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GROUNDWATER RESOURCES
PEMBINA AREA, ALBERTA

by

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ILLUSTRATIONS

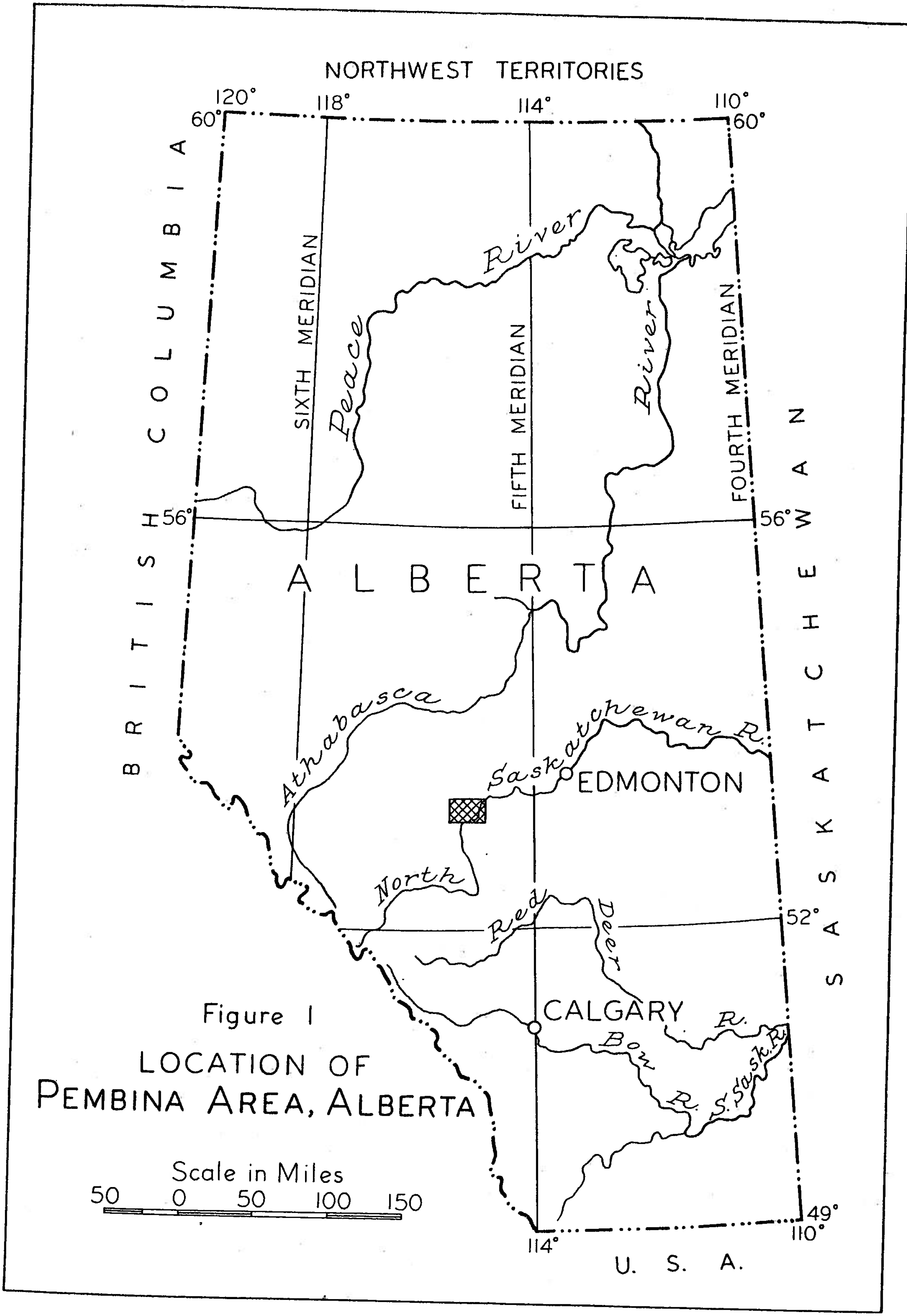

Figure 1
LOCATION OF
PEMBINA AREA, ALBERTA

GROUNDWATER RESOURCES

PEMBINA AREA, ALBERTA

Abstract

Nearly 60 per cent of the water utilized for secondary recovery operations in the Pembina oil field is obtained from the Paskapoo formation. The present annual withdrawal from this formation is about 6 x 10^8 gallons per year.

The apparent transmissibility of the Paskapoo formation is variable; however, in only a few isolated areas are well yields less than 5 gallons per minute. At the present rate of withdrawal, it is estimated that the piezometric surface of the Paskapoo formation will be lowered less than 24 feet over the entire area. In a few parts of the area the local overdraft will be considerably greater. Observation wells completed in the Paskapoo formation indicate that to date there has been no significant decline in the piezometric surface. The decline observed in a few very shallow observation wells is ascribed to changes in surface drainage rather than to withdrawal of water for pressure maintenance.

It is considered that the present rate of withdrawal, continued for the anticipated life of 40 years for the oil field, will not significantly decrease the amount of water available for agricultural development.

INTRODUCTION

The Pembina area of Alberta is the largest area in Western Canada in which groundwater from a low-permeability aquifer is being developed systematically. Groundwater has been used by local residents for domestic and stock-watering purposes since the district was settled and, as is generally the case in this region of Alberta, few problems have been encountered in obtaining a plentiful water supply. In 1953 oil was discovered in the area and this resulted in the development of the largest and most productive oil field in Alberta. The oil is produced principally from the Cardium formation of late Cretaceous age. By 1956 it was apparent that secondary recovery methods would have to be implemented to maintain pressures in the reservoir. Several of the companies with large holdings in the oil field elected to accomplish this by injecting fresh water into the reservoir. Some operators were able to obtain fresh water from the North Saskatchewan River, by direct intake, Ranney collector, or vertical wells, and to distribute it to the injection wells by pipelines. This was not feasible for those companies with small holdings scattered widely throughout the field. Instead, many of these operators have drilled a water-supply well for each injection well.

In the past three years several hundred water wells have been completed for this purpose. The oil wells are on 80-acre spacings and, since every other oil well becomes an injection well in the five-spot injection pattern adopted at Pembina, there are four injection wells per section and up to four water-supply wells per section.

The local residents are concerned about their own water supply and about the possibility that the aquifers will be depleted by the comparatively large withdrawals of water from the oil company water-supply wells. Strict regulations have been imposed in an attempt to ensure that the local rural residents will not suffer from water shortages or from declining water levels resulting from the utilization of fresh water for secondary recovery of petroleum.

The Pembina area is the first large area in Western Canada where disputes over the ownership and utilization of groundwater have arisen. This report is an attempt to present and explain the pertinent facts concerning the groundwater geology and hydrology of the area in order that decisions involving groundwater utilization can be made on a sound basis.

Information has been obtained from drillers logs of numerous wells and test holes. Electric logs are available for approximately 50 test holes. Additional stratigraphic information was obtained from the study of outcrop sections, from aerial photographs, and from published information (Rutherford, 1928; Collins and Swan, 1955). Hydrologic data were obtained from well completion records, interviews with well owners, and the hydrographs of observation wells.

Description of the Area

The Pembina area is located about 70 miles southwest of Edmonton, Alberta (Fig. 1). It comprises townships 47 to 49, ranges 7 to 10, W. 5th Meridian, an area of about 432 square miles.

Swell and swale topography is predominant in the area. A series of long, broad ridges which rise 300 to 400 feet above the intervening valleys cross the area in a southeasterly direction. The ridges consist of bedrock overlain by a thin cover of glacial drift. Sand dunes form low hills in a few places near the Pembina River; morainic features of significant relief are rare.

Two major rivers, the North Saskatchewan and the Pembina, drain the area (Fig. 2). Both flow northeastward and both occupy pre-existing valleys of glacial or preglacial streams which cut through the southeast-trending ridges. The North Saskatchewan River has incised a narrow valley 200 to 300 feet deep, and has cut down below the base of the older channel that followed the same course. Bedrock is exposed in steep cliffs along the valley walls. In contrast, the Pembina River flows in a broad open valley and has not cut through the valley fill of the pre-existing channel.

