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# GROUNDWATER GEOLOGY AND HYDROLOGY OF EAST-CENTRAL ALBERTA

by

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## ABSTRACT

East-central Alberta covers an area of about 17,000 square miles. Two thirds of the area is drained by the North Saskatchewan River, and the remaining one third by the Beaver River.

The bedrock units in east-central Alberta are the Lea Park, the Belly River, the Bearpaw, and the Edmonton Formations. The Lea Park Formation, underlying the northeast region, is a blue to black marine shale and, apart from occasional sandstone beds or lenses, is a poor source of groundwater supply. The Belly River Formation consists of an undivided series of thin alternating sandstones, siltstones, shales, sandy shales, and coal seams in the west region and is divided into a number of distinct alternating continental sandstone and marine shale members in the southeast region. This formation is a poor source of groundwater supply in the west region but is a moderately good source in the southeast region. The Ribstone Creek and Birch Lake Sandstone Members, which occur in the southeast region, are the most important aquifers in east-central Alberta. These aquifers have some wells yielding up to 100 gallons per minute, and locally it may be possible to obtain 150 gallons per minute. From the Bearpaw Formation, a blue to black marine shale, no groundwater is obtained in this area. The Edmonton Formation, a lithologically similar deposit to the undivided part of the Belly River Formation, has poor groundwater potential in east-central Alberta.

Unconsolidated glacial deposits, chiefly till, and some sorted sands and gravels overlie the bedrock throughout the entire area. The till is a poor source of groundwater supply and is suited largely to meeting domestic requirements only, but the sand and gravel deposits, depending on their extent, thickness and permeability, may provide sufficient water for small industrial consumption. The sand and gravel deposits within buried or partly buried preglacial valleys have good groundwater potential, and the supplies may range from domestic to industrial.

Study of the shape of the piezometric surface shows that the movement of groundwater is from centres of high to areas of low relief, with the overall movement of groundwater being toward the east.

Hydrographs, drawn from records of monthly measurements of shallow wells in the area, show that water levels fluctuate in response to changes in precipitation and temperature. These hydrographs help to confirm reports that groundwater supplies from shallow aquifers are uncertain if recharge by precipitation does not occur at regular intervals. Hydrographs drawn from the records of automatic recorders on deep wells terminated in the Ribstone Creek and Birch Lake Sandstones indicate that withdrawal of groundwater does not exceed the potential available for development.

The chemical quality of the groundwaters falls largely within the "saline" category as total dissolved solids commonly exceed 1,000 parts per million. However, much of the water is passed as suitable for human consumption because of the absence of supplies of better-quality water. The number of wells with water that is detrimental to health is assumed to be low.

Groundwater from bedrock aquifers is commonly soft to moderately soft, and only in part of the area from townships 48 to 54, ranges 1 to 8, is it commonly hard enough to require softening. The sulfate and chloride contents of the water from some wells exceed the potable limits of concentration for these constituents, and in many cases the iron and sodium contents of the water are quite high. The amount of sodium present makes many bedrock waters unsuitable or of doubtful quality for use in irrigation. The water from glacial-drift aquifers is very hard and requires softening for domestic and industrial use. The iron, sulfate, and nitrate contents commonly exceed the suggested concentration limits for potable water.

## INTRODUCTION

The purpose of this report is to summarize existing data on east-central Alberta concerning public, industrial and private water wells and to correlate these data with pertinent information supplied by oil companies and with the results of local detailed and reconnaissance groundwater surveys carried out during the summers of 1957 to 1961 inclusive. The available data have been evaluated in order to outline areas of large, moderate and small groundwater supply. The report has also been designed to delineate those parts of east-central Alberta where further detailed studies are necessary for a better understanding of the groundwater resources, particularly for the development of moderate supplies of water for municipal and light-industrial uses.

### Methods of Investigation

For an understanding of the geology of east-central Alberta, reference was made to geological reports and maps and to lithologic and electric logs. Air photos were used to supplement the field studies.

Existing well records on file in the Research Council and supplied by water-well drillers, oil companies, and private well owners were assembled as the basis of this report. Also used were data in water-supply papers published by the Geological Survey of Canada, and from local detailed areal investigations. Additional information was collected by visiting district health units, from which sources most of the data on the chemistry of the groundwaters were obtained and by visiting municipal district, town and village secretaries and by measuring water levels in wells on reconnaissance field trips.

The elevations of most wells were estimated from available topographic maps.

Hydrographs of stream flows for the North Saskatchewan and Battle Rivers and for deep and shallow observation wells have been plotted to obtain estimates of the amounts of surface runoff and groundwater discharge, and to support comments on the effects of both natural and artificial discharge on regional and local water-level fluctuations.

## Previous Investigations

A survey of the groundwater resources of east-central Alberta was begun in 1930 by Dr. R. L. Rutherford, Assistant Professor of Geology, University of Alberta, assisted by J. Tatham, who made trips in the central and southern parts of the area along the routes shown (Fig. 1). Investigations were also carried out by the Geological Survey of Canada in the early 1930's and most of their data were collected in 1935. Some of this information has since been published by the Geological Survey of Canada. Information has been selected from two of these papers (Hume and Hage, 1947a, b).

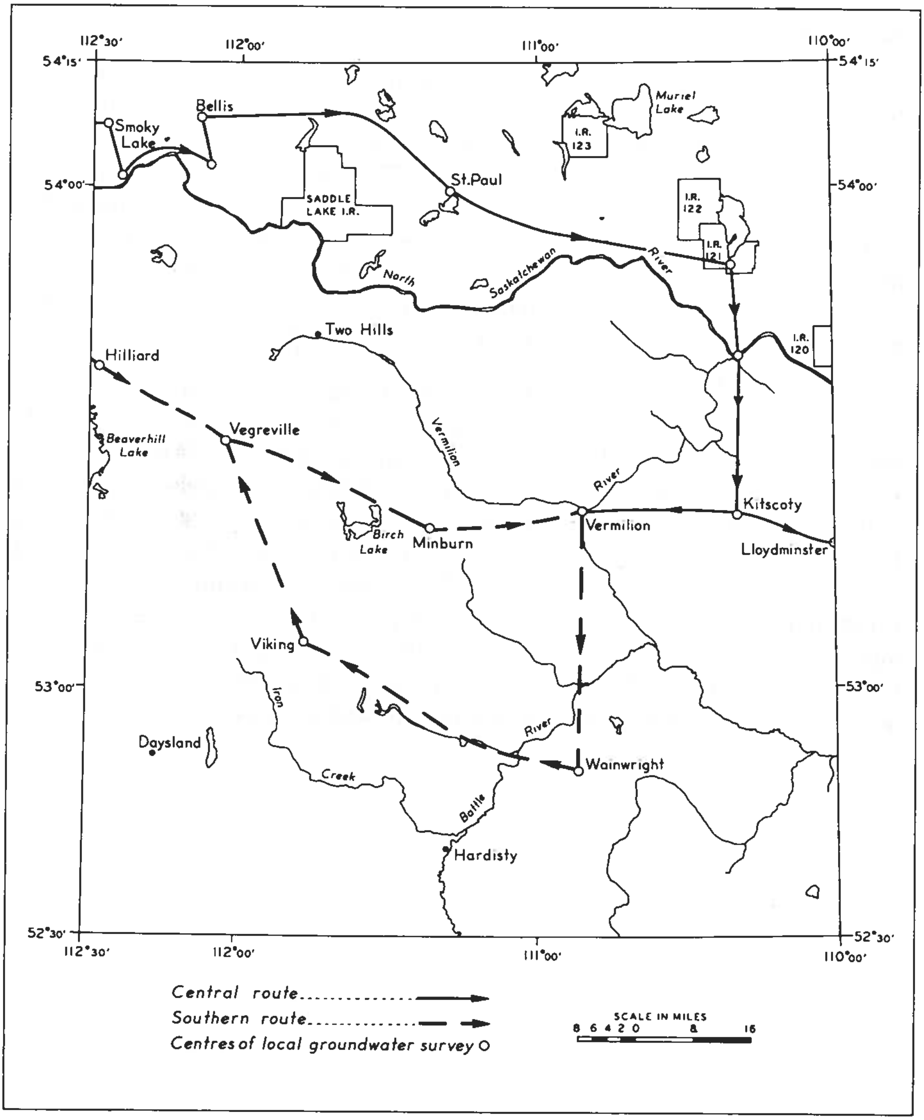

*FIGURE 1. Groundwater survey routes of 1930.*

Though some local groundwater problems were given consideration in the 1940's and early 1950's, no further serious attempts to study the groundwater resources of the area were made until 1956, when provincial groundwater investigations were initiated by the Groundwater Division of the Research Council of Alberta. A report by Foster and Farvolden (1958) has been published subsequently which makes general reference to the area. Two articles referring to specific areas of east-central Alberta have been recently published (Le Breton, 1963a, b). Local reports of areal surveys are on file at the Research Council outlining groundwater prospects in the vicinity of certain towns and villages in east-central Alberta.

## Acknowledgments

The author sincerely wishes to acknowledge the guidance given by R. N. Farvolden, former head of the Groundwater Division, Research Council of Alberta, whose advice and counsel during the first three years of work on this survey proved invaluable. The survey was completed under the supervision of W. A. Meneley and D. H. Lennox, to whom the author is also indebted. The author also wishes to acknowledge the helpful information supplied by water-well drillers, oil companies, municipal districts, town and village officials, and private well owners, without whose co-operation this report would not have been possible.

The section on chemistry of the groundwaters in east-central Alberta is based on about 600 chemical analyses of water made by Mr. C. E. Noble, Provincial Analyst, and his staff, Industrial Laboratories, Edmonton. The vast majority of these analyses were collected from the Minburn-Vermilion and Vegreville Health Units and refer largely to the territories covered by these health units. The writer is very grateful to the respective sanitary inspectors, Mr. W. Boulton and Mr. J. Donnan, for permitting him to go through the appropriate files, and for supplying land locations for many analyses, thus greatly assisting in the work of plotting the data. The writer also wishes to thank Mr. J. Donnan for his comments on possible causes and treatment of nitrate contamination in water wells.

# GEOGRAPHY

## Location and Extent of the Area

The area studied lies between parallels of latitude 52°15′ and 55° north, and between meridians of longitude 110° and 112°30′ west. On the basis of the land-survey system adopted in Alberta, it lies within townships 38 to 69, ranges 1 to 17, west of the fourth meridian* (Fig. 2). The total area is about 17,000 square miles. However, in this report emphasis is placed on the developed part, covering about 12,000 square miles, which is that part of the area south of township 62. The topographical and geological map sheets for the area are listed in appendix A.

## Topography and Drainage

East-central Alberta is part of the Plains region of Alberta and lies within the drainage basins of the North Saskatchewan and Beaver Rivers (Fig. 3). The important tributaries of the former river are the Battle and Vermilion Rivers and, of the latter, the Sand River. Elevations in the area in general decrease from west to east (Fig. 14) and the topography is gently undulating to rolling with some extensive flat-lying areas. The lowest elevation, about 1,600 feet above sea level, is in the North Saskatchewan River valley where the river crosses the Alberta-Saskatchewan boundary in Sec. 25, Tp. 51, R. 1. The highest elevations, over 2,700 feet above sea level, are in Tp. 38, Rs. 13 to 17. Most of the area, however, lies between 2,100 and 2,400 feet above sea level.

Valleys described as spillways and stream-trench systems (Gravenor and Bayrock, 1956), mostly containing only temporary or misfit streams, are common in the area. Along with other features, such as many isolated hillocks called kames, and former lake beds, they owe their existence to glaciation and deglaciation (Gravenor, 1956).

The Beaver River basin lying to the north of township 60 is largely bush covered. It is in this part of the area that the majority of the large lakes and much of the surface water occur. Many rivers and streams drain into and from these lakes, and ultimately discharge their waters into the Beaver River. In contrast, most of the area within the North Saskatchewan River basin, which lies to the south of township 60, has been cleared and settled. This part of the area is characterized by smaller lakes and fewer rivers and streams than the Beaver River basin. The surface drainage is poorly integrated over the North Saskatchewan River basin and much of the surface runoff finds its way into minor internal drainage basins.

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* Unless otherwise stated, all locations given in this report are west of the fourth meridian.

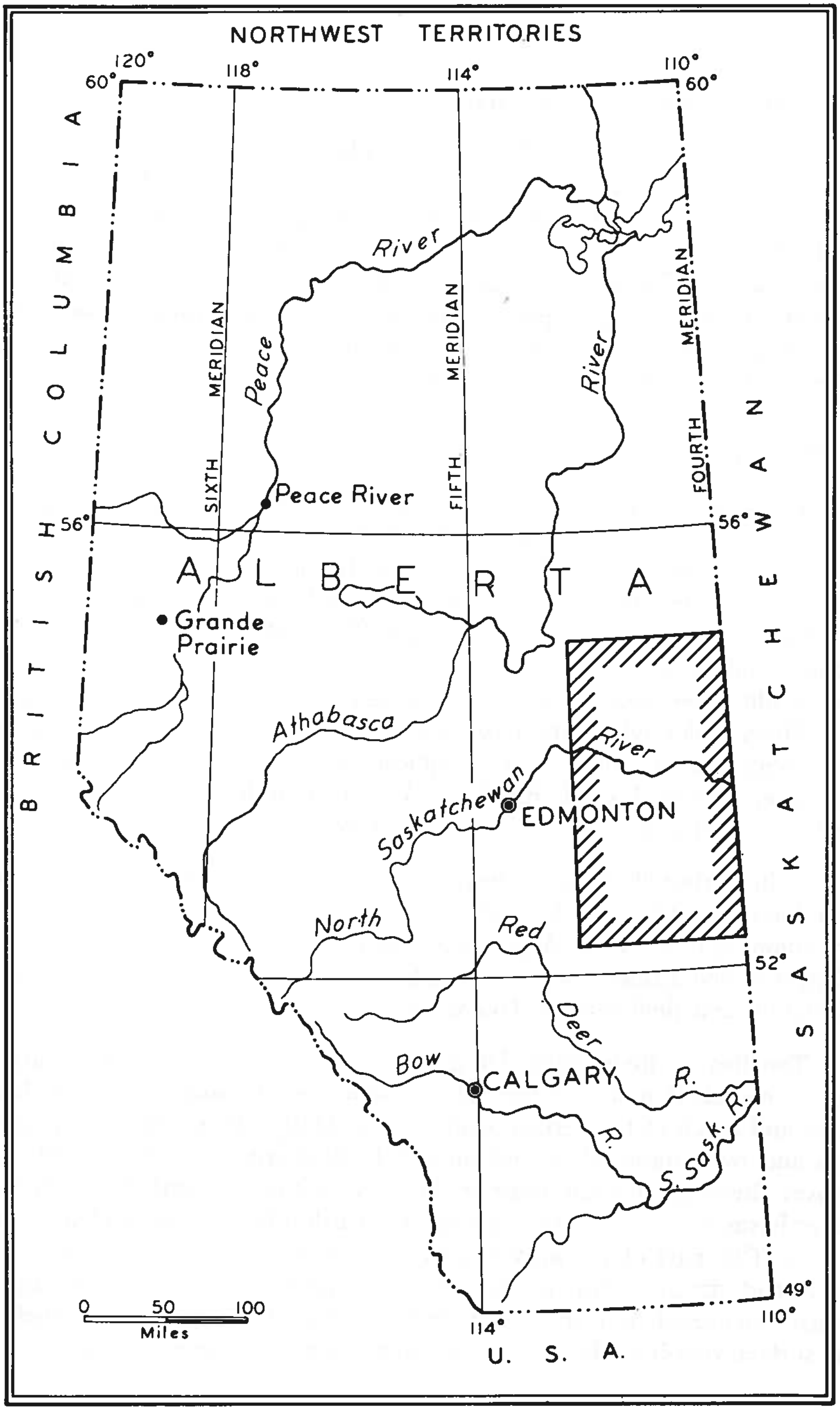

FIGURE 2. *Map showing location and extent of the area.*

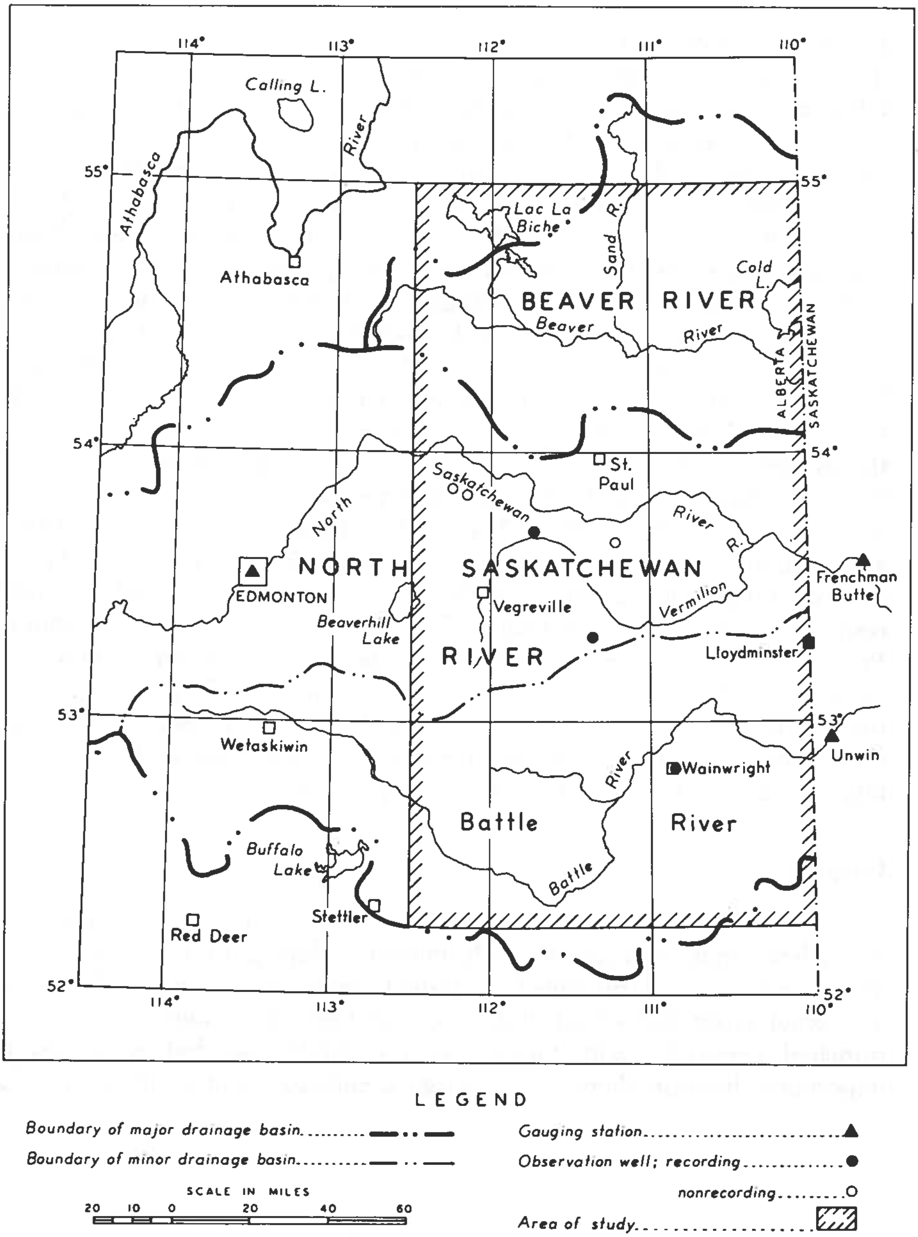

FIGURE 3. *Drainage basins of east-central Alberta.*

## Climate

The climate of the area is humid continental, based on Koppen's classification (Can. Dept. Mines Tech. Surv., 1957). The temperature ranges between extremes of 90°F* in the summer and —35°F* in the winter, and the average precipitation is about 16 inches* per year. For more complete information see figure 4. The spring of the year is short and precipitation may fall as rain or snow. It is about this time of the year that winds are most common, are fairly strong, and are most effective in causing evaporation of snow or surface water. The average wind velocity is 9.8 mph†. The summer is moderately dry and warm, with its growing season being influenced by killing frosts, which may occur as late as June or as early as September. The average relative humidity is 66.5 per cent†. The successful growth of the grain crops is largely dependent upon the amount of moisture in the month of June, and this is normally sufficient to germinate the seed. Though the precipitation during the summer generally occurs as rain, very localized hail storms may sometimes occur. These are most common in the southeast part of the area and may cause serious damage to the grain. July and August provide the hot growing weather with temperatures often between 75°F and 85°F. The fall is mild to cool with several frosts, and, as in the spring of the year, precipitation occurs as rain or snow. Winds during the summer and fall are lighter, averaging 8.1 mph† and 8.3 mph† respectively. The winter is long and cold, lasting for about five months. Precipitation during this season is almost entirely in the form of snow, and temperatures frequently range between 15°F and —10°F. The stillness of the air, or general occurrence of only light winds, averaging 7.7 mph† during the winter makes the cold far more tolerable. The average relative humidity during the winter season is 86 per cent†.

## Commerce

The economic activities of east-central Alberta are predominantly dependent upon agriculture, with industry playing only a minor role. The area is particularly suited to grain farming and raising of livestock. The chief crops are wheat and oats, and beef cattle and hogs are the principal livestock. Dairy farming is also carried on, but is limited in importance because there are no large population centres to serve. The

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* The above figures have been obtained from the meteorological records for the years 1956 to 1960, for the weather station at Vermilion.

† The figures for wind velocities and relative humidities were obtained by personal communication with Mr. Van Volkenburg, Meteorological Branch, Department of Transport.

average farm size is about 450 acres*. The industrial pursuits of the area are related to the exploration for oil and natural gas, and are accompanied by some oil refining, or are based upon agriculture — chiefly slaughtering of livestock and milling of grain. Because of the prime importance of agriculture, the population of east-central Alberta is only 75,000*, and the size of most communities is small, the population figures being mostly between 200 and 700.

