	0.56					
Aug. 13	102	--		1.61	1.66	2.91	3.27	8	--	0	--	0.44	--
				0.07	0.14	0.07	0.16	0.17					
Sept. 3	209	--		1.16	3.47	5.11	2.37	9	--	0	--	0.59	--
				0.05	0.29	0.13	0.12	0.19					
Sept. 5.	20.4	--		0.68	0.34	0.01	0.81	<1	--	0	--	0.10	--
				0.03	0.03	0.00	0.04	0.02					

Table 18 (cont.). Chemical analyses of precipitation samples, 1971.

Sample	Conduct. 25°C.	pH	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl		
Stn. 2													
Aug. 16	388	--		1.39 0.06	5.19 0.43	2.91 0.07	14.5 0.72	50 1.04	--	0	--	1.28	--
Oct. 18	49.5	--		--	1.30 0.11	--	1.82 0.09	8 0.17	--	0	--		--
Oct. 2	31.2	--		--	0.18 0.01	--	0.65 0.03	< 1 0.02	--	0	--		--
Oct. 19	50.0	--		--	0.47 0.04	--	1.16 0.06	1 0.02	--	0	--		--
Snow													
March 16	43.9	--		3.23 0.14	1.47 0.12	0.58 0.01	0.90 0.04	12 0.25	--	0	--	0.31	--

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*Conductivity expressed in micromhos. cm.$^{-1}$.

Table 19. Summary of chemical analyses of precipitation samples near Whitewater Lake, 1971.

	RAIN				RAIN			
	Station No. 1				Station No. 2			
	Mean	High	Low	Number of Samples	Mean	High	Low	Number of Samples
Na^+	1.09*	3.43	0.05	17	2.29	21.4	0.04	27
Mg^{2+}	0.84	3.06	0.09	17	1.37	12.3	0.08	30
Ca^{2+}	1.72	8.49	0.21	17	2.55	14.5	0.24	30
K^+	0.71	1.75	0.07	17	1.41	5.63	0.01	30
SO_4^{2-}	2.4	8	1	17	10.4	70	1	30
Conductivity ‡ at 25°C.	25.7	65.6	6.6	17	62.6	388	8.4	29

*Concentrations in milligrams. liter^{-1} (ppm.)
†Conductivity in micromhos. cm.$^{-1}$.

Table 20. Oxygen^{18} composition of precipitation samples near Whitewater Lake, 1971.

Date	Rain	Snow
March		-19.8*
May 18	-9.7	
May 29	-5.8	
June 10	-5.2	
June 19	-9.8	
June 30	-13.7	
July 22	-12.0	
Sept. 5	-9.0	
Oct. 18	-14.1	

*Values expressed as δO^{18}_{SMOW}.

Table 21. Chemical analyses of creek samples near Whitewater Lake, 1971.

Sample	Conduct.* 25°C.	pH†	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Site 1:													
April 15	440	7.64		23.7	24.1	7.55	47.9	150	155	0	3.75	5.59	5.77
				1.03	1.98	0.19	2.39	3.12	2.59	0	0.11		
April 30	724	8.44		38.6	51.0	9.80	79.3	250	252	8.45	3.75	10.09	9.72
				1.68	4.20	0.25	3.96	5.20	4.13	0.28	0.11		
May 6	761	8.55		41.5	55.5	10.0	79.0	200	264	14.1	3.75	8.42	9.07
				1.81	2.41	0.26	3.94	4.16	4.33	0.47	0.11		
May 14	951	8.28		59.4	68.2	10.5	97.7	200	334	0	6.00	10.69	9.80
				2.58	2.96	0.27	4.88	4.16	5.47	0	0.17		
May 28	900	7.91		59.3	48.3	9.80	94.3	175	334	0	5.25	9.64	9.26
				2.58	2.10	0.25	4.71	3.64	5.47	0	0.15		
June 11	720	7.92		47.5	41.0	9.38	65.0	160	225	0	2.50	7.33	7.09
				2.07	1.78	0.24	3.24	3.33	3.69	0	0.07		
June 25	705	8.34		37.1	48.6	8.10	72.0	150	268	0	3.50	7.52	7.61
				1.61	2.11	0.21	3.59	3.12	4.39	0	0.10		
July 9	741	8.31		37.1	51.3	8.30	87.9	150	296	0	2.75	8.44	8.05
				1.61	2.23	0.21	4.39	3.12	4.85	0	0.08		
July 24 (no flow)	842	7.96		50.5	56.7	9.30	97.8	200	338	0	3.75	9.79	9.81
				2.20	2.47	0.24	4.88	4.16	5.59	0	0.11		
Site 2:													
April 30	1710	8.07		131	99.5	12.5	172	825	361	0	10.0	22.79	23.38
				5.70	8.19	0.32	8.58	17.18	5.92	0	0.28		
May 6	1920	7.95		151	124	14.1	207	950	363	0	10.3	27.46	26.02
				6.57	10.20	0.36	10.33	19.78	5.95	0	0.29		
May 14	2100	8.22		199	149	15.9	168	1175	236	0	10.0	29.71	28.61
				8.66	12.26	0.41	8.38	24.46	3.87	0	0.28		
May 28	2340	8.09		220	161	15.0	233	1300	423	0	10.0	34.82	34.28
				9.57	13.24	0.38	11.63	27.07	6.93	0	0.28		
June 11	1260	7.81		138	62.1	11.8	110	500	278	0	5.50	16.90	15.13
				6.00	5.11	0.30	5.49	10.41	4.56	0	0.16		
June 25	1080	8.25		80.1	65.1	9.80	122	400	419	0	2.50	15.18	15.27
				3.48	5.36	0.25	6.09	8.33	6.87	0	0.07		
July 9	1001	8.24		54.9	63.9	8.14	96.4	375	303	0	2.75	12.67	12.86
				2.39	5.26	0.21	4.81	7.81	4.97	0	0.08		

Table 21(cont). Chemical analyses of creek samples near Whitewater Lake, 1971.

Sample	Conduct.* 25°C.	pH†	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Site 2:													
July 24	1050	8.20		77.2	74.8	9.30	140	475	363	0	4.50	16.72	15.97
(no flow)				3.36	6.15	0.24	6.97	9.89	5.95	0	0.13		
Aug. 26		7.92		89.0	82.6	14.1	63.6	500	269	0	3.75	14.19	14.93
(no flow)				3.87	6.79	0.36	3.17	10.41	4.41	0	0.11		
Site 3:													
April 6△	298	7.50		17.0	10.4	5.3	27.6	60	112.	0	2.50	3.11	3.15
				0.74	0.86	0.13	1.38	1.25	1.83	0	0.07		
April 7△	645	7.60		53.0	22.8	8.8	54.4	200	175	0	4.0	7.12	7.14
				2.30	1.88	0.22	2.72	4.16	2.87	0	0.11		
April 15	1220	8.09		128	52.5	9.96	137	500	296	0	8.25	16.98	15.49
				5.57	4.32	0.25	6.84	10.41	4.85	0	0.23		
April 30	2190	8.15		273	117	11.8	179	1200	260	0	17.5	30.72	29.73
				11.87	9.62	0.30	8.93	24.98	4.26	0	0.49		
May 6	2320	8.41		359	105	14.1	108	1150	169	7.04	21.3	31.01	27.54
				15.62	8.64	0.36	5.39	23.94	2.77	0.23	0.60		
May 14	2530	7.96		371	117	14.1	138	1300	275	0	21.0	33.01	32.17
				16.14	9.62	0.36	6.89	27.07	4.51	0	0.59		
May 28	2860	8.15		430	129	16.2	128	1425	360	0	20.0	36.11	36.13
				18.70	10.61	0.41	6.39	29.67	5.90	0	0.56		
June 11	1630	8.41		187	77.0	12.4	154	800	316	11.3	9.25	22.46	22.48
				8.13	6.33	0.32	7.68	16.66	5.18	0.38	0.26		
June 25	1300	8.30		125	65.7	9.30	148	525	354	0	5.00	18.47	16.87
				5.44	5.40	0.24	7.39	10.93	5.80	0	0.14		
July 9	1430	8.12		141	76.0	10.5	156	525	479	0	5.25	20.43	18.93
				6.13	6.25	0.27	7.78	10.93	7.85	0	0.15		
July 24	1550	8.23		188	82.2	10.7	137	700	382	0	8.00	22.05	21.06
(no flow)				8.18	6.76	0.27	6.84	14.57	6.26	0	0.23		
Aug. 26		7.79		171	73.6	16.3	143	750	273	0	13.5	21.05	20.46
(no flow)				7.44	6.05	0.42	7.14	15.61	4.47	0	0.38		
Oct. 3	932	---		---	---	---	---	---	---	-	----	-----	-----

Table 21(cont). Chemical analyses of creek samples near Whitewater Lake, 1971.

Sample	Conduct.* 25°C.	pH†	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Site 4:													
April 6	399	7.50		17.0	16.7	8.5	38.8	95.0	127	0	3.5	4.28	4.16
				0.74	1.38	0.22	1.94	1.98	2.08	0	0.10		
April 9	478	7.55		23.0	20.1	11.0	46.0	130	139	0	4.5	5.24	5.11
				1.00	1.66	0.28	2.30	2.71	2.28	0	0.12		
April 15	862	8.62		54.9	45.8	12.7	97.9	300	225	10.6	5.5	11.37	10.45
				2.39	3.77	0.32	4.89	6.25	3.69	0.35	0.16		
April 30	1510	8.06		108	89.3	13.1	102	650	360	0	12.8	17.48	19.79
				4.70	7.35	0.34	5.07	13.53	5.90	0	0.36		
May 6	1780	8.04		181	110	16.8	164	950	220	0	12.5	25.53	23.74
				7.87	9.05	0.43	8.18	19.78	3.61	0	0.35		
May 14	1950	7.97		159	129	15.9	117	900	337	0	15.8	23.78	24.71
				6.92	10.61	0.41	5.84	18.74	5.52	0	0.45		
May 28	2116	8.00 8.32°		174	139	15.5	242	1200	341	0	15.0	31.48	30.99
				7.57	11.43	0.40	12.08	24.98	5.59	0	0.42		
June 11	1900	8.22		142	115	16.6	120	850	415	0	16.3	22.05	24.96
				6.18	9.46	0.42	5.99	17.70	6.80	0	0.46		
June 25	1270	8.50		96.4	69.4	10.5	142	450	401	18.3	5.00	17.26	16.69
				4.19	5.71	0.27	7.09	9.37	6.57	0.61	0.14		
July 9	1130	8.29		74.2	69.4	10.0	152	375	412	7.75	3.75	16.78	14.93
				3.23	5.71	0.26	758	7.81	6.75	0.26	0.11		
July 24	1410	8.18		116	91.1	15.9	152	600	398	0	10.0	20.53	19.29
(no flow)				5.05	7.49	0.41	7.58	12.49	6.52	0	0.28		
Aug. 26	1630	7.99		125	88.1	21.8	154	750	234	0	10.0	20.93	19.72
(no flow)				5.44	7.25	0.56	7.68	15.61	3.83	0	0.28		
Oct. 3	1045	--		---	---	---	---	---	---	-	---	----	----
Site 5:													
April 9△	318	7.50		23.0	12.4	8.3	30.0	75	123	0	2.5	3.73	3.65
				1.00	1.02	0.21	1.50	1.56	2.02	0	0.07		
April 16△	330	7.50		22.0	8.7	7.5	26.4	60.0	111	0	3.0	3.18	3.15
				0.95	0.72	0.19	1.32	1.25	1.82	0	0.08		

Table 21 (cont). Chemical analyses of creek samples near Whitewater Lake, 1971.

Sample	Conduct.* 25°C.	pH†	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Site 5:													
May 6	1530	8.27		200	47.7	10.5	87.3	575	255	0	12.5	17.25	16.50
				8.70	3.92	0.27	4.36	11.97	4.18	0	0.35		
May 14	1660	8.06		221	71.2	11.1	69.4	800	231	0	15.3	19.21	20.78
				9.61	5.86	0.28	3.46	16.66	3.79	0	0.43		
May 28	1800	8.18		242	77.8	10.8	117	850	343	0	13.0	23.05	23.69
				10.53	6.40	0.28	5.84	17.70	5.62	0	0.37		
June 11	1250	8.06		144	56.1	9.30	114	525	353	0	7.50	16.81	16.93
		8.00°		6.26	4.62	0.24	5.69	10.93	5.79	0	0.21		
June 25	910	8.07		77.2	41.0	6.31	106	325	345	0	4.50	12.22	12.55
		8.08°		3.40	3.37	0.16	5.29	6.77	5.65	0	0.13		
July 9	740	8.00		62.3	38.0	5.65	86.8	250	3.11	0	3.75	10.31	10.45
				2.71	3.13	0.14	4.33	5.20	5.10	0	0.15		
July 24 (no flow)	1140	8.09		131	59.1	9.10	106	515	387	0	8.25	16.08	17.29
				5.70	4.86	0.23	5.29	10.72	6.34	0	0.23		
Site 6:													
April 6^	297	7.70		22.0	6.3	5.8	20.8	30.0	122	0	2.5	2.66	2.69
				0.95	0.52	0.15	1.04	0.62	2.00	0	0.07		
April 9^	600	7.70		72.0	17.7	6.2	40.4	150	202	0	7.0	6.96	6.63
				3.13	1.46	0.16	2.02	3.12	3.31	0	0.19		
April 15	1113	8.15		175	39.2	8.72	70.8	400	318	0	9.50	14.58	13.81
				7.61	3.22	0.22	3.53	8.33	5.21	0	0.27		
May 6	2210	8.57		368	85.0	11.8	75.0	925	348	15.5	21.3	27.04	26.08
				16.01	6.99	0.30	3.74	19.26	5.70	0.52	0.60		
May 28	2280	7.99		381	92.3	11.7	154	1000	599	0	20.5	32.14	31.22
				16.57	7.59	0.30	7.68	20.82	9.82	0	0.58		
June 11	2050	8.48		334	77.2	10.6	68.8	700	496	17.6	17.5	24.58	23.78
				14.53	6.35	0.27	3.43	14.57	8.13	0.59	0.49		
June 25	1760	8.34		288	62.1	6.6	121	575	604	14.1	6.50	23.85	22.52
				12.53	5.11	0.17	6.04	11.97	9.90	0.47	0.18		
July 9	1040	7.77		141	41.6	5.40	92.3	200	515	0	3.75	14.30	12.71
				6.13	3.42	0.14	4.61	4.16	8.44	0	0.11		
July 24 (no flow)	1020	8.13		160	45.2	6.5	63.7	275	473	0	2.50	14.03	13.55
				6.96	3.72	0.17	3.18	5.73	7.75	0	0.07		

Table21(cont). Chemical analyses of creek samples near Whitewater Lake, 1971.

Sample	Conduct.* 25°C.	pH†	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
Site 7: July 24 (no flow)		8.13		524	142	19.3	156	1500	480	0	53.3	42.74	40.60
				22.79	11.68	0.49	7.78	31.23	7.87	0	1.50		
Site 8: May 28	1290	7.81		78.6	76.0	8.14	161	500	394	0	9.50	17.91	17.14
				3.42	6.25	0.21	8.03	10.41	6.46	0	0.27		
June 11	1170	8.02		66.8	64.5	9.21	146	350	435	0	5.25	15.75	14.57
				2.91	5.31	0.24	7.29	7.29	7.13	0	0.15		
June 25	1030	8.16		53.4	57.6	8.0	140	300	379	0	4.75	14.25	12.59
				2.32	4.74	0.20	6.99	6.25	6.21	0	0.13		
July 9	900	8.36		29.7	48.0	6.8	135	175	430	12.7	3.25	12.15	11.20
				1.29	3.95	0.17	6.74	3.64	7.05	0.42	0.09		
Site 9: July 23 (no flow)	1430	8.34		190	61.5	6.81	65.0	400	334	7.04	13.8	16.73	14.42
				8.26	5.06	0.17	3.24	8.33	5.47	0.23	0.39		
Site 10: May 28	1440	8.16		119	84.4	9.8	177	675	396	0	6.25	21.20	20.72
				5.18	6.94	0.25	8.83	14.05	6.49	0	0.18		
June 25	1010	8.57		78.6	56.7	6.72	130	300	397	28.2	5.00	14.74	13.84
				3.42	4.66	0.17	6.49	6.25	6.51	0.94	0.14		
Site 11: July 23 (no flow)	2550	8.02		183	124	8.14	277	950	796	0	21.8	32.19	33.44
				7.96	10.20	0.21	13.82	19.78	13.05	0	0.61		
Site 12: July 23 (no flow)	1100	8.14		78.6	66.3	6.48	126	250	522	0	2.50	15.33	13.82
				3.42	5.45	0.17	6.29	5.20	8.55	0	0.07		
Site 13: July 23 (no flow)	793	8.10		69.7	48.3	7.80	70.0	200	320	0	2.75	10.69	9.48
				3.03	3.97	0.20	3.49	4.16	5.24	0	0.08		

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* Conductivity in micromhos. $cm.^{-1}$

† Laboratory pH value

° Field pH value

△ Sample analyzed by J. Adams; Water Control and Conservation Branch, 1971.