The drainage system would seem sufficiently well integrated to provide good drainage for the area but, in fact, most of the valleys are swampy in places and swamps or muskegs are common on side-hills and on the upland areas. This situation exists

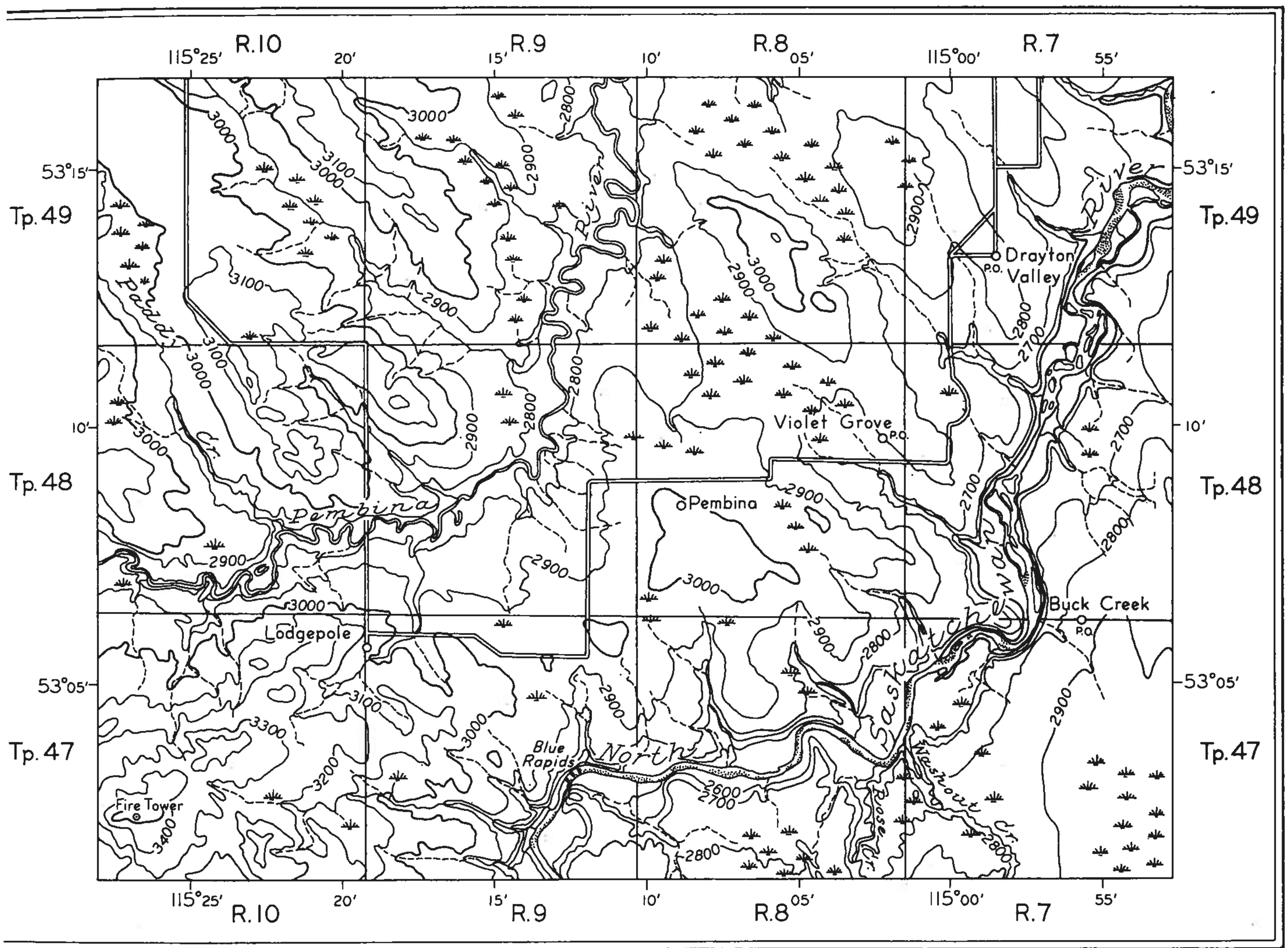

Figure 2

PEMBINA AREA, ALBERTA

(WEST OF FIFTH MERIDIAN)

Scale in Miles

2 1 0 2 4 6

LEGEND

Township boundary ....

Town, hamlet, locality .... o

Post Office .... P.O.

Road ....

Stream ....

Stream, intermittent ......

Swamp ....

Surface contours 3000

(Contour interval 100 feet; elevation in feet above mean sea level.)

because in the valleys the water table is at or very near the land surface, and on the uplands subsurface drainage is poor and the heavy forest cover retards run-off.

The climate is of the sub-arctic type of the humid microthermal class (Department of Mines and Technical Surveys, 1957). The mean annual precipitation is about 20 inches of which nearly six inches falls in the form of snow. The mean daily temperature for January, the coldest month, is 10°F., and for July, the warmest month, is 60°F. The length of the growing season is 170 days.

The district was first settled in the early years of this century by loggers and trappers. Homesteaders soon followed and began to clear the land for farming. Large-scale grain farming is not practiced because the climate and soil conditions are unsuitable, and because there is no railway serving the district. Most farms are small and raise only sufficient cereal grains to feed small stock holdings.

The hamlet of Drayton Valley was established as the main business centre in the district, and soon after oil was discovered in the area Drayton Valley was incorporated as a town. The town is served by two all-weather roads, one of which has been hard surfaced.

Oil production is now the most important industry in the Pembina area.

Acknowledgments

The author has received excellent assistance from the staff of the Alberta Oil and Gas Conservation Board at the Pembina field office in Drayton Valley and at the head office in Calgary. Most of the information used in this report has been supplied by water-well drillers and the oil companies operating in the field. Chemical analyses have been supplied by Mr. C. E. Noble, Provincial Analyst; Mr. D. R. Shaw, Analyst, Oil and Gas Conservation Board; and by Chemical and Geological Laboratories Ltd., Edmonton. Mr. Bastiaan Meyer, Technician, Research Council of Alberta, has braved adverse weather and road conditions many times in order to take measurements of water levels in observation wells.

For all of this help the author is extremely grateful.

GROUNDWATER GEOLOGY AND HYDROLOGY

Geology

The Pembina area lies within the Western Canada sedimentary basin and is underlain by strata of the Paskapoo formation of early Tertiary age. Within the map area the Paskapoo formation varies in thickness from a minimum of about 500 feet in the valley of the North Saskatchewan River in Tp. 49, R. 7, to a maximum of about 2,000 feet in the upland area in Tps. 48, 49, R. 10 (Fig. 2). The Edmonton formation of late Cretaceous age underlies the Paskapoo formation but is not considered further in this report as it is not an economic aquifer in this area. A mantle of drift covers the whole area; thicknesses reach 200 feet in some of the valleys but are usually less than 25 feet.

Paskapoo Formation

The Paskapoo formation consists of non-marine sandstones and shales, with a few thin coal seams. Massive sandstone units 50 to 100 feet thick may be present at the base of the formation; such a basal sandstone outcrops in the valley of the North Saskatchewan River just east of the area and in the valley of the Pembina River several miles north of the area. Throughout the area shallow borings encounter a sequence of sandstone and shale strata in which shale generally predominates. Sometimes correlation can be made between one boring and another using sandstone strata as marker beds, but continuous strata are uncommon and most correlations based on sandstone strata are therefore questionable. Many of the borings are not sufficiently deep to compensate for the topographic relief and thus as different stratigraphic intervals may be penetrated by adjacent wells, correlation may not be possible.

The texture of the Paskapoo sandstones ranges from coarse to very fine grained and the degree of sorting is extremely variable. Sub-rounded to well rounded grains of quartz and chert predominate. The matrix consists of limestone and shale fragments and clay. The sandstones are cemented with calcium carbonate, and they range from friable to a hard, brittle, calcareous rock. It is believed that the permeability is principally intergranular, and that the variation in the degree of cementation may be the reason for the highly variable permeability of the Paskapoo strata.

The shales of the Paskapoo formation vary in texture and composition as much as the sandstones. All gradations between hard, platy, arenaceous or calcareous shales and soft, structureless, plastic clays are found. Shale comprises the major part of the Paskapoo formation in most places but has not been studied in this report because shale is not important as a source of groundwater.

The Pembina oil field lies on the east flank of the Alberta syncline. Thus the Paskapoo beds dip southwestward, the dip increasing from 30 feet per mile in the northeast portion of the field to 60 feet per mile in the southwest portion of the field. According to Nielsen (1957) this increase in dip is due to the location of the field on the hinge line of the east limb of the syncline. This dip information is based on data obtained from deeper horizons but it is likely that structure of the Paskapoo differs only to a minor degree. No study was undertaken utilizing logs from shallow borings because of the difficulty in correlating adjacent sections of the Paskapoo formation.

Surficial Deposits

Between the time of deposition of the Paskapoo formation and the advent of glaciation there was a long period of erosion, during which the major features of the bedrock topography were formed. These features include the rounded hills and ridges with a southeast trend, and the intervening broad valleys now occupied by small streams. The valleys of both the North Saskatchewan and Pembina Rivers cross the aligned features at nearly right angles. Alluvial deposits were laid down in all the ancient channels and were subsequently covered by glacial drift. The drift deposits include till, lake clays, and sand and gravel deposits. Near the Pembina River and in a small area near the North Saskatchewan River, U-shaped sand dunes are present. These dunes have a southeasterly alignment and are concave to the northwest. Extensive sand and gravel deposits are present along the flood plains of the major rivers and of some tributary streams.

A map of the bedrock topography, contoured at 100-foot intervals, has been constructed (Fig. 3) and, on the basis of this, a bedrock channel system has been postulated and is outlined on the map. During the time of formation of these channels probably the entire system drained into the bedrock channel of the North Saskatchewan River through the bedrock channel which crosses Tp. 48, R. 8. Coarse-grained, well sorted, granular deposits have been encountered in drill holes in many places along these bedrock channels but fine-grained, poorly sorted sediments make up the major part of the buried alluvium.

