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HYDROGEOLOGY OF THE WABAMUN LAKE AREA, ALBERTA

by

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OF THE WABAMUN LAKE AREA,

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Abstract

The hydrogeological map of the uppermost 1 000 feet (about 300 m) of strata in the Wabamun Lake area is described. The maps and profiles were constructed from existing data and from data collected by a field survey and drilling operations. Good aquifers are not deeper than 500 feet (about 150 m). The 20-year safe yields range from less than 1 igpm (about 5 l/min) to more than 500 igpm (about 2 250 l/min). The best aquifers are Paskapoo sandstones and Quaternary sands and gravels.

Water quality is good. The total dissolved solids are usually less than 1 000 ppm. The chemical character of the water is Ca+Mg/HCO_3 or Na/HCO_3. Undesirably high SO_4, Cl or Fe contents were found only at isolated locations.

INTRODUCTION

The Wabamun Lake map area (NTS 83G) is located between longitudes 114° and 116° west and latitudes 53° and 54° north. In terms of the Alberta Land Survey system, the map area lies in townships 46 to 58, ranges 1 to 14, west of the fifth meridian. It covers about 5 610 square miles (14 530 km^2).

During the winter of 1968-69 an atlas of 1:50 000 scale Hydrogeological Information Maps was prepared covering the entire map area. It included all hydrogeological data available in the Research Council of Alberta files and in the published literature. A field survey, including helicopter flights and drilling operations, was carried out in 1969. The maps and profiles were constructed in the winter of 1969-70.

Farvolden (1961) conducted a hydrogeological survey concerned with groundwater usage in water-flood operations associated with the Pembina oilfield. The Pembina field is located in the southwest corner of the map area. Extensive hydrochemical studies, which included the Wabamun Lake area, were completed by Le Breton and Jones (1962), Hitchon (1964) and van Everdingen (1968). Some data regarding surface waters were published by Thomas (1956, 1957).

Despite the fact that three paved roads and a number of railway lines cross the area, large regions can only be reached on foot or by helicopter. The eastern half of the map area is populated and is mostly farmland, with a number of settlements and an abundance of wells. The western half is settled only along the highways and in isolated patches and is otherwise covered by forests and muskeg. However, activities connected with the oil industry provide local hydrogeological data. In the Pembina oilfield a number of groundwater wells produce for injection purposes and, in consequence, this is the hydrogeologically best known part of the map area. There are large, unpopulated regions where only spring data, collected mostly by helicopter surveys, are available.

The largest settlements and their populations are Drayton Valley (3326), Stony Plain (1 464) on the eastern border of the map area, and Mayerthorpe (968). Stony Plain uses surface water and the other two use groundwater (Alberta Dept. Health, 1968). There are also popular beaches, such as Seba, Alberta and Edmonton.

The original vegetation, except for the sphagnum muskegs, is aspen poplar and mixed aspen-spruce, both white and black, with lodgepole pine and white spruce on the higher ground. However, more than half the area is now farmland (Atlas of Alberta, 1969).

Acknowledgments

Field operations were financed jointly by the provincial and federal governments through the Agricultural and Rural Development Act (ARDA).

The Water Resources Division, then Alberta Department of Agriculture, contributed by drilling and E-logging three holes near three Research Council of Alberta hydrogeological test sites and by providing unpublished data. A grateful acknowledgment is due personally to G. L. Nielsen, M. Magas, and G. Miller for cooperation in the field.

Structure test hole information or chemical data or both were received from the Energy Resources Conservation Board (formerly Oil and Gas Conservation Board), Sun Oil Co., Great Plains Development Co., the Whitewood Lake and Highvale Coal Mines and the Wabamun and Sundance Power Plants. A number of persons from various oil companies and forestry offices and some farmers and drillers were personally helpful in the investigations.

Test drilling was conscientiously carried out by Kinsella Drilling of Innisfail. Field assistance was provided by N. Zacharko and, at pump tests, by D. Withers. Assistance in data-plotting was provided by A. T. Lytviak.

Most of the chemical analyses on file at the Research Council of Alberta were carried out by the Provincial Analyst. The samples collected during field work were analyzed (including some trace-element analyses) by I. E. Davidson in the laboratory of the Research Council of Alberta.

