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ABSTRACT

The investigated area is located in the southwest corner of the Province of Manitoba, Canada. It covers four municipalities with a total area of 1152 square miles. The study was carried out to determine if the aquifers in the area would provide sufficient water for irrigation and industrial supplies and to appraise ground-water conditions in the area in general.

The surficial deposits of the area consist of 25 to 300 feet of till covered by fairly extensive outwash and lacustrine deposits. Alluvial deposits occur in the Souris River Valley. A large north-south trending buried bedrock valley containing sand and gravel deposits occurs just east of the Village of Pierson. Almost the whole area is underlain by shale of the Cretaceous Riding Mountain formation.

The best aquifers in the area are the outwash deposits at the surface and in the buried valley. The parts of the outwash deposits at surface where saturated thickness is 20 feet or more are suitable for the development of irrigation wells. There are indications that the outwash deposits in the buried valley could yield at rates up to 3000 G.P.M. However, due to high mineral content, particularly sodium, this water is not suitable for irrigation.

The alluvial deposits in the Souris Valley contain some sand and gravel aquifers suitable for the development of fairly high capacity wells producing potable water.

Water for domestic and farm supply, where quality permits, can be extracted from pockets of sand and gravel in the till, lenses of sand in lacustrine deposits, shallow outwash deposits, and the shale bedrock.

The amount of ground water available for irrigation is estimated at 1500 acre feet per year. This would be sufficient to irrigate 0.2 to 0.3 per cent of the investigated area. About 50 acres could be irrigated for each square mile of outwash aquifer, i.e. some 35 acres of outwash aquifer would be required to irrigate one acre of land.

The study leaves little doubt that the ground-water supply for irrigation in the Melita Area is very limited and only a small fraction of the area over and adjacent to the outwash aquifers could be irrigated,
INTRODUCTION

In 1962 the South-West Manitoba Development Commission was founded. The Commission was made up of the Councils of the Rural Municipalities of Albert, Arthur, Brenda, and Edward; the Town Council of Melita and representatives from the Melita Chamber of Commerce and the Melita Development Corporation. The aim of the Commission was to organize and promote more intensive economical development of the area.

It was realized that any immediate development would have to be based on higher agricultural production and industries based on agricultural production. In view of the fact that the shortage of water has in the past been somewhat of a deterrent to development in the area it was deemed advantageous to determine the availability of usable ground water. Of prime interest was the possibility of utilization of ground water for irrigation development.

The ground-water availability study was carried out by the Water Control and Conservation Branch under a Canada-Manitoba A.R.D.A. agreement.

Scope

The study covered the area within the boundaries of the Rural Municipalities of Albert, Arthur, Brenda, and Edward with a total area of 1152 square miles in the southwest corner of the Province of Manitoba within the Souris River Basin. The boundaries of the studied area are shown in Figure 1.

The purpose of the study was to appraise the ground-water resources in the area and the possibility of using ground water for irrigation. Regarding irrigation the answers to the following three questions were sought:
1) Are there any aquifers in the area that can supply a sufficient quantity of suitable water for irrigation?

2) How much water is available for irrigation?

3) How many acres can be irrigated from ground water?

The surficial deposits and ground-water conditions in the area were first investigated by Johnston. Halstead and Elson mapped in detail the surficial deposits and carried out a survey of ground-water resources in the area. These reports contain the available information about wells and well drilling up to 1949 and indicate that in large parts of the area it is difficult to find a good source of potable water and that well failures have been common.

Investigations

The field work of the investigation consisted of well inventory, drilling and electro-logging of test holes, installation of observation wells, and aquifer testing. In 1963 the first observation wells were established. Well inventory, including field chemical analysis of water, was carried out in 1964. In the same year 24 test holes were drilled to determine the geological and aquifer conditions in the area. Each test hole was logged electrically with continuous logs of self potential and resistivity. In 1965 additional test holes were drilled following which an aquifer test was carried out. Several observation wells and piezometer nests were also constructed. In 1966 a large capacity well to supply water for irrigation test plots was installed and an aquifer test conducted.

1. W.A. Johnston, Surface Deposits and Ground-Water Supply of Winnipeg Map-Area, Manitoba, Geological Survey of Canada, Ottawa, 1934, pp. 22-.

2. E.C. Halstead and J.A. Elson, Ground-Water Resources of Townships 1 to 6, Ranges 26 to 29 West of Principal Meridian Manitoba (Melita Area), Geological Survey of Canada, Ottawa, 1948

3. E.C. Halstead and J.A. Elson, Ground-Water Resources of Townships 1 to 6, Ranges 22 to 26 West of Principal Meridian Manitoba (Belmonte Area), Geological Survey of Canada, Ottawa, 1949
During the investigation, a number of water samples for laboratory chemical analysis were collected.

**Topography and Climate**

The area slopes five to 10 feet per mile from the northwest and southeast towards the Souris River. The central part of the area was occupied by Glacial Lake Souris. The lake basin area except for river valleys is very flat. A till plain with numerous depressions up to five feet deep extends both east and west from the lake plain. The Souris Valley trends north and northeast through the lake plain near its eastern side. It is 50 to 75 feet deep and over a mile wide. South of Melita and east of the Souris River a valley known locally as the Blind Souris Valley indicates a former course of the Souris River. Several tributary valleys varying in depths from 10 to 50 feet and up to one half mile wide cut through the plain west of the Souris River.

