THE WATER SUPPLY CAPACITY
OF THE WINKLER AQUIFER

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The Winkler Aquifer is the sole source of water for the 5900 people and industries that reside in the Town of Winkler, Manitoba. The aquifer consists of a buried elongated glaciofluvial sand and gravel deposit. This deposit is 17 miles long, has thicknesses up to 200 feet and widths varying from three miles at the base to less than one mile near the crown. The deposit underlies an area of some 47 square miles. Of this area only two hundred acres can be considered unconfined. The upper segments of the sand and gravel contain potable water with total dissolved solids values between 500 and 1000 mg/l. The lower segments contain brackish to saline water with total dissolved solids values up to 10,000 mg/l. The transmissivity of the aquifer varies from 100,000 to 380,000 USgallons/ft/day in the thick core of the aquifer to 1000 USgallons/ft/day along the thin fine grained outer basal fringes. The specific yield in the unconfined area is 0.25. The storage coefficient ranges from 0.01 to 0.0001 in the confined part. The present recharge rate is in the order of 300 acre feet per year. The municipal water development commenced in 1953 and has steadily increased since that time. This development, combined with private water usage from the aquifer, has resulted in a withdrawal rate of some 1000 acre feet per year. This means the fresh stored water is being nined from the aquifer at a rate of 700 acre feet per year. The rate of usage increase is some 40 acre feet per annum. Withdrawal rates exceeding recharge have resulted in an average yearly decline in the potentiometric surface of 0.7 feet over the past eighteen years. In addition to the decline in the potentiometric surface saline water from the underlying sandstone rock is infiltrating the lower sections of the aquifer at a rate of 230 acre feet per annum. Consequently water quality, particularly in the lower sections of the aquifer, has deteriorated. The aquifer contains some 170,000 acre feet of fresh water. Assuming half this water can be recovered it could supply Winkler’s water requirements at the current projected rate of usage for at least 50 years.
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1 INTRODUCTION

The Winkler aquifer system consists of an elongated thick sand and gravel unit that extends southeast and northwest of the Town of Winkler (Fig. 1). Fresh water which rests on brackish water in the lower parts of the aquifer is the sole source of water supply for the 5900 people and industries that reside in the Town. Therefore the capacity and management of the aquifer is of considerable economic importance to the area. The objective of this paper is to describe the hydrogeology, water supply capacity, and water quality relationships of the Winkler Aquifer and to address future aquifer development considerations.

2 PREVIOUS INVESTIGATIONS

The Winkler Aquifer was first investigated in 1960 as a source of water for the Town of Winkler. Previously water had been obtained from the sand and gravel deposit by means of private wells for water supplies within the Town. Due to the nature of the well construction the water was usually brackish or saline. Several flowing wells were present in the area, particularly south of Winkler.

During the early 1960's the Water Resources Branch carried out test drilling and sites for initial fresh water wells were selected to the northwest of the Town (Fig. 2). In 1962 the Geological Survey of Canada performed test drilling in the Winkler area and carried out a pumping test in the southeast corner of Sec. 36 - Twp. 3 - Rge. 5, WPM. (Charron 1962). The Geological Survey also carried out test drilling programs in 1966 and 1967. During the interval since the early stages of development various test drilling and observation well construction activities have been undertaken. The last significant activities were the installation of five water level observation wells by the PFRA in 1981; and the undertaking of an extensive water quality observation well program in 1989 - 1990.

3 DEVELOPMENT HISTORY

The major pumping from the aquifer commenced in 1963 when two wells were installed northwest of the Town by the Manitoba Water Supply Board (Fig. 2). These wells are pumped at the low rate of 50 gallons per minute or less in order to minimize drawdown and the consequent tendency
of saline water in the lower section of the aquifer to rise towards the well intakes. During 1967 another Town well was installed. In the summer of 1970 a farmer commenced pumping for irrigation from a gravel quarry pond in the north end of the aquifer. Three more wells were installed in 1968 and two more in 1981. By 1990 the Manitoba Water Services Board had eight wells operating for the Town and four community wells for the surrounding municipalities. During 1989 a major change in well construction occurred when a large capacity well capable of pumping over 1000 gpm was installed in the northern section of the aquifer. The pumping rate for this well has been reduced to 200 gpm to retard saline water contamination. The total water usage is shown on figure 3. The Town wells pump 650 acre feet per annum. The current estimated rate for the community wells is 50 acre feet. The irrigation farm reported an average rate of 119.54 acre feet per year for irrigation for the first five years of the 1980's. It is estimated to pump over 260 acre feet during drought years. This accounts for the peak water usage from the aquifer during 1988. It is estimated that several livestock farms in the area withdraw another 40 acre feet. Thus the current total annual withdrawal estimate is in the order of 1000 acre feet. If the water usage continues to increase at the current long term rate of 40 acre feet per year the withdrawals will rise to 1800 acre feet by 2010 and 3000 acre feet by 2040.