The manuscript was critically read by R. Bibby, D. V. Currie, R. Green and O. Tokarsky. The author gratefully acknowledges the help given by them and also by his other colleagues, A. Badry, L. A. Bayrock, and V. A. Carlson. He also thanks R. J. Clouston for the precise draftsmanship of the maps.

TOPOGRAPHY AND DRAINAGE

The map area lies on the western edge of the interior plains and includes parts of both the Eastern and Western Alberta plains physiographic regions. Some parts of the latter exhibit foothills topography. The highest elevation of a little more than 4 050 feet (1 235 m) above mean sea level is in the southwest corner of the map area. The lowest elevations are in the northeast and east, where the Pembina and North Saskatchewan Rivers leave the area. Along the Pembina River the lowest elevation is less than 2 100 feet (640 m) and along the North Saskatchewan River less than 2 150 feet (655 m).

Topography and morphology are varied. There are hill-ranges, a rolling landscape, benchlands, river terraces, hummocky moraines ("knob and kettle" or "pitted" morphology) and numerous lakes, sloughs and muskegs. A zone of Recent uplift traverses the area (Ozoray, 1970a) so that except in the southwest and northeast corners, the rivers run in antecedent courses, with deeply cut meanders. The tributaries have unbalanced longitudinal profiles with oversteepened reaches near their junctions. Tilted glacial lacustrine deposits near Edmonton also give evidence of uplift (Bayrock, in press). The hydrographic network was originally controlled by NW-SE, NE-SW, N-S, and E-W structural directions. The Wisconsin ice sheet overrode the area and partly obscured the structural pattern. During the postglacial period the drainage system tended to recover its structural (fundamentally tectonic) orientation. The result is a complicated patchwork of occupied, abandoned, partly or wholly buried valleys, captures and valley segments. There is an abundance of glacial forms and dunes are also known.

The subcontinental divide between the Arctic Ocean and the Hudson Bay drainage runs through the area. The McLeod and Pembina Rivers are tributaries of the Athabasca River, belonging to the Mackenzie River-Arctic Ocean system. The North Saskatchewan River and its tributaries — the Sturgeon River, which has its source within this area, and the Battle River, which extends only by watershed into the map area — belong to the Nelson River-Hudson Bay system.

There are large lakes of complex tectonic and glacial genesis (Chip, Isle, Wabamun, Pigeon Lakes and Lac Ste. Anne) and innumerable small glacial lakes.

CLIMATE

The greater part of the area is in the "short, cool summer" Koeppen zone. Just the eastern fringe is in the "long, cool summer" zone (Longley, 1968).

The mean temperature in January is about 4° F (-15.6° C) in the northeast and about 9° F (-12.8° C) in the southwest. The mean temperature in July is about 60°F (15.6°C) throughout the area. The mean annual temperature at Thorsby is 36.2°F (2.3°C) (Longley, 1968).

Isohyets, modified from Longley (1968) are shown on the meteorological map. The mean annual precipitation at Thorsby is 17.93 inches (455 mm) and is practically the same at Sion. The annual potential evapotranspiration, estimated from maps of Bruce and Weisman (1967), is about 28 inches (711 mm) at Thorsby and 25 inches (635 mm) at Sion. At both places potential evaporation exceeds precipitation from May to October, inclusive.

GEOLOGY

Some data on the geology and hydrography of the area were provided by explorer-geologists in the last century (Selwyn, 1874; Tyrrell, 1886). The bedrock geology of the area was studied by Rutherford (1928). In parts, where other data were not available, the geological map of Alberta (Geol. Surv. Can., 1951) was used. Formations deeper than 1 000 feet (approximately 300 m) and the literature on them were not considered. The surface geology was described by Collins and Swan (1955), Taylor (1958), and the glacial maps of Canada (Geol. Assoc. Can., 1958; Prest, Grant and Rampton, 1968). A map of surficial materials, covering the east half of the map area, was available (Lindsay et al., 1968).

The near-surface bedrock in the eastern part of the area is the Upper Cretaceous Edmonton Group (Irish, 1970), consisting of grey shales and often bentonitic sandstones and coal seams. In the western part of the area the Edmonton Group is overlain by the Cretaceous-Tertiary Paskapoo Formation. This consists of sandstone (often soft and usually referred to in drillers' logs as sand), shale and coal. The Kneehills Zone was used by Green (1969) as a marker bed for contouring the surface of the Edmonton Group.