The climate in the area is semi-arid with cold winters and warm to hot summers. The average precipitation in the area is 18 inches. About one-half of the annual precipitation occurs during the growing season.
Bedrock

Nearly the whole investigated area is underlain by shale of the Riding Mountain Formation. In the eastern part of Township 1, Range 2, and in the southeast corner of Township 2, Range 24, the Riding Mountain Formation is overlain by the Upper Cretaceous (?) to Paleocene Boissevain Formation, and the Paleocene Turtle Mountain Formation. The occurrence of the bedrock formations is shown on the geological map in Figure 2. The beds are nearly horizontal and there are no major structural features in the area.

The Riding Mountain Formation consists mainly of shale. Thin sandstone beds occur interbedded in the shale southwest of Waskada. The thickness of the Riding Mountain Formation in southwestern Manitoba is about 1100 feet.

The Boissevain Formation consists of fine-grained, unconsolidated, impure sandstone. The maximum thickness of this formation is approximately 100 feet.

The Turtle Mountain Formation consists of interbedded shale, sandstone, and lignite. The formation thins out on the western slope of Turtle Mountain.

The bedrock surface forms a broad north–south trending valley within which is situated a secondary valley some two miles wide and 150 feet deep as shown in Figure 5. The secondary valley is referred

to as the Buried Souris Valley. The location of the Buried Souris Valley is indicated by the bedrock topography in the studied area as shown in Figure 3.

A much smaller bedrock valley was encountered about one mile west of Walsha as indicated on the bedrock topography map in Figure 3. This valley appears to be a tributary to the Buried Souris Valley.

Surficial Deposits

Till: Till is the most widespread deposit occurring at the surface and underlies the other kinds of drift occurring at the surface. The only exception is the alluvium in the Souris Valley which appears to be deposited directly on bedrock. The areal extent of till at the surface is shown in Figure 4, and the stratigraphic relation to other deposits in the area in Figure 5.

East of the Souris River, the till thickness varies from 25 to 100 feet. West of the Souris River, the till thickness generally is between 200 and 250 feet but increases to about 300 feet near the Manitoba-Saskatchewan boundary. Over the Buried Souris Valley the till thickness is in the order of 350 feet.

There are indications that two kinds of till occur in the area: an upper clayey hard till and a lower softer and gravelly till. Thin beds of sand and gravel are interbedded in the till at various depths but appear to be more common in a zone approximately 70 to 100 feet below ground level. There is little doubt that these interbedded sands and gravel deposits are small and discontinuous.

Outwash: Two kinds of outwash deposits occur in the area: outwash deltas and valley trains.
Outwash delta deposits cover some 120 square miles of the area. They occur at the southern end of valley trains where the glacial meltwaters discharged into Glacial Lake Souris. The areas covered by outwash deltas are shown in Figure 4.

The outwash delta deposits consist mainly of gravel and coarse sand. The thickness of these deposits is up to 40 feet. However, the average thickness is not more than 15 feet.

Valley trains are long narrow bodies of outwash confined within a valley. In the Melita Area valley trains occur at the surface and in the Buried Souris Valley.

The valley trains at the surface are confined to a number of shallow north-south trending valleys in the western part of the area. The location of the valley train deposits at surface is shown on the map in Figure 4. The valley train deposits consist mainly of gravel and are up to 30 feet thick.

The investigation indicated fairly thick and extensive valley train deposits within the Buried Souris Valley. Test drilling at Pierson indicated that the gravel deposits there consist of coarse gravel and are at least 30 feet thick. Test holes within the Buried Souris Valley some six and 12 miles north of Pierson encountered up to 15 feet of very clayey gravel that appears to be a continuation of the deposits at Pierson. The test holes indicated that the thick gravel deposits do not fill the whole width of the valley, and that in some parts of it the gravel may be mixed with a considerable amount of clay.

Lacustrine Deposits: Lacustrine deposits cover some 285 square miles of the area. The lacustrine deposits as shown in Figure 4 extend along a six to 10 miles wide belt just west of the Souris River. Only a few small areas of lacustrine deposits occur east of the Souris River. The thickness of the lacustrine deposits generally is five to 10 feet and increases to 20 feet in the central part of the Glacial Lake Souris Basin.

The lacustrine deposits consist of beds of sand, silt, clay and a mixture of these materials. In general, the sand deposits occur along the perimeter of the lacustrine deposit area. The lacustrine deposits become finer toward the central part of the basin and consist mainly of clay and silt. Layers of sand occur interbedded in and at the base of the clay and silt beds.

Alluvium: Alluvial deposits occur in the Souris River Valley, the Blind Souris Valley and the lower part of the valleys of some of the tributaries of the Souris River as shown in Figure 4.