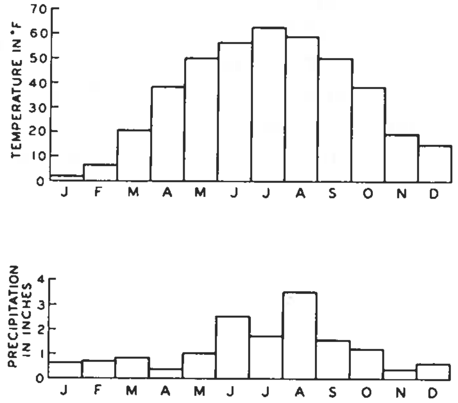

*FIGURE 4. Histograms showing average monthly temperature and precipitation at Vermilion, Alberta.*

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* Information supplied by R. Huene, Alberta Bureau of Statistics, Department of Industries and Labour.

## GEOLOGY

Because the geology of an area exerts the controlling influence upon the amount of available groundwater, an examination of the bedrock geology and surficial deposits is essential. The bedrock formations (Fig. 5) of interest in this report are entirely of late Cretaceous age and are mostly obscured by overlying deposits of glacial drift. The geologic maps (Appendix A) of the area record the ascending stratigraphic succession as Lea Park Formation, Ribstone Creek Formation, Grizzly Bear Formation, Birch Lake Formation, Pale and Variegated Beds—referred to as the Oldman Member of the Belly River Formation by Shaw and Harding (1954)—Bearpaw Formation and Edmonton Formation. Below the Lea Park Formation lies the Colorado Formation. The geology has been described in reports

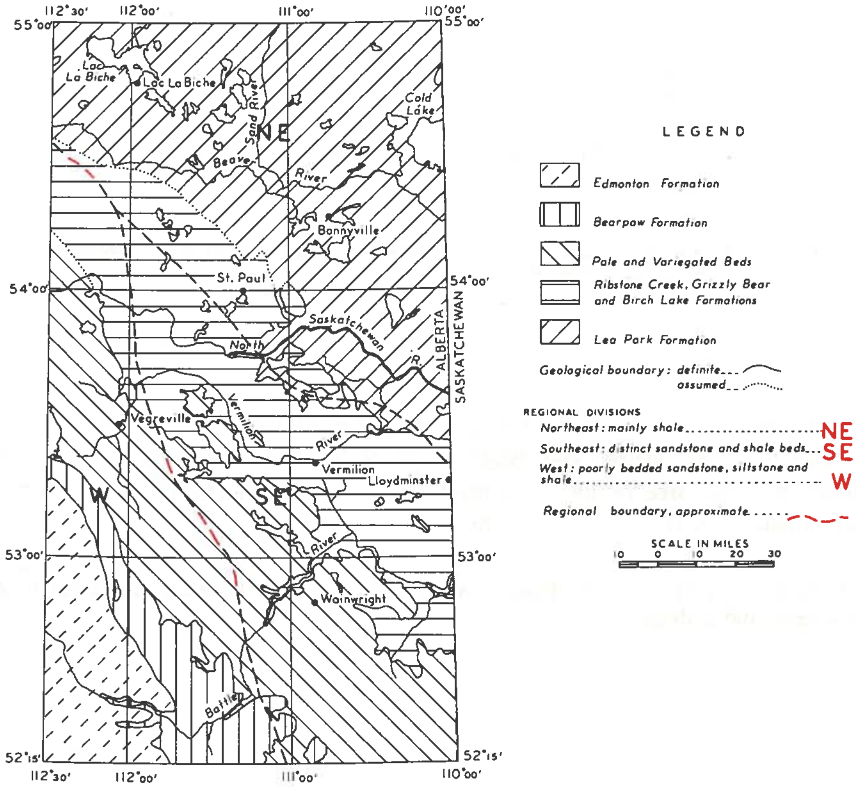

FIGURE 5. *Geologic map of east-central Alberta.*

by Slipper (1917), Allan (1918), Hume (1936) and Hume and Hage (1941). Additional information on the subsurface geology based upon electric-log studies has led to the publication of articles by Nauss (1945) and Shaw and Harding (1954) presenting a modification of the stratigraphic column for east-central Alberta as compared to that in earlier reports and geological maps of the area. Table 1 presents the stratigraphic succession adapted, with additions, from Shaw and Harding (1954). This succession is largely applicable to an area from townships 38 to 56 between ranges 1 and 17 in the area of study. Some lithologic logs (Appendix B) have been selected from records submitted by water-well drillers.

The depositional environment of the bedrock aquifers of east-central Alberta was predominantly continental. In this environment were deposited the coal seams and, in addition, the commonly dirty or bentonitic, fine- to medium-grained sands comprising the hard and soft sandstone beds. The bedrock geology of the area shows significant lateral variations as illustrated by the section in figure 6, and on this basis the area can be divided into three regions: a northeast region, a west region, and a southeast region (Fig. 5). In the northeast region, the bedrock consists almost entirely of shale, the Lea Park Formation, with local dirty sandstone beds or lenses. In the west region, the upper Cretaceous strata consist of thin, alternating, fine- to medium-grained bentonitic sandstones, siltstones, shales, sandy shales, carbonaceous shales, and coal seams. These strata are grouped together as the so-called undivided Belly River Formation. In the southeast region are a series of alternating continental sandstones and marine shale tongues, and these are grouped together as the divided part of the Belly River Formation. The shales, known as Shandro, Vanesti, Mulga and Grizzly Bear, represent marine incursions from the north and northeast and are extensions of the Lea Park Formation into the southeast region. The Brosseau, Victoria, Ribstone Creek, and Lower and Upper Birch Lake Sandstones represent successive periods of continental conditions. They are also the major aquifers of east-central Alberta.

The Ribstone Creek Sandstone is the most important sandstone member of the Belly River Formation and so it is discussed in some detail. This sandstone subcrops beneath the glacial drift in the Lloydminster area, where it is encountered at depths ranging from 50 to 150 feet below ground level. Its thickness in this area varies from 0 to 150 feet and averages about 100 feet. At any particular location, the Ribstone Creek Sandstone consists of a succession of interbedded sandstone, silty sandstone and siltstone strata. Samples from the sandstone show it to be grey, brown, and green, and composed largely of fine- to medium-sized grains cemented with calcite. The degree of cementation ranges from poor to complete. The degree of sorting in the sandstone is variable. In the Two Hills area, the Ribstone Creek Sandstone is a light-blue, hard or soft bentonitic sandstone.

**Table 1. Stratigraphic Units and their Water-yielding Properties, East-Central Alberta**

| System | Series | Formation | Member | Thickness (feet) | Description | Permeability | Groundwater Potential | Well Yields (gpm) |
|---|---|---|---|---|---|---|---|---|
| Tertiary | Pleistocene | Wisconsin? | — | 0-250 | Till | Low | Suited to domestic and small stock supplies | Commonly less than 3 |
| | | | | | Dune sand | Low | Suited to domestic and stock supplies | Up to 5* |
| | | | | | "Quicksand" | Low | Suited to domestic and stock supplies | Up to 5* |
| | | | | | Sand and gravel | High | Suited to domestic, stock, municipal and industrial supplies | Up to 350 |
| | | Preglacial valley deposits | — | ? | River silt, sand and gravel | Low to high | Suited to domestic, stock, municipal and industrial supplies | Up to 350 |
| Cretaceous | Montanan | Edmonton | — | ? | Argillaceous sandstone beds, dark, bentonitic shale and coal seams | Low | Suited to domestic and small stock supplies | Commonly less than 5 |
| | | Bearpaw | — | ? | Grey to dark shale, brownish and green sand, ironstone nodules | Low | Suited to domestic supplies only | 1* |
| | | Belly River | Oldman | ? | Undivided series of alternating thin soft and hard sandstone beds, shale, siltstone, carbonaceous shale and coal seams | Low | Suited to domestic and small stock supplies | Commonly less than 5 |
| | | | Upper Birch Lake | 0-50 | Grey, brownish-yellow, medium-grained sandstones with siltstone beds | Medium | Suited to domestic, stock and municipal supplies | Up to 20* |
| | | | Mulga | 0-45 | Grey shale, siltstone lenses and carbonaceous shale | Low | Suited to domestic supplies only | 1* |

| System | Series | Formation | Member | Thickness (feet) | Description | Permeability | Groundwater Potential | Well Yields (gpm) |
|---|---|---|---|---|---|---|---|---|
| Cretaceous | Montanan | Belly River | Lower Birch Lake | 0-115 | Massive, cross-bedded greenish-grey or buff-colored, medium- to fine-grained sandstone with hard concretionary nodules | Medium | Suited to domestic, stock, municipal and industrial supplies | Up to 150 |
|  |  |  | Grizzly Bear | 0-140 | Dark blue marine shale with ironstone and sandstone nodules | Low | Suited to domestic supplies only | 1* |
|  |  |  | Ribstone Creek | 0-150 | Grey, brown, green, blue, soft to hard, fine- to medium-grained sandstone and some shale | Medium | Suited to domestic, stock, municipal and industrial supplies | Up to 150 |
|  |  |  | Vanesti | 0-140 | Grey shale with some thin fine-grained sandstone lenses | Low | Suited to domestic supplies only | 1* |
|  |  |  | Victoria | 0-95 | Grey, fine- to medium-grained sandstone, silty sandstone and shale | Medium | Suited to domestic and stock supplies | Up to 20* |
|  |  |  | Shandro | 0-85 | Grey shale, with some fine-grained sandstone lenses | Low | Suited to domestic supplies only | 1* |
|  |  |  | Brosseau | 0-100 | Grey, fine- to medium-grained sandstone, silty sandstone and shale | Medium | Suited to domestic and small stock supplies | Up to 20* |
|  |  | Lea Park | — | 450-810 | Grey, blue and black shale with clay ironstone concretions, some fine-grained sandstone beds and lenses | Low | Suited to domestic supplies | Commonly less than 2 |

* Denotes estimated well-yields

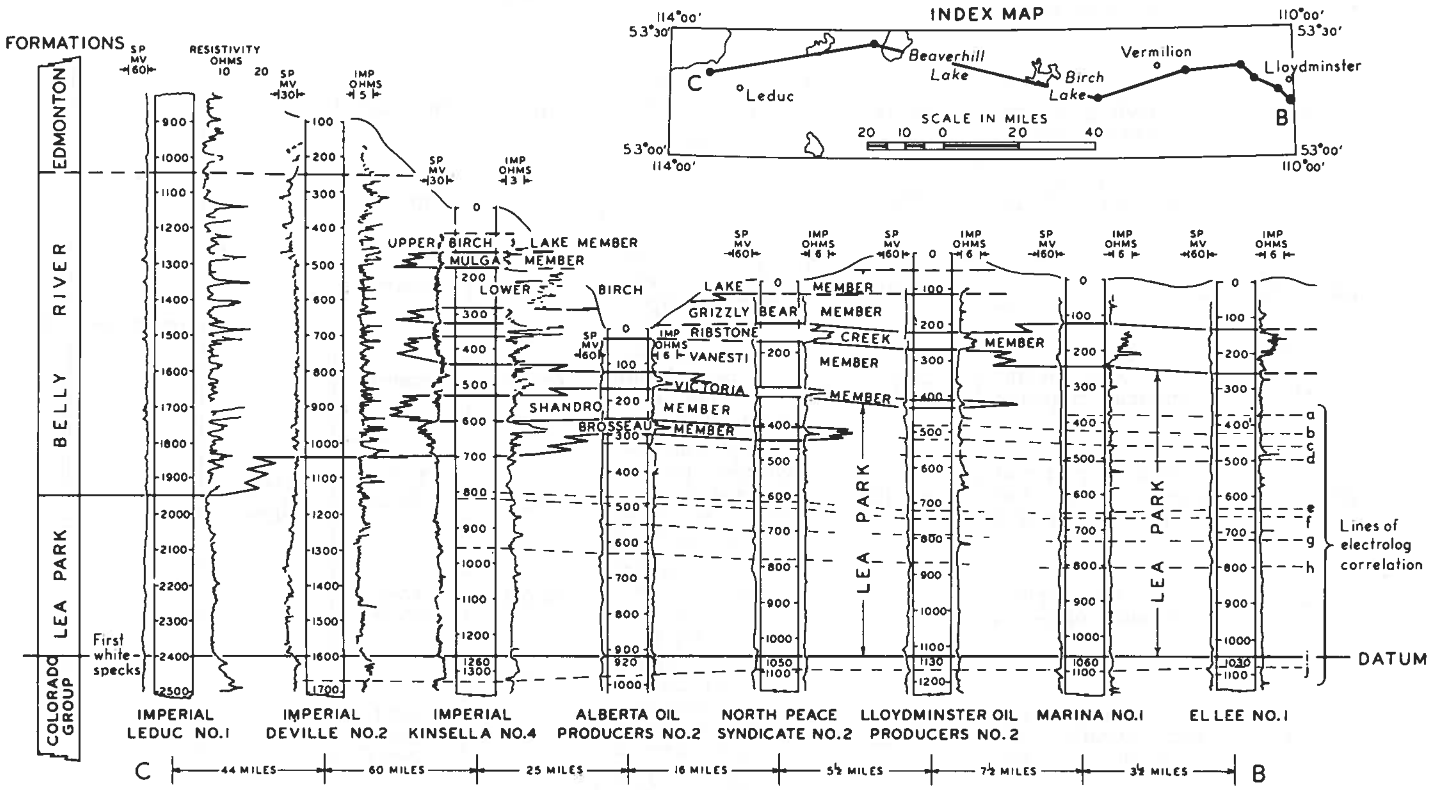

FIGURE 6. *Electric-log cross section showing bedrock geology (reproduced by permission, from Shaw and Harding, 1954).*

Three electric logs have been selected for a cross section (Fig. 7) ten miles long, illustrating differences in development of the sandstone beds in the Lloydminster area. Reference to other electric logs from the area demonstrates that these show the typical irregular occurrence and thickness of the sandstone beds. Another cross section (Fig. 8) of the Ribstone Creek Sandstone*, constructed from electric logs run by Elk Point Drilling Co. and the Research Council of Alberta, is shown for wells and test holes drilled in the Two Hills area. Information from oil- and water-well drilling in the Wainwright area shows that the Ribstone Creek Sandstone occurs about 300 to 400 feet below ground level. The regional dip of this sandstone is to the southwest at about 4 to 5 feet per mile. The lithology, configuration and distribution of the other sandstone members of the Belly River Formation is similar to that of the Ribstone Creek Sandstone. Of the other members, the Lower Birch Lake Sandstone is the next in importance.

## Structure and Bedrock Topography

The contour map of the Lea Park-Colorado contact (Fig. 9), drawn from data listed in the Schedules of Wells Drilled for Oil and Gas (Alberta. Oil and Gas Conservation Board, 1949-1957), is presented to portray the regional structure over much of east-central Alberta. The map shows the structure to be homoclinal, with the dip of the strata increasing from 7 to 14 feet per mile as the area is traversed from northeast to southwest, the regional strike being northwest. This structural effect, which may also be observed on a structural contour may of the Paleozoic surface (Hume and Hage, 1941), is reflected throughout the geologic column and produces a very similar structure in the uppermost strata in the area—those of the Belly River Formation.

The bedrock topography corresponds quite closely to the present-day topography. The significant differences occur where the valleys of preglacial rivers and streams have been buried beneath the cover of glacial drift along part or all of their length. Where such infilling occurs, present-day rivers and streams commonly follow different courses.

## Glacial Drift

The glacial features in east-central Alberta that are of considerable areal extent are ground moraine and "dead-ice" moraine. These areas of moraine consist of deposits of till, which is composed of poorly sorted to unsorted silt, clay, and boulders, with lenses of sand and gravel. Other glacial features of minor areal extent include spillways, stream-trench systems and outwash plains. As a result of a study by Ellwood (1961), a map of the surficial geology is available for the area covered by the Vermilion map sheet (Sectional Sheet No. 316).

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* Additional work may prove that part of this sandstone belongs in the Lower Birch Lake Member.

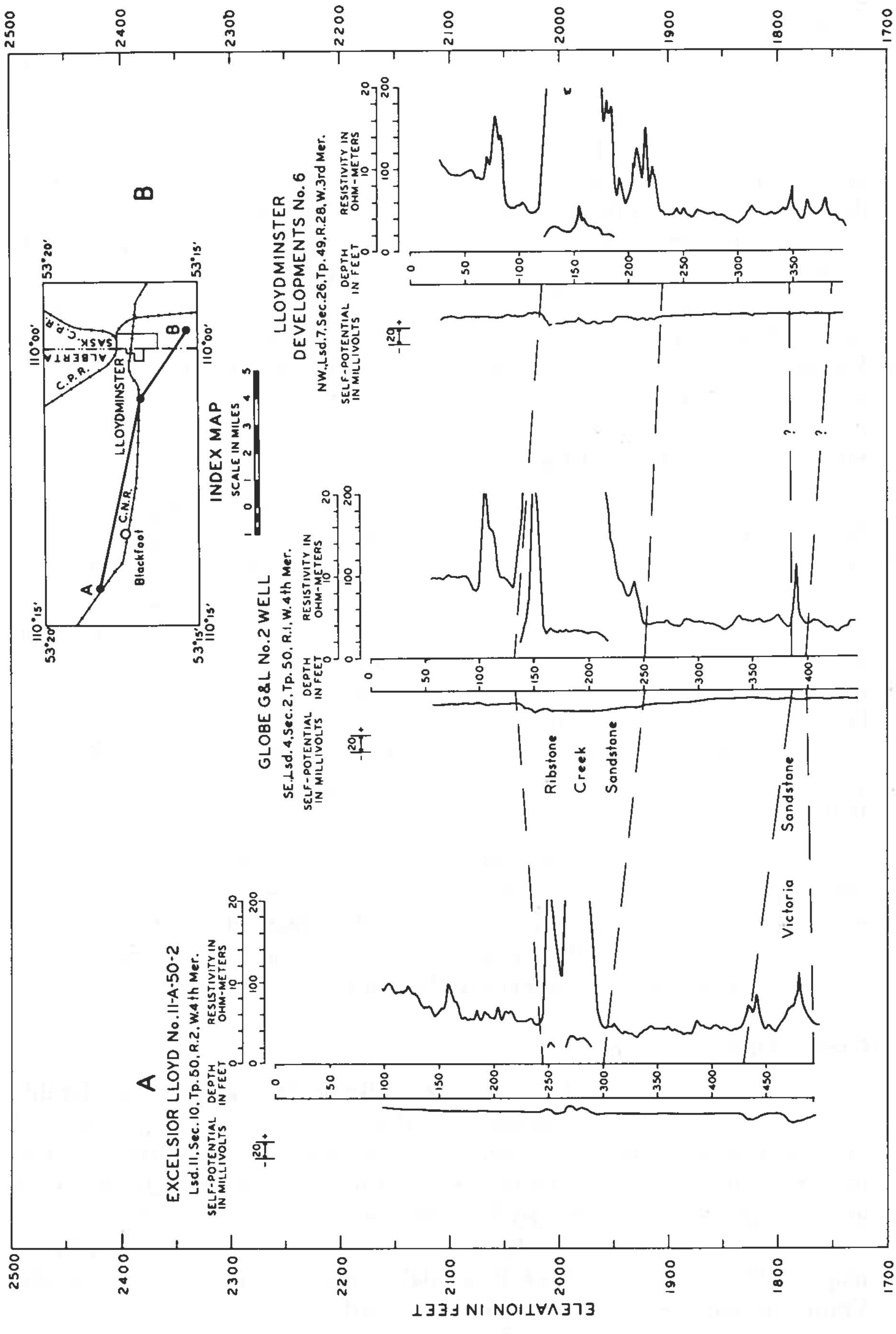

*FIGURE 7. Electric-log cross section of the Ribstone Creek Sandstone, Lloydminster area.*

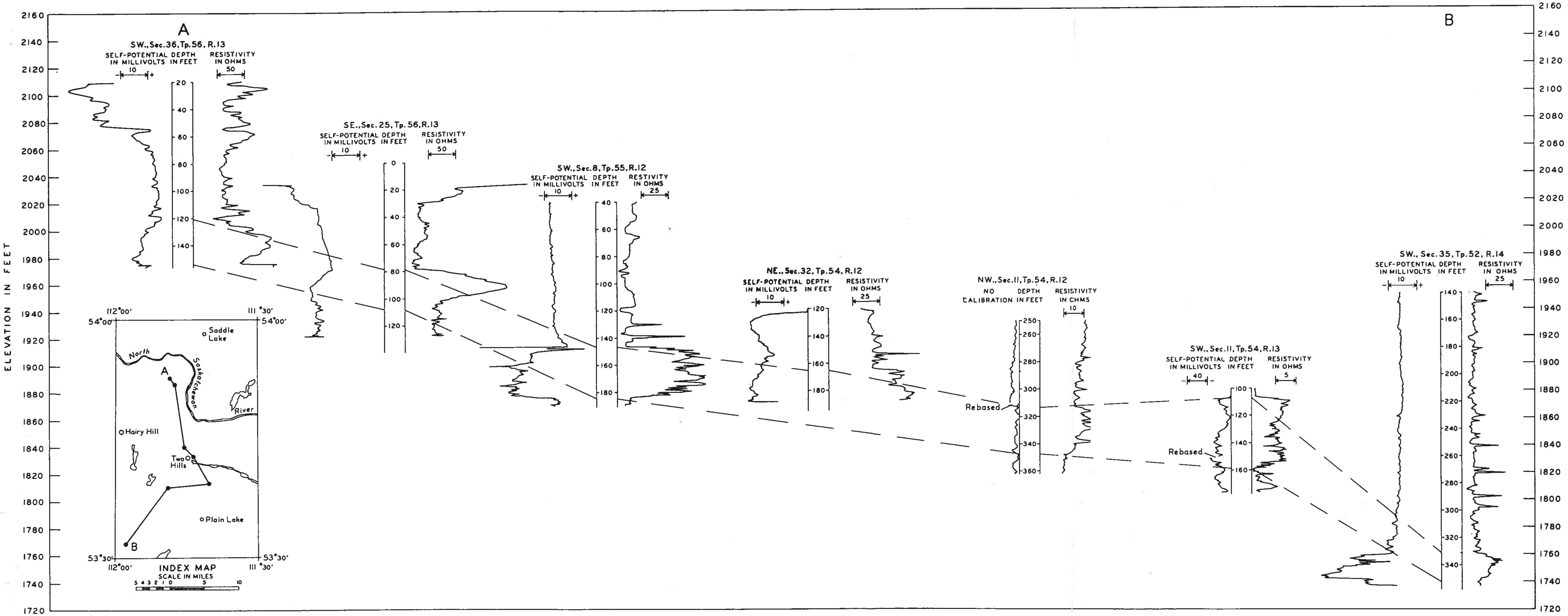

FIGURE 8. *Electric-log cross section of the Ribstone Creek Sandstone, Two Hills area.*

