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

A Thesis
Presented to
The Faculty of Graduate Studies and Research
The University of Manitoba

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
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October 1972

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.

ACKNOWLEDGEMENTS

I wish to thank J.A. Cherry and W.C. Brisbin who supervised the thesis. R.W. Newbury provided helpful comments and suggestions. P. Fritz of the University of Waterloo provided the isotope data and related comments. Field work was aided by N. Brandson, D. Kushnir, V. Semochuk, G. McCullough, R. Eilers and Mr. Wm. Kohut. Drilling was done by C. Pierson of Kelowna, British Columbia. Special thanks are extended to Mrs. H. Baskerville and Mrs. Busman who monitored the meteorological stations. A. Bates and L. Homeniuk aided with the computer programming. The cooperation and laboratory assistance of R. Hill was greatly appreciated. J.M. Walker-Shay of the University of Manitoba, Botany Department provided loan of a Livingstone sampler and identified some plant material in the bottom sediment. G. Brunskill of Fisheries Research Board, Freshwater Institute provided loan of some analytical equipment. The writer is indebted to B.Ransom, coordinator of the Whitewater Lake Resources Planning Project who provided valuable assistance and data. R. Eilers of the Manitoba Soil Survey provided unpublished data and discussed at length many aspects of the Whitewater Lake area. V. Kohut typed the final manuscript and provided many helpful suggestions. Unpublished data were also supplied by; Water Survey of Canada, Manitoba Water Resources Branch, P.F.R.A., Atmospheric Environment Service and D. Delorme.

Financial support for the study was provided by an Agassiz Centre grant awarded to W.C. Brisbin and R.W. Newbury and National Research Council grants awarded to J.A. Cherry. A portion of the drilling expenses was funded by the Manitoba Water Resources Branch.

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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