HYDROLOGY OF THE REGINA AQUIFER, SASKATCHEWAN

A Thesis
Presented to the
Faculty of Graduate Studies
in partial fulfillment of the requirements
for the Degree of
Master of Science
in the Department of Geological Sciences
University of Saskatchewan
by

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TO ROBINA
ABSTRACT

The Regina Aquifer, a Pleistocene outwash complex of Condiean age, underlies about 90 square miles of the Assiniboine River Plain. A method of safe yield determination, based on the application of Darcy's Law to natural, steady, linear flow through a classical aquifer, is developed and its limitations are defined. Based on this method the maximum safe yield of the aquifer is estimated to be 5,500,000 Imperial gallons per day.
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INTRODUCTION

Location

The Regina area of Saskatchewan described in this thesis comprises a 972 square mile portion of the Regina Quadrangle (72 I) and lies within the area of Townships 16 to 20, Ranges 17 to 24, west of the Second Meridian. It is between $104^011'$ and $105^018'$ West Longitude and between $50^018'$ and $50^045'$ North Latitude (Fig. 1). The city of Regina is in the centre of this area.

Previous Work

Lea and Smith (1908) and Wynne-Roberts (1912) submitted unpublished reports to the City of Regina. Stansfield (1918 and 1919) briefly described the ground-water resources of the Regina area in his study of the surficial deposits of southeastern Saskatchewan. Hill et al. (1930) investigated both ground-water and surface-water resources in the Regina area. Simpson (1930) described the ground-water geology for Hill's investigation and presented an accurate account of the history of ground-water development in the Regina area. MacKay et al. (1936) included the Regina area in an investigation of the ground-water resources of 226 Saskatchewan rural municipalities. Lockwood (1959), in an unpublished report to Regina's City Council on the status of the Regina water system, proposed a study of all ground-water resources in the Regina area. The purpose of this study was to establish ground-water supplies to augment the surface-water supply from Buffalo Pound Lake during times of peak consumption. Lissey in 1959 described the geological history and recharge conditions of the Boggy Creek Well Field for a B.Sc. thesis at the University of Saskatchewan. Christiansen (1961) described the Pleistocene Geology and published a ground-water probability map in his study of the Regina Quadrangle (72 I). Lissey (1962)
LOCATION of the REGINA AREA
described the geology, hydrology, and geochemistry of the major aquifers in the area. The Regina Aquifer was described in detail by Lissey (1963). The latter two studies served as the framework for this thesis.

Present Study

This thesis comprises a critical investigation of some analytical methods employed in previous studies. These methods are examined because it is felt that recent theoretical work limits their application. These limitations are discussed with reference to the author's study of the Regina Aquifer (Lissey, 1963).

Acknowledgements

The author is grateful to Professor T.E.W. Nind, University of Saskatchewan, for his assistance, encouragement, and advice pertaining to the section on hydrology. Further thanks are due Professor Nind for his critical reading of the manuscript.

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The writer wishes to acknowledge the City of Regina for providing the data and figures used in this thesis.
PHYSIOGRAPHY

Topography

In their study of the physiographic divisions of Saskatchewan, Acton et al. (1960) divided the Regina area into the Assiniboine River Plain and the Moose Mountain Upland (Fig. 2). Both divisions trend in a northwest-southeast direction.

The Assiniboine River Plain, which is locally known as the Regina Plain, is the dominant feature of the region. The surface is nearly level to gently undulating. Thalwegs\(^1\) of present valleys lie from 20 to 200 feet below the level surface of the plain. In the centre of the area, the Condie Moraine (Christiansen, 1961) rises about 130 feet above the surrounding plain. At this location the moraine has a rugged surface with a local relief of 10 to 40 feet.

A small part of the Moose Mountain Upland lies in the northeast portion of the Regina area. The surface has a knob and kettle topography. Within the report area, the upland rises about 400 feet above the Regina Plain and has a local relief of 20 to 100 feet.

The Qu'Appelle Valley is the most striking topographic feature in the Regina area. The valley flat which is 3/4 miles wide in places, lies 200 feet below the Regina Plain and 500 feet below the northern part of the Moose Mountain Upland.

Soils

The Regina area lies almost entirely within the Dark Brown Soil Zone of Saskatchewan (Fig. 3). A small part of the area to the northeast lies within the Black Soil Zone. With the excep-

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\(^1\) A line drawn through the lowest points of a valley in its downward slope.
tion of a few of the valley sides in the central part of the area, where the bedrock is exposed, most soils are developed from glacial drift, predominantly lacustrine clay. Because soil mapping is based partly on texture which reflects the parent material and because extreme weathering is not generally found in Saskatchewan, the surficial sediments can be interpreted directly from the soil map.

Climate

Precipitation

The precipitation recorded at the Regina Meteorological Station is shown graphically in Figure 4. The monthly precipitation ranges from a trace to 8.15 inches. The highest average monthly precipitation occurs in June, and the lowest average monthly precipitation occurs in February. The annual precipitation fluctuates from 6.26 to 23.73 inches but averages 14.82 inches. The variation in annual precipitation, between successive years, attained a maximum of 14.18 inches in 1916-1917.

Figure 5 shows graphically the precipitation recorded at the Moose Jaw Meteorological Station. The monthly precipitation ranges from a trace to 6.92 inches. The highest and lowest average monthly precipitations occur in June and February respectively. The annual precipitation at Moose Jaw ranges from 8.10 to 22.84 inches. This total variation of 14.74 inches is slightly less than the average annual precipitation which is 14.91 inches. The variation of annual precipitation between successive years has not exceeded 12 inches. The geographical distribution of average annual precipitation in the Regina area is shown in Figure 6.
Figure 4

Maximum monthly precipitation
Average monthly precipitation
Minimum monthly precipitation

Average precipitation: 14.82 in.
Standard deviation: 3.30 in.

Cumulative Departure from Average
Figure 5

Moose Jaw Meteorological Station

Maximum monthly precipitation
Average monthly precipitation
Minimum monthly precipitation

Average precipitation 14.91 ins.
Standard deviation: 2.61 in.

Cumulative Departure from Average

Hydrology Div. City of Regina Engineers Dept
Prepared and drawn by DJACKSON
Temperature

The average monthly range and mean monthly values of temperatures recorded at the Regina Meteorological Station and the Moose Jaw Meteorological Station are shown graphically in Figure 7. At Regina the mean annual temperature is 35.1°F. The recorded temperature extremes are 110°F and -56°F. A mean monthly temperature of 65.4°F has been calculated for July which is the warmest month. The coldest month is January which has a mean monthly temperature of -0.4°F. Mean monthly temperatures at Regina are above freezing from April to October inclusive.

At Moose Jaw the mean annual temperature is 38.8°F. A maximum of 110°F and a minimum of -54°F are the extremes of recorded temperatures at the station. The coldest and warmest months are January and July respectively. The mean monthly temperature for January is 7.0°F and for July it is 68.4°F. From April to October inclusive the mean monthly temperatures are above freezing at Moose Jaw. The geographical distribution of mean annual temperatures in the Regina area is shown in Figure 8.
TEMPERATURES
MAXIMUM, MINIMUM and MEAN
MONTHLY AVERAGES

REGINA METEOROLOGICAL STATION
(1884 - 1960)

MOOSE JAW METEOROLOGICAL STATION
(1894 - 1960)

Figure 7
Distribution of Mean Annual Temperature in the Regina and Surrounding Area

Fig. 8
Table 1

Climatic conditions of the Regina Area

<table>
<thead>
<tr>
<th></th>
<th>Regina Meteorological Station</th>
<th>Moose Jaw Meteorological Station</th>
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<tbody>
<tr>
<td><strong>Precipitation</strong></td>
<td>inches of rainfall</td>
<td></td>
</tr>
<tr>
<td>Average Annual</td>
<td>14.82</td>
<td>14.91</td>
</tr>
<tr>
<td>Minimum Annual</td>
<td>6.26</td>
<td>8.10</td>
</tr>
<tr>
<td>Maximum Annual</td>
<td>23.73</td>
<td>22.84</td>
</tr>
<tr>
<td>Maximum Monthly</td>
<td>8.15</td>
<td>6.92</td>
</tr>
<tr>
<td>Maximum Variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>between successive years</td>
<td>14.18</td>
<td>12.00</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.30</td>
<td>2.61</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Annual</td>
<td>35.1</td>
<td>38.8</td>
</tr>
<tr>
<td>Recorded High</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Recorded Low</td>
<td>-56</td>
<td>-54</td>
</tr>
<tr>
<td>Mean Monthly (warmest month)</td>
<td>65.4 (July)</td>
<td>68.4 (July)</td>
</tr>
<tr>
<td>Mean Monthly (coldest month)</td>
<td>-0.4 (Jan.)</td>
<td>7.0 (Jan.)</td>
</tr>
</tbody>
</table>
Wind and Evaporation

The prevailing wind at Regina is from the southeast (Thomas, 1953) and the average wind speed is 13.0 miles per hour. The Dominion Experimental Farm in Regina has evaporation data from open tanks for May to September from 1952 to 1961 inclusive. These data show that the average evaporation in May is 4.4 inches, in June 4.6, in July 5.3, in August 5.0, and in September 3.5 inches. The average total evaporation for the summer months May to September inclusive is 22.8 inches as compared with the average total precipitation of 9.95 inches for the same period.