The glacial deposits of the area were not investigated in detail because sorted, granular material has been only rarely reported from the drift, and the drift is therefore not an important source of groundwater: till makes up the bulk of the drift cover.

Coarse gravels are common in the postglacial deposits that cover the floor of the North Saskatchewan River valley, but sand and clay predominate in the deposits along the Pembina River valley. Many wells along the flood plain of the North Saskatchewan River penetrate 10 to 30 feet of gravel below the water level of the river.

Aquifer Characteristics

Almost all of the domestic and farm wells in the area obtain water from the Paskapoo formation. In addition, nearly sixty per cent of the water used for injection operations in the Pembina field is obtained from the Paskapoo formation. The remaining forty per cent of groundwater used for secondary recovery is obtained from surficial deposits along the North Saskatchewan River.

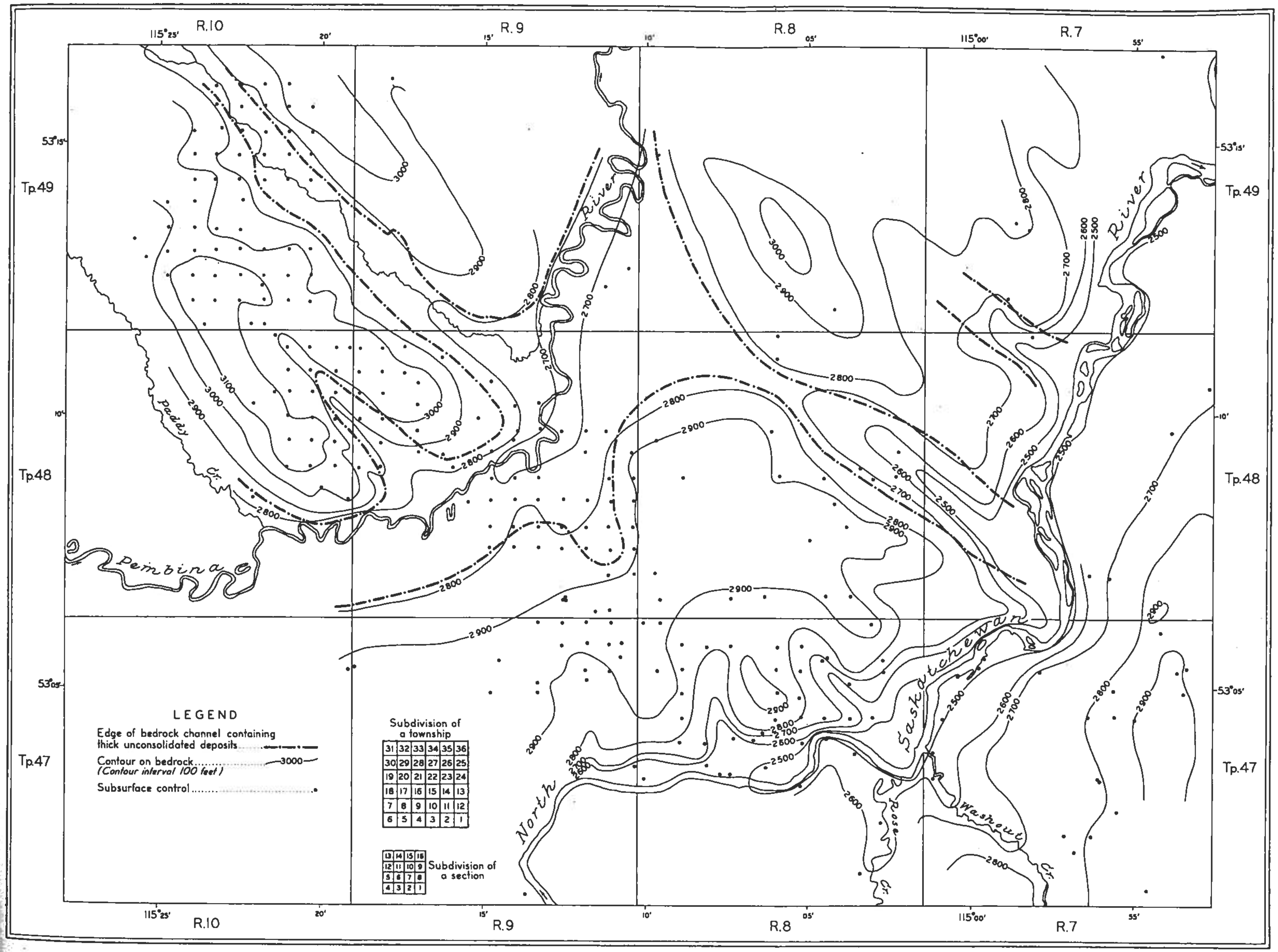

Figure 3

Bedrock Topography, Pembina Area, Alberta

(West of Fifth Meridian)

Scale in Miles

Paskapoo Formation

Water may be obtained from the Paskapoo formation wherever it is sufficiently permeable to constitute an aquifer. Most water is obtained from porous and permeable sandstone strata, although some wells obtain water from calcareous sandstone and siltstone that have fracture permeability. Coal seams are of only minor importance as aquifers in this area.

The sandstone aquifers range from 1 to 30 or more feet in thickness. The total thickness of sandstone strata encountered in a drill hole may range from nearly zero to over 150 feet. The number of individual sandstone beds and the cumulative thickness of sandstone as reported in drillers logs have been found to bear a significant relationship to the water-bearing characteristics of the formation. The best wells are obtained where one or more thick sandstone strata are encountered in the hole, although the cumulative thickness may not be great. In a few locations, however, thick sandstone strata were reported but a good well was not obtained. These failutres may be related to faulty drilling practices. Good wells are not common in areas where sandstone beds are thin, although the cumulative thickness may be great.

No pumping tests have been conducted for the purpose of acquiring data to determine the coefficients of transmissibility and storage of the Paskapoo sandstone. A drawdown test or production test is conducted on nearly every well after it has been completed. The reports of these tests state only the initial or static water level in the well and the water level at the end of the test. The drawdown at the end of each test has been plotted against the logarithm of the time of the test in minutes and the transmissibility of the aquifer has been calculated according to the modified Theis equation*:

$$T = \frac{264\,Q}{\Delta s} \text{ gpd/ft}^{\dagger}$$

where T = transmissibility, imperial gallons per day per foot (gpd/ft)

Q = pumping rate, gallons per minute (gpm)

Δs = change in drawdown in feet during one log cycle of time

The validity of this method of determining transmissibility is open to serious doubt because a number of factors that may have significant influence on the results are not considered. The answers obtained from such a calculation are therefore termed "apparent transmissibility" in this paper. The apparent transmissibility has been used only because little other quantitative data on the aquifer are available. The results of bailing tests tend to confirm the values obtained for apparent transmissibility as do recovery tests on a few of the production wells.

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* For a comprehensive discussion of hydrologic terminology the interested reader is referred to U.S.G.S. Water Supply Paper 887, or Todd, 1959.

† All gallons referred to in this report are imperial gallons = 6.229 ft^3 = 120 U.S. gallons.

The apparent transmissibility was calculated from production test data from each of 138 wells in the Paskapoo formation. The results were plotted on a map (Fig. 4) and show a pattern similar to that obtained by plotting the number and cumulative thickness of sandstone strata. It must be remembered that, because of structure, relief, and variations in the depth of wells, strata of different horizons have been developed in different parts of the area. The map, therefore, does not show horizontal variations within the Paskapoo formation or within one unit of the Paskapoo formation. The values for apparent transmissibility range from nearly zero to 8,000 gpd/ft.

In the areas shown on the groundwater-probability map(Fig. 4) as POOR, the apparent transmissibility ranges from 0 to 300 gpd/ft. In these areas a water supply for a farm or residence is seldom difficult to obtain although "dry" holes have been reported. On the other hand, wells capable of producing more than 5 gpm, are difficult or impossible to develop because the transmissibility is too low. There has been limited success developing wells that will produce adequate quantities for an injection supply well (200 to 400 barrels per day* or approximately 5 to 10 gpm), but only where the hydraulic head within the aquifer is high, so that the available drawdown is large. Several such wells have now been producing for nearly two years, and drawdown measurements indicate that in the vicinity of the well the aquifer is being dewatered. This situation could have been easily predicted if proper pumping tests had been conducted when the well was initially completed. The local dewatering of the aquifer should have no serious consequences as far as the continued availability of water for agricultural or domestic utilization is concerned because the hydraulic gradient toward the well is necessarily very steep where the permeability is low. Thus the cone of influence of a production well cannot be extensive although the drawdown at or very near to the well may be large. The productivity of such wells, however, will gradually decline and may become inadequate in the future.