Table 22. Summary of chemical analyses of creek samples from selected sites near Whitewater Lake during 1971.

Location	Conduct.* 25°C. ppm. epm.	Cations				Anions				
		Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	Cl^-	Ca^{2+}/Mg^{2+}	Number of samples
Site 1:	722	43.9	49.4	7.96	80.1	182	274	3.89	0.99	10
		1.91	4.06	0.20	4.00	3.79	4.49	0.11		
Site 2:	1558	138	97.7	12.3	146	722	335	6.60	0.91	8
		6.00	8.04	0.31	7.29	15.03	5.49	0.19		
Site 3:	1659	227	89.5	12.5	143	888	316	12.9	0.97	10
		9.87	7.36	0.32	7.14	18.49	5.18	0.36		
Site 4:	1345	108	81.9	14.3	130	603	300	9.73	0.96	12
		4.70	6.74	0.37	6.49	12.55	4.92	0.27		
Site 5:	1075	125	45.8	8.73	82.5	442	273	7.82	1.09	9
		5.44	3.77	0.22	4.12	9.20	4.47	0.22		
Site 6:	1374	216	51.8	8.15	78.5	473	409	10.1	0.92	9
		9.40	4.26	0.21	3.92	9.85	6.70	0.28		
Site 8:	1098	57.1	61.5	8.04	146	331	410	5.69	1.44	4
		2.48	5.05	0.21	7.29	5.89	6.72	0.16		

*Conductivity in micromhos. $cm.^{-1}$.

Table 23. Oxygen^{18} composition of creek samples south of Whitewater Lake, 1971.

Date	Site 1	Site 2	Site 3	Site 4
April 15	-17.0*	-19.3		-19.3
April 30			-15.6	
May 6	-14.0	-15.3		-29.5
May 28			-14.4	
June 11			-10.2	
June 25			-12.8	
July 9			-11.0	
July 24			- 8.8	
Aug 26			- 8.7	

*Values expresses as δO^{18}_{SMOW}.

Table 24. Chemical analyses of piezometer samples near Whitewater Lake, 1971.

Piezometer and date sampled	Conduct.* 25°C.	pH^f pH^l	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
P-1-74 Aug.13	11,900	7.25 7.68		2353	603	34.9	277	6400	710	0	575	166.68	161.11
P-2-58 Aug.13	9310	7.33 7.40		1660	478	24.5	676	6300	513	0	150	145.89	143.81
P-3-53 Sept.9	3040	9.97 7.68		484	59.1	35.4	241	1600	41.5	0	99.0	38.85	36.79
P-4-25 Aug.13	2050	7.44 7.66		276	73.6	8.1	119	800	447	0	45.0	24.21	25.26
P-5-23 Aug.13	2000	7.48 7.34		252	21.1	8.1	131	600	397	0	25.0	19.45	19.71
P-6-23 Aug.13	4300	7.53 7.75		540	282	14.9	329	2500	472	0	32.5	63.49	60.71
P-7-53 Aug.13	29,000	7.29 7.36		6255	3609	108.8	652	27,000	1058	0	575	604.30	595.70
P-9-14 Aug.13	1035	7.83 7.41		68.3	64.4	5.4	110	280	360	0	37.5	13.90	12.79
P-10-42 Sept.9	2335	7.54 7.49		306	80.2	12.0	168	900	435	0	30.3	28.60	26.72
P-11-23 Sept.9	2700	8.50 7.83		398	66.3	12.5	230	1500	165	0	18.8	34.56	34.46
P-12-18 Aug.13	14,650	7.46 7.51		2027	2027	58.9	530	13,000	728	0	325	282.88	291.76
P-15-43 Aug.13	7960	7.17 7.56		1292	404	38.4	347	3900	525	0	650	107.73	108.13

Table 24(cont). Chemical analyses of piezometer samples near Whitewater Lake, 1971.

				Cations				Anions					
Piezometer and date sampled	Conduct.* 25°C.	pH^f pH^l	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
P-16-23 Aug.13	15,050	8.06 7.55		2745	1532	157	247	11,800	602	0	400	261.78	266.83
P-17-68 Aug.13	2320	7.41 7.51		225	80.8	13.0	269	1000	534	0	27.5	30.19	30.35
P-18-42 Aug.13	1930	7.51 7.26		134	61.5	22.9	372	1100	382	0	32.5	30.04	30.08
P-20-62 Aug.13	7220	7.09 7.51		1441	95.3	16.6	229	2100	659	0	916	82.37	80.36
P-21-42 Sept.9	5370	7.07 7.21		703	206	19.1	301	2100	542	0	390	63.04	63.60
P-26-27 Aug.13	7140	7.02 7.59		1085	421	28.2	258	3700	796	0	270	95.41	97.08
P-27-16 Aug.13	4040	7.38 7.65		306	302	73.7	347	2200	522	0	22.5	57.35	54.98
P-29-27 Aug.13	6970	8.77 7.38		1104	346	75.9	457	4100	123	0	350	101.22	97.25
P-30-68 Aug.13	7030	8.59 7.42		1399	119	38.5	485	3700	120	0	325	91.21	88.17
P-31-42 Sept.9	6010	9.22 7.87		997	132	126.2	309	3400	108	0	268	72.88	73.31
P-32-47 Aug.13	2530	7.99 8.18		573	21.7	5.1	47.7	700	683	0	85.0	29.22	28.16
P-33-32 Sept.9	13,100	9.38 7.29		3130	251	98.8	272	7600	151	0	346	172.90	170.46

Table 24(cont.). Chemical analyses of piezometer samples near Whitewater Lake, 1971.

Piezometer and date sampled	Conduct.* 25°C.	pH^f pH^1	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
P-34-32 Sept.9	12,900	9.24 7.81		2923	400	315	397	8000	299	0	478	187.91	184.94
P-37-91 Aug.13	4050	7.49 7.46		564	115	27.6	304	1500	449	0	294	49.87	46.88
P-38-77 Sept.9	4300	10.10 8.35		685	236	31.5	94.2	2000	155	0	320	54.72	53.21
P-39-42 Sept.9	3870	8.50 7.56		840	24.1	18.9	99.2	1800	245	0	92.0	43.95	44.09
P-40-52 Aug.13	2440	7.24 7.53		228	103	11.8	279	1200	435	0	40.0	32.61	33.24
P-41-32 Aug.13	2005	7.36 7.23		71.2	115	6.7	308	1000	346	0	65.0	28.10	28.32

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*Conductivity values expressed in micromhos.$cm.^{-1}$

[f] Field pH values

[1] Laboratory pH values

Table 25 . Chemical analyses of well samples near Whitewater Lake.

Well and date sampled	Conduct.* 25°C.	pH_f pH_l	ppm. epm.	CATIONS				ANIONS					
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
17 Aug.17/70† (glacial sand)	28,080	----- 7.25		292.25	249.08	----	24.27	522.24	9.50	0	33.99	565.60	565.73
18 Aug.17/70 (till)	15,350	----- 7.00		166.25	62.42	----	16.93	240.10	4.50	0	0.66	240.10	245.26
19 Aug.17/70 (glacial sand)	3,380	----- 8.03		13.00	23.25	----	7.34	26.31	8.50	0	9.24	43.59	44.05
20 Aug.17/70 (till)	40,950	----- 7.85		484.50	562.22	----	23.05	1040.80	26.50	0	2.31	1069.77	1069.61
21 Aug. 17/70 (till)	17,550	----- 7.88		160.50	135.86	----	20.60	299.67	8.50	0	8.03	316.96	316.20
22 Aug. 17/70 (till)	11,170	----- 7.95		76.00	95.26	----	22.64	185.94	7.00	0	1.54	193.90	194.48
24 Aug. 17/70 (glacial sand)	1.420	----- 8.35		7.56	3.46	----	4.28	12.18	4.50	0	----	15.30	16.68
25 Aug. 17/70 (glacial sand)	1,580	----- 8.65		7.39	5.10	----	5.71	14.12	5.50	0	0.11	18.20	19.73

Table 25 . Chemical analyses of well samples near Whitewater Lake.

Well and date sampled	Conduct* 25°C.	pH_1^f pH	ppm. epm.	Cations Na^+	Mg^{2+}	K^+	Ca^{2+}	Anions SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
22 July 24/71	13,700	------		2217	1665	20.8	166	11,000	474	0	40.0	242.21	237.92
(till)		7.63		96.43	136.97	0.53	8.28	229.02	7.77	0	1.13		
25 July 24/71	2,260	------		312	120	12.9	108	1,000	595	0	22.5	29.16	31.20
(glacial sand)		8.45		13.57	9.87	0.33	5.39	20.82	9.75	0	0.63		
25 Aug. 12/71	2,220	------		323	119	12.9	102	900	585	0	17.5	29.26	28.82
(glacial sand)		8.31		14.05	9.79	0.33	5.09	18.74	9.59	0	0.49		
21 Aug. 5/71	12,000	------		1976	2027	61.6	310	11,000	530	0	169	269.75	242.48
(till)		7.42		85.95	166.75	1.58	15.47	229.02	8.69	0	4.77		
a Aug.26/71	1,870	------		243	68.2	8.7	154	800	384	0	14.0	24.08	23.34
(glacial sand)		7.63		10.57	5.61	0.22	7.68	16.66	6.29	0	0.39		
b Aug.26/71	3,235	------		638	55.5	14.1	136	1,200	681	0	27.5	39.96	36.92
(sand-shale)		7.89		27.75	4.57	0.36	6.79	24.98	11.16	0	0.78		
c Aug.26/71	2,710	------		543	56.7	13.4	86.9	1,400	275	0	22.5	32.96	34.29
(sand-shale)		8.18		23.62	4.66	0.34	4.34	29.15	4.51	0	0.63		
d Aug.26/71	2,120	------		148	79.6	6.5	334	1,200	301	0	19.5	29.87	30.46
(glacial sand)		7.38		6.48	6.55	0.17	16.67	24.98	4.93	0	0.55		

Table 25 . Chemical analyses of well samples near Whitewater Lake.

Well and date sampled	Conduct.* 25°C.	pH_1^f pH	ppm. epm.	Cations Na^+	Mg^{2+}	K^+	Ca^{2+}	Anions SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
e Aug.26/71 (glacial sand)	3,780	---- 7.84		552 24.01	133 10.94	6.8 0.17	170 8.48	1,200 24.98	576 9.44	0 0	270 7.62	43.60	42.04
f Aug.26/71 (shale)	10,900	---- 7.95		2243 97.57	25.7 2.11	14.1 0.36	129 6.44	25 0.52	513 8.41	0 0	3255 91.81	106.48	100.74
g May14/71 (glacial sand)	3,950	---- 7.79		564 24.53	189 15.55	19.2 0.49	307 15.32	2,000 41.64	323 5.29	0 0	188 5.30	55.89	52.23
h Aug.26/71 (shale)	7,230	---- 7.74		1507 65.55	11.8 097	8.3 0.21	63.6 3.17	25 0.52	551 9.18	0 0	2032 57.32	69.90	67.02
i July 2/71 (glacial sand)	2,470	---- 7.70		119 5.18	226 18.59	7.2 0.18	331 16.52	1,600 33.31	259 4.24	0 0	12.5 0.35	40.47	37.90
j July 3/71 (gravel)	1,270	---- 8.49		26.7 1.16	151 12.42	1.7 0.04	21.5 1.07	200 4.16	570 9.34	0 0	22.5 0.63	14.69	14.13

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* Conductivity expressed in micromhos.cm.$^{-1}$

† 1970 data obtained from B. Eilers , Manitoba Soil Survey

Table 26. Summary of groundwater chemistry in the Whitewater Lake area.

Hydrostratigraphic Unit	Facies	Type	Conduct. range*	Number of Samples
1 Riding Mountain Formation	III	sodium chloride	7,200 - 11,000	2
2 Boissevain Formation	I	calcium-magnesium-bicarbonate-sulphate	1,700-2,600	4
5 Sand (5a) and shale gravel (5b)	II,III	calcium-magnesium-sulphate and sodium-sulphate	1,800-7,500	5
6,8 Glacial till	II,III	calcium-magnesium-sulphate and sodium sulphate	2,700-41,000	19
9 Mainly sand and gravel (9a)	I,II	calcium-magnesium-bicarbonate-sulphate and calcium-magnesium-sulphate	1,000-4,300	18

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*Conductivity expressed in micromhos.cm.$^{-1}$ at 25°C.

Table 27 .Electrical conductivity values of piezometers in the Whitewater Lake Basin, 1971.

Ground elevation (in feet)	Piezometer and depth (in feet)	July 24	Aug.5	Aug.8	Aug.13	Sept.9	Oct.3	Oct 20	Nov.25
			(bailed)		(sampled)	(sampled)			
1631.0	P-1-74	------	------	------	11,900*	12,200	------	9000	9400
1636.3	P-2-58	------	------	------	9310	10,900	------	------	------
1634.0	P-3-53	------	------	------	3090	3500	3000	------	2800
1635.8	P-4-25	------	------	------	2050	2500	2000	2200	------
	P-5-23	------	------	------	2000	2100	2000	2200	------
1639.0	P-6-23	------	------	------	4300	5000	4500	4500	------
1629.1	P-7-53	------	------	------	29,200	28,800	25,000	25,000	21,500
	P-8-21	------	------	------	22,700	25,500	24,000	25,000	22,000
1631.8	P-9-14	------	------	------	1035	1100	1100	1200	------
1639.7	P-10-41	------	------	------		2900	------	2200	------
	P-11-23	------	------	------	2625	2900	------	2500	------
1630.3	P-12-17	------	------	------	14,650	14,700	------	------	12,500
	P-13-32	------	------	------	5440	5500	------	------	5800
1630.2	P-14-62	------	------	------	7210	8100	5000	------	7000
	P-15-43	------	------	------	7960	8300	8000	------	7500
	P-16-23	------	------	------	15,050	17,700	17,000	------	14,000
1706.5	P-17-67	------	------	------	2320	2380	2500	2500	------
	P-18-41	------	------	------	1930	1680	2000	2100	------
	P-19-22	------	------	------	dry	dry	dry	dry	------
1633.6	P-20-60	------	------	------	7220	7520	6800	7500	------
	P-21-42	------	------	------	5560	5370	5500	6500	------
	P-22-21	------	------	------	2005	4740	5500	4000	------

Table 27 (cont.) Electrical conductivity of piezometers in the Whitewater Lake Basin, 1971.

Ground elevation (in feet)	Piezometer and depth (in feet)	July 24	Aug.5	Aug.8	Aug.13	Sept.9	Oct.3	Oct.20	Nov.25
			(bailed)		(sampled)	(sampled)			
1683.8	P-25-59	------	------	------	7930	8700	7500	8000	------
	P-26-26	------	------	------	7140	8600	7000	7500	------
	P-27-16	------	------	------	4040	4700	4200	4800	------
1638.0	P-28-50	------	------	------	dry	8000	------	------	6000
	P-29-26	------	------	------	6970	7000	------	------	7000
1628.0	P-30-68	------	------	------	7220	7500	------	------	7700
	P-31-40	------	------	------	7220	6300	------	------	6200
1683.3	P-32-45	------	------	------	2530	3500	2500	2600	------
1629.6	P-33-30	------	------	------	14,200	13,500	------	------	------
1633.0	P-34-30	------	------	------	12,700	13,000	13,000	------	------
1634.3	P-37-91	------	------	------	4050	4600	------	------	3800
	P-38-77	------	------	------	4300	3800	------	------	3500
1684.2	P-39-38	------	------	------	4250	3870	3900	3800	------
1695.1	P-40-41	------	------	------	2440	2510	2600	2600	------
	P-41-32	------	------	------	2005	1765	2000	1800	------

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*Conductivity values expressed in micromhos. cm.$^{-1}$ at 5°C.