Drainage

Drainage of the Regina area is provided by Flying, Boggy, Waskana and Cottonwood, High Hill and Moose Jaw creeks (Fig. 2). These creeks drain northward into the Qu'Appelle River which in turn drains into Lake Winnipeg by way of the Assiniboine and Red Rivers.

Physiographic Factors of Ground-Water Recharge

The major physiographic factors of ground-water recharge in the Regina area are climate, drainage, and soils. The climate of the area is not conducive to recharge of aquifers because during the five frost-free months when the highest monthly precipitations occur, evaporation exceeds precipitation and because during the five frost-bound months when the lowest monthly precipitations occur, the ground is frozen and precipitation accumulates as snow which cannot recharge aquifers (Fig. 9). It is believed that the most
suitable times for aquifer recharge occur generally during April and October when evaporation is low and average temperatures are above freezing for these two months. However, little recharge occurs during October because precipitation is low in this month. It is felt, therefore, that the major recharge of most aquifers in the Regina area occurs during April. Although the precipitation is also low in April, more water is available for recharge during this month because the precipitation which has accumulated as snow is released by thawing.

The amount of released precipitation available for recharge is largely determined by the drainage character of the area. In parts of the area traversed by well developed streams a large part of this precipitation is lost as surface runoff. In the poorly drained parts of the area this runoff is minimized and a large part of the water, made available by thawing, collects in depressions, where some percolates downward to recharge aquifers and some evaporates.

The rate of percolation in the poorly drained parts of the area is determined by the moisture-retention capacities of the soils and the permeability of the related underlying sediments. Where the moisture-retention capacities of these materials are low, percolation is rapid and major recharge occurs. The relationship between topography, permeability and recharge will be discussed in the section on hydrology.

Minor recharge in these same poorly drained areas with materials of low moisture retention occurs during intense rainstorms and in at least one case by influent stream action, as indicated by the author's study in 1959.
Temperature, Evaporation, Precipitation Relationship at Regina

LEGEND
Mean Monthly Temperature
Average Monthly Evaporation
Average Monthly Precipitation

Figure 9
GEOLOGY

Upper Cretaceous

Marine Shale Series

The Marine Shale Series constitutes Upper Cretaceous strata in the Regina area and is equivalent to the Bearpaw, Belly River and Lea Park formations to the west (Fraser et al., 1935). The series is also equivalent to the Riding Mountain formation to the east (Wickenden, 1945). The Marine Shale Series forms the bedrock in the Regina area and consists of medium to dark grey, non-calcareous, soft, uniform shale that is bentonitic in part and contains selenite crystals and ferruginous nodules or concretions (Fraser et al., 1935). Where exposed, these shales generally weather to a reddish brown colour due to the presence of iron. Exposures of this shale occur in the Qu'Appelle, Waskana, and Cottonwood Valleys. Outcrops of bedrock to the west of the area contain fossiliferous beds of buff-coloured fine sand and silt (S.E. 1/4 S. 3, T. 19, R. 25, W. 2).

Bedrock Topography

Contours of the present bedrock surface are shown in Figure 10. This surface indicates the existence of a preglacial, northward sloping dendritic drainage system which has level interfluvial areas containing a few small, isolated erosional remnants. The major bedrock valleys forming this drainage system in the Regina area have been named by Christiansen (1961): Avonhurst, Regina, Adams, and Madrid Valleys. The bedrock topography also shows superposition of glacial drainage channels which were formed by erosional downcutting of meltwater into the bedrock during Pleistocene times. The Qu'Appelle Valley has been superimposed on the bedrock topography in this manner.
Figure 10

Bedrock Topography of the Regina Area

(Partly after Christiansen, 1961)

Contour Interval: 100'

Reference
Structure Test-Hole
Wildcat Well
City Water Well
Seismic Shot-Hole
Private Water Well
Outcrop
Test-

All elevations above Sea Level

by Sask Research Council
Pleistocene Series

Regional Stratigraphy

General Statement. - Because only the upper portion of the drift, which is calcareous in its entirety, is revealed in few good exposures, the stratigraphy of the glacial deposits in the Regina area has been determined from well data. Drift exposures and the map of the surficial sediments, which is shown in Figure 11, were used to interpret the stratigraphy where well information was absent. Test holes and exposures show at least two tills which are separated by an oxidized marker zone in places and by inter-till sand and gravel in other parts of the area. The occurrence of the upper or Condie Till is evidence of a major ice readvance (Christiansen, 1961) which is used as the basis of stratigraphic division in the area. The regional stratigraphy, in which the drift of the area was divided into Condiean, pre-Condiean, and post-Condiean sediments, is shown in Figure 12. A stratigraphic chart of the drift is shown in Figure 13.

Pre-Condiean. - Pre-Condiean till rests on the bedrock and underlies the entire Regina area. Although this till may represent more than one major glacial episode in the area, it has been grouped as one stratigraphic unit because no continuous distinct characteristics have been found in it on which to base subdivisions. The pre-Condiean till, which consists of approximately 30% clay, 30% silt, and 40% sand and gravel sized particles, has filled the topographically low areas in the bedrock and is about 250 feet thick in the preglacial Regina Valley south of Regina, but it is only up to 60 feet thick in the bedrock interfluves south of the Qu'Appelle Valley (Fig. 12). This till is calcareous and contains montmorillonitic clay that is similar to the bedrock clay shale from which it was derived (Christiansen, 1961). Pre-Condiean
Figure 11

SURFACE GEOLOGY of the REGINA AREA
(partly after Christiansen, 1961)
Pleistocene Stratigraphy of the Regina Area
Partly after Christiansen, (1961)

Figure 13
till is grey where unoxidized and weathers to an olive brown. Weathering of the upper portion of this till is believed to have been responsible for the marker zone between Condiean and pre-Condiean tills south of Regina.

Pre-Condiean sand and gravel occurs as stratified drift which is believed to be confined to bedrock valleys, kame-esker complexes, and lenses within till. Stratified drift is found in the Regina Valley in the northern part of the area. Complex kame-esker gravels occur in the Jameson area and are exposed in the lower parts of borrow pits. Sand and gravel lenses are found throughout the pre-Condiean till. The thickness of pre-Condiean gravels varies from 1 foot or less in isolated lenses to about 30 feet in the kames at Jameson. In the northern part of the area pre-Condiean sand and gravel occurs as isolated intertill deposits of varied thickness and development. These deposits separate Condiean and pre-Condiean tills and are believed to be ice-erosional remnants of an extensive sand and gravel outwash. This intertill deposit attains a maximum thickness of about 60 feet in the Mound Springs well field (S. 31, T. 19, R. 19, W. 2) and forms the Intertill Aquifer.

Condiean. - The Condie Till (Christiansen, 1961) is believed to underlie most of the area with its southern limit approximately coincident with the ice front of the Rowatt phase of glaciation (Fig. 17) instead of being limited to north of the Condie Moraine as suggested by Christiansen (1961). There is no lithological distinction between the Condie and pre-Condie tills. The Condie till is grey to greyish brown where unoxidized and olive brown to light brownish grey where oxidized. The clay portion of this till is also montmorillonitic. An exposure of Condie Till in S.E. S.21, T. 18, R. 21, W. 2 contains interbedded volcanic ash which has been named the Waskana Ash (Christiansen, 1961). The thickness of the Condie Till varies from about 10 feet near the southern limit to about 50 feet near the Condie Moraine.
Condiean sands and gravels form the Avonhurst, and Regina aquifers. The gravels comprising these aquifers occur as extensive pro-glacial outwashes, kames and kame-esker complexes. Condiean sand and gravel is exposed in the borrow pits around Pilot Butte and south of Condie. The Condiean gravels are up to 100 feet thick near Armour and are up to 60 feet thick north of Pilot Butte. Lenses of sand and gravel occur in the Condie Till.

The Regina Clay, which was deposited in late Condiean time, mantles most of the sediments in the area (Fig. 11) and is as much as 55 feet thick south of the Condie Moraine. The Regina Clay consists of about 40% to 90% montmorillonitic clay. In places it is very silty and contains occasional ice-rafted lenses of till. North of the Condie Moraine the clay is varved and contorted. The clay is grey where unoxidized and olive brown where oxidized. Deposition of the Regina Clay occurred as proglacial lacustrine sediment in Glacial Lake Regina (Johnston and Wickenden, 1930). Fine-grained beach sands are associated with Regina Clay. These sands are found in T. 17, R. 17 and T. 16, R. 17.