In the areas marked GOOD on the groundwater-probability map (Fig. 4) the apparent transmissibility ranges from 300 to 1,000 gpd/ft. Within these areas there are more wells that show anomalous values of the apparent transmissibility than in the areas shown as POOR groundwater potential. Most of the very low apparent transmissibility values probably are due to poor completion and development practices rather than to low transmissibility of the aquifer, although it is quite likely that true transmissibility anomalies do exist. In these areas domestic and farm water supplies are easy to develop from wells. Such wells are commonly shallow because sufficient water is obtainable from a thin bedrock section.

The GOOD areas differ geologically from those shown as POOR on the groundwater probability map in that the individual sandstone strata are thicker and more porous. The higher transmissibility in the GOOD areas is favorable in that more water can be withdrawn from a well, but is unfavorable in that a cone of influence is of much greater radius. Thus, although the drawdown at the site of a production well is less in the GOOD than in the POOR areas, the influence of the production on distant wells is greater. Even though this influence may be real and measurable, it may still not be harmful to an adjacent well owner.

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* 1 barrel = 35 imperial gallons
bpd = barrels per day

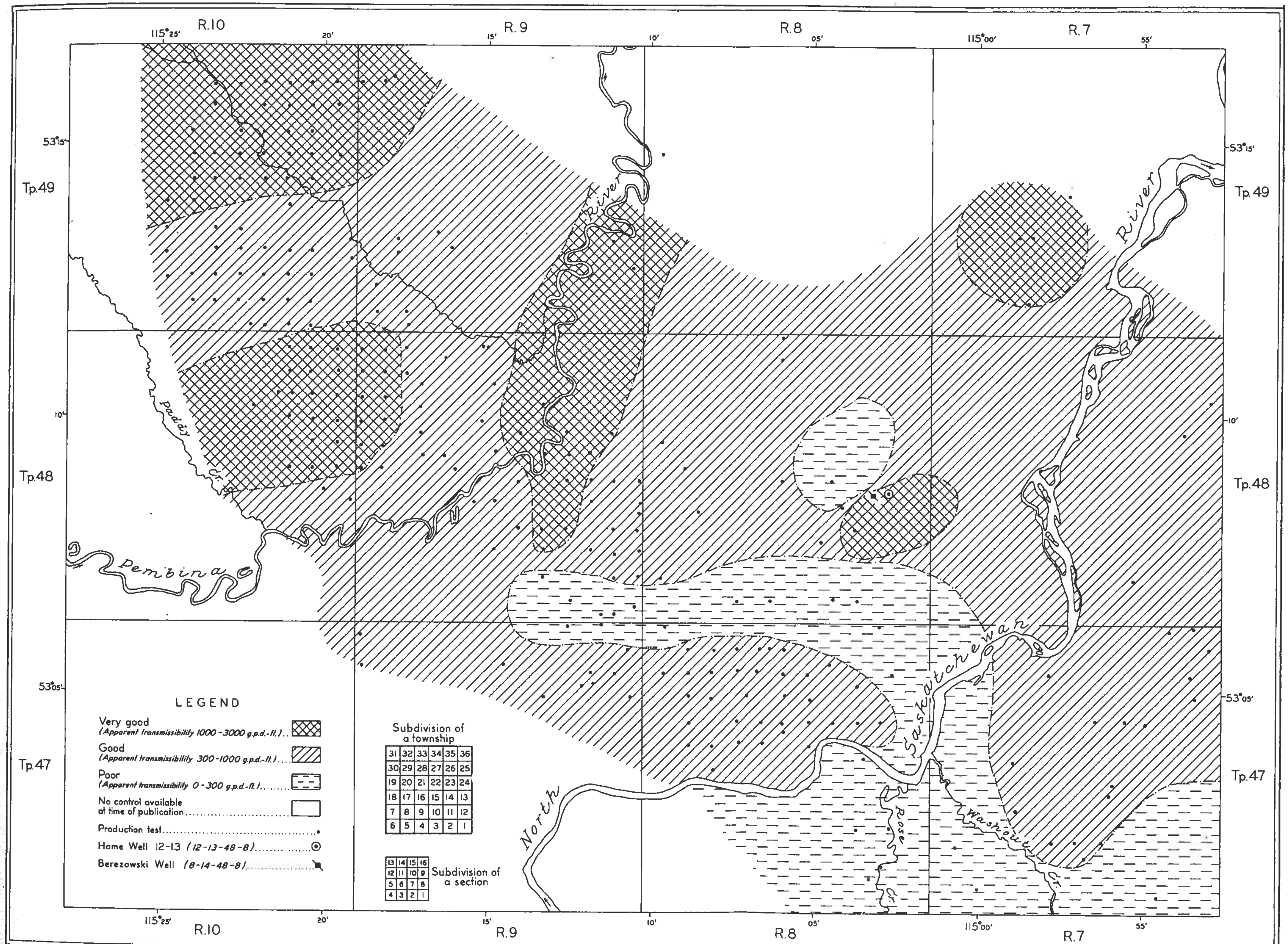

Figure 4

APPARENT TRANSMISSIBILITY OF THE PASKAPOO FORMATION, PEMBINA AREA, ALBERTA

(WEST OF FIFTH MERIDIAN)

In three large areas and two small areas the apparent transmissibility ranges between 1,000 and 3,000 gpd/ft (higher values that have been calculated are not considered valid). These areas are marked VERY GOOD on the groundwater-probability map (Fig. 4). Most wells in these areas are capable of producing more than 2,000 bpd or 50 gpm. Many of the near-failures in these areas are probably due to faulty drilling or completion methods, or both, although it is entirely possible that at certain sites the aquifer is relatively impermeable. For the most part, however, the sandstone strata of the Paskapoo formation are thick, massive, and not tightly cemented in these VERY GOOD areas. Occasionally during rotary drilling there is considerable fluid loss and sometimes complete loss of circulation occurs. Many wells less than 250 feet deep have penetrated over 100 feet of sandstone in that interval.

Surficial Deposits

The sediments of the bedrock channels commonly contain a large proportion of sand and gravel. The locations of these channels in the Pembina area are shown on the map of the bedrock topography (Fig. 3). Many wells in the bedrock channels encounter sand and gravel strata that are excellent aquifers but common practice is to case off these aquifers. Sand and gravel commonly occur adjacent to surface water because of their common relationship to topographically low areas. Where such a situation exists recharge of these aquifers by induced infiltration is a distinct possibility if the permeable beds lie below the water level of adjacent lakes and streams. There are no data on transmissibility values for these aquifers, but high-capacity wells should be easy to obtain where suitable conditions exist. Although it is worthwhile prospecting for gravel aquifers anywhere in the bedrock channels, it must be remembered that clay, silt and fine sand are by far the predominant channel sediments.

Sand and gravel are in some regions associated with the glacial drift, but in the Pembina area such deposits are encountered only rarely and cannot be considered an important source of groundwater.

Extensive deposits of sand and gravel occur along the valley of the North Saskatchewan River and to a lesser degree, the valley of the Pembina River. In the valley of the North Saskatchewan River gravel is the predominant postglacial sediment. In many places the gravel extends 10 to 30 feet below river level. Many vertical water wells and one Ranney-type collector are completed in this aquifer and obtain water by induced infiltration from the nearby North Saskatchewan River. Large quantities of water can be developed in many places from the gravel bars and terraces along this river.

The recent sediments along the Pembina River valley are characteristically finer grained than those in the North Saskatchewan River valley, but they extend to a greater depth below the river level. No data are available from hydrologic testing in this potential aquifer but it would be reasonable to prospect for groundwater anywhere along the valley of the Pembina River within the map area.

Well Completion Methods

Almost all water wells in the Pembina area have been drilled by mobile rotary or cable-tool drilling rigs; of these, more than 75 per cent have been drilled by the rotary method using conventional drilling procedures. The method of well completion used depends primarily upon the ownership of the well being drilled. Wells drilled for local residents are subject to few regulations, while those drilled for oil companies to be used as water supply wells are subject to strict regulations. A copy of the current regulations governing the completion of supply wells for secondary recovery is included in Appendix A. Further, because the quantity of water required from an injection supply well is considerably greater than that required for a domestic water supply, more attention must be paid to proper completion of an injection supply well.

Most domestic wells are completed either as open holes or with slotted casing; surface casing is seldom used, and few problems are encountered with either method. This type of completion is, however, not recommended because it will be inadequate unless the well is located so that surface water drains away from it; a sanitary well completion depends upon a water-tight seal being made between the casing and the hole - this is usually achieved by pouring from the surface an earth or cement seal into the annulus.

Water wells for injection supply usually have surface casing set through the surficial deposits and cemented in place. Wells are generally finished with a liner, slotted at intervals corresponding to the driller's report of the occurrence of sandstone lenses, run into the hole and sometimes cemented in place.

Wells completed in the POOR areas (Fig. 4) all have a low productive capacity. Development of these wells is difficult particularly where the aquifer is poorly consolidated. Such a well cannot be over-pumped to aid development because the final production rate will be equal to the greatest amount of water that the well is capable of producing. Surging and bailing or vigorous bailing are likely to be the best development methods.