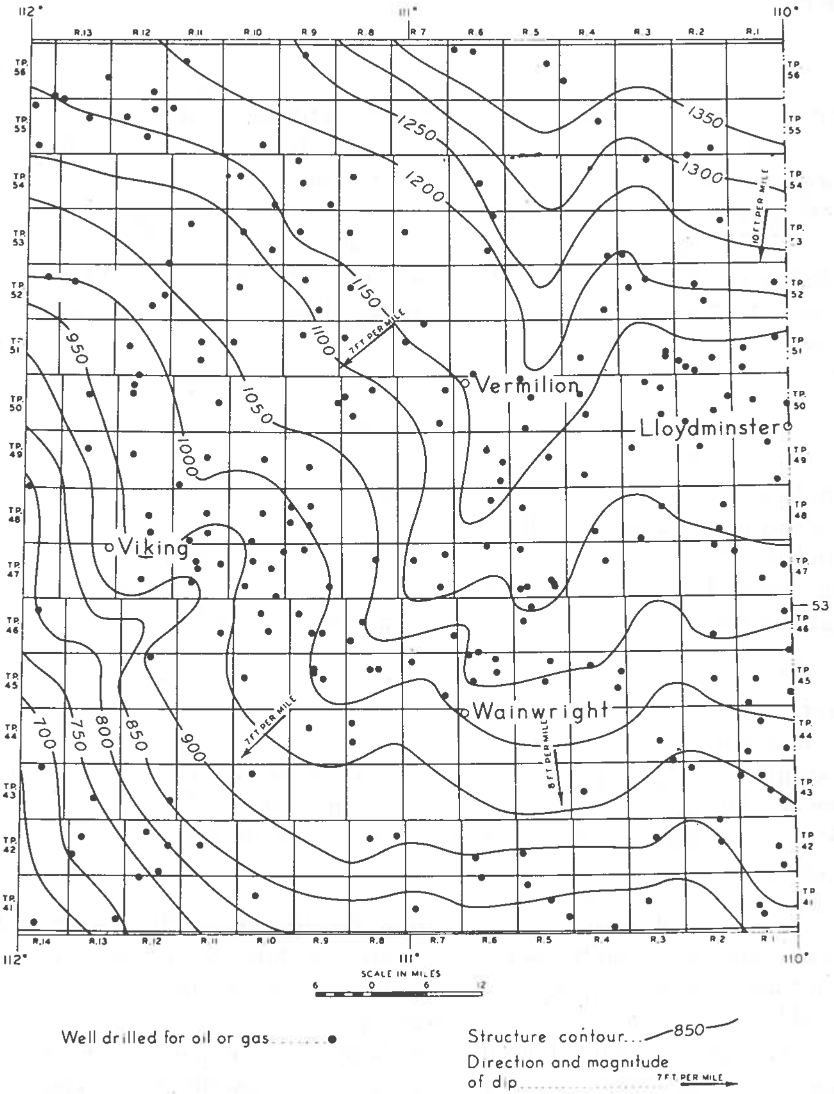

FIGURE 9. *Structure-contour map of the Lea Park-Colorado contact.*

# GROUNDWATER GEOLOGY AND HYDROLOGY

## Source, Occurrence and Movement of Groundwater

It may be considered that the contained waters in bedrock aquifers at the time of deposition in a continental environment were fresh to brackish in nature. Following uplift and erosion of the strata above sea level, local precipitation has been slowly freshening and replacing the original formation waters in the shallower zones, mainly to depths of 300 to 400 feet. In a few instances, well waters with high salt content—over 750 ppm (parts per million)—are known to occur. This may indicate that increasing salinity may be expected locally due to migration of water from surrounding marine shales. In localities where the saline groundwaters are shallow, however, it may be attributed to extremely limited movement of groundwater since uplift and erosion.

The sources from which groundwater supplies are obtained are: fine- to medium-grained, clean or dirty, hard or soft sandstone beds, coal seams and "quicksands" in the bedrock; sand and gravel deposits in the till, stream-trench systems, and spillways; dune sand, outwash sand and gravel, and "quicksands" in the glacial drift; sand and gravel deposits within buried or partly buried preglacial river valleys; and sand and gravel deposits adjacent to rivers and lakes, permitting induced infiltration.

Groundwater occurs in the pore spaces of the materials composing the various strata. The differences between the strata as reservoirs of groundwater depend upon porosity, which is the percentage of the total volume occupied by open spaces. Porosity is controlled by the shape and arrangement, the degree of sorting, and the cementation of the rock materials. Porosity is high in well-sorted deposits and low in poorly sorted or highly cemented deposits.

The rate of movement of groundwater—the permeability—through the strata depends upon the degree of interconnection between the pore spaces and the sizes of the particles comprising the strata. Silts and clays, though highly porous, have such small pore spaces that a very large percentage of the water contained in them is bound to the particles by forces of molecular adhesion, and such materials are described as being impermeable. Coarse gravels with large openings permitting water to move freely are said to be highly permeable.

## Bedrock Aquifers

East-central Alberta can be divided into three regions with distinct differences in bedrock groundwater resources. It is not surprising that these correspond to the previously described regional geologic subdivisions (Fig. 5), because the geologic environment exercises a marked influence upon the quantity of groundwater available. A brief summary of the groundwater properties of the bedrock aquifers is given in table 1.

The northeast region is classed as very poor and may almost be disregarded when bedrock supplies are being considered. This part of the area is underlain by the Lea Park Formation which consists almost entirely of shale. The groundwater supplies that are obtained come from sandstone lenses or silty sandstone beds with very low permeability. This limits wells to very low yields, suited to supply domestic requirements* only. The production of these wells may range from only a few gallons per day (gpd) to about 2 gallons per minute (gpm). Quite often these wells may be pumped dry under normal conditions of usage.

In the west region, which is underlain by the undivided Belly River Formation, groundwater prospects are distinctly better than in the northeast region. Supplies of groundwater from wells in this region may be sufficient to satisfy domestic and limited livestock requirements†. However, many of these wells may also be pumped dry under normal conditions of usage. The low yields of wells in this area, which are estimated from the existing bail- and pump-test data to be less than 5 gpm, are due to the groundwater sources being largely thin, fine-grained sandstones of limited areal extent and low permeability.

The southeast region has the greatest groundwater potential in east-central Alberta. This region is underlain by the divided part of the Belly River Formation, of which the Ribstone Creek and Lower Birch Lake Sandstone Members are the most important aquifers.

Data pertaining to the hydrologic properties of the Ribstone Creek Sandstone aquifer have been mostly obtained from the Lloydminster area, with some from the Wainwright and Two Hills areas. Wells completed in the upper part of the Ribstone Creek Sandstone are believed to be capable of providing more than ample supplies of water for domestic and livestock requirements. Many of these wells in the Lloydminster area are from 100 to 150 feet deep. For the upper 50 feet of this aquifer safe well-yields are estimated to be less than 25 gpm. Data supplied from tests conducted in the military camp at Wainwright record water-bearing sandstone from 362 to 370 feet deep, at an elevation of 1,902 to 1,894 feet above sea level. The safe yield, based on a specific capacity of 0.15 gallons per minute per foot (gpm/ft) of drawdown, was calculated to be 36 gpm.

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* "Domestic requirements" is used to refer to quantities sufficient for rural or individual (private) municipal household needs.

† "Limited livestock requirements" is used to refer to quantities sufficient to supply about 20 to 30 head of cattle, some hogs and poultry.

Because complete pump-test data were not supplied for the wells near Wainwright, safe yields had to be based upon the specific capacities. Use of this method for calculating safe yields is not recommended, except in those cases where data are inadequate, because it assumes that the water level in the well has stabilized. This assumption is almost always unjustified in the case of bedrock aquifers in Alberta, because water levels are observed to decline slowly even after extended pumping periods. Such results indicate withdrawal of water from storage faster than the rate at which it is being recharged. Calculation of the safe well-yield must take account of the declining water-level, if a reliable estimate is to be made. Thus, the safe well-yields based on specific capacities are suspect. Safe yields based on adequate data assume a gradual decline of the water level for a period of 20 years of continuous pumping.

In order to obtain supplies of water for industrial requirements from the Ribstone Creek Sandstone, it appears that wells have to be completed in the lower part of this aquifer. At Lloydminster, the depths of wells in this aquifer range from 150 to 260 feet. Their yields are reported to be from 25 to 120 gpm. These figures are for wells which belong to the city of Lloydminster and to Excelsior and Husky Oil Refineries, and the wells are located within and to the north and west of the city limits. However, test drilling carried out to the south and east of the city located wells estimated to meet only domestic and farm requirements. Calculations based on available bail- and pump-test data give transmissibility* figures ranging from 800 to 4,700 gallons per day per foot (gpd/ft) and averaging about 3,400 gpd/ft, and safe well-yields of 25 to 100 gpm. From work recently carried out in the Two Hills area, a transmissibility of 4,000 gpd/ft was obtained and a safe well-yield of 100 gpm.

Further information from the military camp at Wainwright shows a safe well-yield of 124 gpm based upon a specific capacity of 0.42 gpm/ft of drawdown. This well is in a sandstone bed encountered at 350 to 380 feet below ground level, or at an elevation of 1,853 to 1,823 feet above sea level, in the lower part of the Ribstone Creek Sandstone.

The amount of pump-test data available on the Lower Birch Lake Sandstone is much less than for the Ribstone Creek Sandstone. Drilling records again show that there are two distinct producing zones within this aquifer. A six-hour pump test of Wainwright town well No. 6, completed in the lower zone about 240 feet below ground level, gave transmissibilities of 1,500 and 2,600 gpd/ft for drawdown and recovery respectively. This indicated safe yields of 80 and 150 gpm respectively. Less complete information on one of the Canadian National Railways' wells completed in sandstone beds from 170 to 189 feet and 190 to 191 feet deep, and believed

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* Transmissibility is a product of the permeability of an aquifer multiplied by its thickness.

to be in the upper zone of the Lower Birch Lake Sandstone, indicates that this well has a reported safe yield of 250 gpm. This calculation is based upon a specific capacity of 2.8 gpm/ft of drawdown. A comparison between the town and the railway wells, based on their specific capacities, shows that both wells have a maximum capacity of 250 gpm. No similar comparisons can be made for transmissibility or permeability because of lack of sufficient pump-test data and information on the thicknesses of the aquifers. However, it may be possible that both wells have a similar safe yield of 150 gpm. Though the main producing zone in the Canadian National Railways' well was reported to be the one foot of sandstone at 190 feet, it is believed that the section from 170 to 189 feet is the main producing zone.

The town of Wainwright has its wells completed in the lower zone because the water is very much softer than in the upper zone (see chemical analyses listed in Appendix C). Locally, drilling down to this lower sandstone sometimes presents difficulties, which arise in trying to "mud off" the upper zone. Evidence regarding the availability of groundwater shows the town of Wainwright to be the most favorably situated of the population centres in east-central Alberta for obtaining groundwater supplies for municipal and industrial purposes. From the data available, wells producing about 100 gpm can be obtained from both the Lower Birch Lake and Ribstone Creek Sandstones in the vicinity of Wainwright.

### Apparent-Transmissibility Values for Bedrock Aquifers

The apparent-transmissibility map (Fig. 10) is based on a very limited amount of bail- and pump-test data but, nevertheless, it gives additional support to the validity of dividing the area into three regions with distinct differences in bedrock groundwater resources. The transmissibility values, on which the ranges shown on the map are based, are for wells that may, in some cases, only partially penetrate the aquifer. In some instances the value may be a compound transmissibility for a few minor sandstone lenses and coal seams as well as for other less permeable materials. Also, many of the values for bailed wells will be for only partially developed test holes, well development being completed by the owner, who allows the pump to run continuously for several hours or days. Although these may only be termed apparent-transmissibility values, they have been utilized to illustrate differences in the hydrologic properties of the bedrock aquifers of each region. The northeast region is notable for the low number of bedrock wells. Recorded transmissibilities are less than 60 gpd/ft. In the west region, transmissibilities are commonly less than 100 gpd/ft, but the number of bedrock wells is much higher. In the southeast region, values commonly range from 100 to 300 gpd/ft, with the highest values so far recorded being 4,700 gpd/ft for the Ribstone Creek Sandstone and 2,600 gpd/ft for the Lower Birch Lake Sandstone.

Comparison of apparent-transmissibilities for aquifers in the Paskapoo Formation in the Pembina area (Farvolden, 1961b) with those of the aquifers of east-central Alberta show the latter to be much poorer sources of groundwater supply. However, the southeast region compares favorably with those parts of the Pembina area delineated as "Good." Locally, this region may have values comparable to some of those represented by the "Very Good" areas. The figures of 2,600 to 4,700 gpd/ft obtained in the southeast region are high for bedrock aquifers in Alberta, but elsewhere in east-central Alberta the values are probably below average.

### Glacial Drift and Bedrock Channel Aquifers

The groundwater prospects in the glacial drift and preglacial river valleys range from poor to excellent. Locally, drift and channel aquifers may be expected to be some of the most highly productive sources of groundwater. This is illustrated on figure 11, which is based upon the map of the surficial geology of the Vermilion area by Ellwood (1961).

Most of east-central Alberta is covered by till containing water-bearing sand and gravel lenses. Only domestic supplies and limited livestock-supplies of groundwater may be expected from such sources. Very many wells terminated in the till yield only 200 to 600 gpd*, and frequently are reported to be pumped dry. These reports from well owners and well drillers are substantiated by short pump-tests carried out in the Two Hills area (Fig. 12). For two of these tests (A, C) the results show that little more water was obtained during the period of pumping than the volume of water in the well. This is commonly the case. Because of the difficulties of obtaining water supplies in many areas, bored or dug wells about 2 to 3 feet in diameter are commonly found, most of which are completed in glacial-drift aquifers. These large-diameter wells are preferred to 4-inch drilled wells chiefly for the advantages of their storage capacity. However, the manner of completing bored wells may be partly responsible for their low yields from some aquifers. This is more fully considered under the section on "Well Completion".

Large quantities of water can be obtained only from the granular materials that occur in spillways, in stream-trench systems, in areas of outwash, and in buried or partly buried preglacial river valleys, in particular those that are adjacent to and below the level of large bodies of surface water. In each case, the well yield from these deposits will be dependent on the areal extent, thickness and permeability of the deposits. Because there is only a very limited amount of hydrologic data available on each of these types of aquifers, very little can be written about each source separately.

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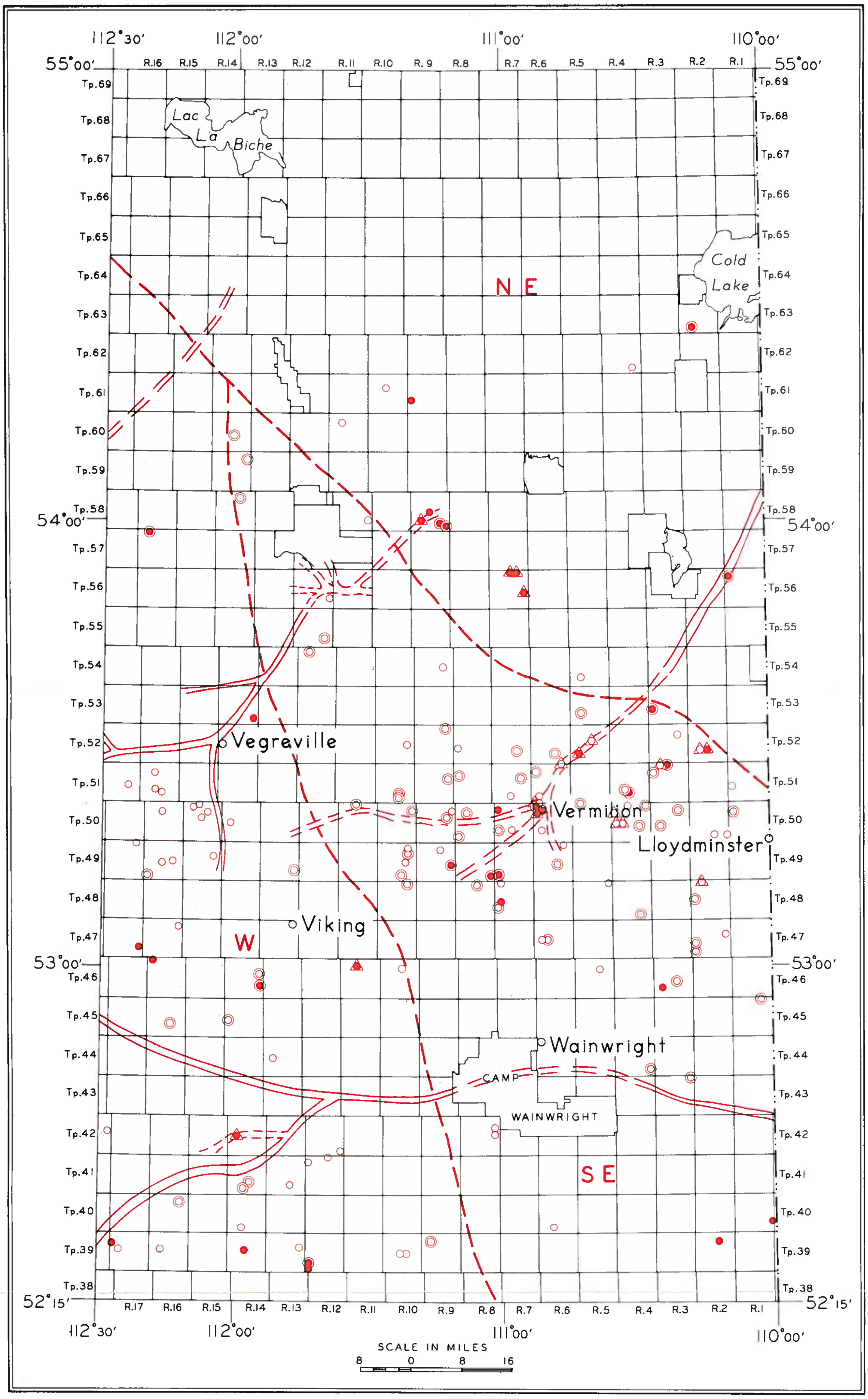
* 1 gpm = 1,440 gpd



LEGEND

Well with transmissibility 1-100 gpd/ft; bedrock, drift ○ ●

Well with transmissibility 101-1,000 gpd/ft; bedrock, drift ◎ ◉

Well with transmissibility 1,001-5,000 gpd/ft; bedrock, drift △ ▲

REGIONAL BEDROCK DIVISIONS — — — —

Northeast: Transmissibility less than 100 gpd/ft; few bedrock wells NE
West: Transmissibility commonly less than 100 gpd/ft; many bedrock wells W
Southeast: Transmissibility commonly 101-1,000 gpd/ft SE
Bedrock channel; defined, assumed ═══ = = =

*FIGURE 10. Apparent — transmissibility map of east-central Alberta.*

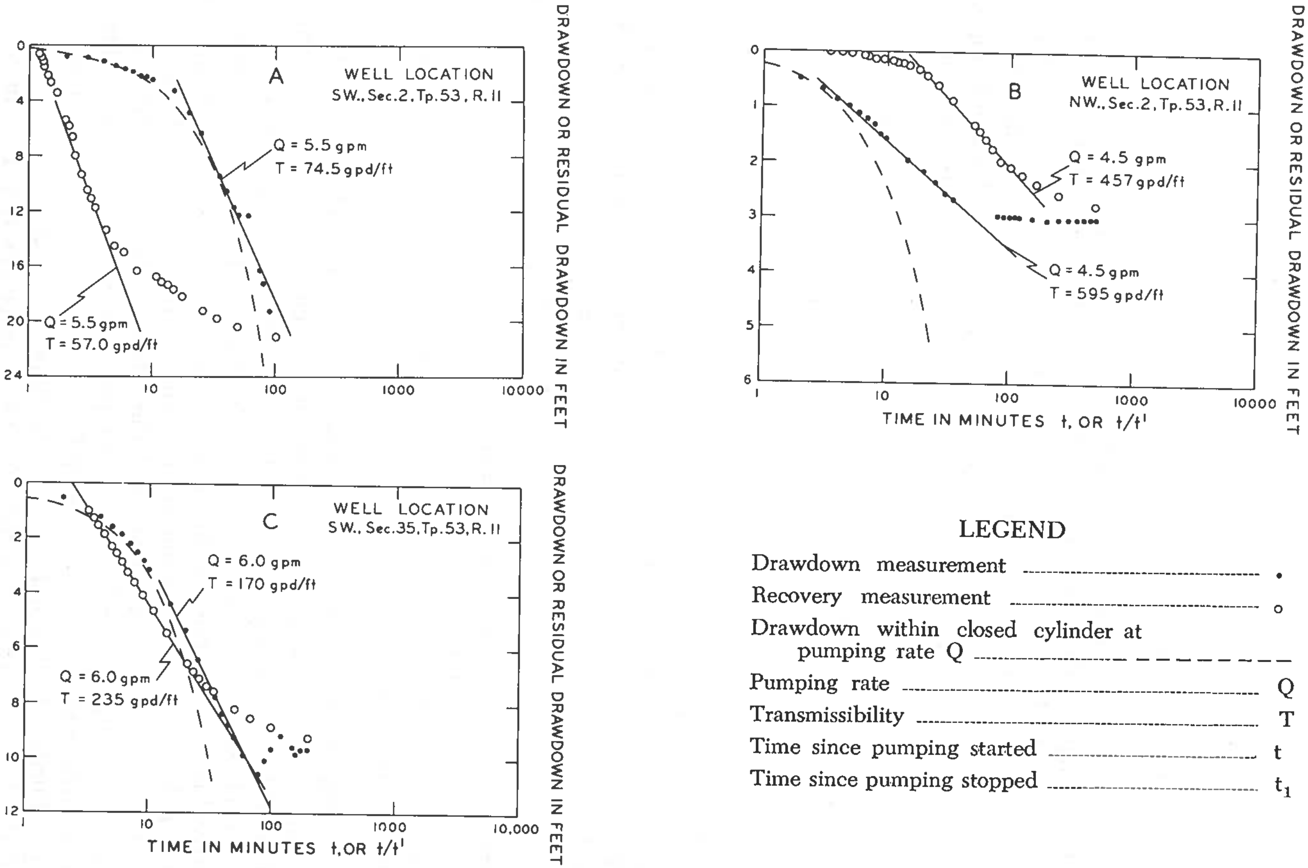


*FIGURE 12. Pump tests conducted on bored wells in the Two Hills area.*

Reference to the transmissibility map (Fig. 10) shows that transmissibilities for some surficial-deposit aquifers are in the range of 1,000 to 5,000 gpd/ft. These values are for sand and gravel deposits in spillways, stream-trench systems and buried valleys. Though many have been estimated from bail tests, some, at least, are believed to be indicative that moderate quantities of water may be developed at these or similar sites.