In the western part of the area a very late Condiean sand and gravel deltaic outwash occurs as a surface sediment which has been deposited on the Regina Clay. This deposit consists of gravel north of Stony Beach which becomes progressively finer eastward and terminates as silt along Cottonwood Creek. This gravel forms the Keystown Aquifer.

Post-Condiean. - In recent times aeolian dune deposits were formed in the Jameson and Cottonwood areas. The deposition of alluvium and colluvium on the valley floors and sides respectively is recent. Soil-forming processes are now active throughout the area.
Glacial History

General Statement. - The glacial history of the Regina area is dominated by four significant phases. The major meltwater features and the ice front at a particular time for each of these phases are shown in a map (Figs. 15-18). The glacial history accompanying each phase was determined from the stratigraphy, surface geology, and the geomorphology of the area. The duration of these phases has not been determined because of insufficient information for dating. The last phase of ice recession in the Regina area is believed to have occurred approximately 10,000 years ago (Christiansen, 1961). Each phase has been named after a present locale which is now situated near where the ice front once stood. The phases have been named the Jameson Phase, the Condie Phase, the Rowatt Phase and the Rocky Lake Phase. A summary of the glacial history of the Regina Area is tabulated in Figure 14.

Jameson Phase. - The first significant phase of the glacial history of the Regina area has been named the Jameson Phase by the author and occurred slightly later than Phase No. 1 of Christiansen (1961). During the Jameson Phase the ice stood at the Davin Moraine, and meltwater from the receding ice sheet drained to the southeast along the ice front between the ice and the higher Davin Moraine into the Manybone Creek Channel via the Jameson Channel (Fig. 15). This phase is correlative with Phase No. 5 of the Moose Mountain Glacial History, and the ice mass shown is part of the Weyburn Lobe (Christiansen, 1956). A complex kame-esker occurrence of sand and gravel is believed to have been deposited in the Jameson area at this time. During later phases of the retreat of the Weyburn Lobe it is believed that an extensive sand and gravel outwash was deposited in the northern part of the area. The ice retreated north of the Qu'Appelle Valley which then provided drainage of the wasting ice front to the east. Downcutting of the Qu'Appelle Valley by meltwater occurred at this time.
# Summary of Glacial History

<table>
<thead>
<tr>
<th>Phase No.</th>
<th>Name</th>
<th>Glacial Episode</th>
<th>Ice Position and Movement</th>
<th>Significant Depositional and Erosional Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Rocky Lake</td>
<td>Late Condiean</td>
<td>Final retreat of ice from Regina area.</td>
<td>- Glacial Lake Regina drained via Qu'Appelle Valley.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- boulder pavement left in drainage channels.</td>
</tr>
<tr>
<td>3</td>
<td>Rowatt</td>
<td>Condiean</td>
<td>Maximum readvanced position of ice in Regina area.</td>
<td>- Glacial Lake Regina at highest level with drainage via Souris Spillway.</td>
</tr>
<tr>
<td>2</td>
<td>Condie</td>
<td>Condiean</td>
<td>Ice readvanced into Regina area.</td>
<td>- Condie Moraine.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- extensive sand and gravel deposition.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- beginning of Glacial Lake Regina.</td>
</tr>
<tr>
<td>1</td>
<td>Jameson</td>
<td>pre-Condiean</td>
<td>Ice front retreated to north of the Qu'Appelle Valley.</td>
<td>- deposited a sand and gravel outwash in northern part of Regina area.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- downcutting of Qu'Appelle Valley into bedrock.</td>
</tr>
</tbody>
</table>

**Figure 14**
Condie Phase. - The second significant phase of the glacial history of the Regina area has been named the Condie Phase and corresponds to Phase No. 3 of Christiansen (1961). The position of the ice front is shown in Figure 16. The author believes that this phase represents cyclic retreat of a major ice readvance into the area. The Condie Moraine was formed during this phase. During the cyclic retreats, sands and gravels were deposited as kames and outwash aprons in the re-entrant area northwest of Regina and in the Boggy Creek-Pilot Butte area. The interbedding of till and gravel which occurs in the Boggy Creek Valley and in the Condie Moraine is postulated to have been formed at this time because of these cyclic fluctuations. Meltwater, which was formed during the cyclic recessions of this latter ice phase, is believed to have drained from the ice front and accumulated south of the Regina area to form the beginning of Lake Regina.

Rowatt Phase. - The third significant phase of the glacial history in the Regina area has been named the Rowatt Phase by the author. The fact that the upper part of the pre-Condiean till is oxidized southeast of Regina supports the theory of ice readvance beyond the Condie Moraine. Assuming that major deposition occurs only during ice recession, the sequence of deposition shown in Figure 12 also suggests that the ice advanced over the Condie Moraine. It is believed that the Rowatt Phase existed when the readvancing ice front attained its maximum southerly limit in the Regina area (Fig. 17). At this maximum position, the rate of ice melting balanced the rate of ice accumulation and the ensuing meltwater created Lake Regina. The lake level was maintained at approximately 1900 feet above sea level because the Davin Moraine, the Missouri Coteau, and the ice confined drainage of the lake to the relatively high Souris Spillway (Christiansen, 1956). Rebound of the sediments after ice recession has left part of the shoreline of Lake Regina above 2,000 feet. As the front of the ice was in water, no prominent recessional moraines were developed. During recession of the ice from its maximum readvanced
Figure 15  GLACIAL HISTORY OF THE REGINA AREA  JAMESON PHASE

Figure 16  GLACIAL HISTORY OF THE REGINA AREA  CONDIE PHASE
position, complex sands and gravels, were deposited east of Regina. These sands and gravels were partly overlain by till which was deposited during the major recession of ice from the area. This till forms the upper part of the Condie Till. Because the retreating ice front confined Lake Regina, the lake spread with ice recession and Regina Clay was deposited as a mantle over most of the Condie Till and over part of the Condiean outwash gravels north and east of Regina.

**Rocky Lake Phase.** - The fourth phase of the glacial history in the Regina area has been named the Rocky Lake Phase and represents one stage in the final retreat of ice from the Regina area (Fig. 18). During the early part of this phase, the ice retreated north of Buffalo Pound Lake but still formed closure of Lake Regina because it blocked the Qu'Appelle Valley to the east. At this time meltwater flowed through the ice marginal channel, which now forms Buffalo Pound Lake, and developed a sand and gravel delta north of Stony Beach where this water entered Lake Regina. A minor readvance of the ice then produced the Rocky Lake Moraine. Shortly following the development of the Stony Beach deposits, Lake Regina was allowed to drain because of further ice recession which exposed the previously blocked part of the Qu'Appelle Valley. The lake was drained eastwards by the Qu'Appelle Spillway via the Moose Jaw and Fairy Hill Channels. Movement of water through the Moose Jaw Channel eroded the Regina Clay, reworked part of the Stony Beach deposits, and left a boulder pavement in the channel. A boulder pavement or lag concentrate was similarly left in the centre of the Fairy Hill Channel which is best exposed in T.21, R.19, W.2, immediately north of the area.

A possible alternate interpretation of the glacial history implies that readvance of ice into the area was not marked by a halt at the ice frontal position attained during the Condie Phase (Fig. 16) but that readvance was continuous until the maximum readvance position of the ice front (Fig. 17), attained during the Rowatt Phase, was reached. This then implies that the Condie Phase marks a halt in the major recession which is characterized by minor cyclic advances and retreats.
The Regina Aquifer, one of five Pleistocene aquifers (Fig. 19) described by Lisse (1962), is an extensive complex of proglacial outwash and ice-contact stratified drift which is of Condiean age. It was deposited in a major reentrant of the ice front (Fig. 20) before the ice attained its maximum readvanced position.