Both the Edmonton Group and the Paskapoo Formation outcrop at several places. A great number of wells also reach them through the drift cover which was rarely more than 50 feet (about 15 m) thick, except in places such as valley sections and along the eastern edge of the area.

Till covers a very large area but only a relatively small number of wells obtain water from it. Deposits of outwash sand and gravel, pitted deltaic silt, sand and gravel and lacustrine clay, silt and sand are widespread, especially in the eastern half of the area. Some gravels and sands are situated beneath till. They are pre-Wisconsin in age (which, for this area, means preglacial), and can be a major source of groundwater. Sand and gravel pockets also occur within till. A number of abandoned or buried valleys are detectable.

The postglacial deposits are alluvium, recent lacustrine mud and sand, windblown sand (at Peers), organic deposits and peat.

HYDROGEOLOGY

Data Used in Map Preparation

Water well drillers' reports giving well location and data on well depth, depth of water level below the surface and vague lithological descriptions were available for more than 1 000 wells. Acceptable yield observations, bail tests, pump tests and computed or computable transmissivity and 20-year safe yield values were rare. It was therefore necessary to use apparent values for the transmissivity and 20-year safe yield.

Groundwater Levels

On the hydrogeological map, contours of groundwater levels (the elevation to which water would rise in a piezometer installed at the well depth being considered) above mean sea level are drawn. Water levels for wells producing from the most commonly used aquifer constituted the basis for contouring. For instance, the water levels contoured near Magnolia were from shallow wells in the buried valley gravel, and at the Pembina oilfield from wells approximately 300 feet

(100 m) deep in the soft sandstone layers of the Paskapoo Formation. In the hilly portions much extrapolation was applied.

Aquifer Lithology

"Sandstone and shale" is shown on the map as the lithology of the main aquifer for the area underlain by the Edmonton Group, where a great number of wells actually yield water from fractured shales. The same is shown for a part of the area underlain by the Paskapoo Formation. The rest of this formation is shown as "sand and sandstone". Here soft and friable sandstones, which are usually reported as sand, are abundant and are connected with a cover of loose sand, which is possibly a weathering residuum of friable sandstones. Coal seams, which are sometimes locally good aquifers, are not shown separately.

"Sand and gravel" lithology characterizes the buried valleys, outwash deposits and alluvial strips. The pitted deltaic deposits are mostly silt, sand and gravel.

Transmissivity and Apparent Transmissivity

Jacob's modified non-equilibrium formula for the calculation of transmissivity based on a pump test is:

$$T = \frac{264\,Q}{\Delta s}$$

where: T = transmissivity in imperial gallons/day/ft (igpd/ft),
Q = pumping rate in imperial gallons/min (igpm),
Δs = drawdown in ft/log cycle of minutes.

Usually these data were not available. In some instances, however, the length and rate of bailing or pumping and the total drawdown were given. These data are often observed during the development of the well, and in the absence of any better data (which was the situation for the Wabamun Lake map area), an apparent transmissivity can be calculated from them (Farvolden, 1961; Ozoray, 1970b). Experience shows that apparent transmissivity values can give a statistically acceptable picture of regional transmissivity variation.

Twenty-year Safe Yield

The 20-year safe yield of a well is calculable by using the formula:

$$Q_{20} = \frac{TH}{2110}$$

where: Q_{20} = 20-year safe yield in igpm; it is defined as the constant rate at which the well can be continuously pumped so that at the end of 20 years the water level will be drawn down to the top of the producing aquifer;

T = transmissivity in igpd/ft;

H = total available drawdown in feet, which is the depth from the static water level to the top of the producing aquifer.

Where apparent transmissivity is used in this formula, the result is naturally an apparent 20-year safe yield. All except 12 of the 631 safe-yield calculations for the map area were apparent values.

Yield Areas

The average available 20-year safe yield from the upper 1 000 feet of strata (about 300 m) is shown on the hydrogeological map by colored areas. There were certain difficulties involved in defining these areas. These resulted from the following deficiencies of the available data:

(a) mostly apparent Q_{20} values were available,

(b) the data were usually only for the shallowest aquifer satisfying the local water demand,

(c) depending on different drilling and well developing techniques and on individual testing habits, data differed, even for the same locality and aquifer.

To overcome these shortcomings, the more accurate measurements were given greater consideration, extrapolation based on geological conditions was used, and test holes were drilled to representative depths and tested with adequate care.