The only transmissibilities that have been calculated from a complete set of pump-test data are those of 16,000 gpd/ft at the village of Andrew and 10,500 gpd/ft near Duvernay. Both the figures are for shallow water-table aquifers consisting of coarse sand and gravel. The results obtained at Andrew indicate a safe yield of about 30 gpm, a more than ample supply for the village, which has a population of 650 persons. The safe yield of a well is dependent upon the transmissibility considered in relation to the amount of available drawdown and the saturated thickness. So aquifers with greater available drawdowns but lower transmissibilities than the aquifer at Andrew may have higher well-yields. Such is the case at Duvernay where the safe well-yield is nearly 70 gpm from 30 feet of saturated sand and gravel. Similarly, town well No. 3 at Willingdon has a transmissibility of 1,500 gpd/ft, an available drawdown of 130 feet, and a safe yield of 90 gpm. Locally, where geologic and hydrologic conditions are favorable to the development of groundwater supplies, estimated safe yields from well fields may be put at 1,000,000 gpd, as in the Vermilion and Lloydminster areas. Wells about 80 feet deep in the Vermilion River valley have been reported capable of producing 350 gpm from buried gravels. In a spillway 11 miles north of the city of Lloydminster, two wells sited quite close to Sandybeach Lake in Saskatchewan (SW. ¼, Sec. 1, Tp. 52, R. 28, W. 3rd Mer.) are also reported to produce 350 gpm (Le Breton, 1963b). However, in this case, there is little doubt that these high yields are due to induced infiltration.

Deposits of outwash sand and gravel are also possible sources of large quantities of groundwater. Test drilling in such deposits to the north of Two Hills, in the summers of 1960 and 1961, indicated that two small adjacent catchment areas, covering 3.5 and 8 square miles, are possible favorable sites for the development of light-industrial supplies of groundwater. In the smaller catchment area, already referred to as the one near Duvernay (above), the thickness of the saturated deposits is about 50 feet at some locations. Similar thicknesses may occur in the larger catchment area from which combined spring-flows are estimated to be about 300 gpm. Further drilling and pump testing to prove the groundwater resources of the larger area are essential. The sites are favorably placed in relation to road and rail communications and in relation to gas and power lines, and are only 6 to 9 miles from Two Hills.

## The Piezometric Surface

"The piezometric surface" of an aquifer is an imaginary surface that everywhere coincides with the nonpumping level of the water in the aquifer. It is the surface to which the water from a given aquifer will rise under its full head. If at any given place the water from different depths in the aquifer will rise to different levels the aquifer has more than one piezometric surface (Meinzer, 1923). Strictly considered, a map of this surface should be drawn from the water levels in wells penetrating to the same elevation above sea level. However, as the data available for the area are inadequate to comply with this requirement, nonpumping water-levels from wells of varying elevations have been used. These wells, the locations of which are shown in figure 13, range in depth from 10 to 600 feet, but the majority (65 per cent) are from 50 to 250 feet deep. Thus, the piezometric surface as portrayed in figure 14 is mostly representative of the fluid potential for the wells within the more restricted depth range. Deviations from this piezometric surface may occur where wells are outside this depth range.

The direction of movement of groundwater is normal to the isopiestic lines which represent the shape of the piezometric surface, and which join nonpumping water-levels having the same elevation above sea level. Movement of groundwater is down the hydraulic gradient from local centres where the piezometric surface is high to areas where it is low, and from figure 14 it can be seen that the overall discharge of groundwater from the area is toward the east and closely corresponds to the pattern of surface water drainage. The steepness of the hydraulic gradient can be determined from figure 14, and this varies from about 250 to about 3 feet per mile and averages about 25 feet per mile. As in the Beaverlodge area (Jones, 1959, map 59-2C) and in the Pembina area (Farvolden, 1961b, Fig. 5), the shape of the piezometric surface and the steepness of the hydraulic gradient closely conform to the local topography. The piezometric map of this area is, however, in marked contrast to that for the Milk River Sandstone of southern Alberta (Meyboom, 1960, p. 42), where the pressure gradient is controlled by the geologic structure. From cross sections A-$A_1$ and B-$B_1$ (Fig. 14) of the piezometric surface from east to west and from north to south, it can be seen that the relief of this surface is less than that of the land surface, the average depth to the piezometric surface in areas of high surface elevation being about 100 feet, and in areas of low surface elevation about 40 feet.

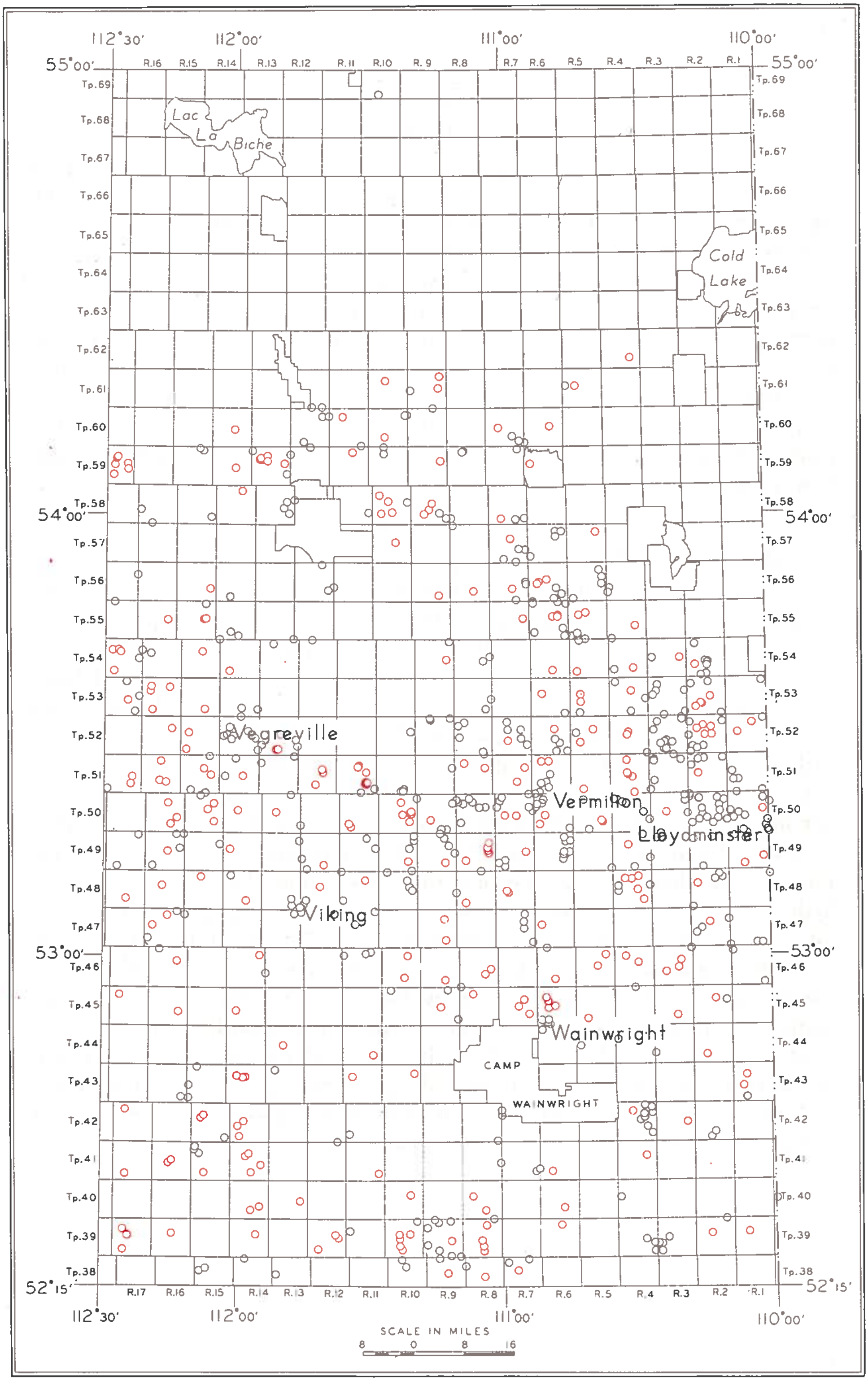


FIGURE 13. *Map of well locations.*

The important observation to be made from a study of figure 14 is the close resemblance of the piezometric surface to a water-table surface. This situation suggests that recharge to the deeper aquifers takes place by local precipitation in a manner analogous to the recharge process for water-table aquifers. Because the movement of groundwater in the area, as revealed by the piezometric surface, is by percolation from the surface to drift and bedrock aquifers and by lateral migration down gradient, the deeper aquifers must also be recharged by local precipitation, and it can be inferred that the aquifers in the area are only partially confined and belong to one hydrologic system: the aquifers are interconnected.

An additional observation to be made regarding the piezometric surface concerns the possible influence of buried channels on the shape of this surface. Significant depressions do occur in the piezometric surface not only in areas of relatively low elevation but in some places in association with the occurrence of buried valleys. The centre where this is best illustrated is around Holden (Sec. 14, Tp. 49, R. 16), from where two such "valleys" radiate, one to the north toward and beyond Vegreville and a second northeast toward and beyond Vermilion. Their courses correspond very closely to those of two of the preglacial valleys outlined on a map of the bedrock channels of southern Alberta (Farvolden, 1963). The preglacial valleys for the study area are shown on figure 10. In these cases, the piezometric surface denotes the presence of buried or partly buried preglacial and glacial valleys. If no other data are available to locate such old valley features, they may thus possibly be revealed by a detailed map of the piezometric surface.

## Water-Level Fluctuations

Automatic water-level recorders have been placed on four deep observation wells at Lloydminster, Two Hills, Mannville, and Wainwright since 1957, and periodic water-level measurements in several shallow wells were taken in the years 1958 and 1959. In both groups of wells fluctuations of the water table or the piezometric surface were recorded (Figs. 15 and 16). The group of shallow wells was later abandoned because the water froze in most wells during the winter, thus prohibiting measurements, and because some wells were later back-filled; the limited data then obtained were of little value.

For the years covered by the periodic measurements, the graphs (Fig. 15) indicate that fluctuations of the water levels occur in relation to changes in local precipitation and temperature. From these records and the information gathered from areal and local surveys, it is firmly believed that there has been no permanent regional decline in the water levels. In areas where groundwater is difficult to obtain, withdrawal from shallow domestic and farm wells often depletes the supply available. Because of the limited

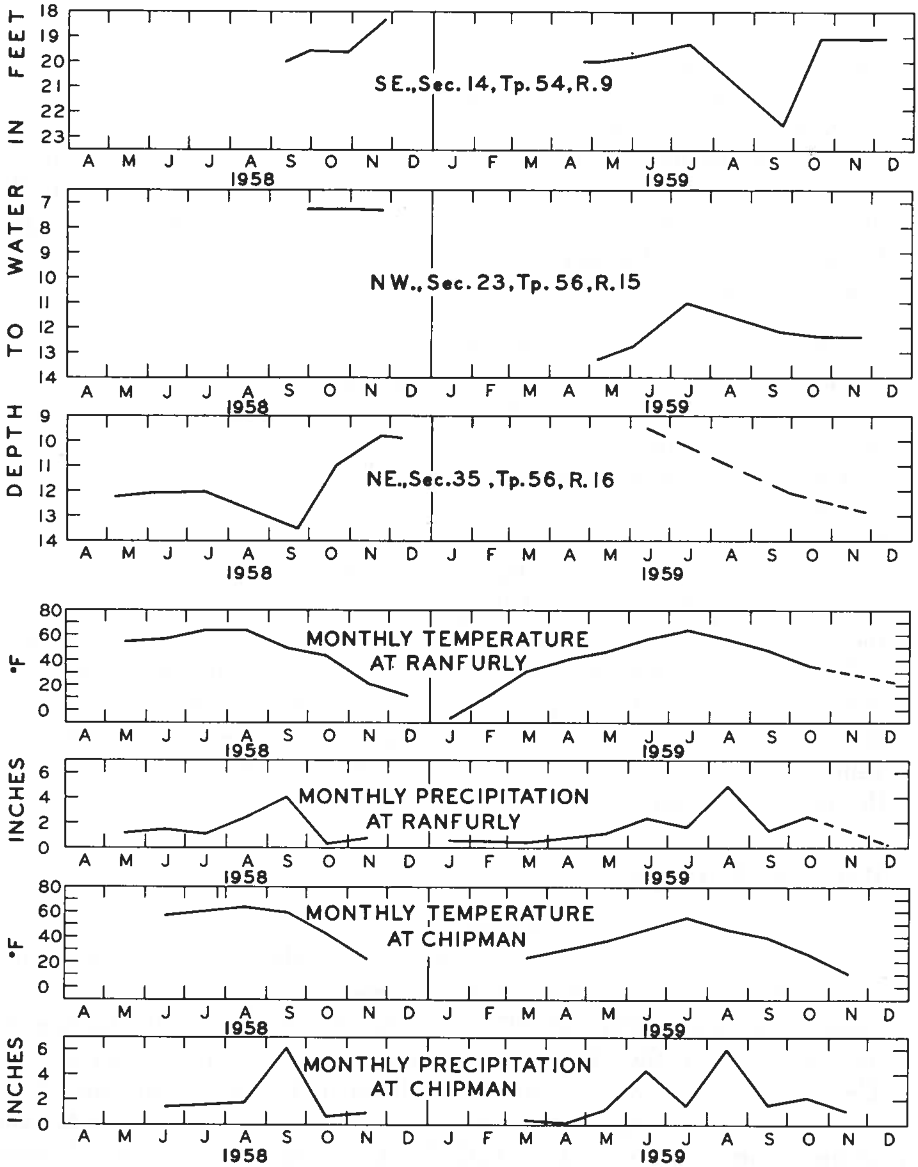


FIGURE 15. *Shallow-well hydrographs and meteorological data.*

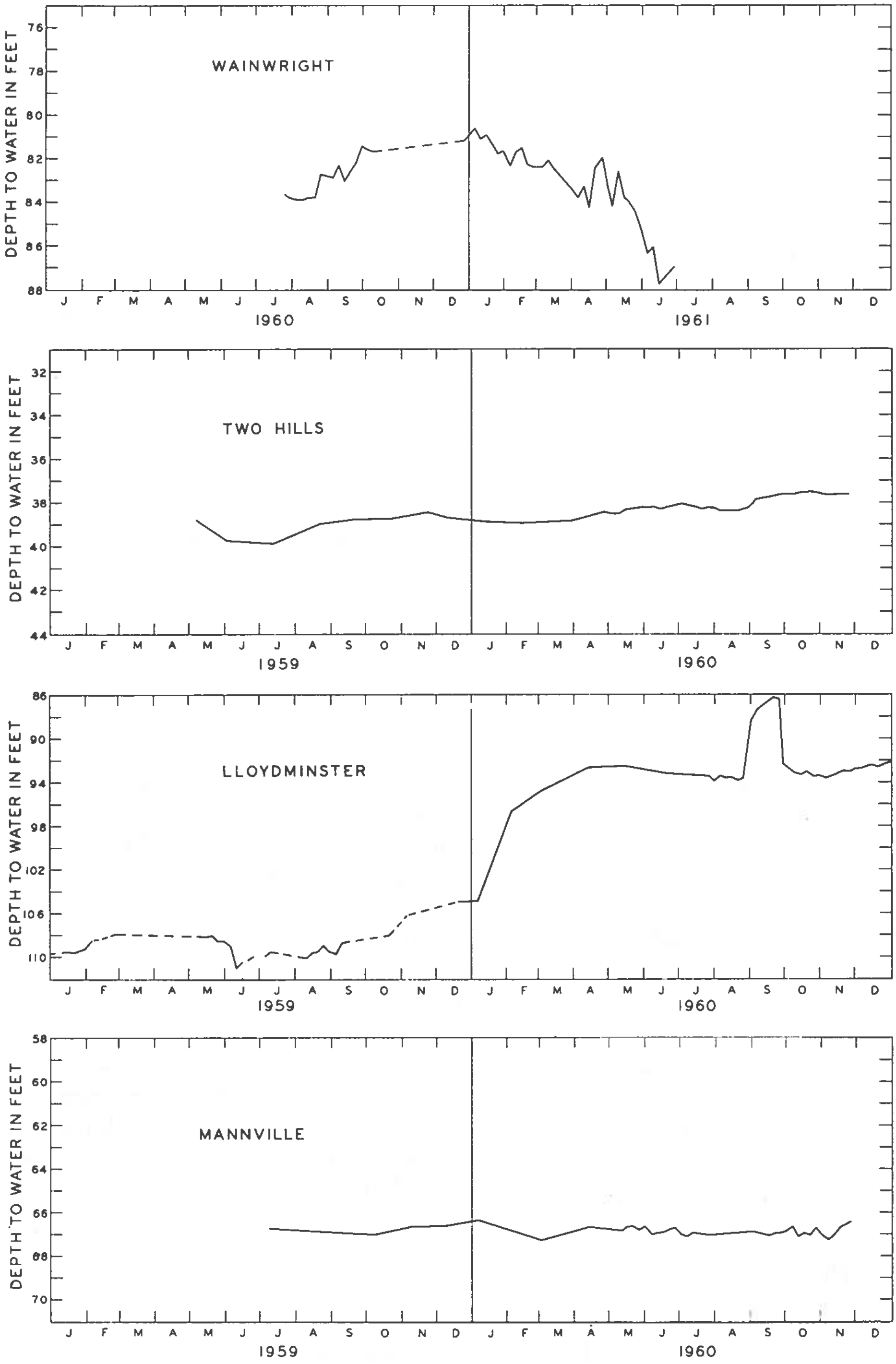


*FIGURE 16. Deep-well hydrographs..*

amount of groundwater in storage in such areas, maintenance of a supply is dependent upon regular rainfall. When rainfall is below normal, the supply of groundwater is quickly exhausted and this is sometimes misinterpreted as a permanent decline in the water level.

The opinion that there is no regional decline in water levels is further supported by hydrographs from observation wells equipped with automatic recorders (Fig. 16). All of these wells are within the radius of influence of pumping wells, and the declines recorded can be directly attributed to pumping. In these cases, pumping from one or more wells causes withdrawal of groundwater in excess of recharge and creates a cone of depression within the well field. Such a cone is necessary to produce movement of water towards the pumping wells, movement which is brought about by the lowering of the pressure head within the area of the cone. The cone will spread only until it intersects sufficient recharge. However, as long as pumping removes water from within the area of the cone depression faster than the rate of recharge into this area of the aquifer, the cone will continue to expand and lower the water levels of any wells that fall within its influence. The only region in which there has been definite proof of the serious depletion of the groundwater resources is around the city of Lloydminster. This is illustrated by the hydrograph for the observation well at the Husky Oil Refinery (Fig. 16) which recorded stabilization of the cone of depression only in the years 1958 and 1959 not long before the city ceased production from its local wells. During an areal survey of groundwater resources for the city of Lloydminster, it was reported that in the years 1947 to 1957, prior to the commencement of this survey, water levels at the Husky Oil Refinery dropped from 74 to 110 feet. There were also reports that the decline in water levels had spread beyond the city limits leading to a need for the deepening of one farm well. The hydrograph for the observation well at Lloydminster (Fig. 16) shows the water level remained at about 110 feet until the year 1959 when the city began to obtain its water supply from a new source 11 miles to the north. After the municipal wells within and outside the city limits were shut down, the hydrograph shows a continuous recovery of the water level. The minor fluctuations shown on the hydrograph for the year 1959 reflect seasonal changes in the municipal demand for water, the decline of the water level occurring in the summer and the recovery in the winter. These effects are more pronounced on the hydrograph for 1958.

## Recharge and Discharge

It has already been stated that recharge to the aquifers is by local precipitation. Of the local precipitation, some runs over the surface and is discharged from the area by streams and rivers, some evaporates from bodies of surface water, some penetrates a little way into the soil and is transpired by vegetation, and some percolates deeper into the land surface to replenish the groundwater resources. The quantity of water that reaches the water table depends upon the permeability of the surface materials, upon the soil moisture deficiency—the capacity of the soil to absorb water at the time of precipitation—and upon the length and intensity of the precipitation.