The alluvium consists mainly of silt and clay. However, locally there are sand and gravel deposits interbedded in or underlying the clay and silt. Sand and gravel deposits were penetrated by wells in the Souris Valley at Melita and in the Blind Souris Valley southeast of Melita. Since outwash deposits occur along the Souris Valley northeast of Melita, it is quite likely that sand and gravel deposits are common in the alluvium in that part of the valley.
AQUIFERS

A rock formation or stratum that will yield water in sufficient quantity to be of consequence as a source of supply is called an "aquifer", or simply a "water bearing formation", "water bearing stratum", or "water bearing strata". The term "rock" here applies to consolidated as well as un-consolidated materials, such as sand and gravel.

The major hydraulic properties of aquifers are quantitatively indicated by the coefficients of permeability, transmissibility and storage.

The field coefficient of permeability is defined as the rate of flow of water, in gallons per day, through a cross sectional area of one square foot of aquifer under a hydraulic gradient of one foot per foot at the prevailing temperature of water.

The coefficient of transmissibility is defined as the rate of flow of water, in gallons per day, through a vertical strip of the aquifer one foot wide and extending the full saturated thickness under a hydraulic gradient of one foot per foot at the prevailing temperature of the water.

The coefficient of storage is defined as the volume of water the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the head normal to that surface.

Under water table conditions the coefficient of storage corresponds to the specific yield. The specific yield is the ratio of the volume of water that deposits will yield by complete gravity drainage to the total volume of deposits.

The various rock formations in the Melita Area have distinctly different water bearing properties, contain water of different quality, and, in most cases, are separated by less permeable strata. Consequently, based on lithology, stratigraphic situation, and water bearing properties the following aquifers can be distinguished in the area:

a) Shale  
b) Sandstone  
c) Till  
d) Buried Souris Valley Train  
e) Valley trains at surface  
f) Outwash deltas  
g) Lacustrine sands  
h) Alluvial sand and/or gravel

Shale:

Hard, fractured and weathered shale that is sufficiently permeable to constitute an aquifer occurs in the shale bedrock area.

Ground-water investigations in other parts of Manitoba underlain by shale indicate that the coefficient of permeability of shale ranges from 10 Imperial gallons per day per square foot for slightly fractured shale to 1000 Imperial gallons per day per square foot for very highly fractured and weathered shale. The water bearing beds usually occur within the upper 100 feet of the shale. Nearly all the highly fractured and weathered shale beds occur adjacent to existing river valleys or bedrock valleys.

Available information indicates that under the plain east of the Souris River the shale is only slightly fractured and is a poor aquifer, and that pockets of more fractured and weathered shale occur near the Souris and Blind Souris Valleys.

It appears that the shale under the thick drift west of the Souris River is not fractured and it is unlikely that shale aquifers occur in that part of the investigated area.
Sandstone:
The sandstone of the Boissevain Formation constitutes a relatively significant aquifer in the southeast corner of the investigated area. It extends over several square miles and is fairly thick and uniform. Due to high silt and clay content the permeability of the sandstone is low. However, it is sufficient to yield adequate supply of potable water for domestic and farm use.

Till:
In general, the permeability of the till is very low and wells penetrating it yield insignificant amounts of water, unless interbedded sand and/or gravel deposits are encountered. These lenses of permeable material could be considered as small aquifers. However, since any water found in the lenses must flow through the surrounding till, the yield ultimately depends on the permeability of the till. Consequently, the till can be considered as the aquifer, and the lenses of sand and/or gravel surrounding a well as part of the well which permits extraction of water from the till.

Because of the limited size of some of the sand and gravel lenses they can be dewatered easily. The dewatering may take from a few days to several years depending on water consumption, the size of the sand and gravel deposits, and the permeability of the surrounding till.

Buried Souris Valley Train:
The sand and gravel deposits in the Buried Souris Valley form one of the more significant aquifers in the area.

Test drilling indicates that this aquifer occupies only a small part of the buried valley and the thickness and permeability varies
considerably. At Pierson one test hole encountered 28 feet of sand
and gravel at 34 feet but a second hole just 125 feet from the first
encountered the aquifer at 358 feet. At two locations six and 12 miles
north of Pierson the sand and gravel deposits in the buried valley were
only about 15 feet thick and contained a considerable amount of clay.

A test well at Pierson pumped at 50 Imperial gallons
per minute indicated a transmissibility of 60,000 Imperial gallons per
minute per foot and specific capacity, or rate of pumping per foot
of drawdown in the well, of 15 Imperial gallons per minute. Since the
available drawdown is over 300 feet it is obvious that a well in this
aquifer could yield much more – probably over 1000 Imperial gallons
per minute. However, since the aquifer is covered by some 350 feet of
till and no outcrops of the aquifer are known, limited recharge may
reduce the sustained yield of the aquifer.

At Broomhill the aquifer was tested but yielded only
3.5 Imperial gallons per minute. This indicates that not every well
penetrating the outwash deposits in the buried valley would have a high
yield. The test holes indicate that the sand and gravel deposits in
the Buried Souris Valley may not be continuous and uniform and that
cautions should be used in assuming the extent of this aquifer. Detailed
evaluation of the sand and gravel deposits in the Buried Souris Valley
would require fairly extensive test drilling along the valley and
construction of high capacity wells (1000 Imperial gallons per minute)
to obtain more reliable estimates of potential yield than is possible
from the test at Pierson. However, the present data are sufficient to
indicate that a fairly large aquifer occurs in the valley and that it could
be considered as a source for municipal and industrial water supply.
Valley Trains at Surface

The valley trains in the shallow valleys in the western part of the studied area form excellent aquifers. This is due to the thickness of the aquifers and recharge from the intermittent streams flowing in the valleys. Except for their elongated form these aquifers are very similar to the outwash delta aquifers and, in general, the discussion on the outwash delta aquifers applies to the valley train aquifers.