Completion methods in the GOOD areas are generally similar to those in the POOR areas. Some wells, however, have not been sufficiently developed when they were initially completed, particularly those where a plentiful supply of water apparently is available. As a result, many of these wells produce considerable fine sand and silt and require frequent costly maintenance. At a few locations where the aquifer is poorly consolidated a well screen, or a screen and filter pack, should be employed to stabilize the formation. The concept that well screens are not required in bedrock aquifers is invalid where the bedrock aquifer is poorly consolidated.

Wells in the VERY GOOD areas are generally completed either as open holes or with slotted casing; either method is usually satisfactory. Treatment with hydrochloric acid, surging (even in open-hole completions) and screening with or without a filter pack may also be utilized to obtain more complete development.

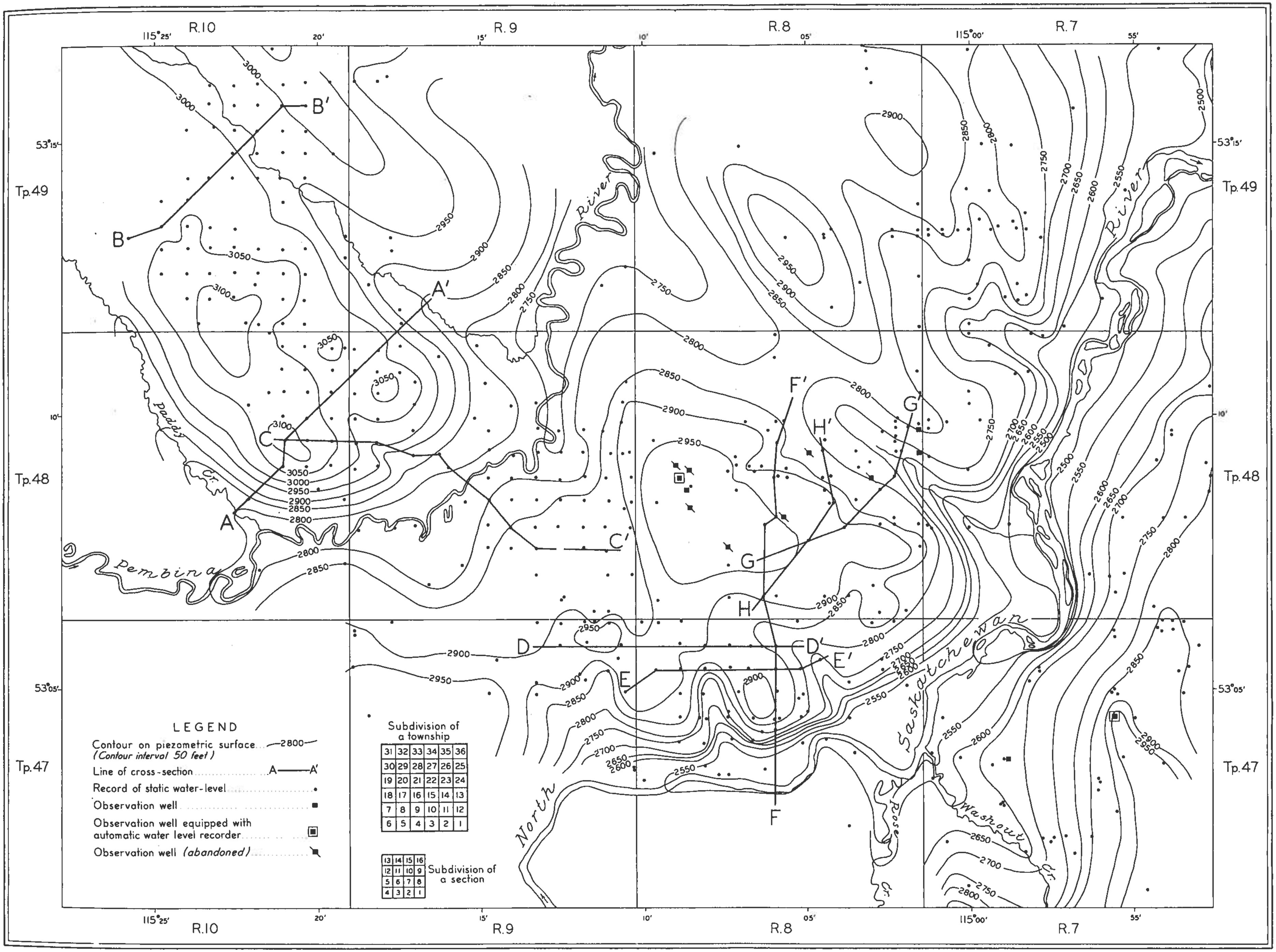

Figure 5

Piezometric Surface in the Pembina Area, Alberta

(WEST OF FIFTH MERIDIAN)

Considerable development work may be required if large volumes of drilling fluid are lost during drilling.

Groundwater Regimen

The piezometric surface shown in figure 5 was constructed by plotting the elevations of the static water levels observed in almost every one of the water wells completed in the Paskapoo formation in the area. This observed piezometric surface is a subdued replica of the topographic surface.

With the exception of the recent alluvial deposits adjacent to the North Saskatchewan and Pembina Rivers, all aquifers in the area are recharged by local precipitation. Proof of this statement lies in the configuration of the piezometric surface (Fig. 5) and the cross-sections shown in figures 6 and 7. The highest potential is found to correspond with the maximum ground surface elevation, and since groundwater will flow toward any point having a lower potential, water must be continually added to the system to maintain the observed potential distribution. The only available source of water in the upland areas is local precipitation. The direction of groundwater movement in the Pembina area will therefore be away from the highs on the piezometric surface, perpendicular to the piezometric contours. Thus a hydrologic system closely comparable to that described by Hubbert (1940, p. 930) prevails, although many local anomalies exist because the flow medium - the Paskapoo formation - is neither uniformly permeable, nor isotropic as required by the example illustrated by Hubbert.

Thus, although the sandstone lenses appear to be completely enclosed by shale they must be connected hydrologically with one another. The entire flow system is in equilibrium and the fluid potential observed at any one site depends only upon the place of measurement within the flow medium.

In an upland area the piezometric surface is below the land surface. A small portion of the water that falls on the land surface infiltrates through the soil cover, and moves downward under the influence of gravity through the zone of aeration to the free water surface. A particle of water will tend to move downward and laterally away from the upland area following the path of least resistance toward an area of lower potential. In a recharge area, therefore, the potential decreases with increasing depth. In the Paskapoo formation lateral movement is greatly magnified because the horizontal permeability of the formation is greater than its vertical permeability (Hubbert, 1940, p. 902).

Topographic lows are also lows in the piezometric surface; these lows must represent areas of groundwater discharge, where groundwater moves upward and discharges to the land surface. Groundwater discharged in lowlands comprises a major contribution to the base flow of streams.

Groundwater thus moves from the zone of recharge to the zone of discharge. In a homogeneous isotropic aquifer the groundwater flow theoretically extends to an infinite depth. In a flow medium made up of interbedded sandstone and shale strata having widely differing permeabilities, refraction of flow lines will be pronounced