4 TOPOGRAPHY

The Winkler aquifer is situated along the forefront of the Manitoba Escarpment. Near the Town of Winkler the land surface rises westward at approximately twenty feet to the mile. The land slope rises rather dramatically six miles west of the aquifer at the Manitoba Escarpment. (Fig. 1). In general the land over the aquifer is devoid of topographic variations being a uniform lake bottom plain. The only significant variations are those formed by creek channels.

5 GEOLOGY

5.1 Regional Geology

The bedrock under the Winkler Aquifer consists predominantly of Mesozoic shale with minor sandstone units and a few carbonate rock beds (Figs. 4 and 5). The Mesozoic rocks are some 200 feet thick under the aquifer and increase in thickness to some 1000 feet under the Manitoba Escarpment. The rock bedding slopes towards the west southwest into the Williston structural basin at approximately 15 feet to the mile. The shale rock units rest on Paleozoic, Silurian and Ordovician carbonate rocks (Davies et al 1962).
The bedrock surface is overlain by clay-rich till that ranges in thickness from a thin veneer along the upper sections of the Manitoba Escarpment where it is often exposed in bedrock outcrops, to over 300 feet in depressions in the bedrock surface east of Winkler (Fig. 6). The till which has a mean thickness in the order of 100 feet in the vicinity of Winkler, contains lenses and zones of glacioluvial sand and gravel. The largest of these form the Winkler Aquifer system.

East of the Manitoba Escarpment area the glacial till is covered by lacustrine clay that formed while glacial Lake Agassiz inundated the area. The clay thickness ranges from zero along the Manitoba Escarpment to 150 feet thick in the vicinity of Winkler. West of the Winkler area the clay unit is overlain by beds of sand and silt that appear to follow old shallow stream channels and rills in the clay lake bed surface. These units are up to 20 feet thick. The surficial sand and silt beds tend to phase out east of Winkler. During the history of Lake Agassiz several sand and gravel beach deposits were formed along the front of the Manitoba Escarpment.

5.2 Winkler Aquifer Geology

The Winkler Aquifer system consists of a sand and gravel unit that rests predominantly on Mesozoic shales of the Melita and Swan River Formations (Fig. 5). The shale units generally contain minor sandstone and carbonate rock beds. However, the Swan River Formation contains a 36 foot thick section of fine grained sandstone. This unit is correlated with similar sandstone beds that outcrop near Swan River, Manitoba and with the Dakota Sandstone to the south in the United States. Thus the sandstone beds in the vicinity of the Winkler Aquifer are part of an extensive system (Rutulis, 1984).

As depicted on the profile (Fig. 7) glacial till has been detected under the gravel at some places. At other locations the sand and gravel are in contact with shale or sandstone (Fig. 5). The occurrence of saline water in the lower parts of the unit and the fact the observation wells constructed into the Swan River Sandstone in 1989 show a direct response to water level changes in the Winkler Aquifer strongly suggest that the aquifer is in direct contact with the sandstone.

The deposit has a mean configuration of one mile wide by 150 feet thick, by 17 miles long (Figs. 5, 7 and 8). The cross-section (Fig. 5) depicts the northern configuration while the hydrogeologic profile, (Fig. 7), illustrates the north-south structure of the aquifer. The mound of sand and gravel which has a volume of some 70 billion cubic feet is generally overlain by substantial thicknesses of clay, silt and till, (Fig. 9).

At the north end the aquifer is overlain at surface by fine sand and silt that covers an area of
approximately two square miles. Test drilling during 1990, (Fig. 10) showed that only 200 acres of this area was directly open to the main sand and gravel body. The remainder is underlain by various thicknesses of glacial till and at some places lacustrine clay.

West of the aquifer the bedrock surface (Fig. 6) rises steeply to an upland plain called the Pembina Escarpment. Along the escarpment and in the upland area many exposures of shale bedrock occur. Gently under the aquifer the bedrock surface forms a shelf several miles in extent. Two miles east there is a valley in the bedrock surface some 200 feet deep. Klassen et al. (1970) postulate this bedrock surface low is part of a buried valley system that extends northerly and south-easterly.