The southern part of the aquifer (Fig. 21) has been divided into upper (A) and lower (B) zones which are separated by Condie Till. The central portion occurs as a thick, undivided zone, while two or more undifferentiated zones form the northern part. The occurrence of the various zones is postulated to be the result of ice fluctuation during deposition of the gravels. The upper and lower zones of the southern part of the aquifer are encountered at average depths of 80 feet and 150 feet respectively (Fig. 22 and Fig. 23). Three outcrops of the aquifer occur in Township 18, Range 20. The largest of these is about two miles south of Condie and forms part of the Condie Moraine (Christiansen, 1961). In its central portion the aquifer has a maximum thickness of about 100 feet (Fig. 24), while in the southern portion both the upper and lower zones attain local thicknesses of over 100 feet (Fig. 24 and Fig. 25). The Regina Aquifer, which lies on pre-Condiean till, is partly overlain by Condie Till and partly overlain by Regina Clay which forms a surface mantle over most of the area. The geologic cross-section (Fig. 26) illustrates the complex occurrence of the Regina Aquifer.
Figure 19

Location of Pleistocene Aquifers in the Regina Area

REGINA AREA West of Second Meridian Refer to NTS Sheet 72-1
Relationship of the Regina Aquifer to the Condie Moraine and the Position of the Ice Front

Legend
- Regina Aquifer
- Condie Moraine
- Ice Front
- Regina City
- Area covered by Ice

Scale

Figure 20
Elevation of the Top of the Undifferentiated, Undivided, and the A Zones of the Regina Aquifer

Figure 22
Elevation of the Top of B Zone of the REGINA AQUIFER

Legend
City Well ······ ●
Private Well ···· △
Slim Hole ······ X
Contour ······ 25-
Outcrop ······

Window of Non-Deposition 1 1 1 1 1 miles 0 1 2 3 4 5 miles

Figure 23
Thicknes of the Undivided and A Zones of the Regina Aquifer

Figure 24
Thickness of the B Zone
of the
REGINA AQUIFER

LEGEND
City Well...... O
Private Well..... △
Slit Hole....... X
Contour...... ~ 26'
Outcrop......
Window of Non-Deposition

Figure 25
Geologic Section A'-A' Across Regina Aquifer

Vertical exaggeration ×13
See Fig. 3 for plan of cross section

Figure 26
Hydrology

General Statement

The general principles underlying the source, occurrence, and movement of ground-water have been described by Meinzer (1923 and 1942), and others. These principles are summarized here to explain the technical terms used in this thesis.

The occurrence of water as ground-water is one stage in the earth's hydrologic cycle which is illustrated schematically in Figure 27. This ground water is derived from that part of the precipitation which does not escape as surface runoff, transpiration, or evaporation but which infiltrates through loose particles of the soil and percolates downward through the earth's materials. Below a certain depth most porous earth material is saturated with ground water. Removal of water from this zone of saturation is referred to as discharge. Addition of water to this zone is called recharge.

The porosity of an earth material is a quantitative expression of its void space as a percentage of the total volume of the material. The facility with which a porous material, having interconnected openings, transmits water under a head gradient is measured by its permeability. Earth materials in the zone of saturation that have porosity and permeability great enough to store an adequate volume of water and to transmit it economically into a well are called aquifers. The term coefficient of storage relates to the capacity of an aquifer to store water. The capacity of an aquifer to transmit water is measured by its average transmissibility which is the product of the average thickness and the average permeability of the entire aquifer. The piezometric head at any point in the zone of saturation is the height, measured from a common datum, to which water at that point will rise against atmospheric pressure. A confined aquifer is one in which all
The Hydrologic Cycle

Figure 2.7
piezometric heads are above the top of the aquifer. An unconfined aquifer is one in which all piezometric heads are at the top of the aquifer. The occurrence of confined and unconfined aquifers is shown in Figure 28.

Movement of water within the zone of saturation is referred to as ground-water flow. The direction of ground-water flow is from points of higher piezometric head toward points of lower head. The rate of ground-water flow between two points, as expressed by Darcy's Law, is directly proportional to the permeability of the material and to the difference in head, and is inversely proportional to the distance between those points.

Pumping of a well is artificial discharge which lowers the piezometric head in the vicinity of the pumped well thereby inducing ground-water flow through the aquifer towards the well from zones of higher head. The lowering of piezometric head, or drawdown, measured at a particular time during pumping, decreases with increasing distance from a pumping well, thus describing an inverted cone or cone of depression with the pumped well as the central axis. In theory this cone of depression has an infinite radius from the instant pumping starts and expands vertically as pumping continues. The shape of the cone of depression and its rate of vertical expansion with increasing duration of pumping are functions of the permeability and storage characteristics of the aquifer. A pumping test consists of measuring drawdowns at various times in nonpumping or observation wells to describe the shape of the cone of depression at any instant, and also its rate of expansion. From analyses of these measurements the average transmissibility and storage coefficient of an aquifer as a whole can be determined.

Analyses of pumping-test data are based on solutions of the continuity equation. Theis (1935) presented a solution of this equation for an infinite, homogeneous, porous, permeable medium through which a slightly compressible liquid is flowing; this medium, which is bounded above and below by impermeable material, is assumed
Recharge Area

Water Table Well

Piezometric Surface

Ground Surface

Flowing Well

Water Table Well

Unconfined Aquifer

Confined Stratum
OR
Confined Aquifer

Impermeable Strata

Slope = $\frac{d}{h}$ = Gradient

Unconfined and Confined Aquifers

Figure 2.8
to be horizontal and of constant thickness. The Theis solution further assumes radial, laminar flow towards a line sink which is discharging at a constant rate, and so is only applicable to cases in which a fully penetrating well is pumping water from a very large flat-lying confined aquifer which is vertically bounded by impermeable strata. According to this solution, the drawdown at any point in a confined aquifer produced by a single well should increase continually although at an ever-declining rate.

Hantush and Jacob (1955) derived a nonequilibrium solution of the continuity equation which includes and supplements the Theis solution by treating confining strata as having varying degrees of permeability through which water enters the aquifer within the zone of depression at rates proportional to the drawdowns therein. According to this solution, the rate of expansion of the cone of depression ceases when the amount of water leaking into the aquifer from confining strata equals the pumping rate, implying that pumping-test drawdowns, measured in an observation well should eventually stabilize. The Theis solution is a limiting case of the Hantush-Jacob equations for leaky aquifers where confining beds are impermeable and no leakage occurs.

Pumping in an unconfined aquifer is characterized by a steep cone of depression which expands at a very slow rate. Because the cone of depression is steep and also because the aquifer is unconfined, the saturated thickness of the aquifer is reduced and the Dupuit assumption of horizontal flow no longer holds in the vicinity of the pumped well. One possible way of overcoming the problems introduced by the reduced aquifer thickness is to use a combination of the Theis solution for a confined aquifer and the correction term for aquifer dewatering that was proposed by Jacob (1944). This has been shown by Nind (personal communication, 1963) to be mathematically sound. Boulton (1954a) showed that because horizontal flow no longer exists in the vicinity of the pumped well, the Theis solution with Jacob's corrections cannot be applied to early time-drawdown data from an unconfined aquifer.
He also showed that the problems introduced by the vertical flow component can be compensated by applying the Theis solution and Jacob's corrections to late time-drawdown data in observation wells placed not too close to the pumped well, when and where the Dupuit assumption of horizontal flow, on which the Theis solution depends, is approximated.

The safe yield of an area is the maximum quantity of groundwater which can be pumped steadily from the zone of saturation beneath that area, the annual discharge being entirely replaced by natural recharge over the course of an average year. One of the prime objectives of ground-water research is to establish a reliable method of determining the safe yield.

A Suggested Method for Determining Safe Yield

The method of safe yield determination used by Lissey (1963) was partly based on the work of Plotnikov et al. (1946). This method is founded upon the classical concept of flow through confined aquifers illustrated in Figure 29 and is based on the following reasoning. Natural ground-water flow through an aquifer is controlled by Darcy's Law and by the relationship between recharge, discharge, and storage of the aquifer. Discharge without fully compensating recharge involves a decrease in storage; if recharge exceeds discharge an increase in storage is implied. Under the equilibrium conditions of constant recharge and no change in aquifer storage, the rate of recharge, that is the rate of ground-water flow through the aquifer, equals the rate of discharge. If such equilibrium conditions are assumed, and if, by some method it is possible to estimate the rate of natural recharge, then an estimate for the safe yield can be given. One way of obtaining a value for the rate of recharge is by using Darcy's equation, which may be written as:

\[ Q = K \cdot \frac{\Delta H}{W} \cdot B \cdot L \]  

(1)
Unconfined part

Confined part

Recharge

Line of flow

Equipotential line

CLASSICAL AQUIFER
FLOW & HEAD DISTRIBUTION

Figure 29
where \(Q\) is the rate of natural recharge, that is, the safe yield of the aquifer in gallons per day; \(K\) is the average coefficient of permeability for the entire aquifer in gallons per day per square foot; \(\Delta H\) is the difference in piezometric head between the recharge and discharge areas of the aquifer measured in feet; \(W\) is the distance between these two areas in feet; \(B\) is the average thickness of the aquifer in feet; and \(L\) is the average width of the aquifer, measured perpendicular to the direction of ground-water flow, in feet. In applying this equation, which assumes that movement of water across the aquifer approximates linear flow, three factors are required: the average permeability, the change in piezometric head, and the physical dimensions of the aquifer.