Discharge of groundwater from the area takes place naturally by evaporation and transpiration, by underflow, by seepage into springs and streams, and artificially by pumping from wells. The discharge of groundwater from wells, except in very small localized areas, is in small quantities for rural domestic and livestock requirements. The quantity of water withdrawn does not appear to be depleting the groundwater resources and is small compared to that lost by evaporation and transpiration and by seepage into springs and streams. The majority of springs in the area are temporary and have small flows of less than 10 gpm. Many of these springs flow from bedrock-drift and sandstone-shale contacts, and most of them are to be found along the banks of the major rivers and coulees in the area. Some groundwater seeps from bedrock aquifers into buried channels and these channels ultimately discharge water away from the area. As discharge is dependent upon the amount of recharge, measurements of the former may indirectly enable estimates of the latter to be made.

Daily stream-flow records are compiled for two of the rivers in east-central Alberta. There are two gauging stations on the North Saskatchewan River, at Edmonton and near Frenchman Butte, just inside the Saskatchewan border; there is also one on the Battle River near Unwin, Saskatchewan (Fig. 3). The daily measurements (Can. Dept. Northern Affairs Nat. Resources, 1949-55) show a wide variation in stream flow throughout the year. Discharge is at a peak in the months of May and June and at a minimum in the months of November to March.

Comparison of the hydrograph records for the two gauging stations on the North Saskatchewan River shows that there is very little runoff added to the river between Edmonton, where the area of the drainage basin is 10,500 square miles, and Frenchman Butte, where the area is 22,000 square miles. For the six-year period from 1949 to 1954, the average annual runoff for the basin at Edmonton was 8,662 cubic feet per second (cfs) or 11.23 inches (ins.). At Frenchman Butte the comparative figures are 9,115 cfs and 5.76 ins. on the basin. The difference in total runoff for the North Saskatchewan River in east-central Alberta is only 453 cfs or 0.54 ins. on the basin. This small increment to stream flow may be due to poorly integrated drainage in the area. As surface runoff may be one half or more than one half of the 453 cfs, then it may be presumed that less than half of the increased flow to the river between these two gauging stations is contributed by groundwater.

As the North Saskatchewan River hydrographs (Fig. 17) are so similar, it is difficult and of little value to determine the amount discharged by the runoff components downstream from Edmonton. Any analysis of these records is relevant primarily to the area west of the city of Edmonton, for the configuration of the hydrographs and the magnitude of flow is determined well upstream from Edmonton.

However, the Battle River is entirely a Plains river and an analysis of its hydrograph (Fig. 17) is of some interest. The terms used in this discussion are surface runoff and total groundwater discharge or base runoff. Surface runoff is that portion of rainfall which runs over the land surface into a stream or river. Base runoff is that quantity of water supplied to a river from groundwater storage. It can be divided into two parts, bank-storage discharge—that quantity of water supplied to a river which originally seeped into the materials immediately adjacent to the river during its high stages—and basin-storage discharge—that quantity of groundwater supplied by springs and artesian leakage and originally derived from precipitation which infiltrated into the deposits of the entire basin.

The period of study covers six years from the beginning of April, 1949, to the end of March, 1955. The average base flow of the Battle River for the 9,820 square-mile area of the drainage basin upstream from Unwin, Saskatchewan, is 160 cfs, of which 125 cfs or 78 per cent is bank-storage discharge, and 35 cfs or 22 per cent is basin-storage discharge. The method adopted for separating bank-storage from basin-storage discharge is a graphical solution used by Kunkle (1962). Basin-storage discharge, which is equivalent to the infiltration rate in excess of evapotranspiration, amounts to 1.5 gpm per square mile. This rate may be said to represent the average recharge under existing natural conditions, or the average theoretical rate of pumping per square mile without depleting the groundwater resources. Although low, a rate of 1.5 gpm is comparable to the safe yield of many wells in east-central Alberta and indicates that only one well may be pumped continuously at this rate for each square mile of basin area without depleting the groundwater resources.

Since the discharge from basin storage is an average, greater and lesser rates of discharge, balanced on a long-term basis by recharge from precipitation, may be expected for different parts of the basin. The actual amount of recharge will depend upon many factors, but predominantly upon the infiltration rate of the surficial deposits. Also, because of internal drainage, a sizeable percentage of the basin (possibly as much as 50 per cent or over) may not be actively contributing to the base flow of the Battle River. If corrections could be made for that quantity of groundwater lost through natural internal drainage, the average infiltration rate might be increased to as much as 3 gpm per square mile. This figure is comparable to that of 4 gpm per square mile obtained in the Calgary area

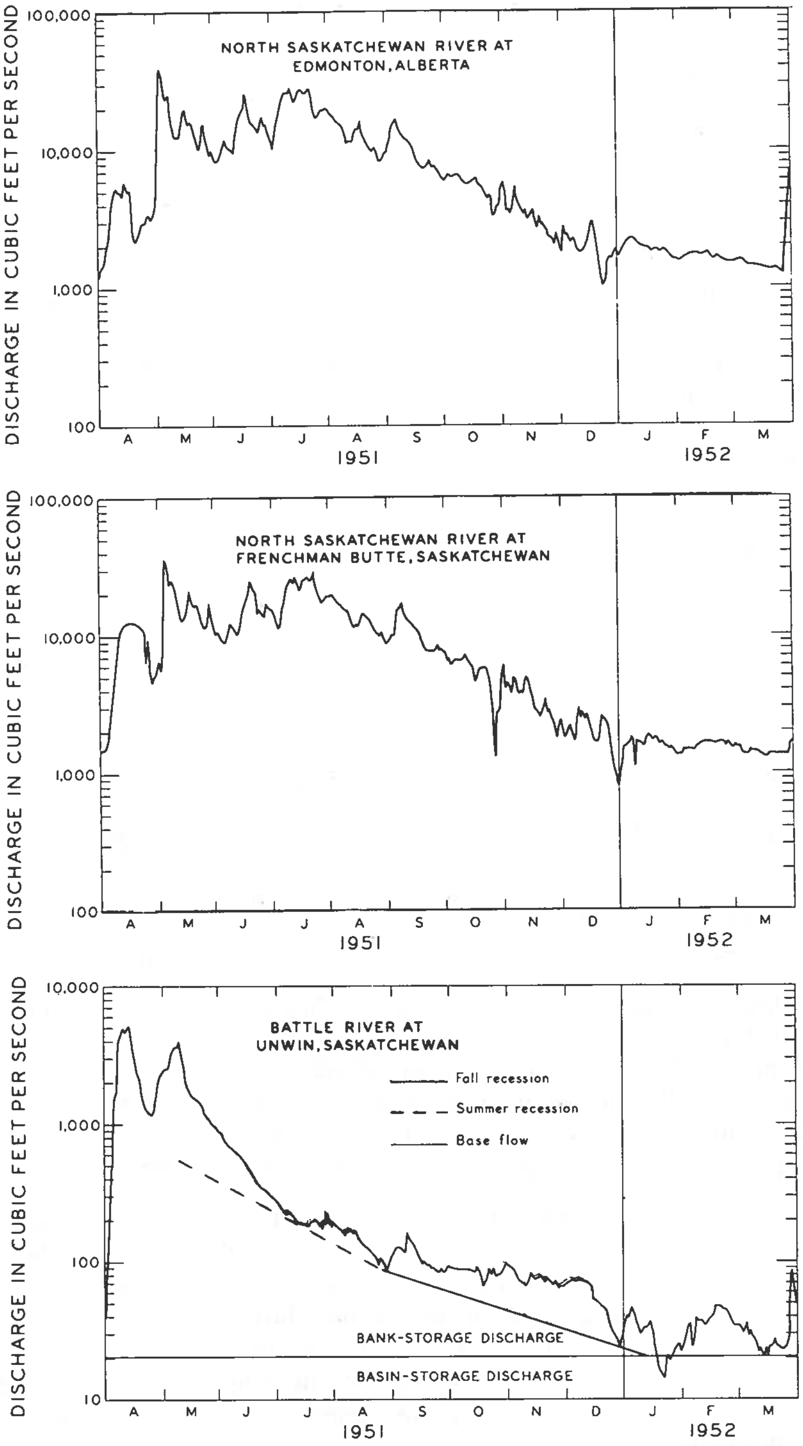


FIGURE 17. *North Saskatchewan River and Battle River hydrographs.*

(Meyboom, 1961). The permeabilities of the deposits in both areas are possibly of similar magnitude, the materials being primarily till, sandy shales, shales, and sandstone beds.

The infiltration rate governs not only the recharge to the drift, but also to the bedrock. The low rate appears to be in contradiction to the suggested well yields of up to 150 gpm as reported for the southeast region. However, evidence from pump tests shows that high-yield wells are actually taking water from storage. The reported continuing decline in water levels in wells at the city of Lloydminster, and the continuing recovery shown by the hydrograph for the observation well there after the city wells were shut down is further proof of the removal of water from storage (Fig. 16). One other reason for high well-yields, as opposed to the low rate of infiltration, is that this rate is for a natural hydraulic gradient. Under pumping conditions, the gradient is steepened around a well inducing a higher recharge rate over the area of the cone of depression.

An average transmissibility value for the area may be obtained using the formula (Darcy's Law)

$$Q = 2TIL \qquad (1)$$

where

$Q$=the basin-storage discharge in gpd

$T$=the coefficient of transmissibility in gpd/ft

$I$ =the hydraulic gradient in feet per foot represented by the piezometric surface and

$L$=the length of the profile in feet through which groundwater movement takes place.

In this case, basin-storage discharge is 35 cfs, the hydraulic gradient is 15 feet per mile, and L, the length through which discharge occurs, is 800 miles. The selected location for calculation was from Tp. 41, R. 8, to Tp. 42, R. 9 (Fig. 14). A transmissibility value of 750 gpd/ft was obtained. This figure is based on the rate of transmission of groundwater into the river from artesian leakage as well as from contact springs in the basin.

From a study of groundwater balance in the Calgary area (Meyboom, 1961), it was demonstrated that just over two thirds of base flow was contributed by contact springs. If it is assumed that this is applicable to the Battle River drainage basin, then only one third of base flow is provided by artesian leakage. On this basis, an average transmissibility figure of 250 gpd/ft is obtained for groundwater derived from artesian leakage. This figure is believed to be a more representative transmissibility value for the basin.

The slope of a recession line on the hydrograph (Fig. 17) is given by the numerical value of c in the equation below, modified from that given by Butler (1957, p. 216):

$$Q = Q_o e^{-cd} \tag{2}$$

in which

Q =discharge in cubic feet per second at the end of d days after termination of surface runoff

$Q_o$=discharge when d equals zero

e =the Naperian base, 2.718

c =a constant.

Two major divisions of groundwater-recession slope are apparent from analyzing the Battle River hydrograph. These are a 4-month trend for the summer (May to August) bank-storage recession curve, and a 5-month trend for the fall (September to January) bank-storage recession curve. The recession equations for this hydrograph are:

$$Q = Q_o e^{-0.01725d} \tag{3}$$

$$Q = Q_o e^{-0.01043d} \tag{4}$$

for the summer and fall recessions respectively. The difference is due to a higher rate of evapotranspiration during the summer months.

The foregoing section has been written on the assumption that groundwater flow within a basin is largely into the main river as is suggested by Hubbert (1940, Fig. 45). Recent work (Tóth, 1962), suggests that is not so, but nevertheless it is felt that the above discussion does provide valuable qualitative information on groundwater availability in the area.

## CHEMISTRY OF THE GROUNDWATERS

The chemistry of the groundwaters of east-central Alberta shows some interesting characteristics relating to the occurrence and possibly to the movement of groundwater in the area. These characteristics are illustrated in figures 18 to 25, notably by the variation in hardness of the groundwaters and locally by some interesting variations in total solids, chloride and iron contents.

The total solids content for bedrock waters (Fig. 18) ranges from 300 to 6,000 parts per million (ppm), and for drift waters (Fig. 19) from 250 to 24,000 ppm, the average for both types of waters being about 1,200 ppm. In both cases about 42.5 per cent of the waters have a total solids content of less than 1,000 ppm, and only 3 per cent from bedrock sources, and 12 per cent from drift sources contain less than 500 ppm. Most of the groundwaters fall within the "saline"* category. According to United States Public Health Service Standards (Appendix D) most of the groundwaters in the area may be described as unsuitable for human consumption. However, by provincial health standards in Alberta, the limit for total solids is between 1,600 and 2,000 ppm, and individual water analyses within this range are considered as suitable—provided that none of the concentrations of the different chemical constituents is excessive. Harmful effects are generally not apparent unless the total solids are largely concentrated as one particular constituent. By Alberta provincial health standards (Appendix D), only 12 per cent of bedrock and 18 per cent of glacial-drift groundwaters are definitely unsuitable for human consumption, and a further 16 per cent of the waters are of doubtful suitability.

The concentration of chlorides in bedrock and glacial-drift groundwaters is very commonly low. However, particularly in townships 46 to 50, from ranges 12 to 17 (Fig. 20), and commonly from sources more than 400 feet deep, the chloride content of bedrock water is quite high. In bedrock waters the chloride constituent has been reported as high as 3,500 ppm, but is commonly less than 50 ppm. Only small amounts of chlorides are normally reported in glacial-drift waters (Fig. 21), typically in the range of 0 to 50 ppm; very few of the analyses record over 100 ppm.

The suggested limit of chlorides for human consumption is 50 grains per gallon (gpg) or 435 ppm, set by the Provincial Analyst. The sodium chloride equivalent, often given in analyses, is obtained by multiplying the chloride value in parts per million by the conversion factor of 1.65. The result obtained is then divided by 14.3† to obtain the salt content in grains per gallon. The limit for salt consumption is set at 50 gpg.

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* "Saline" is here used to refer to a total solids content in excess of 1,000 ppm (Dodge, 1960).

† 14.3 ppm = 1 gpg.

The bedrock waters and to some extent the drift groundwaters from townships 46 to 50, ranges 12 to 17, are notable for their high total-solids contents. The bedrock waters are also high in chlorides. These local characteristics are believed to be the result of extremely slow groundwater movement in bedrock and drift aquifers. In this area of nearly flat topography there is very little potential difference between recharge and discharge areas to induce groundwater movement. Thus, the flushing action upon the bedrock and drift aquifers is so slight as to be very inadequate in freshening the groundwaters.

The sulfates listed in the chemical analyses are in reality sulfites ($SO_3$), because of the method of analysis. These range from 0 to 1,960 ppm and average about 300 ppm for bedrock waters, and range from 0 to 12,300 ppm and average about 400 ppm for drift waters. Ranges-of-values for the sulfate contents of bedrock and drift waters are given on figures 20 and 21. The suggested limit for human consumption is 800 ppm. The sodium sulfate equivalent is often given and is expressed in grains per gallon. The latter expression is obtained by multiplying the value in parts per million by the conversion factor of 1.77 and dividing this figure by 14.3.

By United States health standards for sulfates, 58 per cent of bedrock and 51 per cent of drift waters are suitable for human consumption (containing less than 250 ppm), while 94 per cent and 82 per cent, respectively, of these waters meet the Alberta provincial health standards. However, in the range of 400 to 800 ppm sulfates, water has a laxative effect until consumers become accustomed to it. Waters in excess of 800 ppm sulfates are considered extremely undesirable because of their very laxative effects.

The iron content ranges from 0 to 5.3 ppm and averages about 0.8 ppm in bedrock waters and ranges from 0 to 5 ppm and averages about 0.7 ppm in glacial-drift waters. In bedrock wells, 37 per cent, and in drift wells, 43 per cent of the waters meet the suitability limit for industrial and domestic uses. It is interesting to note that 63 per cent of bedrock waters throughout the whole area, but 79 per cent of those from townships 48 to 54, ranges 1 to 8, have moderate to high iron contents (Fig. 22). Similar comparisons can be made in the case of drift waters for an area from townships 49 to 55, between ranges 1 and 8 (Fig. 23), where 64 per cent of the waters are high in iron, as against 57 per cent for the whole area.

In both types of aquifers the iron content is often above the suggested limit of 0.3 ppm. This may be troublesome in industrial processes and may stain porcelain, enamel and clothing. The use of iron-removal filters, of calgon, letting the iron settle out, or applying the process of aeration, are methods of treating water for the removal of iron. The first three methods can be applied to private supplies, possibly at fairly reasonable cost, but the

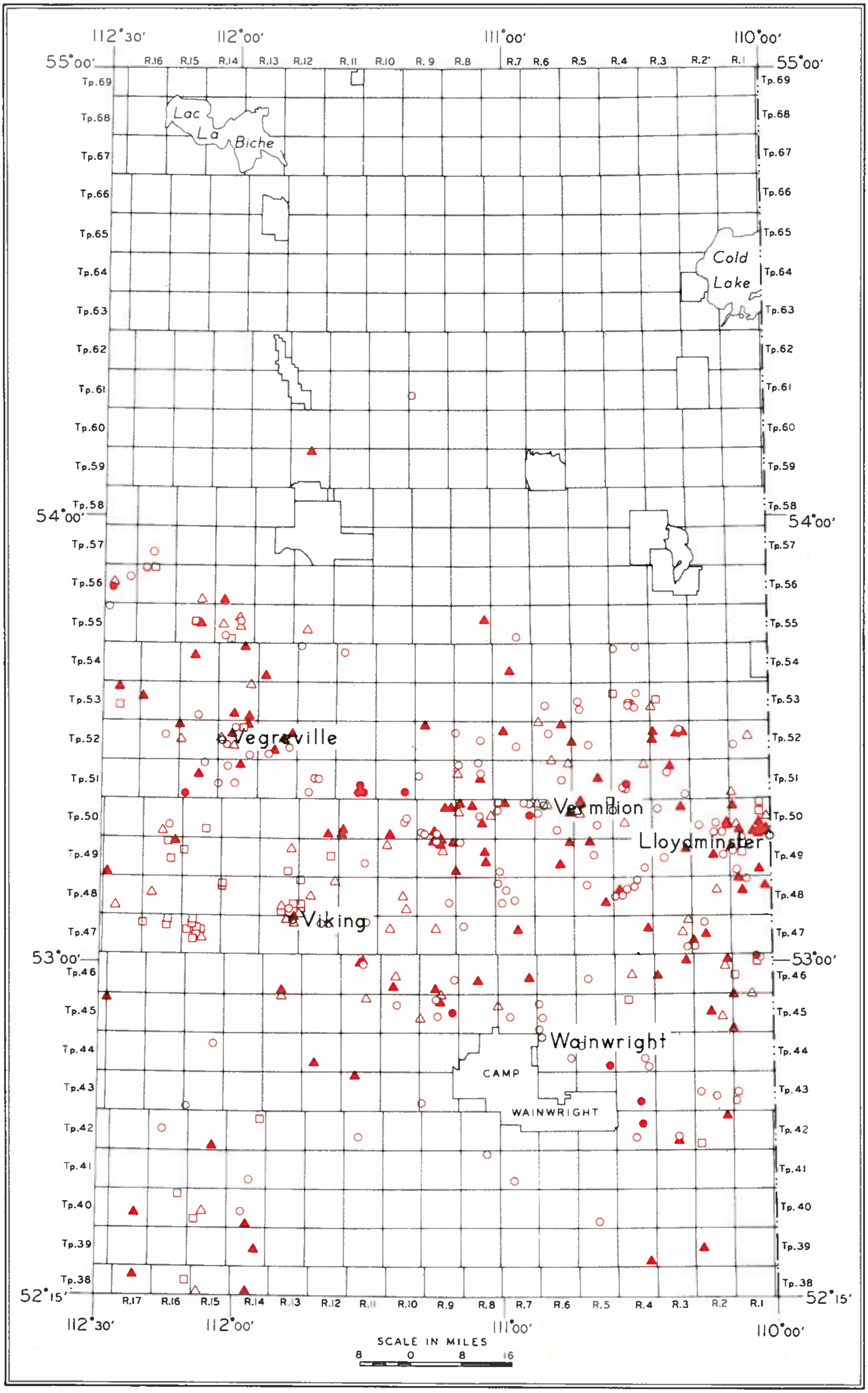

FIGURE 18. *Map of total solids content of bedrock groundwaters.*
*0 - 500 ppm*—● ; *501 - 1,000 ppm*—○ ; *1,001 - 1,500 ppm*—▲ ;
*1,501 - 2,000 ppm*—△ ; *2,001 + ppm*—□ .