The lower sand and gravel unit is situated against the western outside wall of the buried valley. The deposit rests on shale or glacial till. The bottom of the unit is some 200 feet lower than the base of the upper member (Fig. 5). Though coarse sand and gravel have been intercepted most logs suggest this unit is composed of fine sand. At some places the total thickness of the deposit is in the order of 200 feet. Test holes put down in 1989, indicate that the groundwater in these deposits is of poor quality and the hydraulic conductivity of the sediments is low. The feature is overlain by glacial till and a one hundred foot thick layer of lacustrine clay. This aquifer zone is not considered further in this paper.

6 HYDROGEOLOGY

The aquifer consists of the saturated elongated deposit of sand and gravel (Fig. 8). Except for a small area of some 200 acres at its north end the aquifer is confined by overlying till and clay. Thus, the aquifer has a very small direct infiltration area in the classic sense. In the exposed segment of the aquifer the Deadhorse Creek and to a lesser extent the Shinnon Creek interact with the aquifer.

6.1. Groundwater Levels and Potentiometric Surface

Over the past two decades a water level and quality monitoring network has been developed (Fig. 12). Currently the depth to water in wells within the deposit is generally fifteen feet from ground surface. The water levels have generally been in a state of decline since 1972 (Fig. 3). The potentiometric surface slopes from the north towards the south (Fig. 11).
6.2. **Hydraulic Properties**

Pumping tests have generally only been done on single wells. However the Geological Survey of Canada performed a multi-well test (Fig. 10) near the northern thickest portion of the aquifer (Charron 1967). The geology of the site (test hole 8F, Charron 1962) strongly suggests that the aquifer at the site is unconfined. Based on this premise interpretation of the data indicates that the transmissivity at the site was 380,000 USgal/ft/day. Considering that the area affected by the test probably has an average saturated thickness of 200 feet (Fig. 8) the apparent hydraulic conductivity is 1900 USgal/ft/day. This value is in the range for coarse clean sand and gravel. The specific yield is in the order of 0.20.

Depending on the grain size of the soil and the thickness of the aquifer the transmissivity over the whole aquifer could range from 1000 to 380,000 USgal/ft/day. In the thicker northern sections of the aquifer the transmissivity values based on well construction data are in the range of 100,000 to 330,000 USgal/ft/day. In the central sections of the aquifer, near Winkler, the transmissivity is in the order of 100,000 USgal/ft/day. The transmissivity for the southern sections of the aquifer has not been evaluated. However as the aquifer is thinning in that direction the transmissivity will almost certainly be decreasing. The storage coefficient values should range from 0.01 to 0.0001. The specific yield should be in the range 0.01 to 0.25.

7 **GROUNDWATER CHEMISTRY**

Water quality in the bottom section of the aquifer, particularly where it rests on the Swan River Formation is generally brackish to saline having total dissolved solids up to 10,000 mg/L. This feature of the aquifer has a paramount influence on all groundwater development activities.

The water quality in the aquifer varies both with depth and from north to south (Figs. 12 and 13). Water quality in the northern recharge area is excellent; having total dissolved solids less than 500 mg/L. However even under the northern recharge area at depths of 180 to 200 feet the total dissolved solids values can exceed 4000 mg/L and chloride ion concentrations are over 1500 mg/L. In the upper zones of the aquifer varying from the upper 150 feet in the north to the upper 50 feet in the confined southern segments the total dissolved solids vary from under 500 to 2000 mg/L and the chloride ion concentration vary from under 10 in the north to 300 mg/L in the south.
7.1 Effects of Pumping on Water Quality

The aquifer water quality tends to deteriorate adjacent to pumping wells. An example is the deterioration in water quality at depth with relationship to the relatively high capacity 1989 Town well (Fig. 14). Despite the quality deterioration at depth with the reduction of the pumping rate the production water stabilized at 1100 micromhos. This is due to the large amount of fresh water entering the screen mixing with a relatively small amount of brackish water. In considering the ionic increases it must be remembered that the observation wells are located inside the pumping well's drawdown cone and therefore the water quality deterioration is likely localized.

While most of the chemical observation wells are close to a Town pumping well, observation well No. 4 is located some 300 feet from a pumping well. The intake zone for this well is some 180 feet below ground level in the lower section of the aquifer. A hydrograph of the electric conductivity of the water (Fig. 15) shows that the water quality is slowly deteriorating.