It was very instructive to find that the yield values of areas which were checked by test holes were found generally to have been underestimated. This was to be expected, however, partly because of the use of shallow-well data and primitive technology and partly because apparent transmissivity values are usually smaller than the real values. Only at one test hole site was the yield determined from available data found to be correct. This was at Cynthia (Lsd. 1, Sec. 28, Tp. 49, R. 10, W. 5th Mer.) in the Pembina Oilfield, where the wells, producing for injection purposes, were drilled by better technology, planned for higher yield and tested for a longer time and with greater care than is usual for farm wells.

In a number of areas there is a scarcity or an absence of wells. In these areas, yields were estimated by extrapolation and by evaluation of geology and topography. They are shown on the map by lighter shades to indicate that they are only estimates.

The distribution of the yield zones on the map sheet is:

(a) over 500 igpm (approximately 2 250 l/min) for a part of the Pembina Oilfield; the aquifers are friable, soft sandstones of the Paskapoo Formation, overlain by loose sand cover, which is probably a weathering residuum of the sandstone;

(b) 100-500 igpm (approximately 450-2 250 l/min) for the parts of the Paskapoo Formation in which sandstones are abundant in thick layers, more porous, often soft and friable and often referred to as sand; also for Quaternary sands and gravels, including preglacial, glacial and postglacial-recent deposits, such as the buried valley at Magnolia, and meltwater channels and alluvium;

(c) 25-100 igpm (approximately 100-450 l/min) for typical Paskapoo Formation, for the parts of the Edmonton Group with well developed sandstones, and for a part of deltaic and glacial lacustrine deposits;

(d) 5-25 igpm (approximately 25-100 l/min) for those parts of the Paskapoo Formation and Edmonton Group which are predominantly shale: the aquifers are thin sandstone layers or fractured shale; also for deltaic and lacustrine deposits in which silt is predominant;

(e) 1-5 igpm (approximately 5-25 l/min) for unfractured shales, clays and till;

(f) less than 1 igpm (approximately 5 l/min) for clayey and bentonitic lithology.

It appears that in the zones of concentrated discharge, such as the valley bottoms, the bedrock porosity is higher than at other places. For instance, the MacKay test hole (Lsd. 7, Sec. 17, Tp. 54,

R. 11, W. 5th Mer.) does not penetrate terrace materials, but the transmissivity of the Paskapoo sandstone is comparable with that of the gravels. There are two possible explanations, which are not mutually exclusive. The first is that the valleys are tectonically controlled (Ozoray, 1970a) and the sandstones are fractured. The second is that, as Tóth supposes (verbal communication), the intensive groundwater flow maintains the porosity and even increases it; this would be more likely due to a chemical effect (Ozoray, 1964) than a mechanical one.

Areas of Flowing Wells

Areas of flowing wells are shown on the hydrogeological map. They are situated on the lower slopes of hills and on the valley bottoms (and are general along the lines of sudden changes in angle slope). There are much more narrow belts where flowing conditions are predictable but wells have not been drilled yet. These belts are not shown on the map.

The flowing wells of the Wabamun Lake map area are shallow, supplied usually from local flow systems. Typically, in the areas of flowing wells, the piezometric head initially increases with increasing depth and then reverses gradient and decreases with depth. This indicates that another flow system has been reached. The boundary between the shallow and deep flow systems can be fundamentally hydraulic, not lithologic.

Such deep flow systems are found in the valley of the Lobstick River at MacKay and in the valley of the Sturgeon River at Darwell. These flow systems may be intermediate ones directed toward nearby Chip Lake and Lac Ste. Anne, which are erosion bases for the rivers, or they may be parts of a long-range, basin-wide flow system. This is an important but as yet unanswered question, although the former explanation appears to be less likely (see below under "Hydrochemistry").

Test Drilling

Four test holes were drilled and pump and bail tests were carried out. The holes were located at Alsike (Lsd. 13, Sec. 36, Tp. 48, R. 4, W. 5th Mer.), Cynthia (Lsd. 1, Sec. 28, Tp. 49, R. 10, W. 5th Mer.), Darwell (Lsd. 9, Sec. 24, Tp. 54, R. 5, W. 5th Mer.), and MacKay (Lsd. 7, Sec. 17, Tp. 54, R. 11, W. 5th Mer.), and were drilled to depths of 800 feet (244 m), 515 feet (157 m), 765 feet (233 m) and 295 feet (90 m), respectively. The results of the drilling are incorporated into the maps and are shown in greater detail on the profiles.