Table 28 . Electrical conductivity of observation wells near Whitewater Lake.

Well	Date	1969 Conductivity*	Date	1970 Conductivity	Date	1971 Conductivity
17	Feb. 20	29,790	Jan. 2	25,870		
	April 17	20,060	March 19	21,840		
	May 1	frozen	April 14	25,860		
	May 16	13,850	May 5	8190		
	May 29	24,575	May 26	7680		
	June 13	27,310	June 8	23,400		
	July 2	28,080	June 22	19,660		
	July 15	28,080	July 6	25,200		
	July 24	26,570	July 20	24,570		
	Aug. 7	26,570	Aug. 4	21,360		
	Aug. 22	25,200	Aug. 17	28,080		
	Sept. 5	27,300	Aug. 31	27,300		
	Sept. 17	27,300	Sept. 28	25,200		
	Oct. 2	28,910				
	Oct. 16	25,860				
	Oct. 29	26,570				
	Dec. 4	26,570				
18	Feb. 20	15,600	Jan. 2	13,280		
	April 17	11,990	March 19	13,110		
	May 1	13,110	April 14	11,430		
	May 16	12,287	May 5	13,460		
	May 29	12,287	May 26	11,560		
	June 13	12,930	June 8	14,450		
	July 2	14,040	June 22	11,040		
	July 15	17,250	July 6	14,040		
	July 24	16,110	July 20	14,240		
	Aug. 7	15,850	Aug. 4	11,560		
	Aug. 22	15,120	Aug. 17	15,350		
	Sept. 5	15,850	Aug. 31	16,380		
	Sept. 17	15,850	Sept. 28	14,670		
	Oct. 2	16,380				
	Oct. 16	14,040				
	Oct. 29	14,040				
	Dec. 4	14,040				
19	Feb. 20	3930	Jan. 2	2070		
	April 17	2660	March 19	2090		
	May 1	2410	April 14	3640		
	May 16	2934	May 5	2690		
	May 29	3510	May 26	2580		
	June 13	4270	June 8	2780		
	July 2	2800	June 22	2230		
	July 15	3170	July 6	2730		
	July 24	3170	July 20	3010		
	Aug.7	2660	Aug. 4	2690		
	Aug. 22	2980	Aug. 17	3380		
	Sept. 5	2230	Aug. 31	3380		
	Sept. 17	1690	Sept. 28	3060		
	Oct. 2	2280				
	Oct. 16	1750				

Table 28 . Electrical conductivity of observation wells near Whitewater Lake.

Well	Date	1969 Conductivity*	Date	1970 Conductivity	Date	1971 Conductivity
19 (cont.)						
	Oct. 29	1720				
	Dec. 4	1860				
20	Feb. 20	46,810	Jan. 2	35,110	Oct. 20	47,000
	April 17	frozen	March 19	36,410		
	May 1	17,550	April 14	36,400		
	May 16	26,562	May 5	13,280		
	May 29	27,305	May 26	29,790		
	June 13	33,900	June 8	37,800		
	July 2	24,570	June 22	29,780		
	July 15	35,110	July 6	37,800		
	July 24	35,100	July 20	36,400		
	Aug. 7	36,410	Aug. 4	31,700		
	Aug. 22	35,110	Aug. 17	40,950		
	Sept. 5	37,800	Aug. 31	42,730		
	Sept. 17	37,800	Sept. 28	37,800		
	Oct. 2	37,800				
	Oct. 16	36,400				
	Oct. 29	36,400				
	Dec. 4	36,410				
21	Feb. 20	22,860	Jan. 2	19,270	March 15	18,200
	April 17	21,910	March 19	19,660	April 16	5,040
	May 1	15,360	April 14	18,900	Aug. 5	12,000
	May 16	22,340	May 5	1640	Sept. 9	18,000
	May 29	22,860	May 26	6550	Oct. 3	15,000
	June 13	24,580	June 8	14,670		
	July 2	11,980	June 22	13,100		
	July 15	10,920	July 6	15,350		
	July 24	14,040	July 20	16,380		
	Aug. 7	16,380	Aug. 4	13,280		
	Aug. 22	16,380	Aug. 17	17,550		
	Sept. 5	18,200	Aug. 31	17,550		
	Sept. 17	20,910	Sept. 28	16,380		
	Oct. 2	21,370				
	Oct. 16	19,660				
	Oct. 29	20,470				
	Dec. 4	18,900				
22	Feb. 20	12,600	Jan. 2	10,350	April 16	5,610
	April 17	flooded	March 19	10,920	July 24	12,700
	May 1		April 14	11,430	Sept. 9	17,200
	May 16	7,864	May 5	810	Oct. 3	13,500
	May 29	8,547	May 26	5,490		
	June 13	9,830	June 8	9,630		
	July 2	4,910	June 22	8,190		
	July 15	7,560	July 6	10,340		
	July 24	5,780	July 29	9,830		
	Aug. 7	10,680	Aug. 4	8,190		

Table 28 . Electrical conductivity of observation wells near Whitewater Lake.

		1969		1970		1971
Well	Date	Conductivity*	Date	Conductivity	Date	Conductivity
22 (cont.)						
	Aug. 22	10,350	Aug. 17	11,170		
	Sept. 5	11,430	Aug. 31	10,920		
	Sept. 17	11,560	Sept. 28	10,340		
	Oct. 2	11,560				
	Oct. 16	10,340				
	Oct. 29	10,680				
	Dec. 4	10,240				
24	Feb. 20	4,470	Jan. 2	3,070	April 16	1,060
	April 17	610	March 19	3,380	Sept. 9	4,000
	May 1	2,430	April 14	1,780	Oct. 3	4,000
	May 16	2,730	May 5	450	Oct. 20	13,200
	May 29	2,621	May 26	580		
	June 13	2,980	June 8	910		
	July 2	3,780	June 22	720		
	July 15	1,260	July 6	1,012		
	July 24	2,890	July 20	1,112		
	Aug. 7	2,980	Aug. 4	1,040		
	Aug. 22	2,930	Aug. 17	1,420		
	Sept. 5	3,070	Aug. 31	1,400		
	Sept. 17	3,270	Sept. 28	1,440		
	Oct. 2	3,270				
	Oct. 16	2,890				
	Oct. 29	3,170				
	Dec. 4	3,070				
25	Feb. 20	2,290	Jan. 2	1,120	April 16	1,170
	April 17	1,340	March 19	1,020	July 24	2,130
	May 1	1,510	April 14	1,000	Aug. 12	2,220
	May 16	1,404	May 5	1,280	Sept. 9	2,500
	May 29	1,445	May 26	1,400	Oct. 3	2,100
	June 13	2,010	June 8	1,160	Oct. 20	2,200
	July 2	1,920	June 22	1,170		
	July 15	1,820	July 6	1,520		
	July 24	1,750	July 20	1,530		
	Aug. 7	1,640	Aug. 4	1,310		
	Aug. 22	1,590	Aug. 17	1,580		
	Sept. 5	1,690	Aug. 31	1,580		
	Sept. 17	1,820	Sept. 28	1,420		
	Oct. 2	1,890				
	Oct. 16	1,370				
	Oct. 29	1,470				
	Dec. 4	1,118				
39					Sept. 9	10,000

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* Conductivity values expressed in micromhos.cm.$^{-1}$ at 25°C., except for 1971 samples at 5°C. 1969 - 1970 data obtained from R. Eilers, Manitoba Soil Survey.

Table 29 . Oxygen^{18} composition of groundwaters in the Whitewater Lake - Deloraine area, 1970.

Manitoba Soil Survey Hydrometric Site	Depth (feet)	Unit	δO^{18}
Piezometer 1	28	Till	-15.3*
1	76	Till	-15.1
2	38	Till.	-17.2
2	98	Shale	-16.2
3	18	Till	-14.4
3	78	Shale	-16.2
4	28	Till	-15.6
4	93	Shale	-17.6
5	28	Till	-11.2
5	93	Shale	-18.0
6	38	Till	-15.4
6	57	Shale	-14.3
7	13	Till	-15.6
7	28	Shale	-14.4
8	18	Till	-16.5
8	48	Shale	-13.9
9	18	Till	-13.8
9	59	Shale	-15.9
10	18	Till	-11.8
10	68	Sandstone	-14.4
11	18	Till	-13.0
11	43	Shale	-15.5
Observation Well 17	10	Sand	-14.6
20	10	Till	-14.2
21	10	Till	-15.0
22	10	Till	-11.0
24	10	Sand	- 2.0

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*Values expressed as δO^{18} S.M.O.W.

Table 30 . Chemical analyses of Whitewater Lake samples prior to 1970.

Site and date taken	Conduct.* 25°C.	pH$^{f}_{1}$ pH^{1}	epm.		Cations				Anions		Sum Cations	Sum Anions
			Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
July 9,1968† north shore	13,500	----- 9.3	214.79	48.19	9.47	5.39	231.10	11.40	18.60	16.10	277.84	277.21
Nov.6,1968× west shore	4370		27.2	25.52		6.71	59.18			3.13	59.43	63.31
June 13,1969 northshore	3020		17.30	19.60		2.00	30.20	8.50		1.90	39.40	40.60
westshore	4180		26.52	19.60		1.80	41.30	4.00		3.00	47.92	48.30
July 2,1969 northshore	2980		19.78	18.40		3.80	30.70	9.50		2.30	41.98	42.50
westshore	2980		19.78	19.80		4.00	30.35	9.25		1.70	42.58	41.30
July 24,1969 westshore	3640		21.73	19.53		2.23	32.68	6.00		3.50	43.49	42.18
Aug.22,1969 northshore	3070		36.30	13.02		1.86	40.78	8.00		2.90	51.18	51.68
westshore	3780		48.91	15.43		2.20	54.03	8.50		3.50	66.54	66.03
Sept.5,1969 westshore	3930		43.04	16.92		1.67	50.91	7.50		3.20	61.63	61.61
Sept.17,1969 westshore	4270		33.00	20.08			45.05	9.00		4.80	53.08	58.85
Oct.2,1969 northshore	4910		28.20	30.90		2.22	48.48	9.50		3.40	61.38	61.38
westshore	4270		33.00	17.17		4.44	46.35	9.50		3.20	54.61	59.05
Oct.16,1969 northshore	3930		26.95	27.67		3.93	47.67	8.00		3.05	58.45	58.72
westshore	4360		33.67	22.62		3.03	47.16	9.00		3.60	59.16	59.76
Oct.29,1969 northshore	3270		22.50	16.36		2.31	33.63	5.00		2.55	41.17	41.18
westshore	4270		31.50	19.36		2.42	43.98	6.00		4.00	53.28	53.98
Dec.12,1969 westshore	7120		60.00	51.10		5.85	100.10	9.00		7.75	116.95	116.94

*Conductivity expressed in micromhos.cm.$^{-1}$

†Sample obtained by D.Delorme, Inland Waters Branch, Calgary.

×Samples obtained by B. Eilers, Manitoba Soil Survey,Winnipeg.

Table 31 . Chemical analysis of Whitewater Lake samples, 1970.

Site and date taken	Conduct.* 25°C. T.D.S.	pH_f pH_l	ppm. epm.	Cations				Anions					
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
May 19	2840	------		364	163	49	60	1300	406	0	55.0	33.48	35.27
	2391	8.15		15.83	13.41	1.25	2.99	27.07	6.65	0	1.55		
May 21 north	2510	------		319	135	44	41	950	318	0	49.8	28.17	26.39
	1851	7.96		13.88	11.11	1.13	2.05	19.78	5.21	0	1.40		
May 26	2620	------		334	152	46	44	950	349	0	52.8	30.41	27.00
	1922	8.11		14.53	12.50	1.18	2.20	19.78	5.72	0	1.50		
June 1	2700	------		334	157	47	48	1200	387	0	55.0	31.05	32.87
	2222	8.13		14.53	12.92	1.20	2.40	24.98	6.34	0	1.55		
June 8	2850	------		371	165	51	51	1100	415	0	55.3	33.55	31.26
	2202	8.18		16.14	13.57	1.30	2.54	22.90	6.80	0	1.56		
June 15	2730	------		341	164	52	58	1100	406	7.34	56.5	32.54	31.38
	2178	8.28		14.83	13.49	1.33	2.89	22.90	6.65	0.24	1.59		
June 22	3190	------		415	191	66	59	1300	494	0	66.3	38.39	37.04
	2585	8.04		18.05	15.71	1.69	2.94	27.07	8.10	0	1.87		
June 29	3110	------		401	177	61	56	1450	457	0	60.8	36.35	39.39
	2657	8.15		17.44	14.56	1.56	2.79	30.19	7.49	0	1.71		
July 6	3270	------		438	183	69	47	1450	398	16.0	67.8	38.21	39.15
	2663	8.64		19.05	15.05	1.76	2.35	30.19	6.52	0.53	1.91		
July 20	3520	------		482	201	74	48	1600	504	0	68.8	41.80	43.50
	2972	8.15		20.97	16.54	1.89	2.40	33.31	8.26	0	1.94		
July 29	3510	------		490	233	76	39	1550	409	30.2	75.0	44.37	42.10
	2896	8.76		21.31	19.17	1.94	1.95	32.27	6.70	1.01	2.12		

Table 31. Chemical analysis of Whitewater lake samples, 1970.

Site and date taken	Conduct.* 25°C. T.D.S.	pH^f pH^l	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
Aug. 4	3660 2949	------ 8.53		512 22.27	209 17.19	78 1.99	46 2.30	1550 32.27	464 7.60	19.4 0.65	77.0 2.17	43.75	42.69
Aug. 13	3450 2764	------ 8.51		475 20.66	198 16.29	69 1.76	59 2.94	1400 29.15	481 7.88	17.7 0.59	70.3 1.98	41.65	39.60
Aug. 17	3990 3134	------ 8.87		586 25.49	234 19.25	90 2.30	39 1.95	1600 33.31	463 7.59	46.7 1.56	80.8 2.28	48.99	44.74
Aug. 31	4200 3440	------		653 28.40	235 19.33	94 2.40	21 1.05	1850 38.52	478 7.83	20.8 0.70	94.5 2.67	51.18	49.71
Sept. 7 north	4080 3406	9.20 9.08		601 26.14	255 20.98	87 2.22	44 2.20	1800 37.48	463 7.59	80.4 2.68	82.0 2.31	51.54	50.06
Sept. 14	4500 3956	------ 8.52		683 29.71	265 21.80	98 2.51	28 1.40	2250 46.84	517 8.47	18.7 0.62	102 2.88	55.42	58.81
Sept. 20 north	4030 3815	9.31 9.22		601 26.14	250 20.57	89 2.28	44 2.20	2100 43.72	549 9.00	99.1 3.30	83.0 2.34	51.19	58.36
Sept. 27 north	3950 3412	------ 8.98		579 25.19	235 19.33	88 2.25	40 2.00	1800 37.48	536 8.78	54.5 1.82	85.0 2.40	48.77	50.48
Sept. 28	4130 3435	------ 8.50		697 30.32	247 20.32	89 2.29	34 1.70	1950 40.60	479 7.85	17.5 0.58	87.5 2.47	54.63	51.49
Oct. 14 north	4400 3694	------ 8.84		764 33.23	256 21.06	91 2.33	35 1.75	2100 43.72	524 8.59	45.7 1.52	92.5 2.60	58.37	56.43
Oct. 25 north	4420 3787	8.87 8.69		705 30.67	274 22.54	92 2.35	49 2.45	2150 44.76	601 9.85	37.8 1.26	90.0 2.53	58.01	58.40

*Conductivity expressed in micromhos.cm.$^{-1}$

^{f}Field pH value

^{l}Laboratory pH value

Table 32. Chemical analyses of Whitewater Lake samples, 1971.