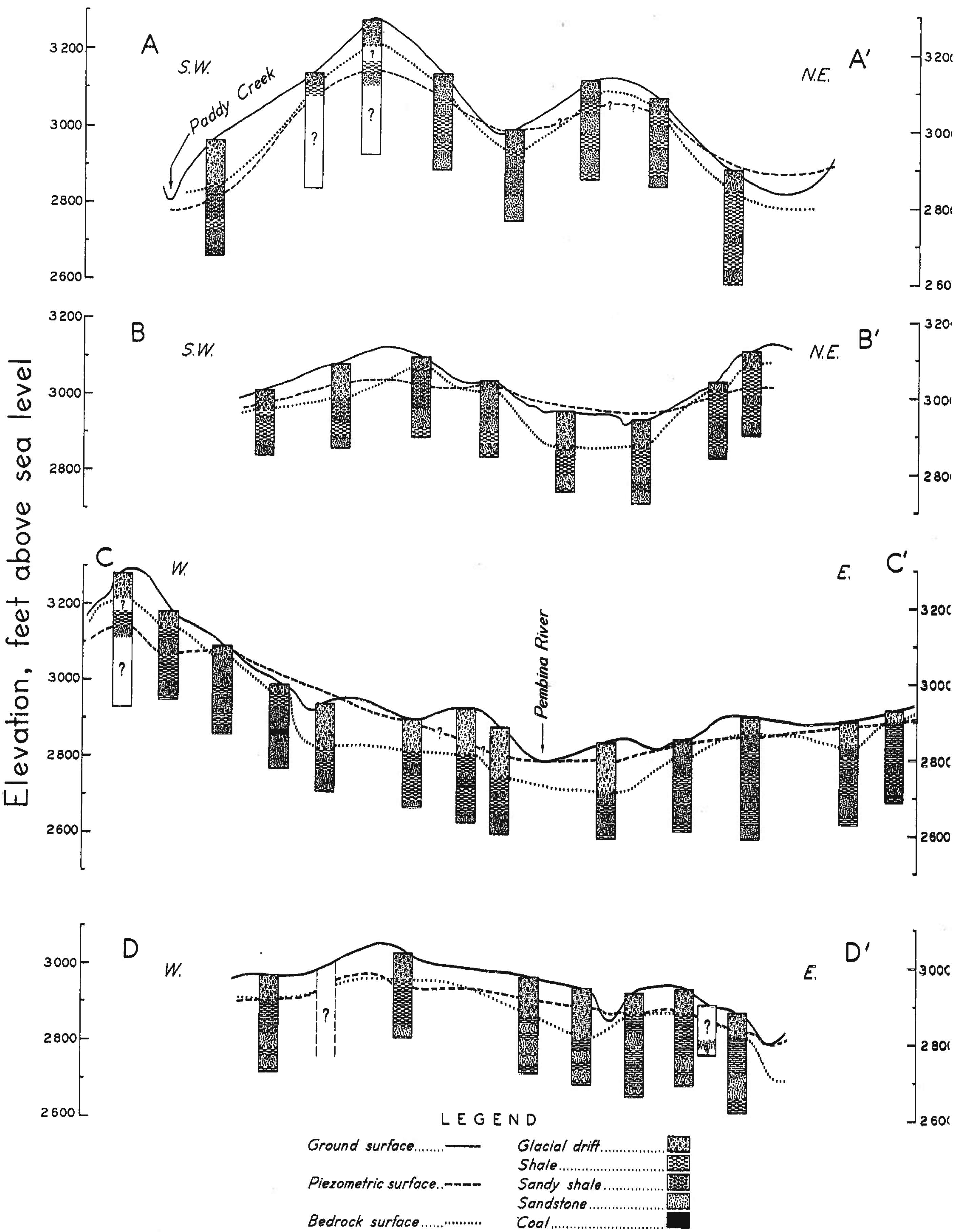

Figure 6. Cross-sections A - A', B - B', C - C', D - D' showing piezometric surface in the Pembina area, Alberta.

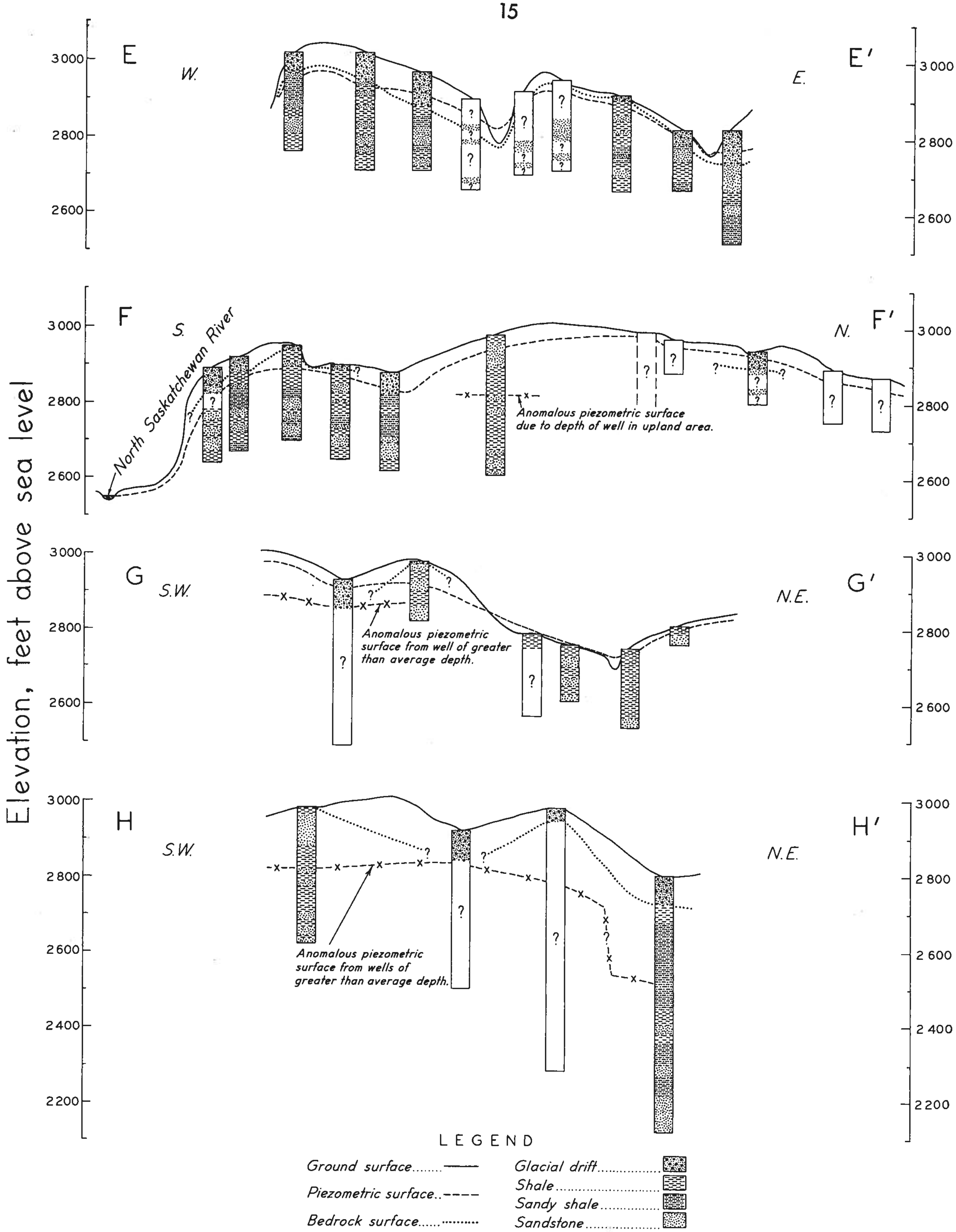

Figure 7. Cross-sections E - E', F - F', G - G', H - H' showing piezometric surface in Pembina area, Alberta.

and the groundwater flow is, for practical purposes, assumed to be confined to the upper several hundred feet of Paskapoo strata.

A knowledge of the hydrologic system can help in the exploration and development of groundwater in the area. A well that is drilled near the crest of a hill can be expected to have a relatively low static water level and the deeper the well is drilled the lower the static level will be. A well drilled in a valley can be expected to have a high static level and the deeper the well is drilled the higher the static level will be. All flowing water wells in the Pembina area can be explained in this way, as can many of the wells with relatively low static water levels. This general situation prevails although some exceptions are found. One such exception is where only shale is penetrated in the entire lower portion of a well, then the observed static water level will likely be anomalous as compared to those of other wells of similar depth. Another exception is found where several wells in Tp. 47, R. 9 and Tp. 48, R. 8 have been drilled much deeper than other wells in the vicinity. The cross-sections G - G' and H - H' (Fig. 7) show that the hydrostatic pressure at depth along these profiles is much less than would be anticipated from the piezometric surface determined from shallower wells. It would have been impossible to construct the map of the piezometric surface if great differences in the well depths had been the rule. Fortunately, most wells are between 150 and 300 feet deep and no correction of the static levels for well depth was considered necessary. The static level is important in the ultimate production potential of the well because it determines the amount of available drawdown.

It is worthwhile noting that all attempts to obtain groundwater from relatively great depths have failed. There is no record of a good well over 500 feet deep in this area. This may be due to hydrologic or geologic factors, or both, but no explanation of this phenomenon can be offered at present.

As stated previously (p. 14), most water wells in the Paskapoo formation are completed as open holes, or with casing slotted throughout the interval below the surface casing. These types of well completion will permit water to enter the well from any sandstone lens encountered. The static water level in a given well, however, is dependent not only upon its location in the flow system, but also upon the pressure differences in, and the relative permeability of, the various sandstone lenses encountered in the well. It is reasonable to expect that, even though a well is not pumped, water may be discharged from one lens to another (see Bennett and Patten 1960). This discharge could constitute a source of contamination of groundwater if a well, completed across two permeable zones of differing hydrostatic pressure, were left open and if the zone under the greater pressure carried water of undesirable quality. The greatest danger of contamination would occur in discharge areas, where shallow fresh-water-bearing strata are underlain by strata containing water under a higher potential - water which generally speaking contains a higher concentration of dissolved solids.