Outwash Deltas

From the standpoint of utilizing ground water for irrigation the outwash deltas shown on the map in Figure 4 and 6 constitute the most significant aquifers in the area.

Over most of the 120 square miles of this type of aquifer the saturated thickness in years of average precipitation probably is between 10 and 15 feet. In about one quarter of the area the saturated thickness is around 20 feet and occasionally it reaches a maximum of 25 feet. However, the thickness of the aquifer varies considerably within distances of a few hundred feet.

The thinner parts of the outwash delta aquifers could provide an ample supply of water for domestic and general farm use except in extensive periods of drought. The thicker parts, where the saturated thickness is 20 feet or more, may be considered as possible sources of water for irrigation.

An indication of the transmissibility, storage coefficient, and permeability of the outwash delta aquifers was obtained from two aquifer tests located approximately seven miles north of Melita on the northwest quarter of Section 12, Township 5, Range 27, West of the
Principal Meridian. Because there is variation in grain size of the sand and gravel and clay and silt content in the aquifer the transmissibility of the aquifer varies considerably. The tests show that within these parts of the aquifers where the saturated thickness is between 20 and 25 feet the transmissibility is between 20,000 and 48,000 Imperial gallons per day per foot and 10,000 to 20,000 Imperial gallons per day per foot over the thinner parts where saturated thickness is 10 to 15 feet. The storage coefficient is up to 0.2 and the permeability from 700 to 2000 Imperial gallons per day per square foot. The best of the test wells was pumped at a rate of 258 Imperial gallons per minute. Analysis of the test indicates that wells in the thicker and more permeable parts of the aquifer could yield around 250 Imperial gallons per minute continuously for periods of up to 40 days. After 40 days of pumping the water level would drop to a point where this pumping rate could not be maintained.

Lacustrine Sands

The lacustrine sands form a fairly extensive but very thin aquifer. The thickness of the sand generally is about six feet, but locally its thickness is 15 feet or more. Recharge of this aquifer depends on local precipitation and the thinner parts of the sand deposits are dewatered in periods of drought. Thus only the thicker parts can be considered as a reliable aquifer. The sand generally is fine and contains a considerable amount of silt and clay. Hence, the permeability and storage capacity of this aquifer is low.

Alluvial Sand and Gravel

The sand and gravel deposits interbedded in the alluvium of the Souris and Blind Souris Valleys appear to constitute a fairly good aquifer. This is indicated by the fact that the Town of Melita
is supplied by wells in the alluvial deposits. Because of possible induced recharge from the Souris River the sand and gravel deposits in the Souris Valley could be considered as a reliable source of water.
HYDROLOGY OF THE OUTWASH DELTA AQUIFERS

The outwash delta aquifers act as conduits for transmission and also as reservoirs for storage of water. Water enters the aquifers from the surface and travels through the sand and gravel deposits until it is returned to surface by evaporation, transpiration, ground-water runoff, and pumping, or leaves the aquifers by subsurface outflow into adjacent or underlying strata.

The hydrology of the outwash delta aquifers is concerned mainly with a quantitative appraisal of the water moving into and out of the aquifers. It involves precipitation and evaporation over the aquifers, observations of ground-water level fluctuations and surface runoff.

The hydrological data and observations are used to estimate the ground-water budget for the aquifers, which, in turn, provides an indication of the amount of water available for use.

Precipitation

The average annual precipitation in the Melita area is 18 inches. The average precipitation for the winter and transition months (October - April) is six inches, and for the summer months 12 inches. Weather records are available for various periods from stations at Bede, Brooshill, Pierson, Iyleton, and Waskada from 1933 to the present.

The lowest winter precipitation on record occurred during the winter of 1933-1934 and totalled 3.3 inches. The highest winter precipitation of 10.4 inches was recorded during the winter of 1934-1935. The lowest total precipitation for two consecutive winters was 7.4 inches (1935-1936 and 1936-1937). As many as three consecutive
winters with below average precipitation have been reported. The maximum recorded summer precipitation is 20.1 inches and the minimum is 8.0 inches. There have been up to four consecutive years with summer precipitation below average. The lowest recorded precipitation for the period of June to August is 2.84 inches in 1961. In the period 1933 to 1966 there were eight winters with below average precipitation followed by a summer with below average precipitation.

The records indicate that in the Melita Area there are large deviations from the average precipitation. The large variations in precipitation would have a considerable effect on the supply and demand of ground water in the area. Hence it can be expected that the recharge of the outwash delta aquifers and the requirements for irrigation water will vary considerably.

**Evaporation and Transpiration**

There are no records of evaporation in the Melita Area.