Site and date taken	Conduct.* 25°C. T.D.S.	pH† pH^{1}	ppm. epm.	Cations				Anions				Sum Cations	Sum Anion
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
March 16	34,000	7.59		7300	3076	674	32.2	23,200	3860	0	1025	589.42	575.49
(under ice)	39,167	8.11		317.53	253.04	17.24	1.61	483.33	63.25	0	28.91		
March 21†	34,000	------		6700	2575	575	236	20,000	4904	0	930	530.6	522.8
(under ice)	35,920	7.80		291.3	212.8	14.7	11.8	416	80.5	0	26.3		
April 9	2790	8.51		433	163	44.2	34.7	1400	343	0	47.3	35.10	36.10
(under ice)	2465	8.22		18.83	13.41	1.13	1.73	29.15	5.62	0	1.33		
April 15	1980	8.31		324	112	33.4	25.9	1000	257	0	32.5	25.44	25.95
north	1785	7.90		14.09	9.21	0.85	1.29	20.82	4.21	0	0.92		
April 15	2010	------		306	113	37.4	34.1	1000	289	16.9	34.5	25.27	27.09
south	1831	8.69		13.31	9.30	0.96	1.70	20.82	4.74	0.56	0.97		
April 17†	2070	------		310	116	35.0	23.2	950	274	0	36.5	25.11	25.31
north	1745	8.15		13.48	9.58	0.89	1.16	19.79	4.49	0	1.03		
May 2†	2640	------		422	140	53.6	32.4	1180	390	0	52	32.91	32.44
north	2270	8.00		18.35	11.57	1.37	1.62	24.58	6.39	0	1.47		
May 6	2705	8.56		463	171	58.0	40.9	1500	413	0	54.5	37.73	39.54
north	2701	7.92		20.14	14.07	1.48	2.04	31.23	6.77	0	1.54		
May 11†	2920	------		447	160	61.6	32.8	1292	327	0	59	35.86	35.24
north	2418	8.40		19.43	13.22	1.57	1.64	26.92	5.36	0	1.66		
May 14	2920	8.76		513	173	64.1	46.6	1500	448	0	61.3	40.51	40.30
north	2806	7.94		22.31	14.23	1.64	2.33	31.23	7.34	0	1.73		
May 20†	2920	8.70		440	157	63.6	34.4	1290	322	0	60	35.45	35.29
north	2410	8.50		19.13	12.97	1.63	1.72	26.88	5.28	0	1.69		

Table 32 . Chemical analyses of Whitewater Lake samples, 1971.

Site and date taken	Conduct.* 25°C. T.D.S.	pH_1^f pH	ppm. epm.	Na	Mg^2	K	Ca^2	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anion
May 27†	2980	------		450	159	65.2	41.6	1292	468	0	60	36.45	36.28
north	2536	8.00		19.56	13.14	1.67	2.08	26.92	7.67	0	1.69		
May 28	2990	8.30		505	188	68.5	50.8	1600	470	0	60.8	41.72	42.85
north	2943	7.89		21.97	15.47	1.75	2.53	33.31	7.83	0	1.71		
June 2†	3130	------		500	169	71.5	41.6	1400	421	30	63	39.61	38.85
north	2696	8.35		21.14	13.96	1.83	2.08	29.17	6.90	1.00	1.78		
June 9†	3130	------		504	165	72.5	44.0	1420	470	0	63	39.61	39.05
north	2739	7.90		21.93	13.63	1.85	2.20	29.58	7.70	0	1.77		
June 11	2910	8.36		499	168	64.3	43.0	1400	439	0	55.5	39.32	37.91
north	2669	8.12		21.71	13.82	1.69	2.15	29.15	7.19	0	1.57		
June 16†	3010	------		470	162	64.4	40.8	1280	482	30	62	37.50	37.32
north	2588	8.30		20.43	13.38	1.65	2.04	26.66	7.91	1.00	1.75		
June 16†	2630	------		407	137	59	41.6	1130	366	30	52	32.60	32.01
west	2223	8.30		17.69	11.32	1.51	2.08	23.54	6.00	1.00	1.47		
June 23†	2890	------		462	155	65.5	43.2	1260	494	0	58	36.71	35.98
north	2538	8.25		20.08	12.80	1.67	2.16	26.25	8.10	0	1.63		
June 23†	1770	------		242	95.1	37	59.2	690	403	0	30.5	22.28	21.83
south	1557	7.85		10.52	7.86	0.94	2.96	14.37	6.60	0	0.86		
June 25	2890	8.65		487	169	64.8	46.5	1500	444	7.04	56.8	39.06	40.34
north	2775	8.34		21.18	13.90	1.66	2.32	31.23	7.28	0.23	1.60		
June 30†	2990	------		475	162	69.0	40.8	1310	354	60	61	37.83	36.81
north	2532	8.60		20.65	13.38	1.76	2.04	27.29	5.80	2.00	1.72		

Table 32 . Chemical analyses of Whitewater Lake samples, 1971.

Site and date taken	Conduct.* 25°C. T.D.S.	pH_f pH_l	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
April 30	2470	------		421	148	51.3	50.2	1200	393	0	48.0	34.30	32.78
north	2312	7.99		18.31	12.18	1.31	2.50	24.99	6.44	0	1.35		
July 7†	2890	------		472	157	68.4	44.8	1325	488	0	61	37.54	37.32
north	2348	8.17		20.52	12.97	1.75	2.24	27.60	8.00	0	1.72		
July 14†	3170	------		522	173	74	51.2	1415	457	42	65	41.49	48.20
north	2584	8.41		22.69	14.30	1.89	2.56	29.48	7.49	1.40	1.83		
July 22†	3230	------		550	178	76	51.2	1525	402	84	69	43.12	43.11
north	2688	8.76		23.90	14.71	1.94	2.56	31.77	6.59	2.80	1.95		
July 24	3640	------		608	206	80.0	57.1	1800	534	31.7	70.3	48.30	49.27
north	3387	8.58		26.45	16.95	2.05	2.85	37.48	8.75	1.06	1.98		
July 30†	3350	8.90		568	180	87	51.2	1560	464	72	70	44.35	44.48
north	3052	8.57		24.69	14.87	2.23	2.56	32.50	7.61	2.40	1.97		
Aug. 6†	3390	9.07		547	186	77.6	53.6	1460	415	96	70	43.76	42.36
north	2806	8.63		23.78	15.30	1.98	2.68	30.39	6.80	3.20	1.97		
Aug. 6	3630	8.96		608	200	81.2	51.5	1800	528	0	70.5	47.55	48.12
north	3339	8.07		26.45	16.45	2.08	2.57	37.48	8.65	0	1.99		
Aug. 13†	3620	9.20		604	198	89	57.6	1635	402	108	78	47.78	46.45
north	3074	8.80		26.26	16.36	2.28	2.88	34.06	6.59	3.60	2.20		
Aug. 20†	3680	9.15		650	201	87	60	1800	439	96	79	50.09	50.13
north	3038	8.72		28.26	16.61	2.22	3.00	37.50	7.20	3.20	2.23		
Aug. 26	4195	8.98		718	239	96.8	55.5	1950	599	62.7	82.8	56.14	54.84
north	3804	8.83		31.23	19.66	2.48	2.77	40.60	9.82	2.09	2.34		

Table 32. Chemical analyses of Whitewater Lake samples, 1971.

Site and date taken	Conduct.* 25°C. T.D.S.	pH[f] pH[1]	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
Aug. 27[†]	3820	9.09		670	211	93.6	59.2	1800	451	96	80	51.92	50.35
north	3194	8.72		29.13	17.44	2.39	2.96	37.50	7.39	3.20	2.26		
Sept. 3[†]	4070	------		734	234	95	53.6	2000	427	120	92	56.36	55.39
north	3466	8.92		31.91	19.34	2.43	2.68	41.67	7.12	4.00	2.50		
Sept. 9	4225	9.24		712	230	93.2	57.2	2000	612	72.1	82.5	55.02	56.40
north	3859	8.93		30.97	18.92	2.38	2.85	41.69	10.03	2.40	2.33		
Sept. 13[†]	4100	------		710	231	99	59.2	1805	396	180	92	55.49	52.68
north	3484	8.82		30.87	19.09	2.53	2.96	37.60	6.49	6.00	2.59		
Oct. 5[†]	3920	8.91		664	217	93	54.4	1715	488	96	88	51.93	49.41
north	3264	8.74		28.87	17.93	2.38	2.72	35.73	8.00	3.20	2.48		
Oct. 13[†]	4170	------		690	228	98	60.8	1850	537	64.0	92.0	54.41	52.06
north	3620	8.70		30.00	18.84	2.51	3.04	38.54	8.80	2.13	2.59		

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*Conductivity expressed as micromhos.cm.$^{-1}$

[f] Field pH value

[1] Laboratory pH value

[†] Sample analyzed by J. Adams; Water Control and Conservation Branch, 1971.

Table 33 . pH readings of Whitewater Lake, 1971.

Date sampling	Date reading	Location	Temp. °C.	pH
May 20	May 20	north of Whitewater village	17	8.68
		north site off "island"	17	8.70
May 20	May 21	west end	14	8.70
May 27	May 29	north site off "island"	12	8.63
		north of Whitewater village	12	8.71
		west end	12	8.71
June 2	June 3	north site off "island"	11	8.74
		north of Whitewater village	11	8.62
		west end	11	8.77
June 9	June 10	north site off "island"	14	8.84
		north of village	14	8.56
		west end	14	8.48
June 16	June 17	north site off "island"	15	8.72
		north of village	15	8.46
		west end	15	8.66
June 23	June 24	north site off "island"	14	8.62
		north of village	14	7.98
		west end	14	8.57
June 30	July 1	north site off "island"	15	8.85
		north of village	15	8.48
		west end	15	8.56
July 7	July 8	north site off "island"	15	8.83
		north of village	15	8.56
		west end	15	8.56
July 14	July 15	north site off "island"	16	8.79
		north of village	16	8.69
		west end	16	8.83
July 22	July 23	north site off "island"	16	9.02
		north of village	16	8.70
		west end	16	8.95
July 30	July 30	north site off "island"	17	8.90
		north of village	17	8.76
		west end	17	8.89

Table 33 . pH readings of Whitewater Lake, 1971.

Date sampling	Date reading	Location	Temp. °C.	pH
Aug. 6	Aug. 6	north site off "island"	20	9.07
		north of village	20	9.13
		west end	19	9.00
Aug. 13	Aug. 13	north site off "island"	17	9.20
		north of village	17	9.03
		west end	17	9.21
Aug. 20	Aug. 20	north site off "island"	16	9.15
		north of village	16	9.12
		west end	16	9.19
Aug. 27	Aug. 27	north site off "island"	15	9.09
		north of village	15	9.17
		west end	15	9.22
Sept. 3	Sept. 4	north site off "island"	15	9.11
Sept. 13	Sept. 14	north site off "island"	15	9.10
Sept. 19	Sept. 20	north site off "island"	15	9.04
Oct. 5	Oct. 5	north site off "island"	17	8.91
Oct. 11	Oct. 13	north site off "island"	15	8.85
Oct. 28	Oct. 28	north site off "island"	15	8.76
Nov. 11	Nov. 12	one mile west of "island" north shore	15	8.79

Data obtained from R. Ransom; Department of Mines, Resources and Environmental Management, 1971.

Table 34. Oxygen^{18} composition of Whitewater Lake samples 1970-71.

Sampling date	δO^{18} SMOW	Sampling date	δO^{18}SMOW
1970:			
May 19	-8.7	Sept. 27	-4.2,-5.9,-5.4,-6.2,-5.5,-5.8,-5.2,-5.7
May 26	-10.5	Oct. 14	-5.5
June 1	-13.0 (E)	Oct. 25*	-5.7,-5.4
June 4	-9.6	1971: *	
June 15*	-8.7	March 16 (under ice)	-10.9
June 22	-7.6	April 15	-8.8
June 29*	-8.5	April 30	-10.9
July 6	-7.1	May 6	-9.1
July 20*	-6.1	May 14	-8.5
July 29	-6.0	May 28	-7.3
Aug. 4	-6.0	June 11	-6.6
Aug. 13*	-6.5	June 25	-7.5
Aug. 17	-5.6	July 24	-5.5
Aug. 31	-4.1	Aug. 6	-5.6
Sept. 7*	-3.4,-4.3,-4.1,-3.7,-4.1,-4.3	Aug. 26	-5.0
Sept. 9	-6.3	Sept. 9	-5.2
Sept. 14*	-2.7		
Sept. 20	-4.7		

* Samples prepared and analyzed by P. Fritz, University of Alberta, Edmonton and University of Waterloo; remaining samples analyzed by W. Buchanon, Chemistry Department, University of Manitoba.
(E) Estimated value.

Table 35. Oxygen^{18} composition of interstitial water samples 1970.

Sampling date	Core	δO^{18}SMOW
Sept. 27, 1970*	C11 top	-5.7
	C11 bottom	-7.4

* Samples prepared and analyzed by P. Fritz, University of Alberta.

Table 36 . Interstitial water chemistry of bottom sediments, Whitewater Lake.

Sample	Conduct.* 25°C. T.D.S.	pH_1^f pH	ppm. epm.	Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-	Sum Cations	Sum Anions
				Cations				Anions					
B1	6800 8258	7.37 7.96		1487 64.68	620 51.00	151 3.86	68.6 3.42	4250 88.48	1538 25.21	0 0	143 4.03	122.96	117.72
B2	4000 5485	7.66 8.13		757 32.93	302 24.84	107 2.74	70.8 3.53	2900 60.38	1248 20.45	0 0	100 2.82	64.04	83.65
C1top	6880 7001	---- 8.16		1134 49.33	533 43.85	164 4.19	104 5.19	3800 79.12	1198 19.63	0 0	67.5 1.90	102.56	100.65
C1bot.	9740 10,919	---- 8.12		1895 82.43	835 68.69	216 5.52	154 7.68	6000 124.92	1724 28.25	0 0	95.0 2.68	164.32	155.85
C2top	5700 5650	---- 8.09		961 41.80	437 35.95	129 3.30	113 5.64	3000 62.46	957 15.68	0 0	52.5 1.48	86.69	79.62
C2bot.	9060 9690	---- 8.09		1677 72.95	791 65.07	189 4.83	145 7.24	5250 109.30	1560 25.57	0 0	77.5 2.19	150.09	137.06
C3top	8210 8589	---- 8.23		1499 65.20	608 50.02	177 4.53	71.5 3.57	4750 98.89	1398 22.91	0 0	85.0 2.40	123.32	124.20
C3bot.	12,300 13,754	---- 8.11		2337 101.65	1103 90.74	236 6.04	69.3 3.46	7900 164.48	1978 32.42	0 0	131 3.70	201.89	200.60
C4top	6560 6470	---- 8.30		1122 45.80	470 38.66	162 4.14	94.3 4.71	3500 72.87	1057 17.32	0 0	65.0 1.83	96.31	92.02
C4bot.	10,400 11,793	---- 8.19		2122 92.30	924 76.01	234 5.98	142 7.09	6600 137.41	1661 27.22	0 0	110 3.10	181.38	167.73
C5top	7500 7656	---- 8.17		1231 53.55	521 42.86	149 3.81	92.9 4.64	4000 83.28	1587 26.01	0 0	75.0 2.12	104.86	111.41
C5bot.	10,310 ----	---- 8.18		2040 88.74	----	----	----	6450 134.29	1904 31.20	0	115 3.24	-----	168.73
C6top	8040 8034	---- 8.69		1543 67.12	536 44.09	183 4.68	80.0 3.99	4600 95.77	1014 16.62	0	77.5 2.19	119.88	114.58

Table 36 . Interstitial water chemistry of bottom sediments, Whitewater Lake.