Local average permeabilities of the Regina Aquifer were calculated from ten pumping tests of the constant-rate type (Bruijn and Hudson, 1958). Analysis of piezometric data, where these tests were run, indicated that part of the aquifer was under confined or artesian conditions and that part was under unconfined or water-table conditions (Fig. 30).

The Hantush-Jacob solution for leaky aquifers was applied to drawdown data from the seven pumping tests which were conducted in the confined portion of the Regina Aquifer (Fig. 30). The graphical method of test-data superposition on logarithmic type curves described by Walton (1960a), which was used in this application, indicated that confining beds behaved as impermeable strata in pumping tests 1, 2, and 3, and that confining beds behaved as permeable, leaky strata in pumping tests 4, 5, 6, and 7.

Because leakage from confining beds was insignificant in pumping tests 1, 2, and 3, the drawdown data from these tests were analyzed by applying the Theis nonequilibrium solution according to the graphical time-drawdown type-curve method of test-data superposition described by Wenzel (1942). The permeability values obtained from this procedure were checked by the steady-state, distance-drawdown, type-curve method of test-data superposition for leaky artesian aquifers (Jacob, 1946) and by the modified, nonequilibrium, distance-drawdown, method (Cooper and Jacob, 1946)
THE HYDROLOGIC CONDITIONS OF THE REGINA AQUIFER

Reference:
- Outcrop
- Artesian Condition
- Water Table Condition
- Window of Non-Deposition

Pump test location

Figure 30
which is based on an approximation to the Theis solution. These two distance-drawdown checks led to very similar estimates of the permeability to that obtained by the time-drawdown method, further indicating that leakage was very slight during those three pumping tests.

Because leakage from confining beds occurred in pumping tests 4, 5, 6, and 7, the drawdown data from these tests were analyzed by applying Walton's method which depends on a numerical analysis (Hantush, 1956) of the Hantush-Jacob solution, and permits reliable estimates of aquifer permeability to be readily obtained.

The results of all pumping tests in the confined portion of the Regina Aquifer indicated that leakage from the confining beds decreased toward the southwest, which may be interpreted as a decrease in the permeability of the Condie Till in this direction.

Pumping tests 8, 9, and 10, which were conducted in the unconfined portion of the Regina Aquifer were analyzed by applying the Theis nonequilibrium solution with Jacob's corrections for reduction in aquifer thickness to late time-drawdown data according to a method described by Walton (1960b). Because this method corrects for errors introduced by the steepness of the cone of depression, it was believed that the permeability values obtained from these three tests were reliable.

Analyses of all ten pumping tests were further checked by the modified, nonequilibrium, time-drawdown method (Cooper and Jacob, 1946) which is an approximation to the Theis solution. All analyses except the modified nonequilibrium checks are included in Appendix A.

In those parts of the aquifer where pumping tests were not run, local average permeabilities were estimated from the initial specific capacity of eight industrial wells according to a method outlined by Theis et al. (1954). All estimates of local average permeabilities were placed on a map and contoured, the result (Fig. 31) indicating that the central undivided portion is the most permeable part of the Regina Aquifer.
PERMEABILITY of the REGINA AQUIFER
(Imperial Gallons per Day per Foot²)

Figure 31
The change in piezometric head across the Regina Aquifer was determined from the map shown in Figure 32. The individual heads used to prepare this map were measured in permanent observation wells and in nonpumping production wells during the winter of 1960-1961. Pumping of industrial wells, indicated in Figure 32 by the regional cone of depression in the northeastern part of the aquifer, was maintained at a constant minimum rate during this time in an attempt to attain a head distribution across the aquifer as similar as possible to the head distribution under natural conditions without pumping. It is interesting to note that the approximate head distribution across the aquifer prior to 1940 (Fig. 33) is similar to that obtained in 1961, indicating that the safe yield had not been exceeded during this 21 year period to such an extent that a regional decline of water levels resulted. This would indicate that the maximum safe yield exceeds 3,000,000 Imperial gallons per day - the average daily pumpage from the aquifer between 1940 and 1962. The distribution of piezometric heads shown in Figure 32 indicates that the general direction of ground-water flow is from northeast to southwest across the aquifer.

An independent study of ground-water chemistry was conducted by Lissey (1963) to substantiate the conclusions reached about direction of flow, based on the distribution of piezometric heads. Water in the Regina Aquifer is composed essentially of sulphates and bicarbonates of calcium and magnesium in solution (Fig. 34). Chemical analyses of water from the aquifer are summarized in Appendix B. The degree of ground-water mineralization throughout the aquifer is shown in Figure 35. Because mineralization of ground-water increases in an aquifer with distance of water travel, areas of low mineralization generally suggest recharge. Figure 35 therefore substantiates the piezometric data by indicating that major recharge occurs to the northeast, and that ground-water flow is to the southwest.
THE PIEZOMETRIC SURFACE OF THE REGINA AQUIFER
(1960-1961)

REFERENCE

City Well
Private Well
Outcrop
Contour
Window of Non-Deposition

Topographic contour ~ 1800

Central undivided zone

Figure 32
THE PIEZOMETRIC SURFACE OF THE REGINA AQUIFER
(1930-1940)

REFERENCE
City Well
Private Well
Outcrop
Contour
Window of Non-Deposition

1860 Piezometric Elevation
(32) Year measured

Figure 33
Quality of Water from Major Pleistocene Aquifers in the Regina Area

Figure 3.4
Concentrations of Total Dissolved Solids in the REGINA AQUIFER
(in parts per million)

Figure 35
The anomalous high mineralization values in the northeastern part of the aquifer are probably due to induced leakage from the confining till within the regional cone of depression established by industrial wells in the northeastern part of Regina (Schneider, personal communication, 1962).

The physical dimensions of the Regina Aquifer were obtained from the geological maps (Figs. 22-25). The cross-sectional area of the aquifer perpendicular to the direction of flow roughly corresponds to that shown in Figure 26.

For the safe yield calculations of the Regina Aquifer, equation (1) was rewritten as

$$ Q = T \cdot L \cdot \frac{\Delta H}{w} $$  \hspace{1cm} (2)

where $T$ is the average area-weighted transmissibility of the aquifer in gallons per day per foot and other terms are as previously defined. Equation (2) can also be written in the form

$$ Q = \frac{T^*}{A} \cdot \frac{H}{w} $$  \hspace{1cm} (3)

by letting $T$ be equal to $T^*$ where $A$ is the plan area of the aquifer in square feet, which is approximately equal to $W \cdot L$. The factor $T^*$ was determined by summing the products of the volume of the aquifer between two adjacent permeability isograms (Fig. 31) and the average permeability between these two lines. Using equation (3) the maximum safe yield of the Regina Aquifer estimated by Lissey (1963) was 5,500,000 Imperial gallons per day.

**Critical Appraisal of this Method of Safe Yield Determination**

The obvious points of criticism with regard to the method of safe yield determination, described in the previous section, concern the assumption of equilibrium, the calculations of permeability, and the assumed distribution of piezometric heads. The
third of these is considered by many present workers to be the
most serious limitation to this method.

The equilibrium assumption, that is of constant recharge
equalling discharge so that no change in aquifer storage occurs,
is invalid on the basis of the data presented in the section on
physiographic factors of ground-water recharge. Because most
recharge occurs only in the spring, the conditions governing the
natural flow of ground water in the Regina area vary between the
two extremes of (1) recharge exceeding discharge, hence an increase
in aquifer storage for a short period of time once each year, and
(2) no recharge but continuing discharge leading to a decrease
in storage for the rest of each year. Thus the rate of natural
ground-water flow and the distributions of piezometric heads are
not constant but fluctuate in an annual cycle. This fluctuation
casts some doubt on the reliability of the method used in the
safe yield calculation, since the method is predicated on
equilibrium conditions.

Permeability calculations from pumping tests suggest that
the unconfined portion of the Regina Aquifer is much more permeable
than the confined part. According to the mode of deposition there
should be no marked difference in permeability between these two
parts. The high permeability values calculated for the unconfined
part may be due to errors in the theory as applied to the pumping-
test data from this part of the aquifer. One possible source of
error may lie in the fact that the analytical methods used do not
account for the slow rate of expansion of the cone of depression
in an unconfined aquifer resulting from delayed yield from storage.
Complete gravity drainage of the interstices within the cone of
depression does not instantaneously accompany a head drop, while
such instantaneous drainage is one of the assumptions on which the
continuity equation, of which the Theis equation is a solution, is
based. If the analytical methods used to determine permeability
values are unreliable, then the method of safe yield determination,
which is based on these values, is also unreliable.
Although pumping tests in part of the confined portion of the Regina Aquifer indicated that water from confining beds is leaking into the aquifer, and results were analyzed with leakage taken into account to obtain reliable values of aquifer permeability, the method of safe yield determination that was used assumes all confining beds to be impermeable. If, however, leakage does occur when production pumping from the aquifer begins, this leakage will tend to increase the safe yield. Therefore, because the assumption of impermeable confining beds is invalid, the method of safe yield calculation is in error.