The nearest available estimates are for Rivers, Manitoba and Broadview, Saskatchewan.\(^7\)

The gross average evaporation for the period May to September from lakes and reservoirs extrapolated from data at Rivers and Broadview is approximately 23 inches. For the growing season comprising the months of June, July, and August the estimated evaporation is approximately 14.4 inches and exceeds the mean rainfall which averages 9.2 inches over the same three months. As evaporation from saturated soil may approach that of a free-water body\(^8\) this indicates that potential

evaporation exceeds rainfall. In addition water is returned to the atmosphere by transpiration which itself may be more important than evaporation directly from the soil. Consequently, during the summer months, if precipitation is near normal, the processes of evaporation and transpiration are likely to cause soil-moisture deficiency. As a result it is reasonable to assume that in most years summer precipitation does not percolate to the water table and there is practically no recharge of the aquifers during the summer months.

Ground-Water Level Fluctuations

Although the ground-water observation wells in the area have been in operation for only a few years, the following general trends of water levels in the outwash delta deposits have been observed.

1. Ground-water levels rise rapidly at the start of the snowmelt period and peak in April or the first half of May. During this period water levels rise approximately four feet.

2. For each 0.1 foot of winter precipitation there is approximately a 0.7 foot rise of water level in the aquifer.

3. In summer, rainfall in the order of one inch or more in one day results in a slight rise of water level, indicating some recharge of the aquifer.

4. Precipitation of less than one inch per day in summer has no effect on water levels.

5. Water levels drop throughout summer and winter. The drop in water levels from the peak in spring to the lowest level at the end of the winter ranges from three to four feet, when precipitation is normal or above normal. Since there have been no dry years since the observation wells were installed, there is no data on water level changes in periods of drought. Information from well owners and weathering of surficial deposits indicate that, because of lack of spring recharge, water levels may drop as much as 10 feet in dry years.
6. A comparison of water levels at the beginning and the end of a year indicates that in years of above average precipitation there is a net rise in water level. The available data are not sufficient to establish a definite magnitude of this fluctuation in relation to deviation of precipitation from average. Indications are that one inch of precipitation above average results in a 0.5 foot increase in water level per year. If the drop of water levels due to below normal precipitation was of the same order, a series of dry years would lower the water level by several feet.

Runoff

Stream flow records are available for Graham Creek at Melita from 1943 to the present. The drainage area of the Creek above the gauging station is 291 square miles. Approximately one half of this is in the area under study.

The total runoff in 1964 was 3937 acre feet which is equal to 0.25 inches of water over the drainage area. In 1965 the corresponding figures were 926 acre feet and 0.05 inches. The precipitation in 1964 was 22 inches and in 1965 it was 20 inches. Comparison of precipitation and runoff in 1964 and 1965 shows that only 1/100 or less of the annual precipitation contributed to runoff. In 1961 and 1962 there was no runoff in the Creek. Since only a small fraction of the precipitation contributed to runoff, it is obvious that the remainder must be accounted for by evapotranspiration losses and ground-water recharge.

Observation wells in the outwash deltas indicate a rapid rise in water levels during spring runoff. During the same period the surface runoff is equivalent to only a small fraction of winter and spring precipitation. This is illustrated by the following:

1. The total winter and April precipitation in 1963-1964 in the Melita area was 6.0 inches. The runoff in Graham Creek to the end of April in 1964 was 2600 acre feet or 0.17 inches of water over the drainage area. This indicates that only 2.5 per cent of the precipitation contributed to runoff.
2. The precipitation of the winter of 1964-1965 and April 1965 was 5.9 inches. The runoff to the end of April, 1965 was 450 acre feet or 0.03 inches. The runoff was only 0.6 per cent of the precipitation.

Because the soil in the outwash delta areas is more permeable than in the rest of the Graham Creek Basin, the percentage of precipitation resulting in runoff over the outwash delta areas probably is considerably lower than in other parts of the Basin. It can be assumed that, except for evaporation losses, all of winter and transition period precipitation contributes to ground-water recharge

**Subsurface Outflow**

An indication of the magnitude of subsurface outflow can be obtained from the decline of water levels in observation wells during the winter months, i.e. November to March. As there is no flow in the creeks running through the aquifers during the winter months, the drop in ground-water levels can be assumed to be due mainly to subsurface outflow. Since the area is sparsely populated, consumptive use is assumed to be negligible.

In two observation wells at Broomhill a decline of water level of about one foot during the five winter months has been recorded. This decline has been fairly constant for several years for both wells. One well at Bernice shows a water level drop of 0.5 feet during the winter and a second well shows considerable variations ranging from 1.0 to 2.0 feet.

Thus it would seem reasonable to assume that the drop of water level due to subsurface outflow is approximately 0.2 feet per month or two feet per year.
Considering that the storage coefficient of this type of aquifer generally is in the order of 0.1 this would indicate that the subsurface outflow is approximately two inches of water per year over the area of the aquifer. This amounts to 12,800 acre feet per year over the 120 square miles of outwash delta aquifers, or a continuous discharge of 17.6 cubic feet per second or 6,600 Imperial gallons per minute. If only the thicker parts of the aquifers (approx. 30 sq. miles) are considered, the corresponding figures are 3,200 acre feet per year, 4.4 cubic feet per second and 1650 Imperial gallons per minute.