Sample	Conduct.* 25°C. T.D.S.	pH_1^f pH^1	ppm. epm.	Cations				Anions				Sum Cations	Sum Anions
				Na^+	Mg^{2+}	K^+	Ca^{2+}	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Cl^-		
C6bot.	11,300 9823	---- 8.13		2166 94.22	919 75.60	234 5.98	78.0 3.89	4900 102.02	1408 23.08	0 0	118 3.33	179.69	128.43
C7top	5260 5121	---- 7.85		878 38.19	410 33.73	161 4.12	129 6.44	2750 57.25	735 12.05	0 0	57.5 1.62	82.48	70.92
C7bot.	7970 8233	---- 8.33		1447 62.94	608 50.02	174 4.45	122 6.09	4500 93.69	1302 21.34	0 0	80.0 2.26	123.50	117.29
C8top	6640 6498	---- 8.18		1056 45.93	511 42.04	143 3.66	108 5.39	3500 72.87	1112 18.22	0 0	67.5 1.90	97.02	92.99
C8bot.	9780 9896	---- 8.12		1743 75.82	885 72.80	195 4.99	133 6.64	5500 114.51	1345 22.09	0 0	95.0 2.68	160.25	139.23
C9top	6780 6513	---- 8.22		1158 50.37	475 39.08	163 4.17	100 4.99	3650 75.99	894 14.65	0 0	72.5 2.04	98.61	92.68
C9bot.	10,000 10,342	---- 8.26		1877 81.64	787 64.74	220 5.63	68.6 3.42	6000 124.92	1289 21.13	0 0	100 2.82	155.43	148.87
C10top	7140 7186	---- 8.2~~x~~0		1237 53.81	601 49.44	154 3.94	49.1 2.45	3800 79.12	1275 20.90	0 0	70.0 1.97	109.64	101.99
C10bot.	11,970 13,667	---- 8.23		2230 97.00	1250 102.83	244 6.24	25.7 1.28	7900 164.48	1904 31.20	0 0	113 3.19	207.35	198.87
C11top	6830 7193	7.76 7.02		1104 48.02	557 45.82	130 3.32	75.0 3.74	3400 70.79	1852 30.35	0 0	75.0 2.12	100.90	103.26
C11bot.	11,640 13,031	7.78 8.15		2255 98.09	1090 89.67	222 5.68	15.0 0.75	6600 137.41	2719 44.56	0 0	130 3.67	194.19	185.64
C12top	5930 5595	---- 7.96		1027 44.67	425 34.96	127 3.25	77.9 3.89	3000 62.46	880 14.42	0 0	57.5 1.62	86.77	78.50
C12bot.	9610 10,250	---- 8.14		1840 80.04	835 68.69	212 5.42	108 5.39	5800 120.76	1370 22.45	0 0	85.0 2.40	159.54	145.61

*Conductivity expressed in micromhos.cm.$^{-1}$

Table 37. Data used in hydrochemical budgets of Whitewater Lake, 1970 and 1971.

Period	Date	Lake Level (feet)	Lake Volume ($x10^6 ft.^3$)	$V_F - V_I$ ($x10^6 ft.^3$)	P (inches)	ET (inches)	ET-P (inches)	ET-P ($x10^6 ft.^3$)	K	X ($x10^6 ft.^3$)	T.D.S. (ppm.)	Cond.*	Na^+ (ppm)	Cl^- (ppm)
(1) 1970	July 6	1628.2	1981.12	460.12	3.63	10.58	6.93	429.19	1.22	-33.93	2663	3270	438	67.8
	Aug.31	1627.4	1521.00								3440	4200	653	94.5
(2) 1971	July 15	1627.9	1908.1	399.11	1.28	10.49	9.21	567.43	1.29	168.32	2584	3170	522	65.0
	Aug.31	1627.3	1509.0								3194	3820	670	80.0

*Conductivity expressed in micromhos.cm.$^{-1}$ at 25°C.

Table 38. Probable groundwater inflow quantities via glacial sand and gravel (Unit 9a) for a period of 45 days, Whitewater Lake.

Seepage Zone	Seepage Length (feet)	Average Thickness (feet)	Seepage Area (ft.^{2})	Average Hydraulic Gradient	Average Permeability (ft. sec.$^{-1}$)	Discharge ($\times 10^6$ ft.^{3})	Discharge (Acre-feet)
south shore	26,400	10	2.6×10^5	5×10^{-3}	1×10^{-1}	510	11,700
					1×10^{-2}	51	1170
					1×10^{-3}	5	117
					1×10^{-4}	0.5	12
					1×10^{-5}	0.05	1.2
				1×10^{-2}	1×10^{-1}	1000	23,000
					1×10^{-2}	100	2300
					1×10^{-3}	10	230
					1×10^{-4}	1	23
					1×10^{-5}	0.1	2.3
		5	1.3×10^5	5×10^{-3}	1×10^{-1}	250	5800
					1×10^{-2}	25	580
					1×10^{-3}	2.5	58
					1×10^{-4}	0.25	5.8
					1×10^{-5}	0.03	0.6
				1×10^{-2}	1×10^{-1}	510	11,700
					1×10^{-2}	51	1170
					1×10^{-3}	5	117
					1×10^{-4}	0.5	12
					1×10^{-5}	0.05	1.2
north shore	15,840	5	7.9×10^4	5×10^{-3}	1×10^{-1}	150	3500
					1×10^{-2}	15	350
					1×10^{-3}	1.5	35
					1×10^{-4}	0.2	4
					1×10^{-5}	0.02	0.4

Table 39. Probable water seepage quantities through Whitewater Lake bottom sediments and glacial till.

Time period = 45 days

Seepage Area (ft.^{2})	Average Hydraulic Gradient	Average Permeability (ft. sec.$^{-1}$)	Seepage (x10^6ft.^{3})	Seepage (acre-feet)
5.6×10^8	0.5	1×10^{-6}	600	13,000
		1×10^{-7}	60	1300
		1×10^{-8}	6	130
		1×10^{-9}	0.6	13
		1×10^{-10}	0.06	1.3
	1.0	1×10^{-6}	1100	25,000
		1×10^{-7}	110	2500
		1×10^{-8}	11	250
		1×10^{-9}	1.1	25
		1×10^{-10}	0.1	2.5
2.8×10^8	0.5	1×10^{-6}	300	7000
		1×10^{-7}	30	700
		1×10^{-8}	3	70
		1×10^{-9}	0.3	7
		1×10^{-10}	0.03	0.7
	1.0	1×10^{-6}	600	13,000
		1×10^{-7}	60	1300
		1×10^{-8}	6	130
		1×10^{-9}	0.6	13
		1×10^{-10}	0.06	1.3

Table 40 Results of hydrochemical budgets based on conductivity, Whitewater Lake.

1970 July 6 - Aug. 31			1971 July 15 - Aug. 31		
Groundwater Outflow (x10^6ft.^{3})	Conductivity of Inflow (micromhos.cm.$^{-1}$)	Groundwater Inflow (x10^6ft.^{3})	Groundwater Outflow (x10^6ft.^{3})	Concentration of Inflow (micromhos.cm.$^{-1}$)	Groundwater Inflow (x10^6ft.^{3})
543.67	1000.00	509.74	885.26	1000.00	1053.58
563.01	1100.00	529.08	929.25	1100.00	1097.57
583.88	1200.00	549.95	977.07	1200.00	1145.39
606.47	1300.00	572.54	1029.26	1300.00	1197.58
630.99	1400.00	597.06	1086.42	1400.00	1254.74
657.70	1500.00	623.77	1149.31	1500.00	1317.63
686.92	1600.00	652.99	1218.85	1600.00	1387.17
719.01	1700.00	685.08	1296.13	1700.00	1464.45
754.41	1800.00	720.48	1382.52	1800.00	1550.84
793.68	1900.00	759.75	1479.76	1900.00	1648.08
837.47	2000.00	803.53	1590.00	2000.00	1758.31
886.61	2100.00	852.68	1716.04	2100.00	1884.36
942.16	2200.00	908.23	1861.55	2200.00	2029.87
1005.45	2300.00	971.52	2031.41	2300.00	2199.73
1078.22	2400.00	1044.29	2232.30	2400.00	2400.62
1162.78	2500.00	1128.85	2473.57	2500.00	2641.89
1262.24	2600.00	1228.31	2768.75	2600.00	2937.07
1380.92	2700.00	1346.99	3138.20	2700.00	3306.52
1524.98	2800.00	1491.05	3613.96	2800.00	3782.28
1703.55	2900.00	1669.62	4249.63	2900.00	4417.95
1930.71	3000.00	1896.78	5142.14	3000.00	5310.46
2229.42	3100.00	2195.49	6486.57	3100.00	6654.88
2639.79	3200.00	2605.86	8742.46	3200.00	8910.78
3238.83	3300.00	3204.90	13312.09	3300.00	13480.41
4195.52	3400.00	4161.59	27502.01	3400.00	27670.32
5966.41	3500.00	5932.48	-525904.50	3500.00	-525736.10
10360.84	3600.00	10326.91			
39866.31	3700.00	39832.38			
-21414.27	3800.00	-21448.20			

Table 41. Results of hydrochemical budgets based on total dissolved solids, Whitewater Lake.

1970 July 6 - Aug. 31			1971 July 15 - Aug. 31		
Groundwater Outflow ($x10^6 ft.^3$)	Concentration of Inflow (ppm.)	Groundwater Inflow ($x10^6 ft.^3$)	Groundwater Outflow ($x10^6 ft.^3$)	Concentration of Inflow (ppm.)	Groundwater Inflow ($x10^6 ft.^3$)
573.14	1000.00	539.21	905.74	1000.00	1074.06
600.77	1100.00	566.84	965.78	1100.00	1134.10
631.38	1200.00	597.45	1032.92	1200.00	1201.24
665.50	1300.00	631.56	1108.52	1300.00	1276.84
703.74	1400.00	669.81	1194.27	1400.00	1362.59
746.91	1500.00	712.98	1292.37	1500.00	1460.69
796.03	1600.00	762.10	1405.69	1600.00	1574.01
852.42	1700.00	818.49	1538.07	1700.00	1706.39
917.82	1800.00	883.89	1694.76	1800.00	1863.08
994.58	1900.00	960.65	1883.14	1900.00	2051.46
1085.94	2000.00	1052.01	2113.90	2000.00	2282.22
1196.50	2100.00	1162.57	2403.16	2100.00	2571.48
1333.03	2200.00	1299.10	2776.38	2200.00	2944.70
1505.90	2300.00	1471.97	3276.33	2300.00	3444.65
1731.84	2400.00	1697.91	3980.75	2400.00	4149.07
2039.71	2500.00	2005.78	5047.35	2500.00	5215.67
2483.96	2600.00	2450.03	6852.09	2600.00	7020.40
3180.98	2700.00	3147.05	10566.59	2700.00	10734.90
4432.29	2800.00	4398.35	22628.28	2800.00	22796.59
7335.49	2900.00	7301.55	-184613.50	2900.00	-184445.10
21513.28	3000.00	21479.35			
-22774.04	3100.00	-22807.97			

July 6 - Aug. 31 1970			July 15 - Aug. 31 1971		
Groundwater Outflow (x10^{6}ft.^{3})	Concentration of Inflow (ppm.)	Groundwater Inflow (x10^{6}ft.^{3})	Groundwater Outflow (x10^{6}ft.^{3})	Concentration of Inflow (ppm.)	Groundwater Inflow (x10^{6}ft.^{3})
124.48	25.00	90.55	487.11	25.00	655.43
126.62	37.00	92.69	501.18	37.00	669.50
128.86	49.00	94.93	515.87	49.00	684.19
131.21	61.00	97.28	531.21	61.00	699.53
133.68	73.00	99.75	547.26	73.00	715.58
136.28	85.00	102.35	564.07	85.00	732.39
139.02	97.00	105.09	581.68	97.00	750.00
141.91	109.00	107.98	600.16	109.00	768.48
144.96	121.00	111.03	619.57	121.00	787.89
148.19	133.00	114.26	639.99	133.00	808.31
151.61	145.00	117.68	661.50	145.00	829.82
155.25	157.00	121.32	684.18	157.00	852.50
159.12	169.00	125.19	708.14	169.00	876.46
163.24	181.00	129.31	733.49	181.00	901.81
167.64	193.00	133.71	760.34	193.00	928.66
172.35	205.00	138.42	788.84	205.00	957.16
177.41	217.00	143.48	819.15	217.00	987.47
182.85	229.00	148.92	851.43	229.00	1019.75
188.72	241.00	154.79	885.90	241.00	1054.22
195.07	253.00	161.14	922.79	253.00	1091.11
201.96	265.00	168.03	962.34	265.00	1130.66
209.47	277.00	175.54	1004.88	277.00	1173.20
217.68	289.00	183.75	1050.73	289.00	1219.05
226.70	301.00	192.77	1100.32	301.00	1268.64
236.65	313.00	202.72	1154.12	313.00	1322.44
247.68	325.00	213.75	1212.67	325.00	1380.99
259.98	337.00	226.05	1276.66	337.00	1444.98
327.59	385.00	293.66	1346.86	349.00	1515.18
351.32	397.00	317.39	1833.01	409.00	2001.33
379.22	409.00	345.29	1970.25	421.00	2138.57
412.50	421.00	378.57	2127.69	433.00	2296.01
452.89	433.00	418.95	2310.15	445.00	2478.47
502.91	445.00	468.98	2524.12	457.00	2692.44
566.50	457.00	532.57	2778.53	469.00	2946.85
650.04	469.00	616.11	3086.02	481.00	3254.34
764.67	481.00	730.74	3465.17	493.00	3633.49
931.69	493.00	897.76	5102.80	525.00	5271.11
2333.07	525.00	2299.14	17653.08	575.00	17821.40
-1563.78	575.00	-1597.71	-13073.47	625.00	-12905.15

Table 43.Results of hydrochemical budgets based on Cl^-, Whitewater Lake.

1970 July 6 - Aug. 31			1971 July 15 - Aug. 31		
Groundwater Outflow (x10^6ft.^{3})	Concentration of Inflow (ppm.)	Groundwater Inflow (x10^6ft.^{3})	Groundwater Outflow (x10^6ft.^{3})	Concentration of Inflow (ppm.)	Groundwater Inflow (x10^6ft.^{3})
294.78	14.00	260.85	712.45	14.00	880.77
311.31	18.00	277.38	777.09	18.00	945.41
330.06	22.00	296.13	851.98	22.00	1020.30
351.54	26.00	317.61	939.74	26.00	1108.06
376.38	30.00	342.45	1044.03	30.00	1212.35
405.43	34.00	371.50	1169.99	34.00	1338.31
439.87	38.00	405.94	1325.16	38.00	1493.48
481.35	42.00	447.42	1521.02	42.00	1689.34
532.26	46.00	498.33	1776.02	46.00	1944.34
596.25	50.00	562.32	2121.68	50.00	2290.00
679.10	54.00	645.17	2616.81	54.00	2785.13
790.58	58.00	756.65	3385.13	58.00	3553.45
948.62	62.00	914.69	4738.82	62.00	4907.13
1190.13	66.00	1156.20	7758.59	66.00	7926.91
1604.90	70.00	1570.97	20441.66	70.00	20609.98
2483.77	74.00	2449.84	-34518.30	74.00	-34349.98
5594.69	78.00	5560.75	-9536.49	78.00	-9368.17
-20573.40	82.00	-20607.33	-5592.00	82.00	-5423.68
			-3984.98	86.00	-3816.66

APPENDIX A

Methods of Investigation

Geologic

Stratigraphy

Forty-one auger holes were drilled and logged in the vicinity of Whitewater Lake during June and July, 1971, in order to investigate the stratigraphy of the basin and to install piezometers. Holes were drilled to depths up to 95 feet (31 m.) with a truck-mounted rotary drill having a solid stem auger with a diameter of 6 inches (15 cm.). Geologic materials were logged during the drilling and samples were taken of the various units encountered. The drill stem could be pulled at any depth up to 95 feet (31 m.) without rotation of the core. The depth of samples obtained from the augers could be determined within an error of about 2 feet (0.7 m.). Drill logs are included in Appendix B, p. 271.

The distribution of the drill holes around Whitewater Lake is shown in Fig. 13, p. 148. Holes were located and spaced around the lake on the basis of: accessibility, surficial geology, location of water wells, drilling costs and interpretation of results as the drilling progressed.

Lake Bottom Sediments

Bottom sediments of Whitewater Lake were first sampled for cursory examination in May, 1970. Surface sediment samples were obtained within 300 feet (98 m.) south of "the island" (Fig. 8, p. 143) from a boat using a thin walled (1 mm.) tube 2 inches (5 cm.) in diameter and 2 feet (62 cm.) in length fitted with a plunger and attached to a wooden rod.

The bottom sediments were then sampled systematically across the width of the lake in September, 1970 to obtain relatively undisturbed core samples and samples from which interstitial water could be extracted. Cores were obtained from a boat using a thin walled (3 mm.) plastic tubing 6 inches (15 cm.) in diameter and 6 feet (2 m.) in length which was pushed into the bottom muds to refusal. The core tube was fixed near the bottom with a cord so the tubing could be tilted and brought to the surface to minimize loss and disturbance of the sample. Cores were extruded carefully and wrapped in cellophane and aluminum foil for later examination. The location of 12 core samples obtained in this manner is shown in Fig. 20, p. 155. Core localitites were staked during the sampling and surveyed relative to each other with a hand compass from the boat. In March, 1971 two shallow drill cores (125 cm.) were obtained near the centre of the lake using a Livingstone sampler. These holes were cored to determine the maximum thickness of the Recent sediments and to investigate the underlying deposits. In late March, 1971, 10 test holes were drilled to an average depth of 10 feet (3 m.) by the Manitoba Water Resources Branch to investigate the soil conditions under the lake. The locations of these test holes are also shown in Fig. 20, p. 155 . These data were used to supplement the information obtained from the shallow cores.