It has been shown that sandstone strata aquifers that appear to be completely surrounded by shale are connected hydrologically to other similar sandstone lenses, and that the hydrostatic pressures in all porous strata are related. This condition exists because although the rate of movement may be extremely slow, sufficient time has elapsed for the system to reach equilibrium. When a well finished in one such aquifei is pumped, the rate of movement of water through the confining beds is no longer sufficiently rapid to maintain equilibrium between the aquifer that is pumped and anothe that is not pumped. A nearby observation well completed in the same stratum as a production well would show drawdown of the water level under the influence of pumpi but the water level in an observation well finished in a different stratum would show r immediate interference. Thus, an analysis of the regional groundwater flow system indicates that the near-surface strata are all connected hydrologically and belong to one flow system, whereas analysis of the drawdown data from pumping tests indicates that the various aquifers are not connected hydrologically. This inconsistency in the interpretation of the hydrologic regimen is more apparent than real, and it indicates certain limitations on the use of hydrologic data. Thus the study of the regional hydrı logic system serves to show the source of the groundwater and its path to the discharge areas, whereas a study of local conditions and phenomena provides evidence so that predictions can be made regarding the effect of long-term production on nearby wells

Chemical Quality of Groundwater

The chemical quality of the groundwater in the Pembina area can be descri as "satisfactory" to "good" for any reasonable use to which the water is likely to be p The water is of a bicarbonate type and sodium is the most predominat cation. It is moderately hard to hard, and locally iron is present in undesirable concentrations.

The groundwater from Cretaceous rocks in most regions of Alberta is very soft due to the presence of bentonite, a natural softening agent. Bentonite is not pre: in the Paskapoo formation in sufficient quantities to cause all the groundwater to become soft. The quality of groundwater changes as it moves through the rock; if the Paskapoo formation is considered to be a more or less homogeneous unit then the quali of the contained water depends only upon the length of time that the water has been in contact with the rocks, and this in turn is solely dependent on the location of the host rock within the hydrologic system.

Table I lists the analyses of groundwater at various sites and depths in the field.

Location of well*				Depth of well (feet)	Concentration of constituents (ppm)											
Lsd.	Sec.	Tp.	R.		Total solids	Cl^-	$CO_3^=$	HCO_3^-	$SO_4^=$	Alkal-inity(2)	Ca^{++}	Mg^{++}	Na^+(1) (ppm)	Soda(2) (gr/gal)	Fe	Hardness(3)
7	15	47	7		604	50	41	480			14	3	223			
2	17	47	7		782	20	67	390	179		6	tr	290		0.6	15
4	19	47	7		568	10	42	325	84		52	14	115		4.5	
14	28	47	7	122	548	14		520	58		16	20	177			
5	28	47	8	220	888	7	24	464	128		8	2	255			
7	33	47	8	110	758	1			163	500				32	0.3	75
1	34	47	8		665	4			190	435					0.5	60
7	36	47	9	140	564	8		500	89		40	22	149		0.8	191
13	36	47	9	175	748	1			61	560				38	0.1	50
15	4	48	8	150	888	8	19	418	185		59	0	199			
15	9	48	8	18	775	9	24	389	132		88	0	133			
4	17	48	8		404	2			15	355					0.1	375
12	17	48	8	276	592	16		500	56		6	2	215			
8	18	48	8		442	10			16	375					3	400
15	18	48	8		546	10			27	455					0.8	590
4	20	48	8		704	3			37	540				29	0.1	140
4	21	48	8		728	14			97	515					1.5	405
5	21	48	8	46	1083	13	27	422	302		88	0	231			

7	22	48	8	120	929	23	21	375	234		55	0	221			
8	22	48	8	680	820	370		195	15		3	1	315		0.5	
8	24	48	8	22	316	78	14	180	13		91	0	0			
11	3	48	9	195	564	10	72	425	23		1	1	230		0.2	
8	9	48	9	252	827	6	24	510	56		26	7	198			
8	11	48	9	233	880	4	54	410	145		3	tr	264			
16	14	48	9	200	810	1			124	555				28	1.5	180
14	15	48	9	350	777	24	59	405	53		7	2	227			
8	16	48	9	250	709	4	37	415	53		26	10	164			
8	21	48	9	217	690	14	9	475	8		38	10	136			
14	22	48	9	245	721	12	9	500	8		38	11	143			
14	29	48	9	236	714	4	24	505	35		62	26	108			
2	30	48	9	112	813	4	42	525	46		80	53	63			
8	32	48	9	108	754	4		620	135		7	3	287		0.2	
2	24	48	10	225	698	6	24	450	51		101	39	27			
4	24	48	10	290	761	4	12	505	54		29	42	115			
12	24	48	10	110	702	6	9	490	40		72	53	32			
8	20	49	9	200	734	16		600	132		22	13	250		0.5	

* All locations west of 5th Meridian.

(1) Analyses showing sodium (Na) were carried out by Chemical and Geological Laboratories, Ltd., Edmonton, or by the Alberta Oil and Gas Conservation Board.

(2) Analyses showing soda (Na_2CO_3) were carried out by Provincial Laboratory, Edmonton. In these analyses alkalinity is expressed as the total equivalent amount of bicarbonate of calcium, magnesium, and sodium.

(3) Hardness is expressed as the total equivalent amount of calcium carbonate.

UTILIZATION OF GROUNDWATER

Groundwater is a valuable natural resource and the policies that control development of other natural resources should be applicable to the development ıroundwater as well, provided that the natural laws concerning the occurrence of ındwater are not ignored. In modern agricultural enterprise, as it is practised ughout most of Alberta today, an adequate supply of water from wells is almost ntial. If the groundwater supply is depleted then the welfare of the rural resits will be adversely affected. Protection of groundwater resources in the form of slation is certainly in order. On the other hand, a natural resource is of little efit until it is developed, and a renewable resource like groundwater is wasted if not developed.

In practice, a groundwater development program can be considered satisory if sufficient water is developed for all users without either harmful interference veen wells or permanent depletion of the groundwater reservoir. The problem in Pembina area is to determine the amount of groundwater available and the effect e development of this water, or a portion of it, on the present well owners.

In order to examine this problem properly it is necessary to speculate on possible benefits that the groundwater resource might provide. The groundwater urces of the Pembina area are rather limited with regard to their possible use ause the aquifers are relatively impermeable. Water is available from wells only latively small quantities and consequently groundwater will never be an important or in either irrigation or in industrial development. In the few sites in the area re large supplies of groundwater are available, the aquifers are recharged by ced infiltration and therefore are not depleted by pumping. Throughout the rest e area the groundwater can only be fully developed by closely spaced wells, each lucing a small quantity of water. Under such circumstances it is usually not omically feasible to utilize groundwater; however, an unusual situation exists in Pembina area for there the groundwater can be put to reasonable use, a use which eally suited to the type of aquifer available.

Available Groundwater

In any area the maximum amount of groundwater permanently available for zation is that amount of water which enters the aquifer as natural recharge. This unt can be calculated if the rate of recharge and the area over which recharge s place are known. The amount of recharge near Edmonton, 60 miles east, is ıt .031 feet per year (Farvolden, 1961). The rate of recharge in the Pembina area obably at least as great as this amount, for although the transpiration may be higher ause of the dense forest cover, the rainfall is also greater and the surface drainage t as well integrated as in the Edmonton area.

In the Pembina area aquifers are recharged by precipitation only where the ometric surface is below the land surface. Thus, areas in which flowing wells t, generally lowlands, cannot be included in the recharge area. In some instances, ever, in what normally would be a discharge area, the piezometric surface has been sufficiently lowered due to pumping to allow recharge by precipitation to take place. Both of the above factors were considered in evaluating the Pembina recharge area.

The total area over which recharge occurs to the Paskapoo formation where water is being utilized for secondary recovery operations exceeds 120 square miles. The average annual recharge can be calculated as follows:

1.2×10^{2} (miles^2) $\times$ 2.77×10^{7} (ft^2/miles^2) $\times$ 3.1×10^{-2} (ft/year) $\times$ 6.23 (imperial gallons/ft^3) = 6.4×10^{8} (imperial gallons per year).

During one month in 1960, 1.4×10^{6} barrels* (4.9×10^{7} imperial gallons) of groundwater were produced from the Paskapoo formation in the Pembina area. On an annual basis this would be:

4.9×10^{7} imperial gallons $\times$ 12 months $\approx$ 6×10^{8} imperial gallons per year.

The total current withdrawal from the Paskapoo formation is thus slightly less than the total calculated average annual recharge. It appears, therefore, that there is no regional over-development of the Paskapoo aquifer at this time. It must be remembered, however, that the hydrologic characteristics of the aquifer are not uniform throughout the area, and also that the pumped wells are not uniformly distributed over the area. It is certain that in those parts of the area where the apparent transmissibility exceeds 1000 gpd/ft, the rate of withdrawal is greater than the rate of recharge. Where the apparent transmissibility is less than 300 gpd/ft, however, the aquifer cannot transmit water to the production wells as fast as it is being recharged to the aquifer, and thus the rate of recharge is greater than the rate of withdrawal. Where the apparent transmissibility lies between 300 and 1000 gpd/ft the rates of recharge and withdrawal are approximately equal.

Water that is removed from the aquifer by a well will not be replenished for considerable time, because of the slow rate of movement in aquifers having low permeability. Analysis of the data obtained from pumping tests on water wells in this region of Alberta almost always indicates that the water is produced from storage and that there is no recharge to the reservoir, whilst regional studies prove that there is recharge to the groundwater reservoir. The reason for this apparent contradiction is that the rate of vertical movement of water in the zone of saturation is so low that the effects of recharge are not apparent within the duration of a normal pumping test.