7.2 Volume of Fresh Water Stored in the Aquifer

During the autumn of 1990 seven water profile lines were established across the aquifer (Fig. 16). These contain 24 wells constructed at various depths in the aquifer. The design of one of the water quality observation nests is shown in (Fig. 17). Some of the water quality relationships established by these wells are shown on (Figs. 18, 19 and 20). For example a one foot thickness of section (Fig. 18) contains 4.5 acre feet of potable water. The water quality profile (Fig. 12) illustrates the changes in water quality along the aquifer longitudinal axis. A volumetric interpretation of the 7 cross-sections and the profile indicates there are 170,000 acre feet of water with an electric conductivity of less than 1500 microsiemens stored in the aquifer.

7.3 Age of the Water Stored in the Aquifer

Oxygen isotopes values were obtained on the water from several of the piezometers Table 1. These data indicate that considerable portions of the southern and lower sections of the aquifer water are relatively light (values of -17.00 or less) and were probably emplaced during the melting of the last glaciers, (Fig. 21). The upper water at the northern end of the aquifer has infiltrated in the last few hundred years. This is consistent with the limited area for recharge and the fact that until 1963 there was very little downward gradient even under most of the recharge area.
<table>
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<th>Observation Well</th>
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<th>(^{18}O_{SMOW})</th>
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</thead>
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<tr>
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<td>75'</td>
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</tr>
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<tr>
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<td>WA90-Q5</td>
<td>160'</td>
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<tr>
<td>WA90-Q6</td>
<td>100'</td>
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<td>WA90-Q7</td>
<td>100'</td>
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<td>WA90-Q8</td>
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</tr>
<tr>
<td>WA90-Q9</td>
<td>100'</td>
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<tr>
<td>WA90-Q10</td>
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</tr>
<tr>
<td>WA91-1</td>
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</tr>
<tr>
<td>STANLEY 1976</td>
<td>71.5'</td>
<td>-15.98</td>
</tr>
</tbody>
</table>
RECHARGE RELATIONSHIPS

The most obvious source of fresh water replenishment for the aquifer is the gravel quarry at the north end. This quarry which covers some 30 acres is estimated to contribute 19 acre feet per year as the net value between precipitation and evaporation.

The next most direct route for replenishment to the aquifer is the small zone of sandy thin overburden that covers the northern end of the aquifer. This is deemed to consist of two zones. The first is an area of 200 acres of silt and fine sand that directly overlies the aquifer (Fig. 22). The average infiltration rate for the test sites shown was one inch per hour. This rate is greater than the rate of nearly all precipitation events. If the fifteen year mean discharge rate of 0.199 feet per annum for the Upper Pine Creek Basin (Render, 1984) with similar soil and hydraulic conditions, can be assumed for the area of direct infiltration, then 22 acre feet of water would accrue to the aquifer on a long term annual basis.

The second zone surrounds the primary zone and has an effective area of about 0.8 square miles. Even though the upper sand in this area is underlain by till it still has a high infiltration rate and ability to store water so that it has time to seep into the aquifer. Therefore the recharge rate for this secondary area is estimated at 55 acre feet.

The third zone has a silt clay cover that ranges up to 10 feet thick (Fig. 9). Under even small gradients the infiltration rate for this zone would be close to that for the silt and fine sand area. Therefore the rate of 0.199 feet of water per annum was also used for this area of one square mile. Under this assumption the portion of recharge from this zone would be 70 acre feet.

b.1 Induced Recharge Through The Clay

Once the water levels in the aquifer started receding below the water table at some 273 m a.s.l. downward infiltration through the clay zone started. The leakage through the clay directly increased as the water levels declined. Currently the potentiometric surface averages 15 feet below the water table (the average water table depth being assumed at 5 feet below ground level). The clay cover thickness and shape are known (Fig. 9). The vertical hydraulic conductivity of the clay based on it being one tenth the mean horizontal clay hydraulic conductivities provided by Day 1977 is 7 x 10^{-10} ft/sec. Using these data the downward leakage estimate for the clay unit is 124 acre feet per year.
8.2. **Induced Recharge Through The Stream Beds**