Meyboom (personal communication, 1962) suggested that, because the confining beds are to some extent permeable, the flow pattern and the distribution of piezometric heads across the Regina Aquifer would not be the same as the flow pattern and head distribution across a classical aquifer (Fig. 29). By deriving a complex equation to describe the head at any point in a theoretical basin underlain by homogeneous material of low permeability, Tóth (1963) calculated that the natural ground-water flow pattern across such a basin would be as shown in Figure 36. Meyboom (1963) indicates that an aquifer of higher permeability than the confining beds would distort Tóth's theoretical head distribution in such a way that natural ground-water flow within the aquifer would be essentially lateral, except in areas of recharge and discharge where vertical flow would predominate (Fig. 37). Flow in the classical aquifer, on which the proposed safe yield method is based, assumes linear flow in plan, which may not occur in an actual aquifer. Thus if the actual head distribution and natural flow pattern across a real aquifer are unlike those of the classical aquifer, the method of safe yield determination used may be unreliable.
THEORETICAL BASIN
FLOW & HEAD DISTRIBUTION

(after Tóth, 1963)
THE PRAIRIE PROFILE

Figure 37

(after Meyboom, 1963)
Corroboration of Safe Yield Method as Applied to Regina Aquifer

It is believed that the justifiable criticisms concerning the assumption of equilibrium, the calculation of permeabilities, the effects of leakage, and the assumed distribution of piezometric heads, do not completely invalidate the method of safe yield determination as applied to the Regina Aquifer by the author (1963). These criticisms do, however, indicate strict limitations to the method.

Although recharge is cyclic, the assumption of equilibrium is considered to be sound when applied to shallow aquifers, such as that at Regina, under certain limiting conditions. Tóth (1963, p. 85) stated that "***water levels at shallow depths are the most affected by seasonal recharge and discharge". In reply to a discussion of this paper by Wolbeer, Tóth stated that "The assumption of a steady state [equilibrium] condition is valid only when the long-term picture is considered [and that]*** an instantaneous configuration of flow may be different from that of the resultant, average flow pattern". Although the head distribution across the Regina Aquifer shown in Figure 32 is, indeed, an "instantaneous" one, it is believed to give an indication of the "resultant, average flow pattern". This belief is based on the fact that the annual precipitation recorded in the Regina-Jaw area during 1960 is close to the long-term average (Fig. 4 and Fig. 5) and also on the fact that heads were measured during the winter when the variation of head distribution from the average, due to seasonal fluctuations, should be at a minimum.

The differences in permeability between the confined and unconfined parts of the Regina Aquifer may be partially due to errors in the theory of the pumping-test analyses used, resulting in higher calculated permeabilities in the unconfined part; but they may also be partially due to the natural occurrence of lower permeabilities in the confined part because of aquifer compaction.
resulting from the additional weight of overlying confining beds. At the present time it is impossible to determine which of these two factors is dominant in creating this difference. Use of a complex equation derived by Boulton (1954b), which allows for the effects of delayed yield, would result in a more reliable determination of the permeability in the unconfined part of the aquifer than the method outlined by Walton (1960b). However, Boulton's equation contains two factors, in addition to the coefficients of permeability and storage, which depend on the physical properties of the aquifer, and which must be evaluated and tabulated for various parameters encountered in actual field tests before it can be used. Because tables for these factors are still in the process of preparation, Boulton's equation could not be used in this study and hence the amount of error, in the method of safe yield, introduced by any errors in theory cannot be presently determined.

Although leakage from confining beds during the initial stages of production pumping may be considerable, indicating that the safe yield might be greater than that calculated by the method presented here, recent studies by the author suggest that compaction of the confining beds would be induced by the head drop within the cone of depression thereby reducing the permeability of the confining layers with the result that leakage of water into the aquifer would eventually become negligible. To date, insufficient work has been done to indicate the length of time involved before leakage might become insignificant, but over a long period of time it is believed that the amount of leakage would not appreciably affect the safe yield.

While it is true that the distribution of piezometric heads across the Regina Aquifer may not be the same as that of the classical aquifer, the method of safe yield evaluation should still apply if the drop in piezometric head was measured across the transition zone between the areas of recharge and discharge where natural ground-water flow is essentially horizontal, and if this natural flow is linear in plan across the transition zone.
Figure 32 indicates that flow across the Regina Aquifer is essentially linear in plan. Because it is difficult to determine the exact boundaries of the recharge and discharge areas of the Regina Aquifer from available data, the head drop across the transition zone cannot be determined exactly. Although the value for $\Delta H$ of seven feet per mile, which was used to determine the safe yield of the aquifer, was measured across the entire aquifer, this value proved reasonable when checked with the head drop across a small part of the aquifer suspected to be within the actual transition zone.

CONCLUSIONS

The suggested method of safe yield determination is based on many assumptions, but it is believed to be applicable where the following limitations are met:

(1) The instantaneous head distribution is measured during the winter of a year receiving average precipitation, after a period of no pumping, so that the head distribution across the aquifer will be similar to that occurring under natural, long-term, average conditions.

(2) The value of $\Delta H$ is measured across an area where natural flow is horizontal and equipotential lines are vertical.

(3) Natural flow across the transition zone is linear in plan.

(4) Leakage from confining beds is insignificant.

(5) The physical dimensions of the aquifer are well defined.
(6) Local average permeabilities are accurately determined from pumping tests.

In the Regina Aquifer most of these limitations were met either fully, or at least in part. However, in addition to these the actual calculation procedure used to determine the safe yield was to employ the average area-weighted transmissibility and a value of \( \frac{\Delta H}{W} \) measured across the entire transition zone. It is suggested that the resultant figure for the safe yield of 5,000,000 Imperial gallons per day should prove to be a reasonable estimate.
REFERENCES CITED


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App, 1960b, Application and limitation of methods used to analyze pumping test data: Water Well Jour., v. 14, no. 2.


Pumped Well TH6-162
Observation Well No. 1 TH10-B161
Observation Well No. 2 TH10-B161

<table>
<thead>
<tr>
<th>Screened Interval</th>
<th>162' - 177'</th>
<th>152' - 177'</th>
<th>115' - 120'</th>
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</thead>
<tbody>
<tr>
<td>Reference Point</td>
<td>Pump Base</td>
<td>Top of Casing</td>
<td></td>
</tr>
<tr>
<td>Water Level</td>
<td>Air line</td>
<td>Electric Tape</td>
<td>Chalked Tape</td>
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<td>Stainless Steel</td>
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</tr>
<tr>
<td>Pump</td>
<td>Peerless Turbine with right-angle drive, 5 stages, 5-5/8&quot; Bore</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor</td>
<td>Wisconsin air-cooled, 4-cylinder, 37 hp Model V44D with clutch and universal gear box</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SE6-18-20W2
Completion and Pump Test Data for Pumped and Observation Wells

Pump test 1
Observation Well 1; r = 220 ft (THH-B-16)

Pumping test on TH6-H62,5554-20W 2
on Regina Aquifer
Test conducted by City of Regina Hydrology
Division
Test started 11:15 a.m., May 8, 1962
Q = 2000 I q.p.m.
T = 220 ft
Static Water Level = 44-55 ft
Test analysis by A. Lister according to
Wenzel, 1942

T = 67,500 I q.p.d./ft
s = 2.42 x 10^3

Pump test 1
Pump Test 3-H61

Completion and Pump Test Data for Pumped and Observation Wells

**TH3-H61 (Pumped Well)**
- **TH8-B16I:** NW33-17-20W2
- **TH7-B16I:** NW27-17-20W2

**Observation Wells**
- **TH3-H6:** TH8-TH10-TH7

<table>
<thead>
<tr>
<th>Well</th>
<th>Static Water Level</th>
<th>Screen Interval</th>
<th>Screen Details</th>
<th>Reference Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH3-H6</td>
<td>49.5'</td>
<td>137'</td>
<td>Johnson Stainless Steel</td>
<td>casing</td>
</tr>
<tr>
<td>TH8</td>
<td>49.5'</td>
<td>144.5'</td>
<td>Johnson Stainless Steel</td>
<td>collared</td>
</tr>
<tr>
<td>TH10</td>
<td>49.5'</td>
<td>152.5'</td>
<td>Johnson Stainless Steel</td>
<td>collared</td>
</tr>
<tr>
<td>TH7</td>
<td>49.5'</td>
<td>122.5'</td>
<td>Johnson Stainless Steel</td>
<td>collared</td>
</tr>
</tbody>
</table>