The volume of water in storage in the groundwater reservoir is controlled by the amount of water being discharged, both naturally and artificially, and by the amount of water being recharged. Changes in the volume of water in storage are indicated by fluctuations in the water levels in the observation wells (Fig. 5). In the case of the

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* 1 barrel = 35 imperial gallons.

nbina area, where the groundwater occurs under more or less artesian conditions, the ·er level in any well is a measure of the fluid potential in the aquifer, which is in ı a measure of the volume of water in storage. This volume can be calculated if the al extent of the aquifer, the average hydrostatic head of the water above the aquifer, l the coefficient of storage of the aquifer are known. The change of volume of water ;torage, which is represented by a change in the elevation of piezometric surface turn indicated by a change in the water level in observation wells), can be calculated he storage coefficient is known. The storage coefficient (S) is defined as the volume water that an aquifer releases or takes into storage per unit surface area of the aquifer unit change in the component of head normal to that surface (Theis, 1938). The ect of the past production on the elevation of the piezometric surface can be calculated uming that no recharge occurs. As mentioned previously, no pumping tests have been nducted to determine the aquifer coefficients of transmissibility and storage, but the fficient of storage for an aquifer of the type will certainly lie between 1×10^{-3} l 1×10^{-4}, if artesian conditions prevail. (The coefficient of storage is dimensionless).

If S equals 1×10^{-3}, the expected drawdown (s) over an area of 120 square es, at a rate of production of 6×10^8 gallons per year will be:

$$\frac{\dfrac{6 \times 10^8 \text{ gal/year}}{6.23 \text{ gal/ft}^3}}{\text{miles}^2 \times 2.8 \times 10^7 \text{ ft}^2/\text{mile}^2 \times 1 \times 10^{-3}} \approx 30 \text{ feet per year}$$

ıe lower limit for the value of $S(1 \times 10^{-4})$ is accepted, then the annual drawdown year will be ten times as great, or 300 feet.

On the basis of the regional study of the groundwater geology a reasonable ıment could be presented to show that the groundwater occurs under water-table ditions rather than artesian conditions. In this case the storage coefficient might n the order of 1×10^{-1}. The predicted annual drawdown of the piezometric surface he present pumping rates would then be 0.30 feet. This would result in a total vdown of less than 24 feet over the whole area in 40 years of production. Such a vdown cannot be considered a serious loss of groundwater storage in this reservoir.

Observations have been made on a few water wells in the area during the · four years. The water levels in most wells have shown no significant change ng the period of observation. A few wells have shown a drop in water level but ıost cases this is attributed to some other cause than water production from the ifer, improved surface drainage due to ditching being the most likely cause. Only observation well (Lsd. 16, Sec. 14, Tp. 48, R. 8; owned by Mr. Berezowski) vs a definite drawdown due to the influence of groundwater production. The decline he Berezowski well does not indicate a general drop in the piezometric surface, but er the local influence of production from Home Water Well 12-13 (Lsd. 12, Sec. 13, 48, R. 8) (Fig. 4). The cone of influence of this well is large because the trans- ibility is high. This means, however, that the drawdown will not be great for present low rates of production. The influence of the Berezowski well has been slight, and is noticeable and objectionable only because it has been sufficient to cause the well to cease flowing. A study of the hydrologic system already described and of the position of the Berezowski well relative to this system indicates that the well would again flow if it were deepened, probably by about 50 feet, and that no harmful deplection of the aquifer has occurred.

CONCLUSIONS AND RECOMMENDATIONS

The most important aquifer in the Pembina area is the Paskapoo formation, but the gravel deposits along the North Saskatchewan and Pembina Rivers offer excellent possibilities for obtaining large quantities of water by induced infiltration. The groundwater that occurs in the Paskapoo formation has been derived by precipitation over the area of the groundwater basin. All of the streams and rivers in the area are gaining, that is, they receive water from the groundwater reservoir. The groundwater reservoir is not recharged by the North Saskatchewan or Pembina Rivers.

In those portions of the area in which the permeability of the Paskapoo aquifer is low (shown as POOR on Fig. 4) the groundwater reservoir cannot be depleted by water wells because, although the drawdowns are great, the cone of depression for each well does not have a wide lateral extent. In some portions of the area in which the permeability of the Paskapoo aquifer is relatively high (shown as VERY GOOD on Fig. 4) the influence of each well may be wide. However, the amount of drawdown is less in such areas and at present rates of production the net effect is one of inconvenience rather than of permanent damage or loss.

Groundwater in the Pembina area is proving to be a valuable natural resource inasmuch as it is an important factor in the production of oil as well as being important in agriculture. All available evidence indicates that this resource is not overdeveloped at present and that reasonable use is being made of the water being produced. A system of observation wells is essential in order to detect changes in the volume of water in storage. The present network of observation wells should be extended to include the newly developed portions of the field.

Disputes have arisen between well owners regarding the harmful influence of relatively heavily pumped wells. In each case the dispute could be settled if an observation well had been drilled to determine the effect of the heavily pumped well on the piezometric surface. In cases where there is a possibility that a dispute of this sort may arise, the well owner should be advised to complete an observation well near the site of the production well.

If it is considered that the water occurs under artesian conditions and that no recharge occurs, then the drop in the piezometric surface at present rates of production would be between 30 and 300 feet per year. Since no significant drop has been detected, recharge must occur at a rate sufficient to compensate for the discharge by pumping.

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APPENDIX A

SUPPLEMENTARY CONDITIONS TO WELL LICENCE NO.

1. The well shall not produce water from a depth of less than fifty feet below the elevation of the base of the lowest aquifer from which, when the well is drilled, water is being taken for farm or domestic use within 2 miles of the well.

2. The licensee shall, before the well is placed on production,

(a) if water for farm or domestic use is being taken within two miles of the well, case the well and cement the casing to the surface from a depth of fifty feet below the elevation of the base of the lowest aquifer from which water is being so taken, or

(b) if the water for farm or domestic use is not being taken within two miles of the well, case the well and cement the casing to the surface from the top of the highest water-producing sand or from a depth of twenty-five feet below the drift-bedrock (Paskapoo) contact, whichever is the shallower.

3. (1) The licensee shall complete the well in a manner that will permit the accurate measurement, at any time, of the water level in the well.

(2) The operator shall equip the well so that continuous accurate measurement may be made of the water produced at the well or an approved group of wells.

4. (1) The licensee, before placing the well on production, shall test pump the well at the proposed production rate until its water level is stabilized for a period of twenty-four hours.

(2) The depth of the stabilized water level shall be measured and reported to the Board.

5. The Board may, at any time, restrict or prohibit the production of water from the well if, in its opinion, it is in the public interest to do so.

6. (1) The licensee shall submit to the Board in duplicate a completion and testing report on forms supplied by the Board within two weeks of the date on which the well is completed.

(2) The licensee shall supply to the Board two copies of each electric log or water analysis taken within one month of when it is taken.

(3) The licensee shall, not later than the 15th day of the month following a month during which water was produced from the well, file in duplicate with the Board a report of the quantity of water produced during the preceding month.

(4) The licensee shall, at the end of each consecutive four-month period during which water was produced, file in duplicate a report of the depth to the stabilized water level.

COMPLETION AND TESTING REPORT FOR WELLS DRILLED TO SUPPLY WATER FOR INJECTION PURPOSES

NOTE:

To be completed by the operator and submitted, within two weeks of the completion date of the well, in duplicate to the appropriate Field Engineer of the Oil and Gas Conservation Board and singly to the Groundwater Geologist, Research Council of Alberta, 87th Ave. and 114th St., Edmonton. This form does not replace, but is to be completed in addition to the Water Well Drillers Report required by the Water Resources Branch of the Department of Agriculture.

SAMPLE LOG		
From	To	Description

WELL: ______________________ LICENCE NO: ____________

ELEVATION: ______________________

DATE DRILLED: ______________ COMPLETED: ____________

TOTAL DEPTH: __________ HOLE SIZE: ____________

SIZE CASING: ______________________

CASING LANDED AT: ______________________

CEMENT: ______________________

SLOTTED INTERVAL OF CASING: ______________________

SIZE TUBING: ______________________

SIZE AND MAKE OF PUMP: ______________________

PUMP LANDED AT: ______________________

BAILER TESTING

DATE OF TEST: ______________________

DEPTH OF HOLE WHEN TEST WAS MADE: __________ Ft.

STATIC FLUID LEVEL: ______________________ Ft.

LENGTH OF TEST: ______________________ Hrs.

ESTIMATED RATE: ______________________ Gals./Min.

FINAL FLUID LEVEL: ______________________ Ft.

PUMP TEST

DATE: ______________________

STATIC FLUID LEVEL: ______________________ Ft.

LENGTH OF TEST: ______________________ Hrs.

VOLUME: ______________________ Bbls.

STABILIZED PUMPING FLUID LEVEL: ____________ Ft.

Signature of Operator's Agent ______________________

Title ______________________

Date ______________________