Meteorologic and Hydrologic

Precipitation and Evaporation

Precipitation in the Whitewater Lake area is measured at federal climatological stations located at Deloraine, 9 miles (14.5 km.) west of the centre of Whitewater Lake and Boissevain, 11 miles (18 km.) east of the centre of the lake. Boissevain and Deloraine are 19 miles (31 km.) apart. Periodically two stations are in operation at Deloraine and also at Boissevain. When this occurs the monthly precipitation values reported in this report are an average of the station readings at the particular locality. Rainfall is measured with a standard Meteorological Service of Canada (MSC) rain guage that has an oriface diameter of 3.6 inches (9.14 cm.) at 1 foot (33 cm.) above the ground.

In May, 1971 two additional meteorological stations (station 1 and 2, Fig. 25, p. 161) were established northwest and southeast of Whitewater Lake to provide more detailed coverage in the vicinity of the lake. A standard rain gauge, Class "A" evaporation pan, rain sampler, air temperature thermometer and humidity gauge were installed at each of the stations. Meteological data were monitored and rain samples were collected until November, 1971.

Surface Water

Surface inflow to Whitewater Lake was investigated by examination of streamflow hydrographs of Turtlehead Creek (Fig. 28, p.164) for the period 1970 and 1971. Hydrographs were based on daily staff gauge measurements taken by the Water Survey of Canada.

Groundwater

The groundwater regime of the Whitewater Lake Basin was investigated by examination of the hydrostratigraphy and analysis of the potentiometric and chemical parameters of the groundwaters. Supplementary groundwater data was obtained from previous studies (Johnston, 1934; Elson and Halstead, 1949; Halstead and Elson, 1949; Halstead, 1959) and current studies (Eilers, 1972) in the area.

Standpipe piezometers were installed in late June, 1971 at the drill site locations shown in Fig. 13, p. 148. One to three piezometers similar to the type described by Schwartz (1970) were installed at each site. Piezometers were constructed of semi-rigid polyvynchloride (P.V.C.) tubing with a diameter of 0.8 inches (2.0 cm.). The piezometer intake consisted of a 2 foot (61 cm.) slotted section wrapped with fiberglass cloth. Medium to coarse-grained silica sand was placed around the piezometer intake. This was then capped by a grout plug of a portland cement and water mixture and the hole was filled with earth. Hydraulic head measurements were begun July 24 and continued at approximately two week intervals until November 25. Measurements were conducted with a canvas tape measure and an electric measuring device (Soil Test Co.). Levels were obtained with an accuracy of 0.05 feet (1.5 cm.). Piezometer readings are shown in Table 14, p. 211. Missed readings were caused by inaccessibility during wet weather.

Additional groundwater data in the area were obtained by monitoring observation wells of the Manitoba Soil Survey. The locations of the Manitoba Soil Survey wells are shown in Fig. 25, p. 161. Well levels prior to 1971 were obtained from R. Eilers for the Manitoba Soil Survey wells. Well levels are tabulated in Table 13, p. 207 and shown diagrammatically in Fig. 29, p. 165.

Lake Levels

Lake levels for the period 1970 and 1971 (Tables 15-17, pp 213-215) were obtained at Whitewater Lake from staff gauge measurements recorded by B. Ransom and a recording gauge operated by the Water Survey of Canada. The locations of these instruments are shown in Fig. 25, p. 161. Estimates of lake level for windy days during 1970 were computed geometrically from available staff gauge measurements to account for the effect of seiches. These estimates are representative of the weighted mean lake level assuming a uni-modal seich. The reliability of these estimates is indicated in Table 15, p. 213. Lake levels obtained from the recording gauge were adjusted for the effect of seiches by the Water Survey of Canada. These are shown in Tables 16 and 17, pp 214 and 215.

Hydrochemical Sampling

Precipitation

Rain samples were collected at stations 1 and 2 from May to November 1971. A rain sampler having a square oriface of 2 feet (61 cm.) and constructed of polyethylene sheeting supported by a wooden frame was used to collect the samples. A Nalgene bottle was mounted at the base of the sampler in order to retain the sample and to minimize handling. Samples were collected after each rainfall and stored in their individual bottles. A snow sample was collected from the surface of Whitewater Lake in March, 1971.

Surface Water

Water samples were collected from creek sites 1 to 13 (Fig. 13, p.148) during the period of active surface runoff from April to the middle of July, 1971. Sites 1 to 6 were visited regularly at two week intervals while the remaining sites were visited periodically. A few samples were obtained from the sites after the creeks had stopped flowing and again when the creeks were flowing. Samples were collected and stored in Nalgene bottles.

Groundwater

One week prior to sampling the piezometers were bailed using flexible plastic tubing and a vaccuum pump. Water samples were collected from the intake zones of the piezometers using the same method.

Lake Water

The lake was systematically sampled during 1970 and 1971. Surface water samples were taken at two-week intervals during the open water season. A small number of samples were also taken from under the ice during March and April, 1971. The locations of the main sampling sites on Whitewater Lake are shown in Fig. 25, p. 161)

Interstitial Waters

Interstitial water samples were obtained from the bottom sediments collected in September, 1970. Two cores, B1 and C11 were split in minutes of recovery and an upper and lower sample were taken from the undisturbed interior of each core. The upper samples were taken 25 mm. below the top of the core while the lower samples were taken 25 mm. above the base of the core. Each sample was placed in a sediment squeezer similar in construction to the one described by Reeburgh (1967). Water samples were extracted under a Nitrogen gas pressure at 60 p.s.i. and stored in polyethelene bottles. The remaining cores were split in the laboratory within 24 hours of recovery and upper and lower samples were obtained and the interstitial waters were extracted. The samples were then stored in polyethylene (Nalgene) bottles.

Analytical Chemistry

Precipitation

Rain samples were analyzed for major cations and anions according to the procedures outlined in Appendix C, p. 291. A snow sample collected from the surface of Whitewater Lake in March, 1971 was analyzed also. The samples were not analyzed for HCO_3^- and Cl^- ions because their concentrations were too low to de determined accurately with the analytical procedures used. Chemical analyses of the precipitation samples are given in Table 18, p. 216. Intervals between dates shown represent periods of dry fallout accumulation. Electrolytic conductivity of each sample was determined (Appendix C, p. 291) and pH was obtained on a representative number of samples. These results are included in Table 18, p. 216. A summary of chemical analyses of precipitation samples is given in Table 19, p. 220.

Surface Water

Creek samples were analyzed for major-ion concentration using the procedures outlined in Appendix C, p. 291. Results of these analyses are shown in Table 21, p. 222. A summary of the chemical analyses of creek samples from selected sites is given in Table 22, p. 227.

Groundwater

In field measurements of pH at groundwater temperature near 5°C. were taken at the time of sampling. The pH of the groundwater was measured within 5 to 15 minutes after each sample was obtained. The samples were maintained at in situ temperatures employing a water and ice bath. pH measurements were made according to the procedures outlined in Appendix C, p. 291. Samples were stored in individual Nalgene bottles and analyzed for major-ion chemistry according to the procedures outlined in Appendix C, p. 291. Results of these analyses are shown in Table 24, p. 229.

Electrolytic conductivity measurements were made near the bottom of the piezometers and observation wells using an extended-cable conductivity cell connected to a Beckman battery operated conductivity bridge. These results are shown in Tables 27 and 28, pp 236 and 238.

Lake Water

Samples were analyzed for major-ion chemistry according to the procedures outlined in Appendix C, p. 291. Chemical analyses were also obtained from the Water Resources Branch, of samples collected by B. Ransom in 1970 and 1971. These analyses are reported in Tables 31 and 32, pp 243 and 245. pH (Appendix C) was determined for a number of samples and these values are also shown in the Tables. Additional pH values were taken of Whitewater Lake samples from selected sites at weekly intervals during 1971 (Table 33, p.249). Chemical analyses available prior to 1970 from Manitoba Soil Survey, 1968-69, and written comm. from Delorme, 1971 are reported in Table 30, p.242 .

Interstitial Waters

In field pH and Eh were determined on interstitial water samples immediately after extraction. All samples were later analyzed for major-ion chemistry according to the procedures in Appendix C, p.291 . These results are shown in Table 36, p. 252.

Stable Isotope Analysis

Natural stable oxygen ^{18} analyses were conducted on a number of precipitation, surface water, groundwater, lake water and interstitial water samples collected in 1970 and 1971. Groundwater samples from the Deloraine area (1970) were provided by R. Eilers of the Manitoba Soil Survey. A brief description of the stable isotope composition of natural waters is given in Appendix D, p. 294. Samples were prepared by P. Fritz at the University of Alberta and the University of Waterloo. The majority of samples were analyzed by P. Fritz while the remaining samples were analyzed by W. Buchanon at the Chemistry Department of the University of Manitoba.

APPENDIX B

DRILL LOGS 1971
WHITEWATER LAKE AREA

Date: July 1
logged by J, Cherry
Hole 1 - 75 feet
TP 3, R22, 15NE
southwest corner

0 - 12 feet	lacustrine silt, loamy clay, very fine sand, laminated, organic streaks, gypsum crystals abundant
12 - 20'	sand, silty, comes up mushy, no free water, olive 5Y, oxidized, calcareous
20 - 24'	clay, massive, dark grey 5Y, lacustrine, speckled with gypsum crystals
24 - 75'	till, dark gray, unoxidized, calcareous, clay loam, pulled at 40 feet, pebbly, calcareous and shale pebbles

piezometer shoved to 74 feet, caving at 15 - 20 feet, hole open below 20 feet, backfilled from 20 to ground

Samples:

70 - 75 feet;	till, 2.5YN3/2 very dark grayish brown, quartz, limestone pebbles mainly, some chert and shale pebbles, same at 37 to 40 feet
20 - 24 feet;	mainly clay, soft, silty, wet 5Y3/1 very dark grey, massive, no apparent laminations
7 - 10 feet;	sandy silty lacustrine, laminated 5Y6/3, 5Y6/4 pale olive and olive yellow 6/6, gastropod shells
4 - 5 feet;	lacustrine, silty, olive 5Y 5/4 laminated with white salts, calcareous

Date: July 1
logged by J. Cherry
Hole 2 - 60 feet
TP 3, R22, 11NE

0 - 2 feet	soil
2 - 7'	lacustrine, silt, clayey, silt and very fine sand, laminated, abundant gypsum crystals, olive 5Y oxidized
7 - 12'	sand, and sandy gravel, poorly sorted, several feet of this unit is probably quite permeable
12 - 20'	interbedded silty sand, till?, silty
20 - 24'	clay, dark grey, calcareous, massive, lacustrine
24 - 60'	till, calcareous, unoxidized, dark grey, pebbly etc. as hole no. 1, limestone and shale pebbles.

open hole, piezometer set, 5 gals. sand and ½ bag grout, hole caved before grout poured in, 58 feet

Date: July 2 logged by A. Kohut	Hole 3 - 70 feet	TP3, R22 7E 1 mi. west of Naples, ½ mi. north

0 - 2 feet	black soil
2 - 8'	lacustrine, laminated, oxidized silt and clay, white salts, becoming sandy at 6', stony to 8', dark grey
8 - 12'	sand, yellow buff, and clay, wet sticky, poorly sorted, appears laminated to 16'
12 - 65'	wet till, oxidized, yellowish, pebbly up to 1 inch diameter, iron stains, chert pebbles, shale, granitic, and limestone pebbles greater than 2 inches in diameter at 50 feet, more sandy also
62 - 68'	soft zone in till, sones, gravelly till
68 - 70'	end in till
	piezometer set to 53 feet
Samples:	9 feet; lacustrine, olive 5Y5/4, laminated, gypsum 3 feet; silty clay, 2.5Y3/2 very dark grayish brown, appears laminated, white salts

Date: July 2 logged by A. Kohut	Hole 4 - 80 feet	TP3,R21,20SE 1 mi. east of Whitewater town, 1 mi. north

0 - 2 feet	soil
2 - 6'	silt and clay, lacustrine, laminated dark and light, medium grey and yellow buff, no salts
6 - 17'	good sand, interbedded caly, laminated orange brown, lots of water at 12 feet, 12' organic material dark brown, sand and clay interbedded 15' good sand, light grey, olive, clay, fine to medium grained sand at 17', still laminated
17 - 44'	clay, medium dark grey, lacustrine, dense, massive
44 - 80'	stratified till? and shale conglomerate, no really good till, stones at 44', medium dark grey, unoxidized, coarse granule of limestone and chert, H_2S smell, at 60' mainly shale with minor granule
	piezomter set only to 20 feet, 3 feet above ground, no sand or cement emplaced, bad sloughing
Samples:	60 feet; conglomerate? silt and shale, crumbly, 5Y3/1 very dark grey, odd limestone granule 45 feet: as at 60', very fine-graied sand with shale pebbles angular, odd limestone granule

Hole 4 (cont.)

18 feet; clay, massive, soft, conchoidal fracture, shiney 5Y4/1
15 feet; clay, laminated, 2.5Yn4 dark grey to 2.5Y5/6 light olive brown
12 feet; rich organic spots, organic rich laminations, and very fine-grained sand, very dark brown 10YR2/2
6 feet; sand and silt, laminated, orange., buff, organic spots
3 feet; clay, lacustrine, massive, minor laminations, 2.5Y7/3 pale yellow and dark grey 2.5YN/4, leached calcareous soil zone

Hole 5 - 20 feet beside hole 4

piezometer set to 20 feet, 2.7 feet above ground, sand , cement emplaced, good hole

Date:July 2 Hole 6 - 60 feet TP3,R21,20SE
logged by A. Kohut 1 mi. east of hole 4

0 - 2 feet	soil
2 - 7'	lacustrine clay and silt
7 - 9'	coarse sand, wet sand, saturated, granule, pebbles, yellow, buff, orange
9 - 18'	silt, sand, clay, lacustrine, laminated, medium buff
18 - 19'	till, oxidized, pebbly, lake clay, massive, dark
19 - 35'	clay and till interbedded? [illegible], [illegible], [illegible]
35 - 60'	till , sandy, soft, calcareous, wet at 47' till, mainly shale composition, dark grey, unoxidized, dense, massive, minor pebbles, granules, stoney bands, small pebbles, coarse gravelly till 50 to 60' gravelly lenses? coarse gravel and clay, end at 60'

piezometer set to 23 feet, put in 1 pail of sand, no cement, caving badly

Samples:
59 feet; till, calcareous, soft, damp, granules of limestone, chert, clay matrix, pebbles up to ½ inch diameter, matrix 2.5YN3/0
20 feet; clay
18 feet; laminated lacustrine clay, grey and buff orange
9 - 10 feet; laminated lacustrine clay, orange and grey

Date:July 2
logged by A. Kohut

Hole 7 - 50 feet

TP3,R21,21NE
1 mile north of hole6

0 - 5 feet	lake clay, shells, silty, some grit, medium grey, smooth
5 - 9'	as above
9 - 10'	clay, yellow, sticky, oxidized, iron stains, appears laminated, wet, gypsum rosettes up to ½ inch diameter
10 - 15'	organic material, softer oarange layers, laminated, note gravel contamination here not observed as a unit but probably 1 to 2 feet thick around 13 foot depth
15 - 35'	gravelly till, oxidized, soft, granules, unoxidized at 18', sandy, breaks up easily, limestone pebbles, granitic and chert pebbles
35 - 50'	somewhat firmer till, stoney zone quite firm at 42 to 45'

piezometer set, emplaced sand and cement, very good hole, 53 feet

Samples:
40 feet; till, massive, good pebbles, ¼ to ½ inch chert, shale, limestone pebbles, wet, soft and sticky till
12 feet; lacustrine clay, massive, soft, organic, gypsum rosettes up to ½ inch, clay 2.5Y4/2 dark grey brown
7-9 feet; lacustrine laminated, pale olive 5Y6/4 ,5/3 to 2.5Y6/6, organic spots