Ground-Water Budget

The ground-water budget is a quantitative statement of the balance between recharge and discharge of an aquifer over a given period of time. In the following discussion a period of one year is considered and the quantities of water are expressed in inches of water over the aquifer.

The observation wells in the outwash deltas and the ratio of precipitation to runoff indicate that annual recharge of the outwash delta aquifers is due to the winter and spring precipitation. In the Melita Area the average precipitation for this period is six inches. From ground-water level rise in the spring it appears that four inches of this percolates to the water table and contributes to the recharge of the aquifer and two inches are lost by evaporation at the surface.

The annual discharge from the outwash delta aquifers consists of ground-water evapotranspiration and subsurface outflow. The observation wells indicate that subsurface outflow is approximately two inches. To balance the ground-water budget two inches of water then must be lost by ground-water evapotranspiration. Since on the
average evaporation exceeds precipitation by 11 inches, this appears to be a reasonable assumption.

The average annual ground-water budget then is:

Four inches recharge = two inches ground-water evapotranspiration + two inches subsurface outflow.

The above equation applies to average natural conditions with insignificant or no pumping, as is the case under present conditions.

If discharge by pumping was significantly increased, there would be an inevitable decrease in water level, provided that evapotranspiration and subsurface outflow were not decreased by the same amount. It is unlikely that evapotranspiration would decrease. Therefore, only a decrease in subsurface outflow would balance the equation. If it could be stopped completely then two inches of water per year would be available for irrigation. This should, therefore, be considered as the maximum amount of water available annually for irrigation on a sustained basis.
GROUND-WATER QUALITY

In general, the quality of ground water in the Melita area deteriorates with depth, i.e. the best water is obtained from aquifers near the surface. However, not all aquifers near the surface yield good water; in the vicinity of Waskada water is highly mineralized even in the surface aquifers located at 30 feet or less below ground level.

The concentrations of common ions in water are expressed in milligrams per litre (mg./l.) or milliequivalents per litre (me./l.). A milliequivalent is the unit used for one thousandth of gram equivalent weight per litre of solution. The total ionic concentration, usually referred to as the total dissolved solids, is expressed in milligrams per litre.

The total dissolved solids concentration can be measured in terms of electrical conductivity. Electrical conductivity or specific electrical conductance is the conductance of a cube of the substance one centimeter on a side. The units in which specific conductance is reported are reciprocal ohms or "mhos". In order to avoid inconvenient decimals, data are reported in millionths of mhos or micromhos. Specific conductance values in micromhos multiplied by 0.7 are approximately equal to dissolved solids concentration in milligrams per litre.

Quality Criteria for Irrigation Water

The criteria used for classification of suitability of water for irrigation are absolute or relative concentrations of ions that may be detrimental to plant growth or soil conditions, total dissolved solids concentration and/or specific conductivity.

The concentration of sodium is important in classifying an irrigation water because sodium reacts with soil to reduce its permeability.

The sodium content is usually expressed in terms of per cent sodium,
defined by:

$$\text{Per cent sodium} = \frac{\text{Na} \times 100}{\text{Na} + \text{Ca} + \text{Mg}}$$

where all ionic concentrations are expressed in milliequivalents per liter.

The concentration of potassium, which is generally quite small in water, is often included in figures stated for sodium concentration.

The sodium (or alkali) hazard of irrigation water can be expressed best in terms of the Sodium Adsorption Ratio, or SAR. The ratio expresses the relative activity of sodium ions in exchange reactions with soil. It is defined as follows:

$$\text{SAR} = \frac{\text{Na}}{\frac{1}{2} (\text{Ca} + \text{Mg})}$$

where Na, Ca, and Mg are concentrations of the respective ions in milliequivalents per liter of water. The sodium hazard for values of SAR and conductivity of irrigation water is shown in Table I, p. 25.

The effects of salinity can be evaluated by the “potential salinity”, defined as the chloride concentration plus half the sulphate concentration, both in milliequivalents per liter. Limiting potential salinity for various soil conditions and for the three classes of irrigation water is shown in Table II.

Although traces of boron are essential for all plant growth, it is doubtful whether more than 0.5 mg/l. can be applied continuously to soils without ultimately producing some plant injury. Agricultural authorities agree that the critical concentration for irrigation water

10. C.S. Scofield and L.V. Wilcox, "Boron in Irrigation Waters", in Ground Water Criteria, p. 110
11. W.P. Kelley, "Permissible Composition and Concentration of Irrigation Waters", in Ground Water Criteria, p. 110
is 0.4 milligrams per liter\(^{12}\).

Many studies have resulted in the division of irrigation waters into broad categories designated as:

a) "Excellent to good" or "suitable under most conditions",
b) "Good to injurious" or "harmful to some plants under certain conditions",
c) "Injurious to unsatisfactory", or "harmful to most plants under most conditions"\(^{13}\).

Designations (a), (b), and (c) correspond to irrigation water classes I, II, and III respectively. Some of the most significant criteria suggested by various authors and compiled by McKee and Wolf\(^{11}\) for classification of irrigation water are summarized in Table III.