8.2.1. **Shannon Creek Channel**

Since 1972 as the groundwater levels declined the hydraulic head in Shannon and Deadhorse Creeks, at times of significant flow, rise above the potentiometric surface in the aquifer. Currently during the spring floods and following periods of heavy rain the water levels in the streams are some 15 feet above the elevations of the potentiometric surface. The discharge data for Shannon Creek indicate that water would be available in the channel some 100 days per year. However the 1990 test drilling has shown that the surficial sand and gravel that is hydraulically connected to the stream is underlain by dense clayey till. It is estimated that the vertical hydraulic conductivity of the till would be in the order of $7 \times 10^4$ ft/sec. A reasonable estimation of the vertical hydraulic gradient would be 1. It is estimated that the length of the channel over the aquifer would be 1 mile. The average water surface width is placed at 29 feet. Based on these gross assumptions the natural yearly average recharge through the bottom of the Shannon Creek channels would be less than 1 acre foot.

8.2.2. **Deadhorse Creek and Deadhorse Creek Diversion**

The 1990 test drilling data indicated that in the sections of the Deadhorse Creek Channel and the Deadhorse Creek Diversion where they cross the primary recharge area, there is a direct connection to the aquifer. Infiltration tests in these channels indicated an average saturated infiltration rate of 0.5 inch per hour. Assuming the water is present in the channel bottom 100 days per year; that the average wetted surface is 29 feet wide and that the effective infiltration length of both channels is 1000 feet the average yearly infiltration rate through the Deadhorse Creek system would be 46 acre feet.

8.2.3. **Total Recharge**

The recharge estimate from all sources is 320 acre feet per year. This value is therefore the non-mining yield of the Winkler Aquifer. The original natural rate of replenishment is estimated at 150 acre feet per year.

It is pertinent to observe (Fig. 3) that until the estimated yearly withdrawal rate exceeded 286 acre feet per year the aquifer water levels fluctuated about a median level of 273.2 metres. As the
withdrawal rates exceeded 280 acre feet per year the aquifer commenced to decline steadily. This phenomena continued despite the fact that the declining water levels caused steadily increasing downward hydraulic gradients through the aquifer roof. The only significant interruption of the water level decline occurred during intervals of above average precipitation. The recovery through 1986 and the first two-thirds of 1987 coincides with above mean precipitation during the spring and summer.

Water levels have receded since 1987 due to continued pumpage and insufficient recharge resulting from drought.

8.2.3. Evaluation of Water Flow to the Bottom of the Aquifer from the Swan River Formation.

A major feature of the 1989-90 study was the evaluation of the amount of saline water flowing from the Swan River formation sandstone into the bottom of the Winkler Aquifer. Three wells some 250 feet deep were placed into the aquifer as a triangular pattern (Figs. 23 and 24). These wells allowed the assessment of the aquifer's potential surface (Fig. 25), the salinity of the water (15,000 mg/L of total dissolved solids) and the transmissivity of the aquifer by means of pumping tests (Fig. 26). This data combined the length of the contact zone with the aquifer (Fig. 4) allowed the estimation of the current saline water inflow at 230 acre feet per annum.

9 AQUIFER WATER BUDGET

Comparison of the discharge estimates with the yearly recharge rate of 320 acre feet indicates that fresh water is presently being mined from the aquifer at a rate of 700 acre feet per year. The rate of water withdrawal (Fig. 3) indicates that with the continued growth in the area the water mining rate will increase.

Over the past eighteen years since the major water level decline commenced (Fig. 3) it is estimated 10,000 acre feet have been withdrawn from the aquifer. Of this amount it is estimated that 3500 acre feet was recharged through the thin overburden area and creek channelms inside the 10 foot clay thickness contour (Fig. 9). The declining water levels induced a gradual increase in leakage through the confined 45 square miles confined which accumulated to 1100 acre feet over the eighteen years. Assuming that the unconfined area of the aquifer north of Deadhorse Creek has a specific yield of 0.20 the 12 foot water level decline would withdraw 3100 acre feet from storage. A lower specific yield (rather than 0.3) was used because the outer portion of this area has a considerable clay content. The confined 45 square miles of the aquifer contributed 36 acre feet because of elastic release due to the declining water levels. The total amount of water contributed by recharge and mining is estimated
at 7740 acre feet. Presumably the difference between discharge and recharge would have been made up by the some 2000 acre feet of saline water seepage from the underlying Searl River sandstone aquifer. Thus the estimation of the eighteen year replenishment to the aquifer amounts to 9700 acre feet. If water development follows the historic trend the water level decline (Fig. 3) will continue, at a rate of about 0.7 feet per annum.