Hole 8 - 30 feet

besdie hole 7

set piezometer to 22 feet, emplace sand and cement, excellent hole

Date:July 3
logged by A. Kohut

Hole 9 - 50 feet

TP3,R21,18E
south of gravel ridge
3/4 north of Whitewater
town

0 - 1 feet	black soil
1 - 3'	clay and silt, lacustrine, minor sand, transition to coarse sand, lacustrine is light buff with dark clay laminae
3 - 6'	coarse sand, yellow orange, wet, granules
6 - 10'	lacustrine silt and clay as 1 - 3', rotten smell like sewage from free water, at 8' coarse sand (no smell), interbedded lacustrine and sand, lots of water in hole
10 - 12'	sand and lacustrine interbedded, orange organic zone
12 - 13'	lake clay, dense dark grey, uniform, smooth, odd granule, limestone grains
13 - 27'	light greenish blue lake clay same texture as 12 - 13',

white shell material, actually laminated light grey and greenish blue grey laminae
at 22' interbanded? with tan coloured clay

27 - 32' change in drilling, lake clay, brownish grey with gypsum crystals, change from blue clay to underlying dark brown, fragments of brown clay in blue clay

32 - 45' definately stones (driller), till at 32' (driller) won't come up auger, pulling from 45 feet, dark grey till with limestone pebbles, end hole at 50 feet.

piezometer set, 2 pails of sand, cement, piezometer 3.8 feet above ground, 48.3 feet left out, only 13.7 feet length

Samples:
50 feet; good clayey till
29 feet; lake clay, massive, 2.5Y3/2 very dark grayish brown, conchoidal fracture, gypsum crystals to $\frac{1}{2}$ inch
22 feet; lacustrine clay, soft, massive, 2.5Y4/4 olive brown, conchoidal fracture
14 feet; laminated clay-silt, 2.5YN/6 gray, shell debris
13 feet; clay, bluish green, laminated, shells, minor organic plant material
7 feet; laminated 2.5Y4/2 and 2,5Y5/4 and 2.5YN3, organic material, shells and granules of limestone and chert
4 feet; sand, 2.5Y5/2 grayish brown, very coarse sand, some clay, quartz, limestone grains, very calcareous

Date: July 4 Hole 10 - 60 feet TP3,R22,11NW
logged by A. Kohut 1 mi. north, 2 mi. east of Naples

0 - 1 feet black soil

1 - 2' light medium grey lamianted silty clay, lacustrine

2 - 6' yellow buff lacustrine, laminated, more sandy than above

6 - 9' lacustrine silt - clay, organic material, medium grey

9 - 22' coarse sand, greenish grey and yellow orange (13-15'), granules, soft, wet, appears getting coarser, water in hole, 16' shale pebbles $\frac{1}{4}$ to 1 inch in diameter, gravelly zones, some silt-clay interbeds to 20'

22 - 29' silty caly, medium dark grey, gritty, dense, appears getting more clayey

29 - 35' good stiff lacustrine clay, dry shale composition, medium dark grey, fractures, something at 33 feet, lake clay, dark grey smooth, dense

35 - 60' till, good till at 44', probably begins at 35', soft, few stones at 35', limestone pebbles
39' good till, sandy, chert, limestone and granitic granules, calcareous

end hole at 60 feet, piezometer set to 41.3 feet, 2 pails of sand, cement, good hole, piezometer 3.3 feet above ground

Hole 10 (cont.)

Samples:	60 feet;	till as other stations
	39 feet;	clayey till
	32 feet;	stiff clay, massive, 5Y3/2 dark olive grey, soft, silty [illegible]
	23 feet;	silt, very fine-grained sand, clay, appears massive, wet, organic fragments, 2.5Y3/2 very dark greenish brown, rare black organic fragments
	18 feet;	clayey sand

Hole 11 - 30 feet

beside hole 10

cleaned hole once, set piezometer, samd, cement, good hole
piezometer total length 22.6', 3.3 feet above ground

Date: July 4
logged by A. Kohut

Hole 12 - 60 feet

TP3,R22,20NE
5 mi. east of Deloraine,
3 mi. north

0 - 2 feet	black soil on lake clay
2 - 4.5'	lake clay, bluish green, and sand interbeds, coarse-grained sand zones
4.5 - 10'	sand and clay interbeds probably 2 to 6 inches thick, orange yellow sand (granule size), white round elliptical concretions $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter at 8 - 10', clay is black to bluish grey, smooth, laminated probably with silt
10 - 17'	coarse-grained sand, buff to orange, gets finer to bottom
17 - 18'	lake clay, brownish buff, laminated
18 - 19'	transition zone clay and till
19 - 35'	good till, iron staining, gypsum crystals along fractures, dark grey to black, hard, pebbles up to 1 inch in diameter, limestone pebbles, till oxidized to 30 feet.
35 - 60'	till appears softer at 35', just below,more clayey till, sticks badly to auger

drilled to 60', piezometer set 3 feet from surface, badly sloughed hole, sand, cement put in, piezometer 17.7 feet

Hole 13 - 30 feet

beside hole 12

try to set into till, piezometer 35.6', put in 31.6', 2.7' above ground level, sand , cement, good hole

Date: July 4 logged by A. Kohut	Hole 14 - 60 feet	TP3,R22,34NE south of gravel ridge, northshore

0 - 1 feet	black soil on lacustrine silt-clay
1 - 2'	light-medium grey silt and clay lacustrine, laminated zone underlain by a couple of inches of gravel (yellow to orange granules)
2 - 4'	laminated gravelly lacustrine with till material incorporated
4 - 60'	good till, oxidized, buff to orange grey, shale pebbles, iron stains, limestone pebbles, calcareous, 6 inch rocky zone at 25', till getting firmer downwards, oxidized to 27', quite uniform, no soft zones

piezometer set 2.1 feet above ground, put in sand and cement, cement plugged 20' down, peizometer 62 feet

Hole 15 - 40 feet	beside hole 14 3 feet south

set piezometer 42.6 feet, 2.5' above ground, sand, cement, good hole

Hole 16 - 20 feet	beside hole 14

set piezometer, sand, cement, 2.4' above ground, 22.6 feet

Date: July 4 logged by A. Kohut	Hole 17 - 90 feet	TP3,R22,SW12 on Boissevain-Deloraine road,2mi. west of Whitewater

0 - 5 feet	till, oxidized, orange buff brown, iron stains, chert pebbles, calcareous, limestone pebbles, hard, no salts
5 - 16'	till as above
16 - 19'	coarse sand, orange-buff, damp
19 - 22'	finer sand
22 - 24'	sand with shale pebbles, uniform
28 - 30'	very damp sand, interbedded material (driller)
30 - 87'	sand, water, more shale pebbles at 50'
87 - 90'	tiny coal seams, clay zones, interbedded material

put in sand, cement, good hole

Samples:	87 feet; very fine-grained sand, coal fragments, 2.5YN/2 black, calcareous, note bedded coal fragments

Hole 17 (cont.)

60 feet; shale pebbles in sand, 2.5Y 3/2, calcareous
50 feet: shale pebbles in sand

Hole 18 - 45 feet   beside hole 17

piezometer set 42 feet, 2.7 feet above ground, sand, cement, good hole

Hole 19 - 25   beside hole 17

W .19 .18 .17 E

piezometer set 2.2' above ground, sand, cement, good hole

Date: July 5   Hole 20 - 60 feet   TP3, R22, 12NW
logged by A. Kohut   2 mi. west of Whitewater town

0 - 1 feet	black soil developed on lacustrine clay
1 - 3'	very coarse sand, gravel actually, well sorted, variety of pebbles, $\frac{1}{4}$ inch diameter, mainly chert and limestone
3 - 4'	dark grey till?, lacustrine mixed, some shells, clay and sand, white salts
4 - 5'	good lacustrine laminated clay-silt, crystal pockets (calcite?), buff and grey laminated
5 - 8'	clay, white concretions $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter at 6'
8 - 45'	till? buff-orange, pebbly clay, iron stains, pebbles to 1 inch diameter, soft until 12 feet, getting firmer, oxidized to 15 - 20 feet, at 30' good firm till, gypsum crystals along fractures, iron stains, not really unoxidized yet, coal fragments
45 - 60'	change in till, hard uniform, dark grey-black calcareous shale till, no stones, sticky shale fragments at 50', also limestone pebbles up to $\frac{1}{4}$ inch in diameter

21. N
20. ↑ piezometer set 4.8' above ground, sand, cement, good hole, 62 feet
22.

Samples: 50 feet; shale pebble gravel, dark 2.5YN/2 with odd limestone pebble, appears bedded
45 feet; shale gravel with silty matrix, shale is soft, waxy when wet, angular fragments

Hole 21 - 47 feet   besdie hole 20

good till to 40 feet, put in piezometer 42 feet, 2.4' above ground, sand, cement, good hole

Hole 22 - 20 feet beside hole 20

down to 20 feet, piezometer set 2.7' above ground, sand, cement, good hole

Date: July 5 Hole 23 - 50 feet TP3,R21,7NW
logged by A. Kohut at railway tracks just north of corner

0 - 0.5feet	black soil
0.5 - 4'	eolian , few tiny granules, sand and silt, uniform buff
4 - 50'	till, orange buff as at site 22, oxidized, dry at 5', at 19' coal fragments and red clay? at 25' pebbles of limestone, shale, granite up to 1 inch

no piezometer installed, filled hole

Sample: 50 feet; very fine-grained sand, shale gravel, oxidized olive brown 2.5Y4/4

Date: July 5 Hole 24 - 60 feet TP3,R21,18SW
logged by A. Kohut 1 mile west of Whitewater town

0 - 4 feet	dark black, loamy organic soil, probably on lacustrine
4 - 6'	lake clay, silt lacustrine laminated, carbonate specks, light buff, maybe eolian
6 - 60'	till, oxidized, organic buff as at site 23, unoxidized at 33 feet, at 10 - 12' appears interbedded with light grey lacustrine silt, rocky at 41 - 44 feet, pebbles, appears different at 47 - 49', no stones at 60 feet, more clayey, softer but still stones, iron stains along fractures (sample at 60')

no piezometer set, open hole

Date: July 5 Hole 25 - 60 feet TP3,R21,7W
logged by A. Kohut ½ mi. south of site 24

0 - 2 feet	black soil
2 - 3'	till, orange buff, pebbles, disentegrated granitic pebbles, white salts
3 - 4'	coarse sand, buff orange
4 - 9'	till as above
9 - 11'	very fine sand, buff
11 - 12'	till
12 - 14'	wet sticky clay, sand buff

Hole 25 (cont.)

14 - 47'	till as above, 30 - 45' wet till, still oxidized to 45'
47 - 54'	oxidized clay till? light buff, silty
54 - 57'	dark grey calcareous clay till, no stones
57 - 60'	sandy green, very fine-grained to fine-grained sand, Boissevain sandstone? or sand in Riding Mountain Fm. at 60' same sand, no pebbles, no shale fragments, greenish zones intermittent

piezometer set 4.7 feet above ground, sand cement, good, 62'

Samples:	58 feet; sand, fine to very fine-grained, non-calcareous, 5Y4/2 olive grey, well sorted, Boissevain S.S.?
	54 feet; oxidized clay conglomerate, 2.5Y3/2, ¼ inch clay fragments, soft, waxy
	50 feet; very fine-grained sand, oxidized, clayey, silty

Hole 26 - 30 feet

beside hole 25

piezometer set 2.6 feet above ground,
1 sand, cement, good, 27 feet

27. S
26. ↑
25.

Hole 27 - 18 feet

beside hole 26

piezometer set 2.1 feet above ground,
1 sand, cement, good, 16 feet

Date: July 6
logged by A. Kohut

Hole 28 - 80 feet

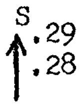
TP4,R21,8NE
north shore, 2 mi. east of oil wells, in ditch

0 - 1 feet	top soil (grey-black, sandy)
1 - 4'	coarse sand, buff, odd granules, well sorted generally
4 - 80'	till, oxodized, sandy, buff to orange-grey, salts, gypsum crystals along fractures, pebbles up to 2 inches, limestone, granitic, chert, unoxidized till to 18 - 20' (gypsum crystals at 20 feet), at 51 -52' stones, more clayey till, smoother matrix, not as sandy as till above at 80 feet, clayey till, dark grey, smooth matrix

piezometer set 2.1 feet above ground, sand , cement, good

Hole 29 - 25feet beside hole 28

pulled at 15', sand layer 6 inches thick in till with dark black organic layers, probably coal,
at 20 feet, getting unoxidized?
23' unoxidized till with sand pockets (clean well sorted, quartz, chert)
rusty layers, partings? or along fractures in till
possibly two tills here, at 25' unoxidized till



piezometer set 4.4 feet above ground, 27 feet

Date:July 6
logged by A. Kohut

Hole 30 - 90 feet

TP4,R21,SE9
northeast shore of lake, salts at surface

0 - 3 feet	light grey to light orange buff till? and lacustrine? appears lamianted
3 - 4'	till, orange buff, sand, thin sand zones, coarse sand
4 - 5.5'	orange-buff sand, wet, coarse-grained
5.5 - 24	till as above, oxidized to 16 - 17', some rusty fractures for 1' zone at change to unoxidized, gypsum crystals along fractures, rusty zones are along fractures
24 - 33'	well sorted coarse-grained sand, mainly quartz, granules of shale, well sorted in $\frac{1}{4}$ inch beds, Boiss. S.S.? or lacustrine sand
33 - 66'	till, dark grey, hard, clayey, smooth matrix, chert, limestone pebbles, another till?, shale pebbles,
66 - 86'	dark fine-grained to medium-grained sand, well sorted, black coaly looking, coal fragments?, shale fragments, very tiny granules of shale, Boissevain S.S.?, progressively getting harder, getting to contain larger shale fragments at 75 -80', getting finer grained also, laminated dark and light beds, dark appears to be coal, coal fragments up to $\frac{1}{4}$ inch, sample at 83'
86 - 90'	hard drilling, bedrock? till?, poorly sorted gravel?, very hard, compact, unsorted, dark grey-brown to greenish brown, lots of chert (brown, black) limestone, oxidized, carbonated, looks weathered, iron stains, streaked with carbonate, quartzite pebbles, pebbles are $\frac{1}{4}$ to $\frac{1}{2}$ inch, generally calcareous, weathered surface at 86', 1 inch of regolith, carbonated (sample)

piezometer set, cement, good, 2.6 feet above ground, 67.5 feet

Samples:	88 feet; till, light olive brown 2.5Y5/6 and grey 2.5YN6
	86 feet; i inch bedded crust, 2.5YN8, calcareous,

Hole 30 (cont.)

70 feet; sand, lacustrine, shells?, 2.5YN4 dark grey, fine-grained, coal fragments,
80 feet: micaceous, laminated, fossiliferous, bedded plant fragments, coal

Hole 31 - 40 feet

beside hole 30
3 feet east

no sand here at 24 feet, down to 40 feet only in till
piezometer 42.1 feet, 4.1 feet above ground, put in sand, cement, checked

Date: July 7
logged by A. Kohut

Hole 32 - 95 feet

TP3,R21,8NW
½ mi. south of Whitewater town

0 - 2 feet	black soil, organic matter
2 - 5'	light grey and buff zones, laminated lacustrine silt and clay, minor coarse sand pockets at 4'
5 - 11'	sand, orange-buff, coarse-grained, wet
11 - 37'	probably till, rocky till, orange-buff, sandy, oxidized, chert, limestone pebbles, unoxidized 15 - 20' at 33' more solid till
37 -38'	soft zone, dark grey smooth shale, slightly calcareous
38 - 51'	sandstone, greenish grey, very fine-grained, well sorted, slightly calcareous, Boissevain S.S.?, till also between 40 and 50 feet, medium grey, clayey matrix, chert, limestone pebbles, sandy pockets, probably interbedded till and Boiss. S.S., but is bedded, pebbles oreintated in plane of bedding, might be stratified till
51 - 55'	hard banded layers (driller), 6 to 8 inch bands of clay with limestone granules
55 - 71'	soft zone, shale gravel
71 - 95'	shale, Riding Mountain Fm.,? shale pebbles, well rounded, various sizes, well sorted locally up to 1 inch in diameter, some shale bedding, fissile, soft shale, dark grey, calcareous note till above 71 feet has shale fragments in clay matrix, may not be till, shale pebbles to 95', slightly more angular

piezometer set to 47 feet, 2.7 feet above ground, lots of water in hole

Samples: 85 feet; shale gravel, loose, platy, soft shale, 5Y3/1 very dark grey,

Hole 32 (cont.)