**Water Quality in Aquifers**

**Buried Soils Valley Train:** Some of the characteristics of water from this aquifer that are used to determine its suitability for irrigation are listed below.

a) The per cent sodium is from 80 to 95.
b) The total dissolved solids content is 1700 to 2000 milligrams per liter and specific conductivity 2500 to 2850 micromhos.
c) The potential salinity is 13 to 15 milliequivalents per liter.
d) The sodium adsorption ratio (SAR) is from 11 to 31.
e) Boron concentration is up to .59 milligrams per liter.

Based on the per cent of sodium the water falls into Class III for irrigation water. According to the classification based on potential salinity the water is near the upper limit of Class II for easily drained soils, and in Class III for slowly drained soils. The SAR ratio combined


\(^{13}\) Ibid., p. 107

\(^{14}\) Ibid., p. 109
### TABLE I - SODIUM (ALKALI) HAZARD

<table>
<thead>
<tr>
<th>Sodium Hazard</th>
<th>SAR</th>
<th>SAR</th>
<th>SAR</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0 - 10</td>
<td>0 - 8</td>
<td>0 - 8</td>
<td>0 - 4</td>
</tr>
<tr>
<td>Medium</td>
<td>8 - 18</td>
<td>6 - 15</td>
<td>6 - 15</td>
<td>3 - 9</td>
</tr>
<tr>
<td>High</td>
<td>15 - 25</td>
<td>12 - 23</td>
<td>6 - 18</td>
<td>7 - 14</td>
</tr>
<tr>
<td>Very High</td>
<td>More than 23</td>
<td>More than 19</td>
<td>More than 14</td>
<td>More than 11</td>
</tr>
<tr>
<td></td>
<td>100 - 250</td>
<td>250 - 750</td>
<td>750 - 2250</td>
<td>2250 - 5000</td>
</tr>
</tbody>
</table>

Conductivity Microhors/cm. (EC = 10⁻⁶ at 25°C C)

### TABLE II - LIMITING POTENTIAL SALINITY

<table>
<thead>
<tr>
<th>Soil Condition</th>
<th>Limiting potential salinity, Meq/l.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Class I</td>
</tr>
<tr>
<td>A. Little leaching, owing to low percolation rates</td>
<td>3</td>
</tr>
<tr>
<td>B. Some leaching, but restricted, drainage slow</td>
<td>5</td>
</tr>
<tr>
<td>C. Open soils, deep percolation easily accomplished</td>
<td>7</td>
</tr>
</tbody>
</table>

### TABLE III - SUMMARY OF CLASSIFICATION OF IRRIGATION WATERS

<table>
<thead>
<tr>
<th>Class</th>
<th>Per-Cent Na⁺</th>
<th>Chlorides in Meq/l.</th>
<th>Sulphates in Meq/l.</th>
<th>Specific Conductivity E.C.×10⁻⁶ at 25°C</th>
<th>Total Salts in Meq/l.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Less than 30-60% (Most recent work favors a 60% limit)</td>
<td>Less than 2-5.5.</td>
<td>Less than 4-10</td>
<td>500 - 1000</td>
<td>Up to 7000</td>
</tr>
<tr>
<td>II</td>
<td>30 - 75%</td>
<td>2-16</td>
<td>4-20</td>
<td>500 - 3000</td>
<td>350 - 2100</td>
</tr>
<tr>
<td>III</td>
<td>More than 70-75%</td>
<td>More than 6-16</td>
<td>More than 12-20</td>
<td>More than 2500 - 3000</td>
<td>More than 3750 - 2100</td>
</tr>
</tbody>
</table>

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15. After diagram from USDA handbook No. 60, in Ground Water Criteria, p. 111

16. "Limiting potential salinity, Meq/l.

17. "Summary of classification of irrigation waters"
with very high total dissolved solids content indicates very high sodium hazard. It is apparent that all the criteria applied for classification of irrigation water indicate that the water from the Buried Souris Valley Train cannot be recommended for irrigation.

However, the samples obtained at Pierson indicate that the water with some treatment may be suitable for municipal or industrial use. In some cases, as for vegetable washing or cooling purposes, the water might be suitable for industrial use without treatment.

**Outwash Delta**: The following data indicate that water from outwash delta sand and gravel is good to excellent for irrigation.

- **a)** The per cent sodium is generally less than 30 and often less than 10.
- **b)** The concentration of chlorides in most cases is less than 10 per cent.
- **c)** Specific conductivity is less than 1000 micromhos. Upper limit for Class I water is 1000 micromhos.
- **d)** Potential salinity is from 1.5 to 3.0 milliequivalents per liter. Regarding potential salinity the water is in Class I for all soil conditions.
- **e)** SAR is less than two and commonly less than one. This together with low electrical conductivity indicates low sodium hazard.
- **f)** Boron was not detectable.

**Other Aquifers**: A water sample from the shale west of the Souris River indicates that it is highly mineralized. The total dissolved solids content is 5120 milligrams per liter and the water has high sodium, chloride, and sulphate concentrations. Salty and alkaline water is common in the shale aquifer east of the Souris River.
Water samples from wells in the till indicate that the quality of water extracted from till varies considerably from place to place and with depth. The total dissolved solids content is between 350 and 3000 milligrams per liter.

Ground water in the valley train aquifers near the surface generally is of good quality. The total dissolved solids concentration is around 400 milligrams per liter.