Hydrogeological Profiles

Four hydrogeological profiles were constructed. Their cross-points are the four test holes. The profiles show the 20-year safe yield of the important formations without showing the individual aquifers, and the variation in chemical composition with depth and length of flow. The map shows by color the sum of the yields of the formations in the upper 1 000 feet. However, because of the logarithmically chosen yield ranks (see the legend of the map), they practically agree with the highest ranked formation.

Travertine-depositing Springs

In the wooded parts of the map area, a number of calcareous tufa-depositing springs are found. The travertine forms encrustations, pools, or, as at Jackknife Springs, crater-like tufa cones. They seem to be connected with forests or their climatological zone in the Wabamun Lake map area as in other parts of Alberta. The spring water is cold (3-5°C, 37.4-41° F) and contains a surprisingly small quantity of total dissolved solids, usually only about 250 ppm. Both low Na and high (sometimes predominant) Mg percentages show that they are discharge features of short, local flow systems. It is often found that the first discharging point is about 50-100 feet (15-30 m) uphill on a gentle slope or higher terrace in a wood of larch and/or black spruce, with clumps of labrador tea and sphagnum moss. The puddles are dark with humic acid. However, calcareous precipitations do not occur at these higher-up discharge points.

The same water coming to the surface for a second time a little further downhill or in a patch of open meadow starts to deposit travertine. There is only an insignificant difference in total dissolved solids between the two springing points. The cause of the phenomenon is probably that the acidic media of the boggy forest retards the precipitation of carbonates. In the open meadow where, by movement and perhaps by biological effects (algae?), excess CO_2 leaves the water, the carbonate precipitates.

HYDROCHEMISTRY

A chemical map has been constructed based on 897 analyses of groundwater, including springs, and 44 analyses of surface waters (rivers, lakes, sloughs, muskegs).

The area shows little variety in chemistry. Total dissolved solids content is usually lower than 500 ppm and rarely exceeds 1 500 ppm.

Except for some isolated wells, the predominant anion all over the map area is HCO_3. In areas of coal and dark shale lithology, SO_4 is considerable, but becomes predominant only at some individual wells. Areas in which SO_4 is considerable are encircled by a dashed line on the map. Chloride, except where present due to contamination, becomes an important constituent only in the deepest wells.

Of the cations, Ca+Mg predominate on the western, forested parts in recharge areas and in discharge areas of short local flow systems. In discharge areas of longer flow systems and generally in the eastern parts with meadows and cultivated lands, Na becomes the predominant cation.

Only small patches of alkaline soils are known in the area of investigation (Lindsay et al., 1968).

The low total dissolved solids content and Ca+Mg/HCO_3 character of lake waters show that groundwater feeding is secondary and usually confined to local flow systems.

The general chemical character of groundwater of the Wabamun Lake area agrees well with the presupposed one. The low total dissolved solids content and the bicarbonate dominancy corresponds with the climatic and topographic zone. The tendency for increase of total dissolved solids content and the changing sequence from Ca to Mg towards Na along the flow lines with increasing distance is the norm in the temperate climate.

CONCLUSIONS

Well yields vary greatly within the map area. Yields of 25-100 igpm (about 100-450 l/min) are available in the greater part of the area within the presently explored depth. The yield rank of any part of the area may well be underestimated due to lack of good data. The best aquifers are: soft sandstones of the Paskapoo Formation, from which 20-year safe yields of more than 500 igpm (2 250 l/min) can be obtained; locally sandstones of the Edmonton Group; Quaternary sands and gravels in sheets or valley fills, at or near the surface. There are practically no good aquifers deeper than 500 feet (about 150 m).

The poorest aquifers are the thick, unfractured shale sequences, highly bentonitic sandstones and some tills. Topographically, the high hilltops and the fringes of plateaus near escarpments are unfavorable well sites.

Water quality is very good. Total dissolved solids content is usually below 1 000 ppm and often below 500 ppm. The chemical character is Ca+Mg/HCO_3. Undesirable SO_4, Cl or Fe contents are limited to small areas in isolated locations.