39 feet; fine-grained sand, 5Y4/2 olive grey, odd limestone granule, calcareous

Date: July 7
logged by A. Kohut

Hole 33 - 65 feet

TP 4,R21,SW1
4½ mi. west of Schaffner,
east end of Whitewater Lake

0 - 1 feet	soil on lacustrine clay
1 - 5'	lacustrine clay-silt, gypsum crystals, shells
5 - 6'	coarse-grained sand amd clay lenses, iron stain, orange - grey
6 - 45'	till, orange-buff, iron stain at 8', sandy, red clay alteration, oxidized,unoxidized at 20 -25', gypsum crystals unoxidized till is dark grey, smoother texture, clayey, few pebbles, soft, sticky at 32' silty till, smooth texture, more shale pebbles appearing with depth
45 - 65'	transition from overlying till to pebbly shale with minor limestone and pink sandstone granule, slightly calcareous, shale fragments up to 1 inch

set piezometer at 32 feet, 2.4 feet above ground, sand, cement

Date: July 7
logged by A. Kohut

Hole 34 - 65 feet

TP3,R20,30NE
4 mi. west, 1 mi. north of
Boissevain

0 - 2 feet	black soil on lacustrine clay
2 - 4'	laminated black and buff grey silty clay, lacustrine, calcareous
4 - 5'	lacustrine as above, buff-orange, more sandy, laminated orange-buff and grey, calcareous
6 - 12'	smooth, orange clay (silt) no laminations, becomes tan silt at 9', gypsum crystals, organic spots?, clacareous
12 - 13'	clay, medium grey, smooth, lacustrine probably, gypsum rosette ½ inch in dicameter, calcareous
13 - 27'	till, dark grey, unoxidized, sandy, limestone, chert and quartz pebbles
27 - 43'	till, smooth clay till, shale, limestone pebbles, calcareous at 37' shale pebbles more prominent up to 1 inch at 43' stones (driller) than softer next 6 feet at 40 feet shale fragments in shale, soft material, sticky when wet, shale probably coming in at 43'

Hole 34 (cont.)

43 - 65'	at 45' shale gravel, as at stations 33 and 32, rounded shale fragments up to ½ inch at 50' more till like material, possibly till on Riding Mountain shale; some Riding Mountain material incorportated?, stones at 58', between 50 and 55' shale with whitish-green soft material (bentonite), softer zones, crumbly, limestone pebbles occasionally, dry shale at 61 -62', looks like good bedrock, Riding Mountain Fm.?

piezometer set, 32', 2.6 feet above ground, put in sand and cement

Date: July 7 Hole 35 - 65' TP3,R20,19NE
logged by A. Kohut 1 mi. and 1/3 south of hole 34

0 - 0.5 feet	black soil
0.5 - 4'	sand, silt, orange-buff, fine-grained sand, silt
4 - 5'	laminated lacustrine clay, dark brown-black, organic, gypsum crystals
5 - 5.5'	light grey, soft clay, carbonate accumulation zone, smooth, silty, gypsum rosettes
5.5 - 12'	very fine-grained sand, buff, orange grey, gypsum crystals, stones at 12 feet
12 - 38'	till, orange-buff, pebbles up to ½ inch, limestone, chert, at 16' unoxidized till
38 - 45'	interbedded till and shale? or contact zone, till and shale, shale as wispy structures, ½ inch beds of shale alternating with till
45 - 65'	good bedrock? shale, pebbles of limestone and granules , well rounded, probably Riding Mountain shale, gypsum rosettes in shale at 50', shale gravel, marcasite concretion, white spots, still in gravel zone, at 56' shale pebbles, poorly sorted, fissile, good lithic fragments up to 2 inches

no piezometer installed

Date: July 8 Hole 36 - 95 feet TP4,R21,9NE
logged by A. Kohut north shore of lake in ditch

0 - 7 feet	sand, fine to medium-grained at surface, coarser near 4', few pebbles and granules throughout, wet, orange buff to grey, limestone pebbles, chert
7 - 80'	till, buff-orange, oxidized to 16 feet, then a dark grey till, rusty fractures at 16', two tills? or just unoxidized till as above

Hole 36 (cont.)

appears more shaley below, shale pebbles, limestone and chert in lower till, evevly peppered with small pebbles up to $\frac{1}{2}$ inch diameter, matrix is very fine-grained sand and clay
at 28 tO 39' quite sandy matrix
at 35 to 40' not as many stones (driller), very dry hole, mud is only damp, at 48 50 50' less stones, smooth textured till, granules and odd larger pebble up to $\frac{1}{2}$ inch, no stones at 53' (driller)

80 - 85'	shale gravel; pebbles with no matrix, well sorted generally, some limestone pebbles, brown oxidized pebbles but black shale under coatings, minor unoxidized till also
85 - 90'	interbedded shale and oxidized till? shale is unoxidized and till oxidized, gypsum crystals present
90 -95'	oxidized sandy shaly gravel? or till? pebbles of chert, limestone, somewhat well sorted, appears bedded

no piezometer installed, filled hole

Date: July 8
logged by A. Kohut

Hole 37 - 95 feet

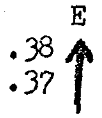
TP4,R22,SE1
on gravel ridge, beside trail
on "island"

0 - 6 feet	sand, very coarse-grained, granule, few large pebbles, angular fragments, quartz, chert, limestone, damp, brownish grey (wet)
6 - 7'	lacustrine clay-silt with minor sand, light grey, laminated, calcareous, salts
7 - 8'	light grey lacustrine silt-clay, salts, laminated orange buff and grey, white concretions up to $\frac{1}{2}$ inch
8 - 10'	mainly orange silt with minor grey, laminations, plastic, dense, organic material
10 - 58'	till, orange buff, chert. limestone pebbles up to $\frac{1}{4}$ inch, oxidized to 16-17', lots of gypsum crystals along fractures, gypsum rosettes up to 2 inches in diameter at 25 to 40', at 30' till is dark grey, spft, shale composition, smooth texture with minor limestone granules, shale granules, at 25' large granitic and limestone pebbles up to $2\frac{1}{2}$ inches, appear wind faceted, hole is quite dry at 40', at 50' till as above with tiny marcasite concretions ($\frac{1}{4}$ inch), at 55' minor sand in till?
58 - 72'	shale gravel, wet, mushy, soft shale and fine-grained sand, interbedded shale and sand in $\frac{1}{2}$ - 1 inch bands
72 - 77'	till? possibly stones in above material
77 - 95'	change in drilling, sand, very fine-grained, wet, greenish grey, compact, Boissevain S.S.?

put in piezometer, sand cement, very good hole, piezometer 3' above ground, piezometer 94 feet

Hole 38 - 75 feet

beside hole 37



58 - 64'	stones again as in hole 37, saturated zone, water in hole here
64 - 75'	sand and shale interbeds, dark grey sand, black soft shale

piezometer set, sand, cement, good, piezometer 1.5' above ground, 77.3 feet

Date: July 8
logged by A. Kohut

Hole 39 - 40 feet

TP3,R22,SW12
just downhill (north) 1/3 mile from hole17

0 - 3 feet	black soil
3 - 4'	lacustrine clay, buff and laminated, calcareous, odd limestone pebble
4 - 6'	sandy lacustrine, laminated, buff, gypsum crystals
6 - 25'	till, good stones (6-7'), orange buff, chert, limestone and altered biotite, oxidized to 18', unoxidized at 20', appears to be more shale pebbles at 25', at 25' smooth, sandy fine-grained matrix in till, dark grey
25 - 30'	shale gravel, shale pebbles up to 1inch, no matrix, prob. Boissevain S.S., or Turtle Mountain Fm?
30 - 35'	interbedded shale pebbles up to 1 inch and hard shale beds with odd limestone pebbles
35 - 40'	shale gravel (conglomerate)

piezometer set 4' above ground, 42 feet , sand, cement, good hole

Date: July 8
logged by A. Kohut

Hole 40 - 82 feet

TP3,R22,SW12
uphill south of hole 39, 1/5 mile from north (E-W) road to south

0 - 1 feet	black soil
1 - 5'	loess? with pebbles, very fine-grained, light buff, appears wind blown material? leached
5 - 8'	lacustrine silt-clay?
8 - 9'	sand, dark buff-orange, medium-grained
9 - 12'	till, orange-buff, oxidized same as hole 39
12 - 26'	sand, coarse-grained, buff, appears well sorted, wet at 18'

Hole 40 (cont.)

26 - 73'	hard layers (driller) at 26' and 29', fine-grained grey sand, (samples), change at 30'(driller) to harder material, sand, at 43' tough (driller) interbedded sand and clay, very fine-grained sand, laminated dark and light grey, stones at 57', hard layer at 73 - 75', shale pebbles at 70' in very coarse sand
73 - 82'	very hard material, extremely difficult to drill, slow drilling, very coarse-grained sand, at 81' calcareous weathered zone, top of Riding Mountain?, or very hard conglomerate-sandstone in Boissevain Fm?, altered, white alteration products, laminated, coal fragments, cross laminations, soild Boissevain Sandstone at 81 feet?

piezometer set 3' above ground, 52 feet, cemented,

Hole 41 - 35 feet

TP3,R22,SW12
just south of hole 40,
same location

0 - 15 feet	as hole 40
15 - 20'	silt-clay pebbles in sand (sample)
20 - 35'	as hole 40, water coming in at 25 feet, at 26' hard compact sand, very fine-grained (2' to 18 inch beds), brownish appearance, oxidized Boissevain Sandstone or layer in Turtle Mountain Formation? at 28' very fine-grained dark greenish grey sandstone, Boissevain Fm.? at 30' coal rich bed, fragments of coal, shale pebbles

put in piezometer, cement, good hole, 2.6 feet above ground, piezometer 32 feet

MANITOBA SOIL SURVEY
OBSERVATION WELLS

(Whitewater Lake)

Date: Aug.14/68	Well 17	TP2, R23,SW19,W1
0 - 1 feet	loam	
1 -2'	clay loam - clay	
2 -3'	clay	
3 -4'	clay	
4 -6'	silt clay loam	
6 -8'	clay loam and sand, wet	
8 -10'	clay loam and sand	

Date: Aug.14/68	Well 18	TP2,R23,SE34,W1
0 - 1 feet	loam	
1 - 2'	clay	
2 - 3'	clay	
3 - 4'	clay loam	
4 - 5'	silt clay loam	
5 - 7'	silt loam, wet	
7 - 9'	silt loam , wet	
9 - 10'	silt clay, wet	

Date: Aug.14/68	Well 19	TP3,R23,SC11,W1
0 - 1 feet	loam	
1 - 2'	heavy clay and loam	
2 - 3'	heavy clay and loam	
3 - 4'	clay and sand	
4 - 5'	clay and sand	
5 - 6'	clay loam	
6 - 7'	clay	
7 - 9'	sand clay and sand loam	
9 - 10'	no sample, wet	

Date: Aug.14/68	Well 20	TP3,R22,WC7,W1
0 - 1 feet	clay	
1 - 2'	very fine sand loam	
2 - 3'	light fine sand	
3 - 4'	clay loam and sand, gravel	
4 - 5'	clay loam, coarse sand lumuc	
5 - 7'	clay, till	
7 - 9'	clay, till	
9 - 10'	clay, till	

Date: Aug.14/68 Well 21 TP3,R22,NE29,W1

0 - 1feet	loam
1 - 2'	clay
2 - 3'	silt clay loam and sand
3 - 4'	clay loam
4 - 6'	clay, till
6 - 8'	clay,till
8 - 10'	clay , till

Date: Aug.14/68 Well 22 TP3,R22,WC8,W1

0 - 1 feet	light fine sand
1 - 2'	heavy clay
2 - 3'	heavy clay
3 - 4'	fine sand and silt clay
4 - 5'	silt clay loam
5 - 7'	clay loam, till
7 - 9'	clay,till
9 - 10'	clay, no sample , till

Date: Aug. 14/68 Well 24 TP3,R22,SW9,W1

0 - 1 feet	clay loam
1 - 2'	silt clay loam and clay
2 - 3'	heavy clay
3 - 4'	clay
4 - 5'	clay
5 - 6'	clay loam
6 - 9'	sand, silt loam and silt clay loam , wet
9 - 10'	clay, till

Date:Aug.14/68 Well 25 TP3,R21,SE20,W1

0 - 1 feet	loam
1 - 2'	loam
2 - 3'	loam
4 - 5'	very fine clay loam
5 - 7'	very fine clay loam
7 - 9'	fine sand and sand clay loam
9 - 10'	clay loam and sand, silt clay loam, wet

APPENDIX C

Chemical Analysis of Water Samples

Major-ions

Major cations; Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were determined on a Perkin-Elmer 303 atomic absorption spectrophotometer according to the procedures of Fishman and Downs (1966). HCO_3^{-} and CO_3^{2-} anions were determined by potentiomertic titration according to the procedures of Barnes (1964) for samples exhibiting a pH less than 8.2 and according to Rainwater and Thatcher (1960) for samples exhibiting a pH greater than 8.2. Cl^{-} was determined by the titration method with $AgNO_3$ according to Rainwater and Thatcher (1960). SO_4^{2-} was determined according to the turbidometric procedure with a Hach field chemical kit. The accuracy of SO_4^{2-} values determined was within 20 percent. Accuracy of the other determinations is discussed by the authors mentioned above.

Total Dissolved Solids

Total dissolved solids were calculated as the sum of the major-ions analyzed.

Electrolytic Conductivity

Electrolytic conductivity of water samples in the field was measured with a temperature controlled portable Beckman conductivity meter. Laboratory measurements were taken at room temperatures between 22 and 25 25°C. with a Barnstead conductivity meter.

pH

pH was measured in the field and laboratory with a battery operated temperature controlled, null balance, Radiometer type PHM4 portable pH meter and combination glass electrodes standardized with two buffers (7 and 4) in the manner outlined by Barnes (1964).

Eh

Eh was measured in the field with a temperature controlled, null balance, Radiometer type PHM4 portable meter and a platinum Eh electrode. The Eh electrode was first cleaned in concentrated HCl for a few minutes and the potential difference between the Eh electrode and a standard calomel was recorded over a period of 30 minutes at one minute intervals. Eh values were reported as the potential difference between the Eh electrode and the standard calomel electrode plus the calomel electrode against the standard hydrogen electrode.

APPENDIX D

Stable Isotope Composition of Natural Waters

The main source of atmospheric water vapor comes from the oceans which have an almost constant isotope concentration of 997,680:2,000:320 ppm. for $H_2{}^{16}O$, $H_2{}^{18}O$ and HDO respectively (Dincer, 1968). Ocean waters are isotopically heavy, enriched in the heavier isotopes HD and O^{18}, and fall in a narrow range of 1 percent and 0.1 percent for deuterium and O^{18} respectively (Degens and Chilingar, 1967). The HD/H1 ratio of natural waters is usually expressed in terms of the percent difference beteeen a sample and a standard (Friedman, 1953). Oxygen results are generally given as the per mil percent difference in the O^{18}/O^{16} ratio of a sample from the ratio in a standard CO_2 sample obtained from belemnites of the Peedee Formation of North Caroline (Epstein and Mayeda, 1953). This deviation may be written:

$$\delta = \frac{O^{18}/O^{16}\text{sample}}{O^{18}/O^{16}\text{standard}} - 1 \cdot 1000$$

Standard mean ocean water (SMOW) may also be used as the standard where the relationship between $\delta\ {}^{18}{}_{\text{PDBI}}$ and $\delta O^{18}{}_{\text{SMOW}}$ is:

$$\delta O^{18}{}_{\text{SMOW}} = \delta O^{18}{}_{\text{PDBI}} \cdot 1.03 + 29.5 \qquad \text{(Craig, 1957).}$$

Values of $\delta O^{18}{}_{\text{SMOW}}$ are in the order of -0.04 and a value of 0.00 is chosen for convenience (Epstein and Mayeda, 1953). Hence values less than ocean water are negative or enriched in the lighter isotope O^{16} as in rain and snow while positive values indicate enrichment in the heavier isotope O^{18} as found in highly saline evaporating water bodies.