The chemistry of water from the lacustrine sands varies considerably. The total dissolved solids content is from 300 to over 2000 milligrams per liter. It appears that the quality of water is good where these deposits are at the surface and mineralization is high where the sands are covered by clay and silt deposits.

Water in the alluvial sand and gravel aquifer is of fairly good quality. The total dissolved solids content is from 500 to 600 milligrams per liter.
IRRIGATION

Water Requirements

Maximum rates of soil moisture used by crops for moderately dry climatic conditions are 0.20 inches per day, and for hot dry conditions 0.30 inches per day. For 90 days of growth this would amount to 18 and 27 inches of water, respectively. The conditions in the Melita Area probably vary between moderately dry and hot dry, and therefore, 23 inches of water can be considered as the average moisture requirement for crops. The average growing season precipitation is nine inches. The average moisture deficiency is therefore 14 inches. Since the lowest recorded precipitation for the growing season is three inches the moisture deficiency may be as high as 20 inches. The moisture deficiency also was computed by the Thornthwaite method. Using soil moisture storage of two inches, good agreement with observed water level fluctuations in the aquifer was obtained. By this method the moisture deficiency between 1933 and 1964 was a minimum of 4.92 inches and a maximum of 20.18 inches. The average moisture deficiency was 12.7 inches. The above figures indicate that the average moisture deficiency is in the order of one foot or one acre-foot per acre of land. In dry years the moisture deficiency would increase to ½ acre feet per acre or more. Thus, on the average, at least one acre foot of water would be required for each acre of irrigated land.

Available Ground Water

The sand and gravel outwash deltas form the only aquifer suitable for irrigation.

Because ground-water levels in the thinner parts of the aquifer may drop several feet in periods of drought, no water would be available for irrigation when it would be needed the most. Furthermore, 10 to 15 feet should be allowed for drawdown for high capacity wells. Consequently, only those parts of the outwash deltas where the saturated thickness is 20 feet or more could be considered as possible sources of water for irrigation. The area where saturated thickness is of this order is approximately 30 square miles.

To maintain the outwash delta aquifers as sources of irrigation water indefinitely, the amount of water extracted should not cause continuous decline of water levels in the aquifers. This means that on the average the annual recharge should be equal to the annual discharge and the ground-water budget for a period of several years should balance without negative changes in ground-water storage.

Maintenance of the ground-water budget without negative change in storage requires that the amount of water available for use, must not exceed the amount of water lost from the outwash delta aquifers by subsurface outflow. Expressed in inches of water per year over the aquifer this amount is approximately two inches. This would be the case where subsurface outflow would be stopped completely by increasing pumping from the aquifer. Consequently, two inches or 100 acre feet of water per year per square mile of outwash delta aquifer should be considered as the maximum yield. It is doubtful that the subsurface outflow would be stopped completely, and hence a more conservative figure of 50 acre feet of water per year per square mile should be considered as the amount available for irrigation. Since the total area of the outwash delta aquifers suitable for irrigation water supply is 30 square miles, the
total amount of water available from these aquifers is 1500 acre feet.

It is possible that lower water levels in the aquifer due to pumping would reduce evapotranspiration and make more water available for use. However, it is unlikely that this factor would increase the available amount significantly. It should only be considered as a safety factor in regard to the estimated quantity.

Well Spacing

The distance between the wells of different owners should be sufficient to prevent serious well interference.

Aquifer tests of the outwash delta aquifers indicate that the following minimum well spacing should be adequate:

1. For wells pumped at approximately 250 Imperial gallons per minute for periods of 40 days, i.e. extracting 50 acre feet or all the allowable water per square mile of aquifer in one period of pumping, the spacing should be about one mile.

2. For wells pumped at approximately 250 Imperial gallons per minute intermittently for periods of several days during a growing season the spacing should be approximately one-half mile.

3. The distance between wells pumped at 250 Imperial gallons per minute and low capacity domestic and farm wells should be about one half of that between high capacity wells under pumping conditions considered in (1) and (2) above, i.e. one-half to one-quarter of a mile.

4. The spacing of well pumped at less than 250 Imperial gallons per minute could be reduced accordingly.

Irrigable Area

Since the total safe yield of the outwash delta aquifer is approximately 1500 acre feet and the average annual water requirement for irrigation is about one acre-foot per acre a total of 1500 acres could be irrigated.
Allocation of Water

The allocation of water for irrigation using private wells (as opposed to wells operated by a central agency) should be based on the following considerations.

1. The allowable quantity of water for irrigation, providing other uses are insignificant, is 50 acre feet per year per each square mile of outwash delta aquifer. This means that for each acre of irrigated land there should be 13 acres of aquifer.

2. The irrigation wells on one parcel of land should have only negligible interference with irrigation or other wells on adjacent property. To satisfy this requirement it would be necessary to regulate well spacing and location of irrigation wells.

It follows, that in each case where irrigation using ground water from the outwash delta aquifers is considered, it will be necessary to establish the thickness and areal extent of the aquifer. Without this information it would be impossible to determine the amount of water available for irrigation and the location of wells. Furthermore, each individual considering irrigation should have this information to determine how much land could be irrigated and whether or not irrigation is economically feasible.