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Appendix A. Data of Some Characteristic Water Samples, Wabamun Lake Area, Alberta

Location West of 5th Meridian: Lsd. or 1/4	Sec.	Tp.	R.	Water source	Depth from surface: aquifer ft	aquifer m	static level ft	static level m	Flow system	Limb of flowline	Chemistry: Total dissolved solids (ppm)	Character (m = mixed)	Geology of aquifer	Remarks
1	28	54	14	well	50	15	30	9	local	descending	404	Ca/HCO_3	Paskapoo sandstone? Pleistocene sand?	---
1	28	49	10	test hole	55	17	flowing		local (short)	ascending	468	Mg/HCO_3	Paskapoo sandstone	Cynthia test hole
1	28	49	10	test hole	340	104	25	8	intermediate	lateral	702	Na/HCO_3	Paskapoo sandstone	Cynthia test hole
7	17	54	11	test hole	56	17	flowing		intermediate	ascending	594	Na/HCO_3	Paskapoo sandstone	MacKay test hole
10	14	56	14	well	156	48	70	21	local	lateral	584	m/HCO_3	Paskapoo sandstone?	---
16	15	54	7	well	60	18	?	?	local	lateral	1300	$Na{+}Ca/SO_4{+}HCO_3$	Paskapoo coal & sandstone and drift	coal seams
SE	7	48	1	well	40	12	30	9	stagnant?	---	3346	Na/SO_4	drift	---
8	22	48	8	well	680	207	311	95	regional	lateral?	820	Na/Cl	Paskapoo sandstone and shale	---
SW	17	54	10	lake	---	---	---	--	---	---	180	$Ca{+}Mg/HCO_3$	---	Chip Lake
12	11	53	5	lake	---	---	---	--	---	---	284	$Na{+}Ca/HCO_3$	---	Wabamun Lake
10	35	55	1	lake	---	---	---	--	---	---	438	Na/HCO_3	---	Sandy Lake

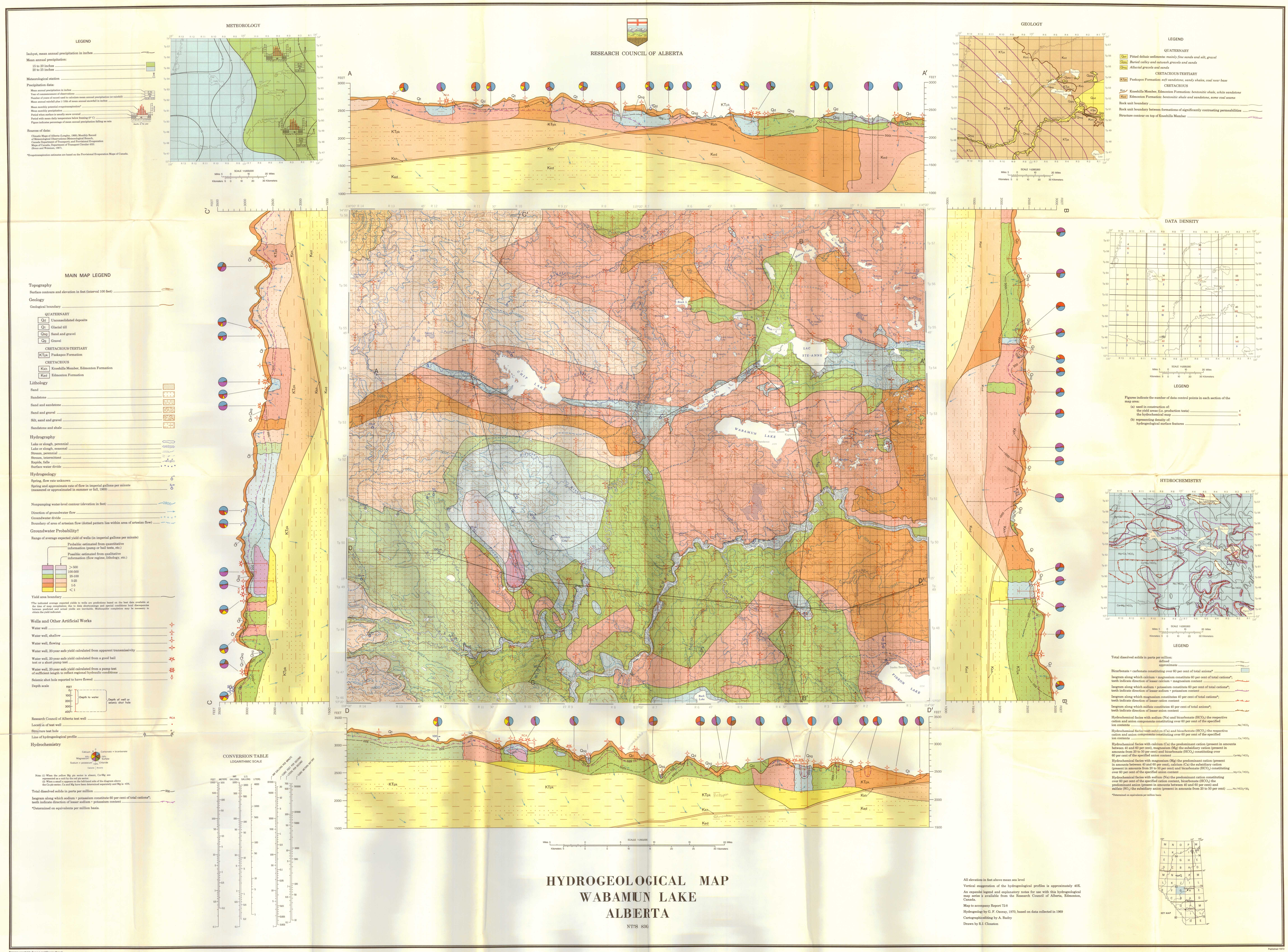
Appendix B. Trace Elements of Some Selected Groundwater Samples, Wabamun Lake Area, Alberta