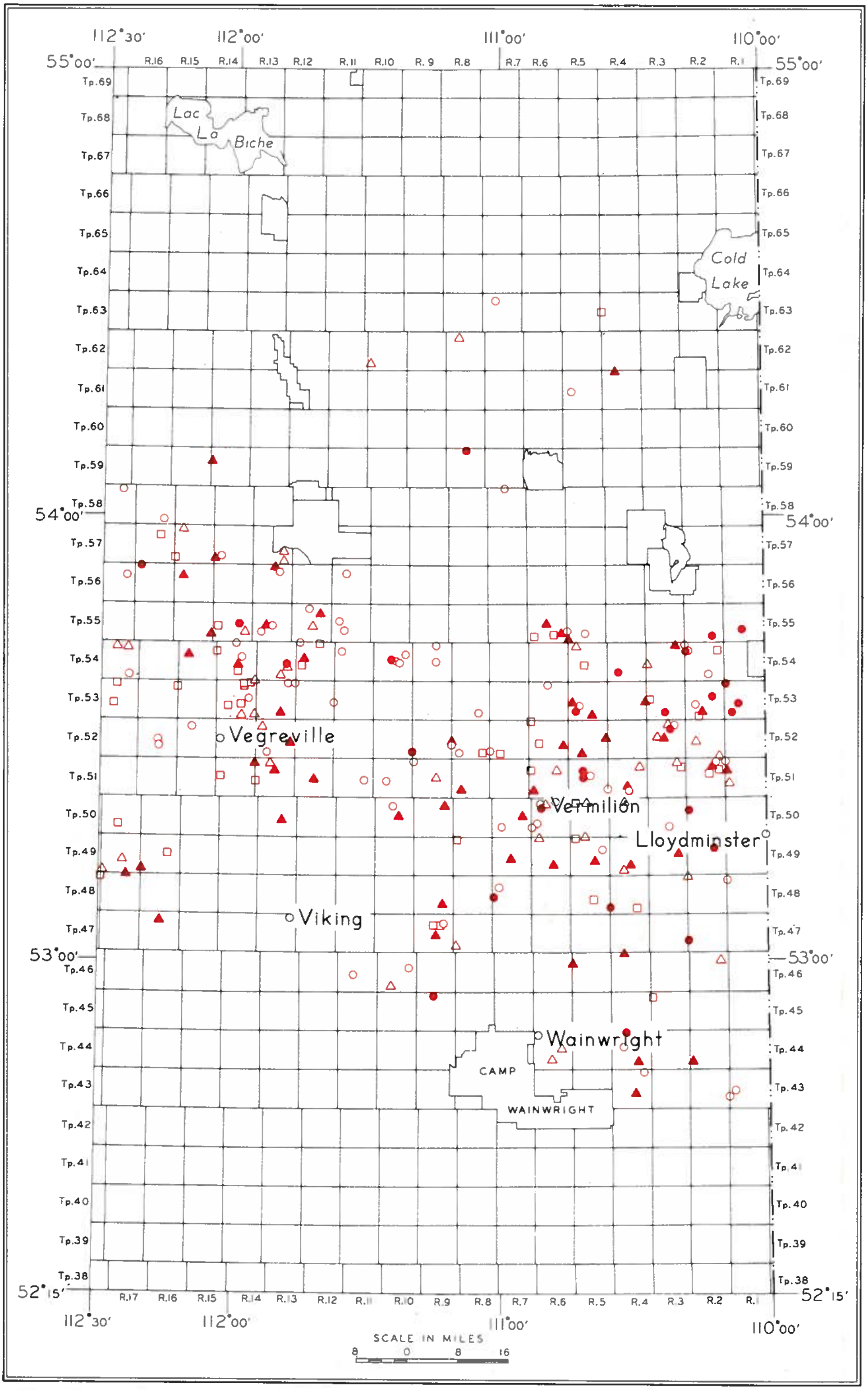

FIGURE 19. *Map of total solids content of drift groundwaters. 0 - 500 ppm—● ; 501 - 1,000 ppm—○ ; 1,001 - 1,500 ppm—▲ ; 1,501 - 2,000 ppm—△ ; 2,001 + ppm—□ .*

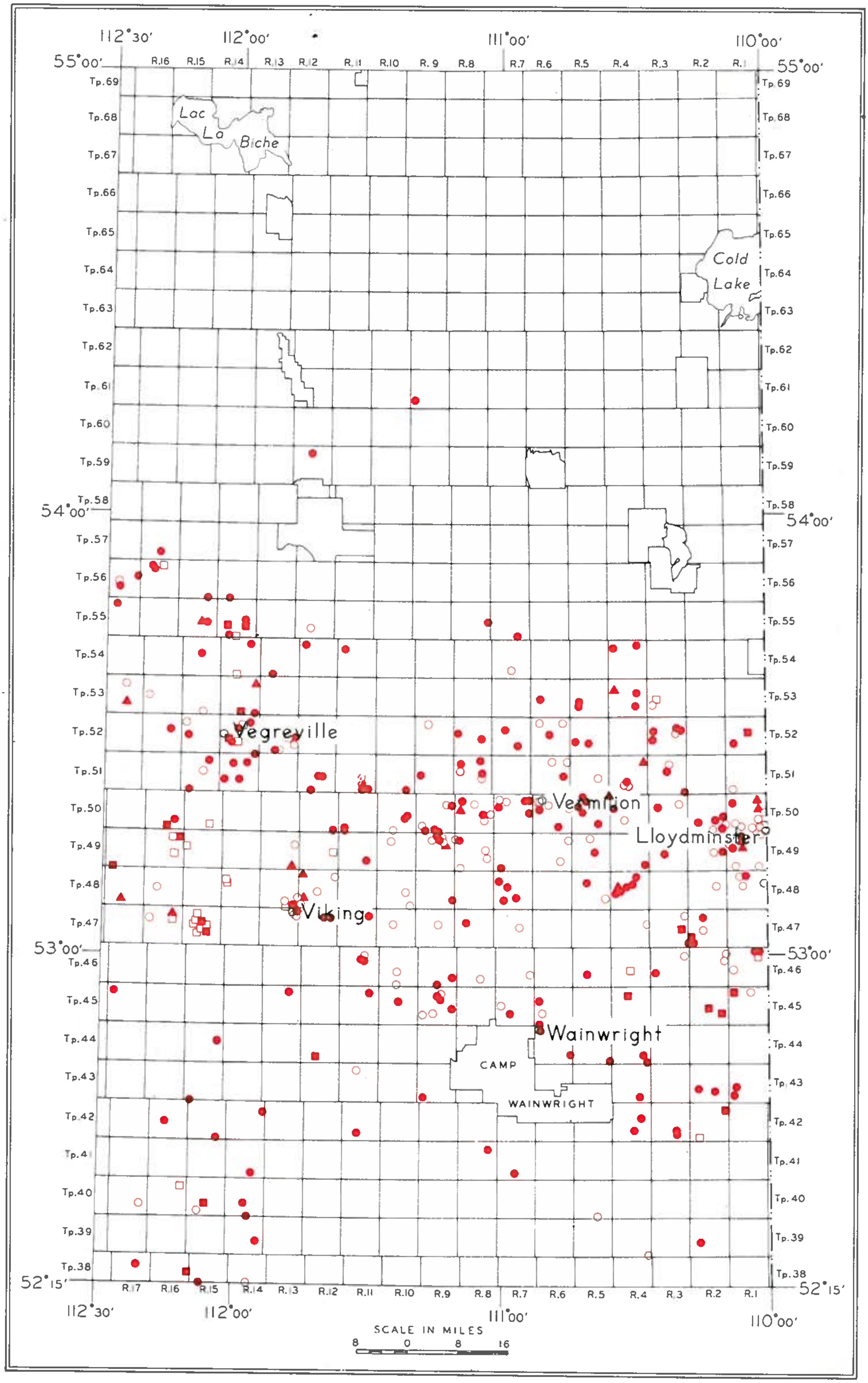

*FIGURE 20. Map of sulfate and chloride content of bedrock groundwaters.*
*Sulfates: 0 - 250 ppm— ● ; 251 - 800 ppm— ○ ; 801 + ppm— ▲*
*Chlorides: 250 - 1,000 ppm— ■ ; 1,001 - 5,000 ppm— □ .*

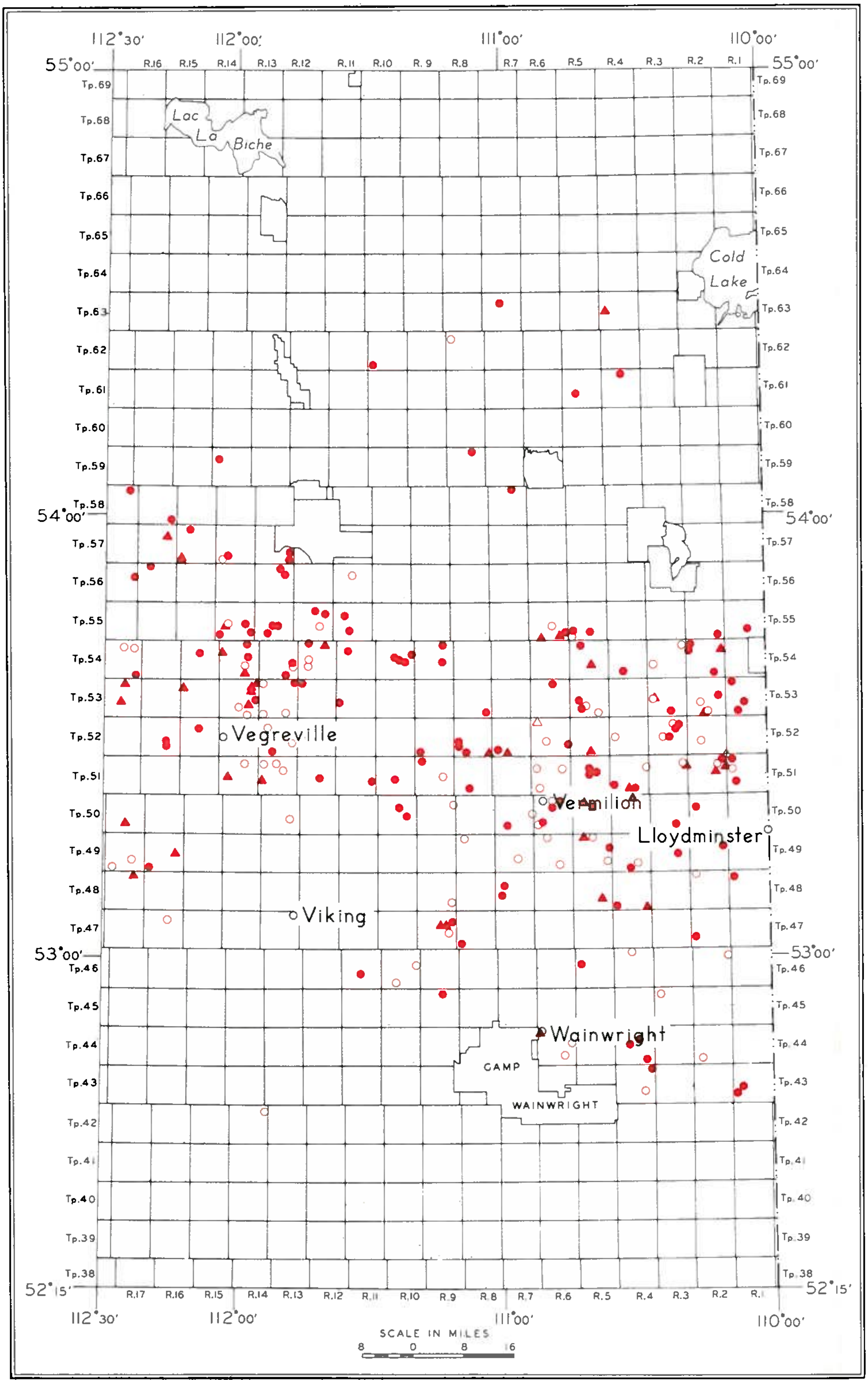

FIGURE 21. *Map of sulfate and chloride content of drift groundwaters.*
*Sulfates: 0 - 250 ppm*—● ; *251 - 800 ppm*—○ ; *801 + ppm*—▲
*Chlorides: 250 - 1,000 ppm*—■ ; *1,001 - 5,000 ppm*—□ .

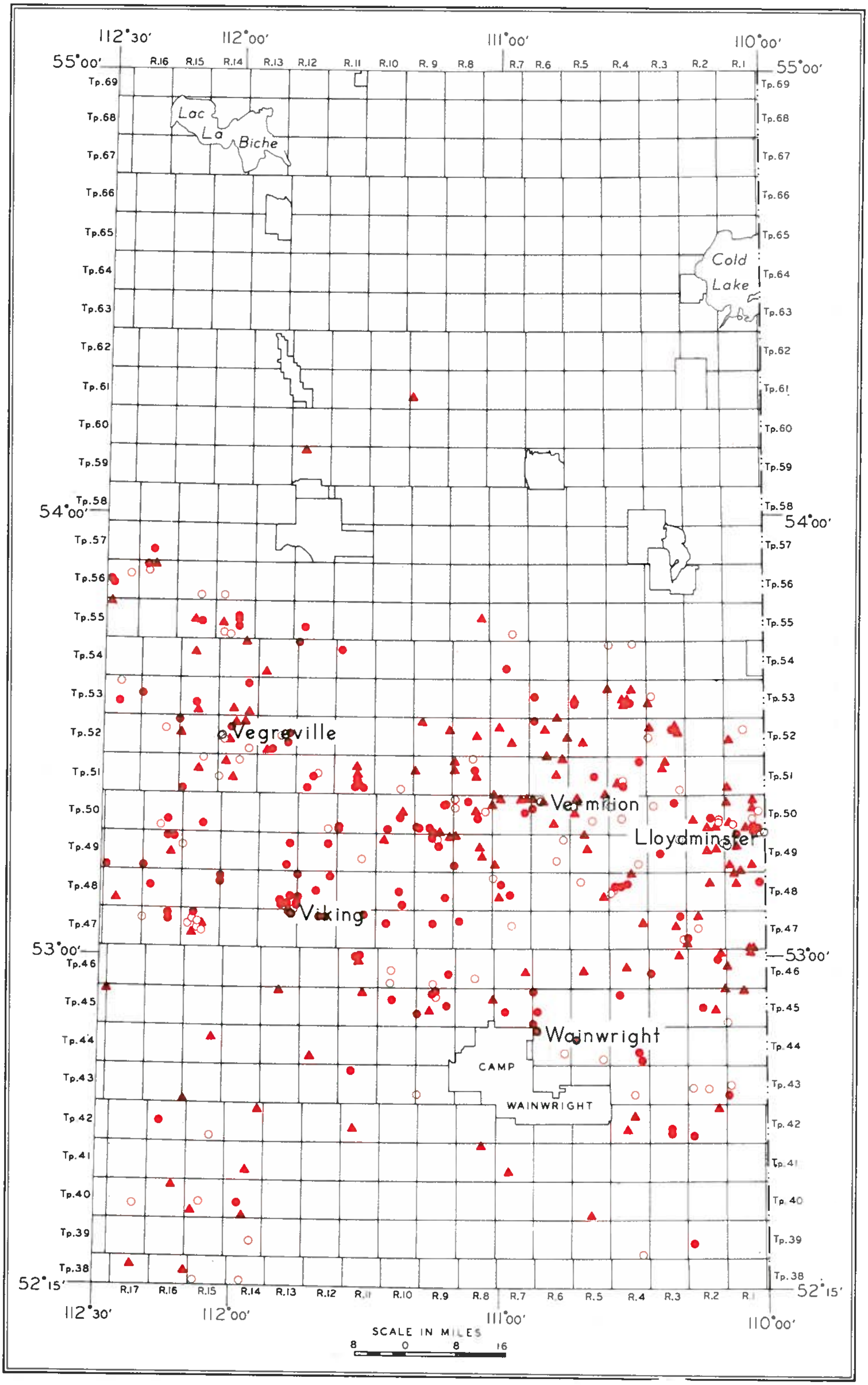

*FIGURE 22. Map of iron content of bedrock groundwaters.*
*0 - 0.3 ppm—* ● *; 0.4 - 1.0 ppm—* ○ *; 1.1 - 6.0 ppm—* ▲ *.*

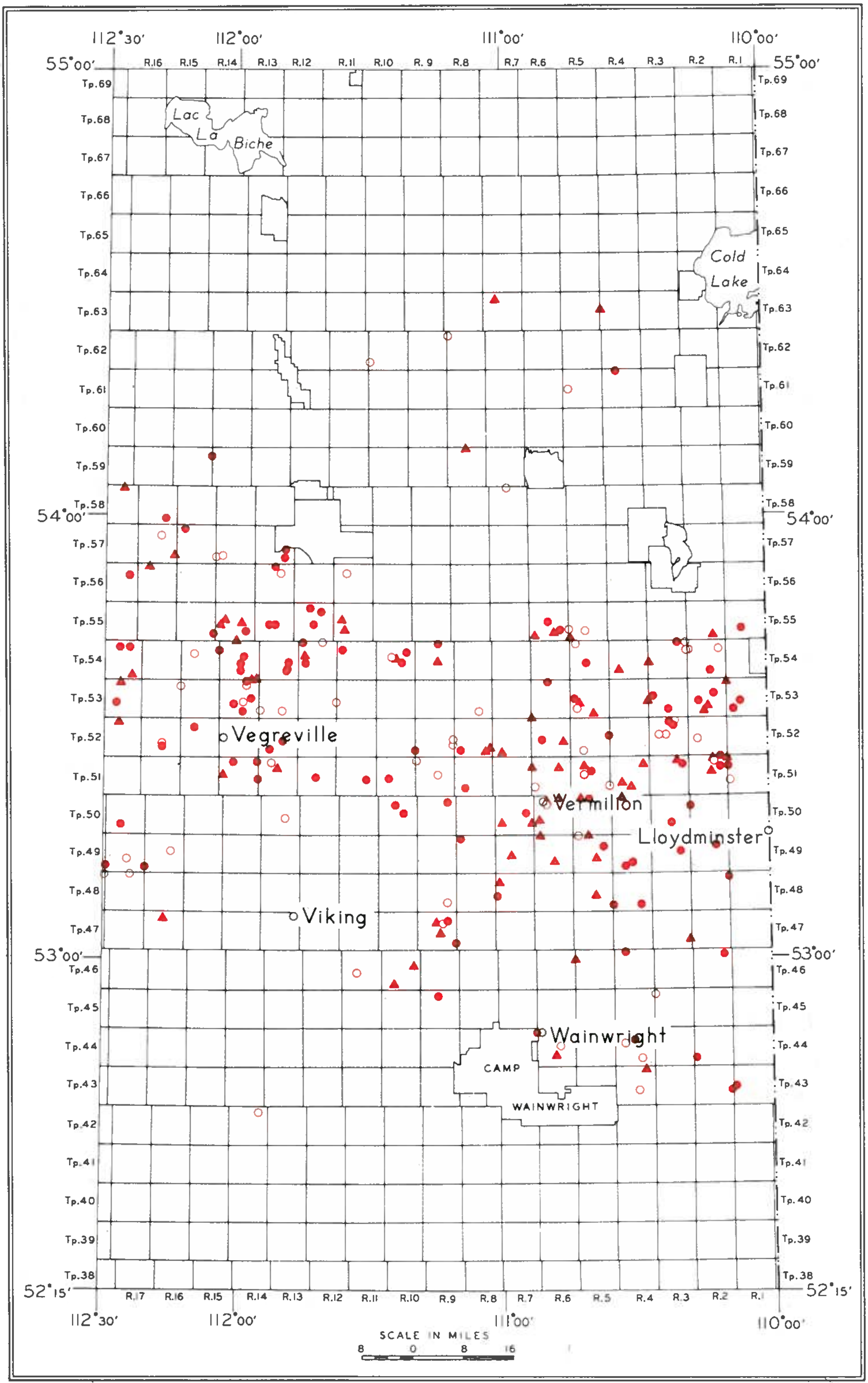

*FIGURE 23. Map of iron content of drift groundwaters.*
*0 - 0.3 ppm—* ● *; 0.4 - 1.0 ppm—* ○ *; 1.1 - 6.0 ppm—* ▲ .

last only to municipal or industrial waters because of the capital costs involved in the construction of a treatment plant.

The hardness, which is measured as the calcium carbonate ($CaCO_3$) equivalent of the constituents causing hardness, is generally low in bedrock and high in drift groundwaters. The hardness in bedrock waters ranges from 0 to over 1,000 ppm and averages about 300 ppm. Of the bedrock waters, 43 per cent are soft, the hardness being less than 100 ppm, and they are suitable for use for domestic and for some industrial purposes. However, for that part of the area from townships 50 to 55, between ranges 1 and 8 (Fig. 24) groundwater from bedrock aquifers is observed to be very hard, the hardness commonly ranging from 300 to 700 ppm. The analyses show that 84 per cent of the waters are hard. This is rather unusual, for the bedrock aquifers in Alberta are characterized by soft water (Foster and Farvolden, 1958). It is believed that bedrock water is hard in this part of the area because the clay materials, through which the water percolates, lack natural softening agents such as bentonite, which occur commonly in similar deposits in other parts of the province. The hardness map (Fig. 24) shows that soft waters are predominant in bedrock aquifers. These aquifers occur mostly within, or are overlain by, the Oldman Member which contains much bentonitic material. However, in the area delineated as containing hard groundwaters, the Oldman Member is absent and the aquifers are overlain by the Grizzly Bear Shale.

In glacial-drift groundwaters, hardness is high (Fig. 25), ranging from 0 to over 1,000 ppm and averaging about 600 ppm. Only 1 per cent of the waters is soft.

Depending on the source of supply, bedrock water is often likely to be sufficiently soft for domestic use and locally, as at Wainwright, it may be suitable for industrial use in boilers. However, at Lloydminster, the hard water is unsuitable for use by the oil refineries, and the cost of treating the water is reported to be high. Groundwater from the glacial drift is commonly very hard and should usually be softened for industrial and domestic uses.

The alkalinity, which is expressed as calcium carbonate ($CaCO_3$), commonly ranges from 600 to 900 ppm and is often the same as the hardness of the groundwaters. If the water is hard, the alkalinity is predominantly due to bicarbonate of calcium and magnesium, but if it is soft, the alkalinity is due to bicarbonate of sodium. Consequently, the nature of the alkalinity may often be inferred by reference to the hardness. Water containing more than 700 ppm or 50 gpg of sodium is considered unsuitable for human consumption. In this case, the grains per gallon is a direct conversion of the sodium content in parts per million as given in the analysis.

The nitrate content of the groundwater, indicating the degree of surface contamination, is generally low or nonexistent for a deep well drilled into the bedrock, but is high in approximately 50 per cent of the shallow bored and dug wells finished in the glacial drift. This high degree of contamination is believed to be due to badly situated and poorly completed wells. The glacial-drift wells which are lined only with wood cribbing have vertical openings from the surface down and allow seepage from the surface to take place more readily. The cause of contamination is believed to be nearness to hog pens, corrals (kraals) and barns, and to decaying vegetable matter. However, in some cases the well-water supplies can be rendered suitable for human consumption by thorough cleaning of the wells (personal communication, J. Donnan, Vegreville Health Unit). It may be necessary to do this several times or for several days. The analyses quoted for well locations listed in Appendix E show the results of pumping or complete cleaning out of the wells. It is further suggested that in order to keep the water supplies sufficiently clean the well should be pumped out once a week. It would appear, then, that insufficient use of some wells is a contributory factor in contamination of the water supplies. The nitrate content of water wells terminated in drift is frequently reported to be in excess of 10 ppm, which is considered dangerous for infants less than one year old.