**Measurements**
- **Top:** 149-5'
- **Bottom:** 144-5'
- **Reduction Coupling:** 130'
- **Reducer Coupling:** 135'

**Additional Details**
- **Steel Casing Collar Joint:** 1'05
- **Reduced Coupling:** 0.025" slot opening
- **Screen:** 131-144.5' - 117-130-122'-135'-132'
- **Telescopic Joint:** 8/0.25" Fitt T' Ball Bottom
- **Fig T' Bell Bottom:** 152.5'
- **Flow Measurement:** 6" x 4" Orifice with gate valve to maintain rate of 332 LPM.
Steady State Leaky Artesian
Method of Analysis
Pumping Test on THB: HG-1, NW3-62-2002
on Regina Aquifer
Test conducted by City of Regina
Hydrology Div.
Test started 10:30 a.m. Nov. 16, 1981
Q = 35.6 l.p.m
T = 800 minutes
Test analysis by J. L. Barry, according to
J., 1946

Pump Test 2

(1) Distance in feet from Pumped Well

(2) Observation Well L = 150 ft (THB: BL 61)

Pumping Test on THB: HG-1, NW3-62-2002
on Regina Aquifer
Test conducted by City of Regina Hydrology Div.
Test started 10:30 a.m. Nov. 16, 1981
Q = 35.6 l.p.m
T = 800 minutes
Test analysis by J. L. Barry, according to
J., 1946, using These Non-equilibrium
Method

T = 15,000 l.p.m

Pump Test 2
Completion and Pump Test Data for Pumped and Observation Wells

TH8-B.61
NE35-117-20W2

Pumped Well
TH4-6.61

TH9-B.61
SW3-I-20W2

Pump Test 4 - H.61, Dec. 6-7/61

PUMP TEST DATA

<table>
<thead>
<tr>
<th>Pumped Well</th>
<th>TH7-B.61</th>
<th>TH8-B.61</th>
<th>TH9-B.61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Water Level</td>
<td>49'</td>
<td>46.68'</td>
<td>49.34'</td>
</tr>
<tr>
<td>Screened Interval</td>
<td>157-6-1726</td>
<td>127-132</td>
<td>104-5-1095</td>
</tr>
<tr>
<td>Screen Details</td>
<td>Johnson Stainless Steel</td>
<td>Telescopic Drivepoint</td>
<td>6'0.D, 2'6 Pipe Thread</td>
</tr>
<tr>
<td>Reference Point</td>
<td>Top of Casing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Level Readings</td>
<td>Airline Electric Tape Wetted Tape</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump</td>
<td>Peerless Turbine with Right-Angle Drive Head, 5 stages, 5-5/8 Bowls</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor</td>
<td>Wisconsin Air Cooled, 4 Cylinder, 37 H.P. Model VO4D with Clutch &amp; Universal Drive to Pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Measurement</td>
<td>6&quot;x4&quot; Orifice with Gate Valve to maintain a Constant Rate of 290 G.P.M.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bedrock 699' G.D.

1987.32' G.D.

Ground Level

1867.61' G.D.

Lake Clay

Fine Sand & Gravel 42' Lake Clay

1967.64' G.D.

Welded Joint: Adapter, Stainless Steel, 10' 57/8' Threaded Joint

25 slot Screen

Reducer Coupling 130'

1932' G.D.

25 slot Screen

Sand & Gravel

1949' G.D.

25 slot Screen

192.6' G.D.

Fig.1'Bail Bottom

157.6-1726' G.D.

Reducer Coupling

132'

144.5' G.D.

25 slot Screen

149.5' G.D.

Screened Interval 157-6-1726 127-132 104-5-1095 130-135'
Completion and Pump Test Data for Pumping and Observation Wells

PUMPED WELL

Geodetic Elevation

Ground Level = 0'

149'

5-1/2” OD Inserted Joint Casing

147'

5-1/2” OD Inserted Joint Casing

5-1/2” OD Inserted Joint Casing

5-1/2” OD Inserted Joint Casing

Screened Interval 139’-144’

4” Johnson Everdur Telescopic Screen

0.025” Slot Opening

Screened Interval 139’-144’

2” OD Johnson Everdur Drivepoint

0.025” Slot Opening

Screened Interval 139’-144’

Total Depth of Hole

147’

146’

145’

144’

143’

142’

141’

140’

139’

138’

137’

136’

135’

134’

133’

132’

131’

130’

129’

128’

127’

126’

125’

124’

123’

122’

121’

120’

119’

118’

117’

116’

115’

114’

113’

112’

111’

110’

109’

108’

107’

106’

105’

104’

103’

102’

101’

100’

99’

98’

97’

96’

95’

94’

93’

92’

91’

90’

89’

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87’

86’

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84’

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78’

77’

76’

75’

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72’

71’

70’

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68’

67’

66’

65’

64’

63’

62’

61’

60’

59’

58’

57’

56’

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54’

53’

52’

51’

50’

49’

48’

47’

46’

45’

44’

43’

42’

41’

40’

39’

38’

37’

36’

35’

34’

33’

32’

31’

30’

29’

28’

27’

26’

25’

24’

23’

22’

21’

20’

19’

18’

17’

16’

15’

14’

13’

12’

11’

10’

9’

8’

7’

6’

5’

4’

3’

2’

1’

0’

Silt Water Level

49’8"

Screened Interval 139’-144’

2” OD, 25 slot Telescopic Screen

Flow Measurement

4” x 2 1/2” orifice

Gate valve in discharge

time to maintain constant

937 US gpm or 751 gpm

Pump test 4
TH 6-Br60 NW 35-17-20 W2
Completion and Pump Test Data for Pumped and Observation Wells

PUMP TEST DATA

<table>
<thead>
<tr>
<th>Pumped Well</th>
<th>Observation Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Water Level</td>
<td>55'</td>
</tr>
<tr>
<td>Aquifer Type</td>
<td>Artesian</td>
</tr>
<tr>
<td>Screened Interval</td>
<td>125'-135'</td>
</tr>
<tr>
<td>Water Level Drop</td>
<td>Direct Reading</td>
</tr>
<tr>
<td>Joint Casing</td>
<td>Johnson Everdur Drivepoint</td>
</tr>
<tr>
<td>Reference Point</td>
<td>Ground level</td>
</tr>
</tbody>
</table>

Pump: Fairbanks-Morse Pomona 'Little Chief' Turbine

- Pump column length: 125'
- Bottom of suction: 122'
- Bowl size: 3-3/4' O.D.
- Power: IHC 4 cylinder, 4 cycle 27 HP gasoline motor with clutch and V-belt drive to pump.

Flow Measurement: 4'X2'Z orifice
- Gate valve in discharge line to maintain constant rate of 92 USgpm or 76.5 lgpm.

Pump test 5

(1) Time since pumping started in minutes

OBSERVATION WELL:

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Flow (gpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Pumping test on TH 6-Br60, NW 35-17-20 W2
on Region A Aquifer.
Test conducted by City of Regina Hydrology

Test started 8:00 A.M., Sept. 25, 1960
Q = 74.5 Gpm
P = 100 ft
Static Water Level = 55'2"
Test Analysis by A, L., Iles, according to
Walton 1960 A

Pump test 5
Pump test 6

Completion and Pump Test Data for Pumping and Observation Wells

<table>
<thead>
<tr>
<th>PUMPED WELL</th>
<th>OBSV. WELL No.1</th>
<th>OBSV. WELL No.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Water Level</td>
<td>52'-7&quot;</td>
<td>58'-0&quot;</td>
</tr>
<tr>
<td>Aquifer Thickness</td>
<td>12'-0&quot;</td>
<td>12'-0&quot;</td>
</tr>
<tr>
<td>Aquifer Type</td>
<td>Artesian</td>
<td>Artesian</td>
</tr>
<tr>
<td>Screened Interval</td>
<td>190'-200'</td>
<td>192'-207'</td>
</tr>
<tr>
<td>Screen Type</td>
<td>4'-Telescopic</td>
<td>2-1/2'-Spraypoint</td>
</tr>
<tr>
<td>Screen Size</td>
<td>0.025 slot</td>
<td>0.025 slot</td>
</tr>
<tr>
<td>Water Level Readings</td>
<td>Direct reading air-line gauge (Fisher M-Scope)</td>
<td>Electric tape</td>
</tr>
<tr>
<td>Reference Point</td>
<td>Ground level</td>
<td>Casing top</td>
</tr>
<tr>
<td>Pump Data Type</td>
<td>Turbine (Fairbanks-Morse Pumping Little Chief)</td>
<td></td>
</tr>
<tr>
<td>Slides</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Bottom of Suction</td>
<td>152'-4&quot;</td>
<td></td>
</tr>
<tr>
<td>Pump Column Length</td>
<td>154'-6&quot;</td>
<td></td>
</tr>
<tr>
<td>Bowl Size</td>
<td>3.3'-4&quot;</td>
<td></td>
</tr>
<tr>
<td>Powered by</td>
<td>4-cylinder 4-cycle 4-stroke 27 HP gas motor with clutch and V-belt drive to pump</td>
<td></td>
</tr>
<tr>
<td>Flow Measurement</td>
<td>2-1/2'- orifice</td>
<td>Side valve in discharge line to maintain constant 65 USgpm or 542 gpm</td>
</tr>
</tbody>
</table>