Location West of 5th Mer. Lsd. or 1/4	Sec.	Tp.	R.	Water source	Depth from surface: aquifer (ft)	aquifer (m)	static level (ft)	static level (m)	Flow system	Limb of flowline	Cultivation of land	Geology of aquifer	Remarks	Chemistry: Total dissolved solids (ppm)	Character (m = mixed)	Trace elements: SiO_2 (ppm)	Al (ppm)	Hexa Cr (ppm)	Cu (ppm)	Br (ppm)	I (ppm)	Zn (ppm)	Mn (ppm)	Se (ppm)
13	36	48	4	test hole	90	27	8	2	local	desc	pc	Pleistocene, fluviatile sand	Alsike test hole	624	Na/HCO_3	9.3	0.06	<0.01	<0.01	<0.02	<0.01	0.05		
1	28	49	10	test hole	55	17	flowing		local	asc	f	Paskapoo sandstone	Cynthia test hole	468	Mg/HCO_3	9.8	0.10	<0.01	<0.01	<0.02	<0.01	0.03	<0.01	
4	29	52	4	seepage	-	-	-	-	local	lat	mining	Edmonton coal & shale	Highvale mine	888	Na/HCO_3	21.3	<0.02	<0.01	0.03	<0.02	<0.01	0.07		
16	24	52	8	well	110	33	?	?	int	lat	c	Paskapoo sandstone	---	1434	$Na+Ca/SO_4+HCO_3$	13.5	0.13	<0.01	<0.01	<0.02	<0.01	0.13		
16	24	52	8	well	22	8	20	7	local	asc	c	drift		544	$Ca+Mg/HCO_3$	14.5	0.06	<0.01	<0.01	<0.02	<0.01	0.04		
NW	15	53	4	seepage	-	-	-	-	local	desc or lat	mining	Pleistocene gravel	mine	384	$Na+Ca/HCO_3$	23.3	0.05	<0.01	<0.01	<0.02	0.03	0.04		
NW	15	53	4	seepage	-	-	-	-	local	desc	mining	Pleistocene gravel/ Edmonton coal	mine	316	Ca/HCO_3	13.3	0.06	<0.01	<0.01	<0.02	0.04	0.05		
3	13	53	7	test hole	52	16	6	2	local	asc	c	Pleistocene gravel & sand		576	$Ca+Na/HCO_3$	17.0	0.09	<0.01	0.04	<0.02	<0.01	0.03	0.03	0.01
12	7	54	4	well	36	?	?	?	local	asc	pc	Pleistocene gravel & sand		948	Ca/HCO_3	12.3	0.10	<0.01	0.03	<0.02	<0.01	0.03		
12	7	54	4	well	155	47	?	?	int	lat	pc	Edmonton sandstone		574	Na/HCO_3	13.3	0.05	<0.01	<0.01	<0.02	<0.01	0.06		
9	24	54	5	test hole	50	15	flowing		local	asc	pasture	preglacial fluviatile sand	Darwell test hole	912	$Na+Ca/HCO_3+SO_4$	10.0	0.06	<0.01	<0.01	<0.02	<0.01	0.06		0.02
9	24	54	5	test hole	375	114	2	1	int	lat	pasture	Edmonton sandstone	Darwell test hole	1022	Na/HCO_3	8.0	0.33	<0.01	<0.01	1.5	<0.01	0.06		
6	10	54	7	seepage	-	-	-	-	local	asc	f	coal seam		470	Na/HCO_3+SO_4	15.2	0.05	<0.01	0.05	0.18	<0.01	0.06		
7	17	54	11	test hole	56	17	flowing		int	asc	pasture	Paskapoo sandstone	MacKay test hole	594	Na/HCO_3	5.0	0.04	<0.01	<0.01	<0.02	<0.01	0.04	<0.01	
5	25	47	1	well	50	15	40	12	local	lat	f	drift		497	$Mg+Ca/HCO_3$	8.8	0.10	<0.01	<0.01	<0.02	<0.01	0.22		
8	13	47	6	well	?	?	10	3	local	lat	f	drift		250	m/HCO_3	7.2	0.04	<0.01	<0.01	<0.02	0.04	0.04		