There is little likelihood that the Winkler water system is in jeopardy. Indications are that there are 175,000 acre feet of potable water in the northern portions of the aquifer. At least 85,000 acre feet of this water should be recoverable. Therefore as long as the development is done carefully so as not to cause the saline water to rise excessively upward through the fresh water zone the aquifer should sustain the water system for 50 years.
CONCLUSIONS

The Winkler Aquifer system is a major and presently the sole source of fresh water for the Winkler area. The 170,000 acre feet of stored potable water is sufficient to supply the Town for at least 50 years. The overall rate of recharge to the aquifer is estimated at 320 acre feet per year. The rate of withdrawal of 1000 acre feet per annum exceeds the natural rate of recharge by 700 acre feet. The stored fresh water is being mined at a rate of 700 acre feet per annum. Due to the fact that recharge does not equal the rate of withdrawal, aquifer water levels have declined since 1972 some 12 feet, or at the average rate of 0.7 feet per annum. The nature of the physical and hydraulic relationship between the Swan River Formation and the bottom of the Winkler Aquifer indicates that 230 acre feet of saline water is flowing from the sandstone into the bottom of the Winkler Aquifer each year.

ACKNOWLEDGEMENTS

The investigations would not have been possible without the financial support of the Canada-Manitoba Agri-Food Agreement. Special appreciation is directed to Messrs. J Lebedin and H. Rhode of the Agriculture Canada Prairie Farm Rehabilitation Administration who cooperated in the drilling operations and arranged for the special soil sampling that was done by a P.F.R.A. drill crew in the recharge area of the aquifer. The aquifer evaluations and the preparation of the paper were done under the direction of Mr. M. Austford, Deputy Director of the Water Resources Branch and Mr. L. Gray, Head, Groundwater Section. Portions of the paper are based on hydrogeologic information that was gathered by a number of previous investigators; in particular Messrs. L. Gray, M. Rutulis, and A. Pedersen. Mr. N. Heppner has obtained most of the water level data. Mr. M. Rutulis provided a number of concepts about the aquifer situations through discussion. The paper was reviewed by Messrs. M. Austford, L. Gray, M. Rutulis and J. Petsnik. Mr. W. Hrydluk assisted in the field investigations and compilation of information. Mr. A. Dubicki supervised the drafting which was undertaken by Mr. F. Rogowy. Mrs. D. Morin assisted in the organization of the paper and did the typing. Publication of the manuscript was authorized by Mr. L.J. Whitney, Director, Manitoba Water Resources Branch.
REFERENCES


LEGEND

▲ - TOWN WELL
■ - COMMUNITY WELL

MILES

0 1 2 3

KILOMETRES

ROLAND 1973
3
SHANNON CREEK

DEADHORSE CREEK

'89 ▲

'81 ▲

'81 ▲

'76 ▲

'68 ▲

'63 ▲

'68 ▲

'63 ▲

WINKLER

Twp. 3
Twp. 2

1980
STANLEY

1975
RHINELAND

RGE. 5W.

RGE. 4W.

PRODUCTION WELLS

Fig. 2
WATER LEVELS VS PUMPING

TOTAL GROUNDWATER WITHDRAWAL

POTENTIOMETRIC ELEVATION

SNOw WATER

MAR. - OCT. MONTHLY PRECIP.

Fig. 3
BEDROCK SURFACE (FT.)
HYDROGEOLOGIC PROFILE

Fig. 7
SAND & GRAVEL THICKNESS (FEET)
LEGEND

- CLAY BETWEEN SURFACE AND AQUIFER
- OPEN SAND TO SURFACE
- TEST HOLE w 2" Ø PIEZOMETER

Fig. 13
WATER QUALITY
CROSS-SECTION B-B'

Fig 13
DISCHARGE VS QUALITY
1989 TOWN WELL

ELECTRICAL CONDUCTIVITY
AT 160'

TOWN WELL

GAL./DAY X 1000

0  100  200  300  400  500  600  700  800

MAY 31 JUN 30 JUL 31 AUG 31 SEPT 30 OCT 31

1990

E.C. AT 160'
WATER LEVELS VS QUALITY

GROUNDWATER ELECTRIC CONDUCTIVITY - MN 4

POTENTIOMETRIC ELEVATION

Fig. 15
Q3 SAMPLING WELLS
Q = 36 US g.p.m.
△s = 1.476'
T = \frac{264(36)}{1.476}
T = 6400 \text{ US g/ft/day}

SWAN RIVER FORMATION NO. 1
PUMPING TEST