Pump test 6
Pump test 6
T.H.I-P61 NW24-17-2OW2
Completion and Pump Test Data for Pumped and Obs. Wells

PUMPED WELL OBSERVATION WELL

PUMPED WELL DATA

Static Water Level 53' 57'
Aquifer Thickness 30' 25'
Aquifer Type Artesian Artesian
Screened Interval 170'-95' 177'-182'
Screen 6" D. S. 25, 28 slot 2 1/2", 25 slot
Telesteptic Johnson et Sud Drivepage

OBSERVATION WELL DATA

Water Level Reading Air Line Gauge 1/4 Copper of line Electric type
Reference Point Ground Level Casing top

Pump: Peerless Turbine with Right Angle Drive Head 9 Stages (20 of Pump Column Suction end at 117', Bowl Sizes 5'-6')
Powered by Hercules 3 Cylinder, 4 stroke, 45 H.P.
Gasoline motor with clutch and Universal Drive to Pump
Flow Measurement: 6" orifice
Gate Valve in discharge line to maintain constant rate of 395 USgpm or 329 Ipm

Pump test 7
Completion and Pump Test Data for Pumped and Observation Wells

PUMP TEST DATA

<table>
<thead>
<tr>
<th></th>
<th>Pumped Well</th>
<th>Observation Well</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Water Level</td>
<td>125.4'</td>
<td>126.2'</td>
</tr>
<tr>
<td>Aquifer Thickness</td>
<td>63'</td>
<td></td>
</tr>
<tr>
<td>Screened Interval</td>
<td>160'-170'</td>
<td>167.5'</td>
</tr>
<tr>
<td>Water Level Readings</td>
<td>Direct reading air line</td>
<td>Electric tape</td>
</tr>
<tr>
<td>Reference Point</td>
<td>Ground level</td>
<td>Casing top</td>
</tr>
</tbody>
</table>

Pump: Fairbanks Morse "Pomona" Little Chief Turbine
13 stages, bowl size 3-3/4", 160 Pump Column
Powered by "Dana" 2 cylinder, 4-cycle, air-cooled
161 HP gas motor with V-belt drive to pump

Flow Measurement
4" 2-1/2 orifice, Gate valve in discharge line to maintain constant rate of 100 US gpm, or 833 gpm

Pump test 8
PUMPED WELL
TH3-1959

OBSERVATION HOLE

Ground Elevation
Top Soil
Lake Clay
45
Sand with Clay
104'6" Casing
104'6" Layne Shutter
112'

Approx.
112' 3/2" Casing

104'6" Casing

PUMP TEST DATA

<table>
<thead>
<tr>
<th>WELL</th>
<th>PUMPED WELL</th>
<th>OBS. WELL</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATIC WATER LEVEL</td>
<td>89-42'</td>
<td>89-46'</td>
</tr>
<tr>
<td>AQUIFER TYPE</td>
<td>Water</td>
<td>Table</td>
</tr>
<tr>
<td>AQUIFER THICKNESS</td>
<td>112'</td>
<td>112'</td>
</tr>
<tr>
<td>SCREENED INTERVAL</td>
<td>104'-114' approx 107'-112'</td>
<td>2&quot; slotted pipe</td>
</tr>
<tr>
<td>SCREEN DETAILS</td>
<td>104'6&quot; Layne Bronze Shutter</td>
<td>2&quot; slotted pipe</td>
</tr>
<tr>
<td>WATER LEVEL READINGS</td>
<td>Air Line Electric Tape</td>
<td></td>
</tr>
<tr>
<td>REFERENCE PT</td>
<td>Ground Level Casing Top</td>
<td></td>
</tr>
<tr>
<td>FLOW MEASUREMENT</td>
<td>150 10 P.M.</td>
<td></td>
</tr>
</tbody>
</table>

PUMP TEST AT ALBERT ST. RESERVOIR
NOVEMBER, 1959

Pump test 9

Pumping Test on TH 3-106, Wk 12B-20, W2
Observation Well 1
T=50 FT.
AQUIFER TESTED: Original Aquifer
Test Conducted by International Water Supply
Test Started at 8:00 am Nov. 1, 1959
Q = 150 G.P.M.
T = 175,000 - 1,200 G.P.D.
S = 0.96
AQUIFER TESTED: Original Aquifer
Test Conducted by International Water Supply
Test Started at 8:00 am Nov. 1, 1959
Q = 150 G.P.M.
T = 175,000 - 1,200 G.P.D.
S = 0.96

Pump test 9
Observation Well 2
Observation Well 1
Pumped Well 1
Production Well R2
Albert St. Reservoir

Pumped Well 2
Observation Well No.1
Observation Well No.2
Observation Well No.3

<table>
<thead>
<tr>
<th>Pumped Well</th>
<th>Observation Well No.1</th>
<th>Observation Well No.2</th>
<th>Observation Well No.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Water Level</td>
<td>95.55'</td>
<td>92.56'</td>
<td>95.05'</td>
</tr>
<tr>
<td>Screen Interval</td>
<td>106'-116'</td>
<td>104'-116'</td>
<td>106'-111'</td>
</tr>
<tr>
<td>Ref. Level</td>
<td>CASING</td>
<td>TOP</td>
<td>CASING</td>
</tr>
<tr>
<td>Water Level Reading</td>
<td>NIL</td>
<td>CHALKED</td>
<td>T APE</td>
</tr>
<tr>
<td>Screen Details</td>
<td>Layne Shutter</td>
<td>Slotted Casing</td>
<td>Non-Slip Driveway</td>
</tr>
<tr>
<td>Pump</td>
<td>Johnson Turbine with Right Angle Drive Head</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>R.A. Lister 3 cylinder Diesel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow</td>
<td>260 g.p.m.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen Johnson</td>
<td>Slotted Casing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well</td>
<td>Steel Casing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6&quot; D. Black Steel Casing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layne Shutter Screen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump Shanp Size</td>
<td>6&quot; D. Black Steel Casing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen Johnson Details</td>
<td>Pump Shanp Size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Casing</td>
<td>Slotted Casing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Casing</td>
<td>Non-Slip Driveway</td>
<td></td>
<td></td>
</tr>
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</table>

Pump test 10

-83-
### SUMMARY OF PUMPING TEST DATA

<table>
<thead>
<tr>
<th>Part of Aquifer</th>
<th>Test no.</th>
<th>Solution method</th>
<th>Permeability (I.g.p.d./ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confined</td>
<td>1</td>
<td>Theis type-curve</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>&quot; &quot; &quot; &quot;</td>
<td>2800</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>&quot; &quot; &quot; &quot;</td>
<td>1120</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Walton leaky artesian type-curve</td>
<td>622</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>&quot; &quot; &quot; &quot; &quot;</td>
<td>1390</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>&quot; &quot; &quot; &quot; &quot;</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>&quot; &quot; &quot; &quot; &quot;</td>
<td></td>
</tr>
<tr>
<td>Unconfined</td>
<td>8</td>
<td>Walton application Theis type-curve</td>
<td>815</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>&quot; &quot; &quot; &quot; &quot;</td>
<td>6230</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>&quot; &quot; &quot; &quot; &quot;</td>
<td>5500</td>
</tr>
</tbody>
</table>
APPENDIX B
### ANALYSES OF WATER IN THE REGINA AREA

(Results in parts per million)

<table>
<thead>
<tr>
<th>FORMATION OR Aquifer</th>
<th>WELL</th>
<th>LOCATION</th>
<th>DEPT. SAMPLED</th>
<th>TOTAL SOLIDS</th>
<th>HARDNESS</th>
<th>ALKALINITY</th>
<th>CATIONS</th>
<th>ANIONS</th>
<th>Source/Analyst</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regina Aquifer</td>
<td>NE19-17-19</td>
<td>City of Regina Park</td>
<td>NE19-17-19</td>
<td>159-169</td>
<td>Ca: Mg:</td>
<td>HCO3</td>
<td>Ca: Mg:</td>
<td>Cl: SO4:</td>
<td>Andrews &amp; Cruick</td>
</tr>
<tr>
<td>Do.</td>
<td>NE30-17-19</td>
<td>City of Regina PW #14</td>
<td>NE30-17-19</td>
<td>159-159</td>
<td>Ca: Mg:</td>
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<td>Ca: Mg:</td>
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## Analyses of Water in the Regina Area

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