The concentrations of the different chemical constituents in the groundwater are of varying interest according to the use that is to be made of the water. However, the analyses studied have been made almost entirely to determine the suitability of the water for human consumption. Consequently, their value for industrial purposes is very limited because they are not sufficiently detailed. For use in certain industries, as in the chemical industry, excellent-quality water is necessary. Very low mineral concentrations are desired, and a preferred absence of such constituents as nitrates, iron, manganese and nickel. The last-named item placed one possible source of groundwater on the margin of suitability for use by a chemical company. According to the type of industry, the cost of treating the available groundwater supplies may be an important factor in precluding its exploitation and use.

The supply of groundwater in much of the area is likely to be sufficient for only limited application to irrigation practices. A consideration of the chemical quality further restricts this application in the cases where the quantities available may prove to be adequate. Based upon the classifications of the U.S. Salinity Laboratory Staff (1954) and Wilcox (1948), the groundwater in the area falls largely within a range from doubtful to unsuitable with respect to its suitability for irrigation. The preferred upper limit for total solids is set at 750 ppm, but limits up to 2,000 ppm are permissible in certain cases, depending upon the soil composition, permeability and drainage, and upon the salt tolerance of the various

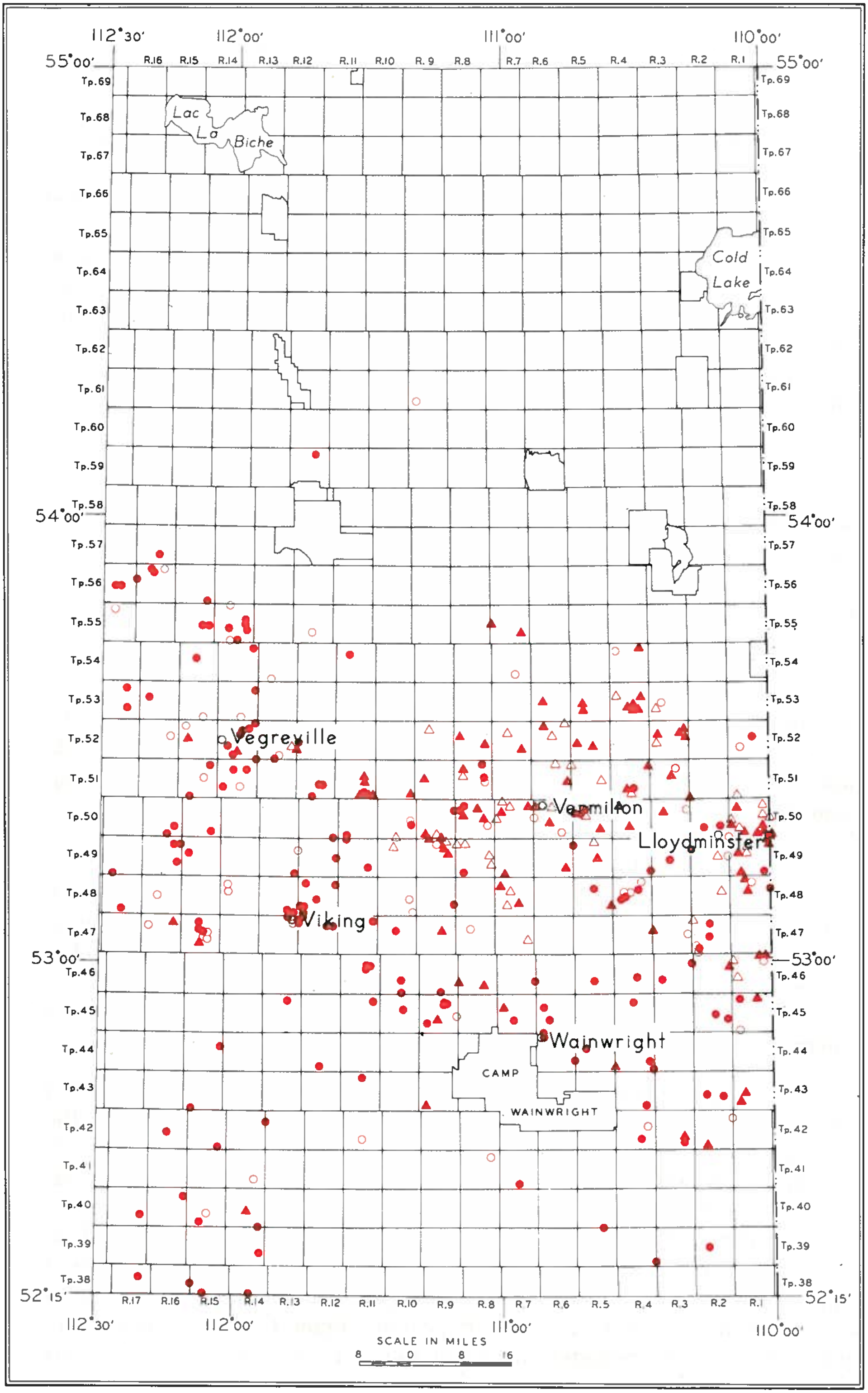

*FIGURE 24. Map of hardness content of bedrock groundwaters.*
*0 - 100 ppm— ●; 101 - 250 ppm— ○; 251 - 600 ppm— ▲;*
*601 + ppm— △.*

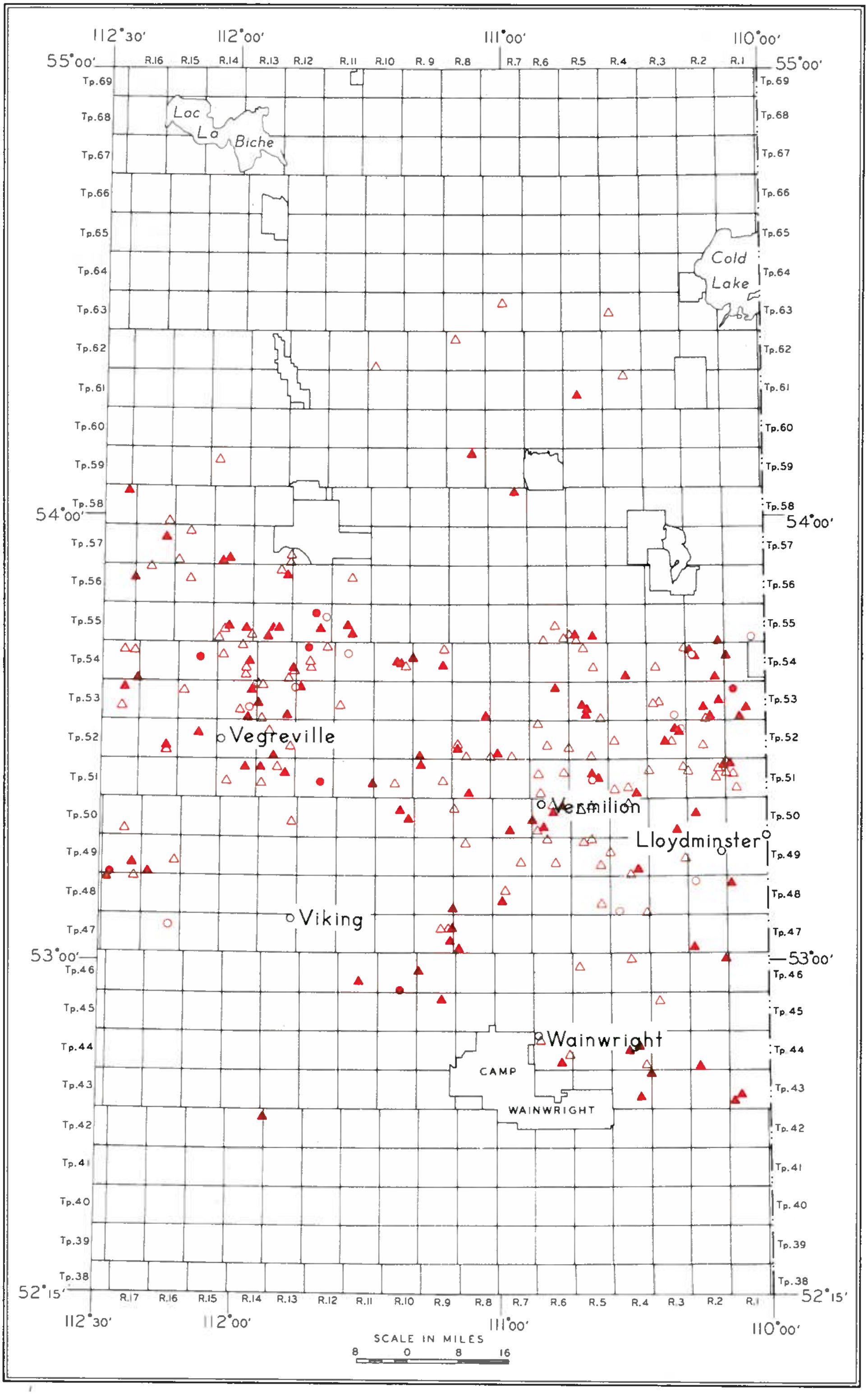

*FIGURE 25. Map of hardness content of drift groundwaters.*
*0 - 100 ppm— ● ; 101 - 250 ppm— ○ ; 251 - 600 ppm— ▲ ; 601 + ppm— △ .*

crops selected. Groundwater from bedrock aquifers is often of doubtful suitability, because not only are the total solids likely to be high, but these are also largely composed of bicarbonate of sodium. Sodium is quite harmful to soils because it is precipitated out from the water at about 18 inches below ground level. In time this forms a hard salt layer preventing the roots of plants from reaching far enough down into the soil for growth. Groundwater from drift aquifers is somewhat more suitable because the total solids are largely bicarbonates and sulfates of calcium and magnesium. In any application of groundwater for irrigation, very careful consideration has to be given to all the aspects of the problems involved.

## UTILIZATION

Most of the groundwater withdrawn in the area is utilized for domestic, livestock, and municipal requirements, and only small quantities are used by commercial establishments and industries.

### Domestic and Livestock Water Supplies

The majority of pumps on domestic and stock wells are set to yield at rates of less than 5 gpm. The water produced is largely for drinking, cooking, and laundering purposes. It is estimated that the average water consumption for rural domestic use is 35 gallons per person per day (Anderson, 1955).

The average consumption of water by livestock is estimated to be 25 gpd for milk cows, 10 gpd for beef cattle, 2 gpd for hogs and 4 gpd for each 100 chickens (Anderson, 1955), and these livestock are the only significant consumers of groundwater in the area.

### Municipal Water Supplies

Many, but not all, towns and villages in east-central Alberta draw water from public wells. Private wells usually fulfill water requirements where public supplies are not available. Municipalities with public wells include Two Hills, Derwent, Edgerton, Wainwright, Lloydminster, Kitscoty, Marwayne, Mannville, Innisfree, Hughenden, Mundare, Smoky Lake, Lougheed, Willingdon, and Vermilion. All of these municipalities except Smoky Lake, Lougheed, Willingdon and Vermilion obtain their groundwater from bedrock aquifers. Of these towns, the first ten lie within the southeast region. Bedrock wells producing 50 to 100 gpm may be obtained at or near Two Hills, Wainwright and Lloydminster (Le Breton, 1963b), and wells yielding possibly up to 50 gpm at Mannville and Edgerton. The fact that only one bedrock municipal supply is found outside the southeast region reflects the difficulty of obtaining supplies for such uses from bedrock sources in the western and northeastern regions. Villages in these areas requiring large quantities of water have to rely on, or search for, aquifers in the glacial drift or buried channels.

Wells in glacial-drift and buried-channel aquifers yielding over 300 gpm can be found at Vermilion and at locations eleven miles north of Lloydminster (Le Breton, 1963b). Yields up to 100 gpm may be possible near Galahad, Killam, Lougheed, and Smoky Lake.

In planning water-supply systems for the towns and villages of east-central Alberta, it is customary to allow for an average consumption of 50 gallons per person per day. The anticipated consumption of water is often not above 30 gallons per person per day, and often only two thirds of the homes can be connected to the system at the time of its installation because of economic conditions. Under these circumstances some allowance for an increase in demand for groundwater has been made. In some villages the demand for water by establishments such as hospitals raises the per capita consumption. Also, considerations of quality may considerably affect the consumption of groundwater, and accordingly the demand for water may be well above or below the average figure already quoted (personal communications from consulting engineers with Associated Engineering Services Ltd., Stanley, Grimble, Roblin Ltd., and Strong, Lamb and Nelson Ltd.).

### Industrial Water Supplies

The number of wells using groundwater for industrial as compared to other purposes is small. In the early years of railway transportation, relatively large quantities of water were required to refill the boilers of steam locomotives. To meet these needs, high-capacity wells or large storage facilities were essential. It was as a result of drilling for water for railway needs that the largest reported producing bedrock well was drilled in east-central Alberta—one of the Canadian National Railways' wells at Wainwright, with an estimated maximum yield of 250 gpm.

The growth of oil refineries following the exploration for oil in the area has created another important demand for groundwater. Husky Oil and Excelsior Oil Refineries at Lloydminster (Le Breton, 1963b) and Wainoco Oil Refinery at Wainwright utilize fairly large quantities of water. The first-named has four wells with capacities ranging from about 15 to 40 gpm, and the second has two wells, one of which is reported to be pumped at 120 gpm. The refinery at Wainwright has three wells, one of which is always in production, the other two being pumped alternately. The pumping rate for each well is about 60 gpm.

Other users of groundwater for commercial purposes include slaughter houses and creameries. Some of these establishments have their own wells and some purchase water from municipal authorities. However, the demands for groundwater for these latter purposes are small, and they are met by wells yielding less than 5 gpm.

### Well-Completion Methods

Apart from some localities in which the water flows from wells, groundwater is obtained from wells over 100 feet deep largely by means of pumps powered by electric motors or gasoline engines, and from wells shallower than 100 feet by drawing water by pail or using a hand pump. Some wells are equipped with windmills.

The bedrock wells commonly are drilled wells, mostly from 2 to 4 inches in diameter with pumping rates set at less than 5 gpm. It is a customary practice to leave the wells completed as open holes, with the casing set at the top of the aquifer or at a depth beyond which it is thought the hole will not cave. In many wells, the casing may be run almost to the bottom of the hole, perforations being made in the casing over the depth range over which the aquifer is encountered. The purpose of substituting perforated casing for an open-hole completion is to overcome sand problems caused by the caving of very soft sandstone aquifers.

The glacial-drift wells are mostly bored, lined with wooden cribbing, and are 1½ to 2½ feet in diameter. In these wells, from which groundwater is obtained from unconsolidated deposits, the well driller tries to drive the cribbing completely through the aquifer. Frequently, however, due to caving problems, the well has to be terminated in the top part of the aquifer. Because the wood cribbing rots in the ground and the openings between the planks comprising the cribbing permit water to seep into the well throughout its entire depth, these wells are subject to contamination from surface seepage. In some bored wells, cement cribbing is used for about the top 12 feet to prevent surface contamination.

Figure 26 illustrates the old customary practice of searching for groundwater supplies in east-central Alberta by using a horse-drawn boring rig. Well boring is gradually being replaced by the modern process of well drilling, and the latter method of obtaining water supplies is shown in figure 27.

In some bedrock and glacial-drift wells, very troublesome sand problems have been encountered, and these wells are pumped very slowly, and either require frequent cleaning or else are abandoned. Because of the fine-grained, very soft sandstones in which bedrock wells are commonly completed, 2-inch diameter holes may be too small. For a given pumping rate, the entrance velocity of water into a well of small diameter will be much greater than that into one of larger diameter, and will often be sufficient to wash fine sand into the well so as to eventually destroy it. By simply drilling 6-inch holes, sand problems may commonly be eliminated.

In some domestic, municipal, and industrial wells, screening and gravel-packing methods of well completion have been carried out, but due to the high costs involved such completions are rare. However, many wells could be prevented from being poor or having to be abandoned if recommendations concerning screen sizes were made and acted upon. In order to make these recommendations, it is necessary to collect, for sieve analysis, half-pint samples of the water-bearing sands in which wells are to be completed. Screened wells have the advantage over wells that are cribbed or have slotted casing, because they have a larger percentage of openings and consequently much greater efficiency.

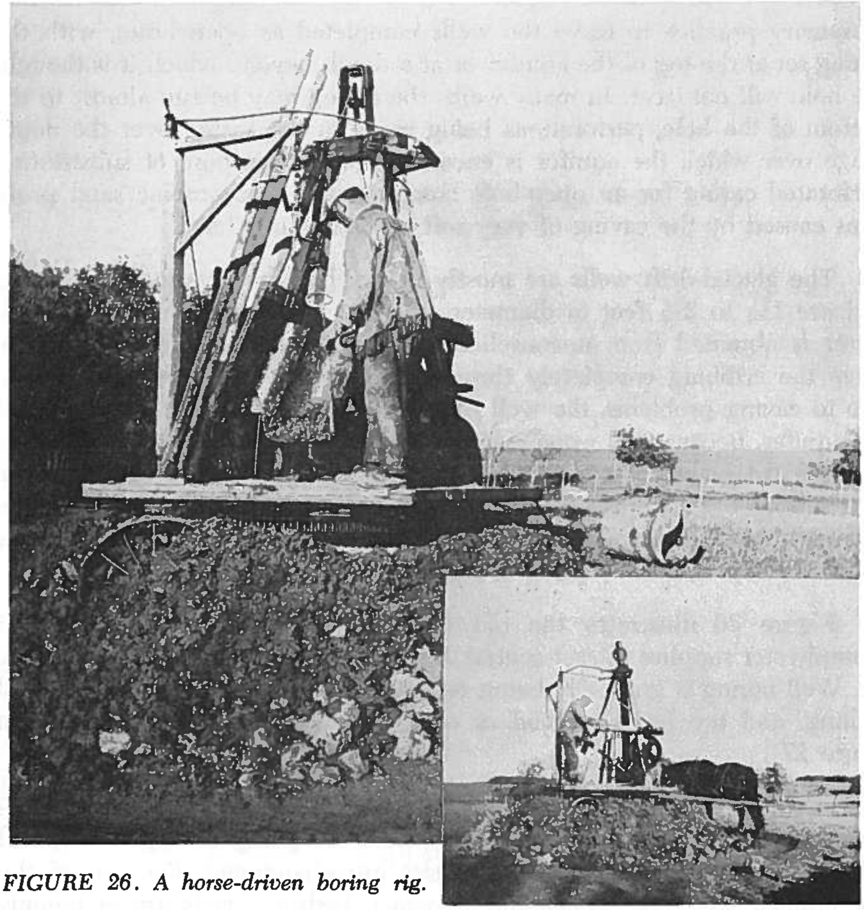

*FIGURE 26. A horse-driven boring rig.*

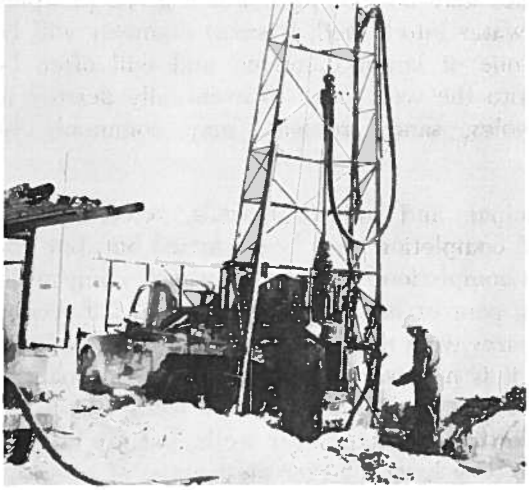

*FIGURE 27. A hydraulic rotary well-drilling rig.*

## POTENTIAL GROUNDWATER DEVELOPMENT

In areas where groundwater supply from bedrock and drift aquifers is small, and consumers are dependent on rainfall to replenish the limited storage capacity of the aquifers, there is no scope for increased utilization of groundwater. This situation is largely confined to the west and northeast regions. However, in the southeast region, particularly in the bedrock aquifers, the available groundwater supplies for rural domestic, livestock and some industrial requirements have not been fully developed. For irrigation purposes, though, on the basis of both quantity and quality, the prospect is generally unfavorable. From what has been stated previously regarding current usage of groundwater, it is believed that around centres where moderately high consumption occurs, such as Lloydminster and Wainwright, there is still scope for some increased utilization of groundwater. It must not be expected that unlimited supplies of water can be obtained at any centres in the southeast region. The hydrograph of the observation well at Lloydminster (Fig. 16) confirms the opinion that only limited quantities of water may be withdrawn from the bedrock aquifers there.

The mutual interference produced by several closely spaced pumping wells should not be interpreted to mean that no further large-capacity wells can be developed within a given area. Rather, it is a case of siting new wells sufficiently far away from existing wells to insure that interference effects are small. The correct well-spacings can be only determined by hydrologic studies based on test drilling and pump testing. Such programs, if carried out prior to situations creating increased demands for groundwater, should eliminate many groundwater supply problems. If such programs reveal insufficient quantities of groundwater, then conservation measures may be necessary in order to prevent exploitation of the resources to the point of depletion, and conflict between too many users.

Apart from bedrock aquifers of the southeast region, other potential sources for increased utilization of groundwater are bedrock-channel and glacial-meltwater channel aquifers, alluvial deposits suitable for development of induced infiltration, and surface sand and gravel. Illustrations of the prospects of developing groundwater from some of these sources have already been given in reference to their use at Vermilion and Lloydminster.

From drilling and pump tests in the Two Hills area, in the summers of 1960 and 1961, it was demonstrated that untapped reserves of groundwater occurring in bedrock and drift aquifers locally offer potential for development for industrial purposes. In particular, the situation of the surface sand and gravel aquifers north of Two Hills deserves special mention. These deposits are close to power and natural-gas lines and to a center of population favored with good communications, and such an advantageous combination will not be commonly repeated in east-central Alberta. Added to this is the advantage of a nearby chemical plant around which subsidiary industries may possibly develop.

Mapping of the Pleistocene deposits of the region will aid in the location and outlining of many of the above possible sources of groundwater. However, much detailed work delineating the bedrock topography of east-central Alberta on large-scale maps is necessary to locate preglacial channels.