2	19	47	7	well	187	57	?	?	local or int	lat or asc?	f	drift	for injection	794	Na/HCO_3+SO_4	5.8	0.04	<0.01	<0.01	0.18	0.01	0.13	<0.01	
10	14	47	10	spring	-	-	-	-	local	asc	f	Paskapoo sandstone & drift	Little Jackknife spring in tuff core	248	$Mg+Ca/HCO_3$	12.8	0.15	<0.01	<0.01	<0.02	<0.01	0.03		
3	23	47	14	well	210	64	?	?	local & int	desc	f	Paskapoo sandstone		238	m/HCO_3	9.3	0.05	<0.01	<0.01	<0.02	<0.01	0.15		0.01
4	2	49	1	well	100	30	?	?	int	asc?	c	Edmonton sandstone		1112	Na/HCO_3	8.0	0.03	<0.01	0.04	<0.02	<0.01	0.32		
1	6	50	4	well	140	43	50	15	local	lat	f	Paskapoo sandstone		652	Na/HCO_3	14.3	0.05	<0.01	<0.01	<0.02	<0.01	0.04		
13	22	51	2	well	300	91	150	46	local	lat	pc	Edmonton sandstone		830	Na/HCO_3	7.2	0.05	<0.01	<0.01	0.46	0.04	0.10		0.01
4	29	53	6	well	125	38	50	15	local	desc	pc	Paskapoo sandstone?		312	$Ca+Mg/HCO_3$	14.6	0.10	<0.01	<0.01	<0.02	<0.01	0.12		
16	4	53	9	well	34	10	24		local	asc	f	drift		586	$Mg+Ca/HCO_3$	9.6	0.10	<0.01	<0.01	<0.02	<0.01	0.04	<0.01	
1	2	55	10	well	95	29	?	?	local	lat	pc	Paskapoo sandstone?		336	$Ca+Mg/HCO_3$	11.8	0.02	<0.01	<0.01	0.02	<0.01	0.07	<0.01	
13	35	56	1	well	170	52	24	7	local	lat	c	Edmonton sandstone & shale		848	Na/HCO_3	7.2	<0.02	<0.01	0.03	0.14	0.03	0.07		0.01
16	36	56	2	well	sh	sh	sh	sh	local	asc	pc	drift	dug well	1072	$Na+Ca/HCO_3$	18.0	0.16	<0.01	0.05	0.14	<0.01	0.07		
9	15	56	9	well	200	61	?	?	local	desc	c	Paskapoo sandstone		1206	Na/HCO_3	12.8	0.05	<0.01	0.02	0.05	<0.01	0.05	0.03	

Abbreviations:

Depth from surface: sh – shallow; Flow system: int – intermediate; Limb of flowline: asc – ascending; desc – descending; lat – lateral; Cultivation of land: c – cultivated; pc – partly cultivated; f – forest or bush.



Basemap provided by Surveys and Mapping Branch, Department of Energy, Mines and Resources, Ottawa; modified by Surveys Branch, Alberta Department of Highways and Transport, Edmonton.

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