Potential supplies of groundwater for irrigation purposes are minor. The chemical quality of most of the water is of marginal suitability, selection of crops of moderate tolerance to salinity would be necessary, and careful consideration would have to be given to soil conditions and to drainage.

Rarely considered sources of groundwater are bedrock and drift "quicksand" aquifers, and in many cases these aquifers may be the only source of supply for domestic and farm requirements. Well-completion experiments (Farvolden, 1961a) have shown there is a distinct possibility of development of wells in these sands. Because of the difficulty of obtaining groundwater from the bedrock in the west and northeast regions, the application of quicksand-completion methods will most likely be in the glacial drift covering these regions. However, quicksand is in some places encountered in bedrock wells in the southeast region. Thus, the prospect of obtaining water from quicksand aquifers increases the potential supply of groundwater.

To evaluate further the potential supplies of groundwater in east-central Alberta, detailed areal investigations are necessary, especially to determine localities where water for municipal and industrial uses may be obtained. Such studies should provide adequate information on the geology and hydrology of the locality and include long-term measurements of water levels, stream flows and regular analyses of the chemical quality of the water.

## CONCLUSIONS

Most of east-central Alberta has only poor to moderately good bedrock and glacial-drift aquifers. In the northeast and west regions, yields of 5 gpm or less may be anticipated, and only in the southeast region may well yields of up to 100 gpm be obtained from bedrock sources. In order to locate higher-capacity wells for industrial purposes, exploration should be directed toward bedrock channels, glacial-meltwater channels, sand and gravel outwash, and sites adjacent to rivers and lakes and suitable for induced infiltration.

The shape of the piezometric surface corresponds closely to the topography and this indicates that recharge takes place by local precipitation. Significant lows in the piezometric surface relative to the present-day topography may possibly be taken as an indication of the presence of buried valleys.

Regional fluctuations of the water table are observed to occur in response to changes in precipitation and temperature, and any continuous decline in water levels is local and due to depletion of aquifers by excessive artificial discharge.

In areas where groundwater supplies are limited, it is believed that the maximum utilization of available groundwater resources has been reached. Where groundwater is in plentiful supply, there is sufficient for increased utilization for domestic and livestock needs, and limited opportunity for development for municipal and industrial purposes.

More careful consideration of the type of well and completion practices may result in somewhat increased well-yields and fewer contaminated supplies. The additional cost of good well-completion usually pays dividends in a longer well-life, greater yield, and lower maintenance costs.

The chemistry of the groundwaters shows that the waters are generally acceptable for human consumption. They may often have to be treated for use in a municipal or industrial supply and may very often be unsuitable for use in irrigation.

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# APPENDIX A. GEOLOGIC AND TOPOGRAPHIC MAP SHEETS OF EAST-CENTRAL ALBERTA

## Geologic Map Sheets

Canada. Geological Survey: Geology, Wainwright-Vermilion area; Map 2058, 1 inch to 4 miles (73 D (N¼))

———————— Edmonton, Alberta; Map 506A, 1 inch to 4 miles; geology by R. L. Rutherford. 83-H (W)

———————— Hardisty, Alberta; Map 502A, 1 inch to 4 miles; geology by P. S. Warren and G. S. Hume. 73-D (W)

———————— Ribstone Creek, Alberta; Map 501A, 1 inch to 4 miles; geology by P. S. Warren and G. S. Hume. 73-D (E)

———————— Stettler, Alberta; Map 503A, 1 inch to 4 miles; geology by R. L. Rutherford. 83-A (E)

———————— Tofield, Alberta; Map 505A, 1 inch to 4 miles; geology by R. L. Rutherford. 83-H (E)

———————— Innisfree, Alberta; Map 674A, 1 inch to 4 miles; geology by C. H. Crickmay, G. S. Hume and C. O. Hage. Brief notes on each formation. 73-E (W)

———————— Kitscoty, Alberta; Map 673A, 1 inch to 4 miles; geology by C. H. Crickmay, G. S. Hume and C. O. Hage.

## Topographic Map Sheets

Canada. Department of Mines and Technical Surveys, Ottawa: Wainwright, Alberta, Sheet 73D. Scale 1 : 250,000.

———————— Red Deer, Alberta, Sheet 83A. Scale 1:250,000.

———————— Vermilion, Alberta, Sheet 73E. Scale 1:250,000.

———————— Edmonton, Alberta, Sheet 83H. Scale 1:250,000.

———————— Sand River, Alberta, Sheet 73L. Scale 1:250,000.

———————— Tawatinaw, Alberta, Sheet 83I. Scale 1:250,000.

## APPENDIX B. SELECTED WATER-WELL LOGS

Driller: G. Downey, Vermilion, Alberta
Location: SE. ¼, Sec. 16, Tp. 48, R. 6
Total depth: 100 feet

| Depth (feet) | Description |
|---|---|
| 0 - 2 | Top Soil |
| 2 - 19 | Clay |
| 19 - 37 | Crumbly clay |
| 37 - 45 | Blue sand mixture |
| 45 - 53 | Clay |
| 53 - 77 | Hard shale |
| 77 - 85 | Shale |
| 85 - 90 | Sand and water |
| 90 - 100 | Clay |

Driller: Prosser and Beckett, Mannville, Alberta
Location: NW. ¼, Sec. 6, Tp. 49, R. 8
Total depth: 210 feet

| Depth (feet) | Description |
|---|---|
| 0 - 20 | Clay and boulders |
| 20 - 38 | Clay |
| 38 - 60 | Sand |
| 60 - 85 | Blue clay |
| 85 - 87 | Bedrock |
| 87 - 102 | Blue clay |
| 102 - 103 | Rock |
| 103 - 135 | Blue clay |
| 135 - 136 | Sandstone |
| 136 - 145 | Sandy clay |
| 145 - 148 | Grey sand |
| 148 - 180 | Sandy clay |
| 180 - 181 | Sandstone |
| 181 - 190 | Sandy clay |
| 190 - 192 | Rock |
| 192 - 206 | Watersand |
| 206 - 210 | Sandstone |

Driller: R. McAllister, Lloydminster, Alberta
Location: NE. ¼, Sec. 1, Tp. 50, R. 2
Total depth: 229 feet

| Depth (feet) | Description |
|---|---|
| 0 - 20 | Brown clay |
| 20 - 40 | Blue clay |
| 40 - 45 | Sand and gravel |
| 45 - 160 | Blue clay, very stony |
| 160 - 161 | Soft sandrock |
| 161 - 195 | Blue clay |
| 195 - 200 | Shale |
| 200 - 201 | Soft rock |
| 201 - 209 | Blue sand and sandstone |
| 209 - 220 | Shale |
| 220 - 221 | Soft rock |
| 221 - 229 | Sandstone and sand |

Driller: Laws and Byrt, Lloydminster, Alberta
Location: SW. ¼, Sec. 4, Tp. 52, R. 7
Total depth: 175 feet

| Depth (feet) | Description |
|---|---|
| 0 - 19 | Brown clay |
| 19 - 21 | Sand |
| 21 - 24 | Rock |
| 24 - 35 | Black sand |
| 35 - 38 | Sandy blue clay |
| 38 - 85 | Blue clay |
| 85 - 115 | Intermittent shale in blue clay |
| 115 - 153 | Blue clay |
| 153 - 160 | Fine black sand |
| 160 - 162 | Blue clay |
| 162 - 175 | Black sand |
| 175 - ? | Clay |

Driller: M. Zarowny, Elk Point, Alberta
Location: NW. ¼, Sec. 12, Tp. 56, R. 7
Total depth: 48 feet

| Depth (feet) | Description |
|---|---|
| 0 - 4 | Clay |
| 4 - 12 | Sand |
| 12 - 13 | Gravel |
| 13 - 16 | Sand |
| 16 - 48 | Blue clay |

Driller: J. E. Frederickson, St. Paul, Alberta
Location: SW. ¼, Sec. 12, Tp. 58, R. 11
Total depth: 198 feet

| Depth (feet) | Description |
|---|---|
| 0 - 25 | Yellow clay |
| 25 - 40 | Blue clay |
| 40 - 45 | Sand |
| 45 - 60 | Blue clay |
| 60 - 62 | Sand |
| 62 - 192 | Blue clay |
| 192 - 198 | Sand and water |

## APPENDIX C. CHEMICAL ANALYSES OF GROUNDWATER IN THE UPPER AND LOWER ZONES OF THE LOWER BIRCH LAKE SANDSTONE AT WAINWRIGHT, ALBERTA

| | Upper zone. Canadian National Railways No. 1 well (ppm) | Lower zone. Town storage tank (ppm) |
|---|---|---|
| Total solids | 740 | 970 |
| Ignition loss | 88 | 30 |
| Hardness | 210 | 25 |
| Sulfates | 140 | 246 |
| Chlorides | 3 | 8 |
| Alkalinity | 475 | 475 |
| Nature of alkalinity | Bicarbonate of soda, lime and magnesium | Bicarbonate of soda, lime and magnesium |
| Nitrites | Trace | Trace |
| Nitrates | 1.2 | 4.2 |
| Iron | 0.2 | 0.3 |
| Fluorine | — | 0.4 |

## APPENDIX D. DRINKING-WATER STANDARDS

| | United States Public Health Service (ppm) | Alberta Provincial Analyst (ppm) |
|---|---|---|
| Total solids | 1,000 | 1,600 - 2,000 |
| Sulfates | 250 | 800 |
| Chlorides | 250 | 435 |
| Nitrates | 10 | 10 |
| Iron | 0.3 | 0.3 |

## APPENDIX E. CHEMICAL ANALYSES OF GROUNDWATER BEFORE AND AFTER CLEANING WELLS

Location: SE. ¼, Sec. 2, Tp. 52, R. 14

| | Water before cleaning (ppm) | Water after cleaning (ppm) |
|---|---|---|
| Total solids | 4,984 | 2,520 |
| Ignition loss | 832 | 582 |
| Hardness | 1,000+ | 1,000 |
| Sulfates | 2,160 | 948 |
| Chlorides | 24 | 7 |
| Alkalinity | 480 | 460 |
| Nature of alkalinity | Bicarbonate of lime and magnesium | Bicarbonate of lime and magnesium |
| Nitrites | Trace | Trace |
| Nitrates | 22.0 | 5.0 |
| Iron | 2.5 | 1.6 |

Location: NW. ¼, Sec. 22, Tp. 55, R. 12

| | Water before cleaning (ppm) | Water after cleaning (ppm) |
|---|---|---|
| Total solids | 8,824 | 1,866 |
| Ignition loss | 1,272 | 206 |
| Hardness | 1,000+ | 350 |
| Sulfates | 3,980 | 677 |
| Chlorides | 85 | 24 |
| Alkalinity | 675 | 560 |
| Nature of alkalinity | Bicarbonate of lime and magnesium | Bicarbonate of lime, magnesium, and some soda |
| Nitrites | Trace | Trace |
| Nitrates | 24 | 2 |
| Iron | Nil | Nil |

## LEGEND

🟦 Areas of sand and gravel deposits classified as outwash, esker, kame moraine, lake deposit – sand and gravel phase, and alluvial deposits – undifferentiated
Well yields commonly less than 100 gpm, and possibly up to 350 gpm.

🟩 Areas possibly containing sand and gravel deposits in, and adjacent to, buried or open meltwater channels
Well yields commonly less than 15 gpm, and possibly up to 25 gpm.

☐ Areas of clay, silt, sand and gravel classified as ground moraine, ground moraine transitional, hummocky moraine, moraine plateau, lake deposits – silt and clay phase, terrace deposits – undifferentiated and eroded slopes and landslide area
Well yields commonly less than 5 gpm and possibly up to 10 gpm.

Bedrock outcrop ........ ×
Buried and open meltwater channels ........
Buried channel of unknown origin ........
Geological boundary; definite ........
approximate ........

### WATER-WELL SYMBOLS

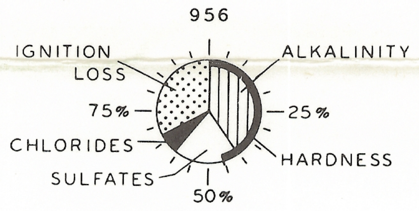
● 60 Gr 30 / 55 H 27 — Well depth (ft). Water-bearing formation. Static water level (ft) / Depth to bedrock (ft). Degree of hardness. Yield (gpm)

WATER-BEARING FORMATIONS
S = Sand
Gr = Gravel
C = Clay

DEGREE OF HARDNESS
H = Hard
M = Medium hard
S = Soft
Note: DH = Dry hole
F = Flowing well

### GROUNDWATER COMPOSITION

The major constituents of the groundwater composition are presented, as percentages, in a pie diagram. The figure above the diagram represents the sum in ppm of these constituents. Hardness is represented by an inset arc overlain first upon alkalinity, the primary source of hardness, and then upon sulfates, the secondary source of hardness

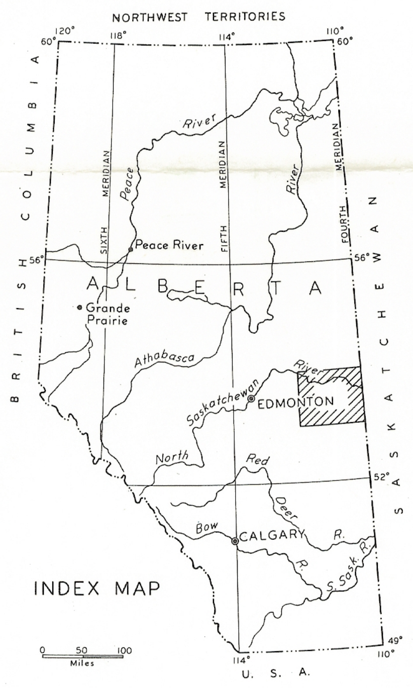


Groundwater probability interpretation by E.G. Le Breton, 1961-1962
based on surficial geology by R.B. Ellwood, 1961

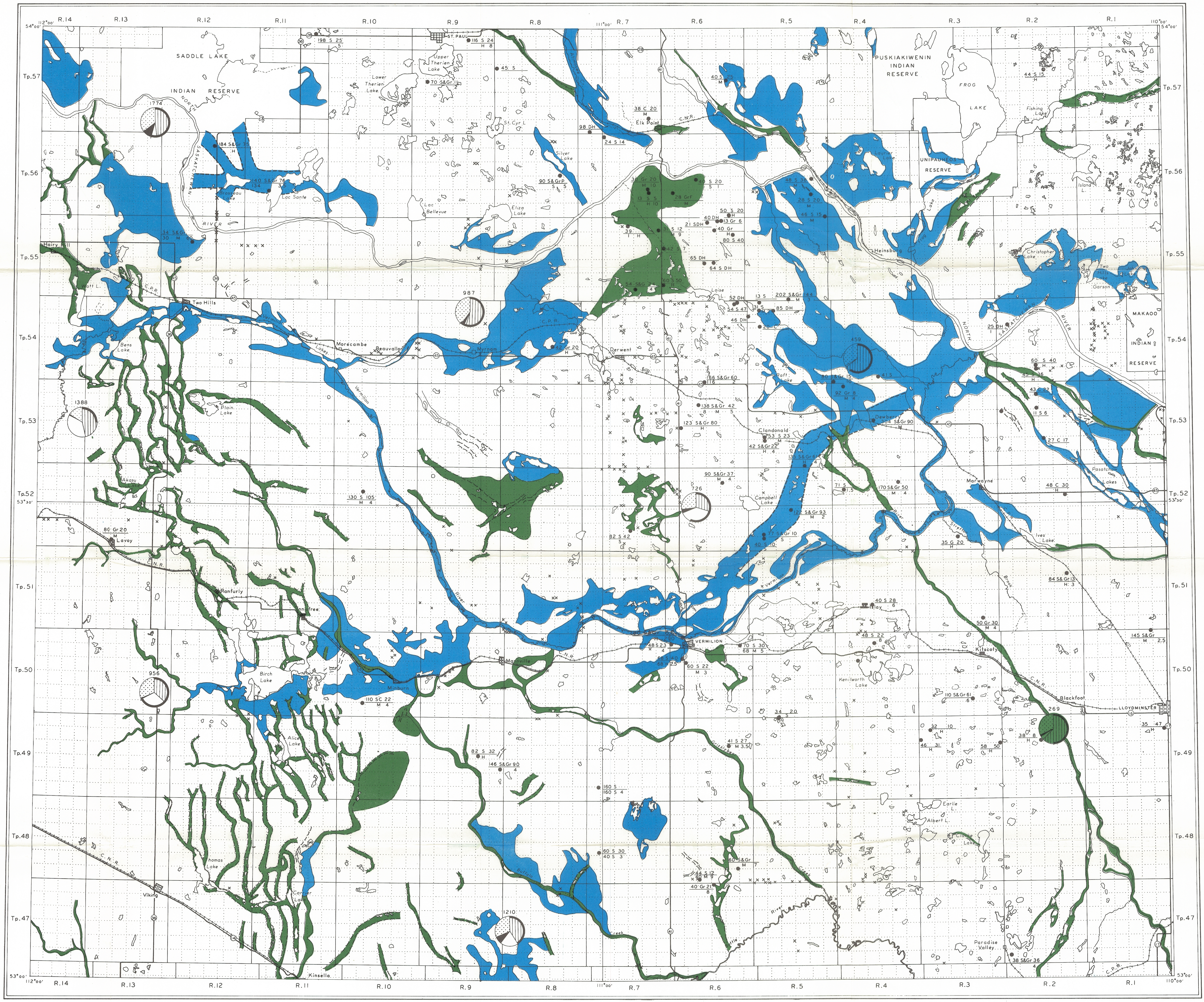
### REFERENCE

Provincial highway ........ ②
Railway ........
Township boundary ........
Section line ........

Cartography taken from Department of Lands and Forests, Alberta, Map-Area 73E, Sheets 1-16



INDEX MAP



To accompany Research Council of Alberta Bulletin 13

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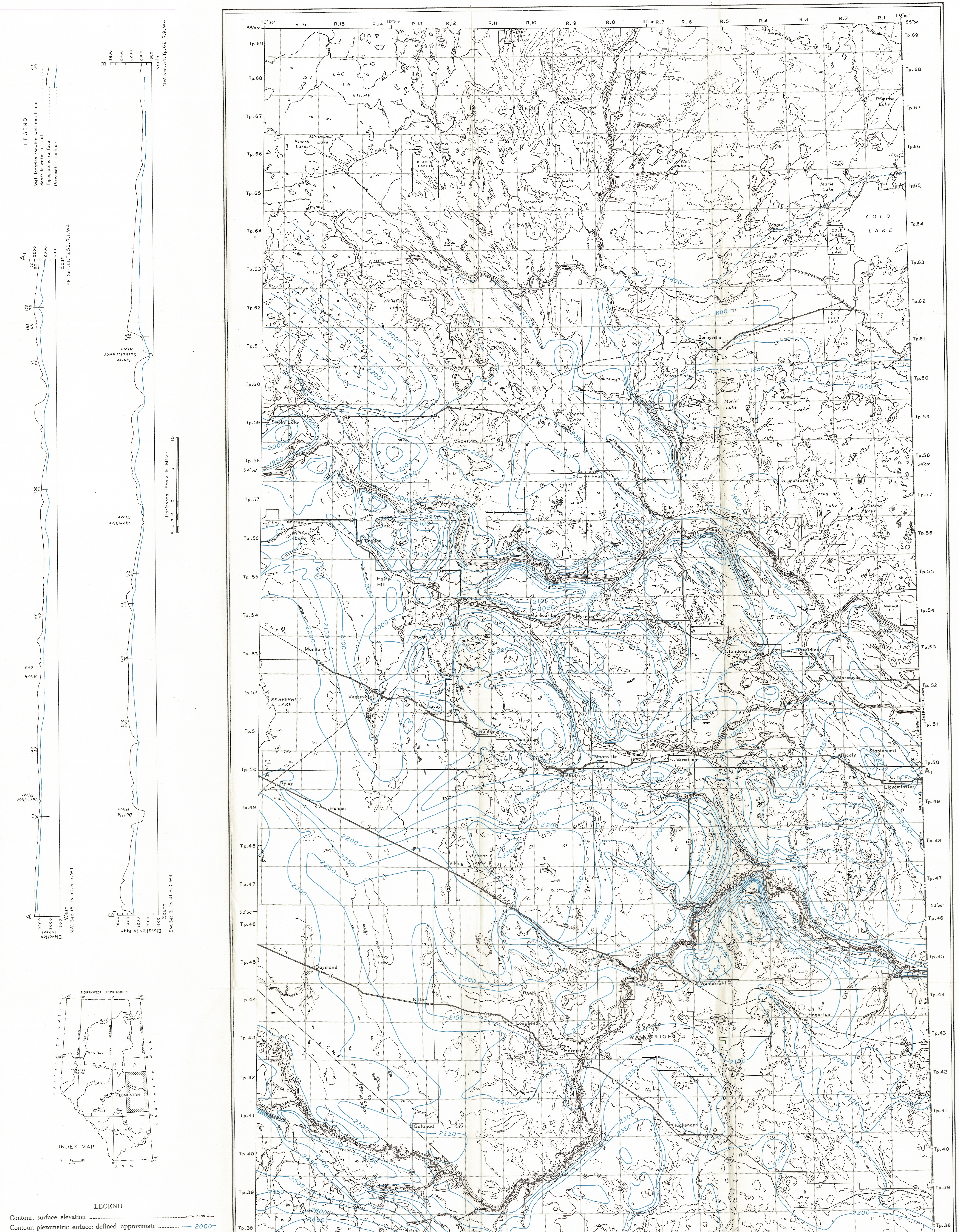
# GROUNDWATER PROBABILITY MAP OF THE SURFICIAL DEPOSITS OF THE VERMILION AREA, ALBERTA

WEST OF FOURTH MERIDIAN

SCALE IN MILES
4 3 2 1 0 4 8

FIGURE 11.



CONTOUR INTERVALS
Surface elevation 100 feet
Piezometric surface 50 feet

SCALE IN MILES
4 3 2 1 0 4 8 12 16

FIGURE 14. *Piezometric surface of east-central Alberta.*