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BULLETIN 17

# GROUNDWATER GEOLOGY, MOVEMENT, CHEMISTRY, AND RESOURCES NEAR OLDS, ALBERTA

by

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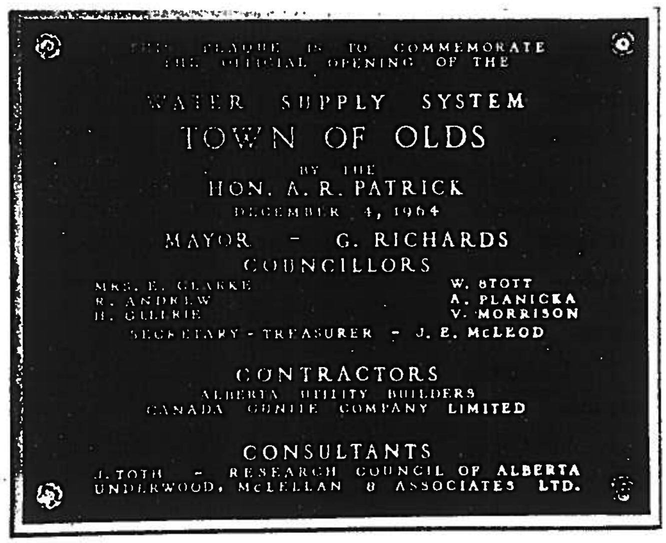
THIS PLAQUE IS TO COMMEMORATE
THE OFFICIAL OPENING OF THE
WATER SUPPLY SYSTEM
TOWN OF OLDS
BY THE
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DECEMBER 4, 1964
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## PREFACE

The "Olds water-supply problem" has been the object of considerable public interest in the Province of Alberta. The Research Council of Alberta played an active role in the final parts of the investigations for groundwater. The combination of the publicity and the inside knowledge of the history of the problem created a good opportunity to put into writing the often realized but never published shortcomings of groundwater-exploration practices in Alberta. Such deficiencies are only too natural for an area where systematic investigations of the groundwater resources date back approximately eight years. The relevant parts of the present work should be considered as an attempt to improve the situation by revealing the weaknesses rather than as an expression of criticism.

During the course of the investigation, observations of both practical and scientific interest were made. This work is, therefore, offered to three groups of people: (1) governments (municipal, industrial, and provincial administrators), (2) groundwater practitioners (consulting engineers, water-well drillers) and, (3) groundwater hydrologists. An attempt has been made to write and arrange the topics of this report in such a manner that a person with a specific interest may be able to read the relevant parts without having to consult other sections. Pages 9 to 14 and 94 to 95, and the Summary should be of most interest to government administrators, pages 70 to 96 to consultants and water-well drillers, and pages 17 to 69 to groundwater hydrologists.

It is hoped that the observations and principles presented in this work will lead to better planning and superior performances of groundwater test-programs, thus avoiding wasteful expenditures in exploring the groundwater resources in the Province of Alberta.

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# Groundwater Geology, Movement, Chemistry and Resources near Olds, Alberta


## ABSTRACT

During 1964 the Research Council of Alberta carried out a groundwater exploration program to alleviate a water shortage problem in the town of Olds, a central Alberta farming community with a population of 3,000. A groundwater reserve estimated capable of yielding 375 igpm (1,700 l/min) for 20 years has been located, tested, and developed by means of three production wells approximately 5 miles (8 km) southeast of Olds. Another area, approximately 4 miles (6 km) northeast of the town is believed capable of producing groundwater at a rate of 200 igpm (900 l/min) for 20 years, although no pumping tests have been conducted here.

Detailed investigations were carried out in an area of approximately 17.5 square miles (45 $km^2$). Nineteen test holes were drilled, the deepest 690 ft (210 m), in order to evaluate the geology, movement, chemistry, and resources of groundwater.

The geological investigations resulted in: (1) the discovery of a volcanic ash bed which may be a useful marker bed in the Tertiary succession of Alberta; (2) the locating of a system of buried bedrock channels; (3) the finding of some evidence for faulting in Tertiary strata; and (4) evidence indicating a strong lithologic similarity between rock units believed to be of late Cretaceous and early Tertiary ages.

Partly from theoretical considerations and partly from water-level measurements, the natural fluid-potential distribution and groundwater flow pattern have been established in the Olds area. One regional and five local flow systems have been outlined. Two anomalies in the configuration of the fluid-potential distribution are caused by an impermeable barrier and by a relatively high-permeability rock unit.

Chemically, the types of groundwater at Olds are either sodium bicarbonate or sodium sulfate, or, locally, calcium-magnesium bicarbonate, the total solids content varying between 288 ppm and 2,314 ppm. Areas of the different types of water are well separated, with total solids contents generally increasing in the direction of groundwater flow. Using Piper's method for representing the chemical composition of water, it is possible to separate groundwater flow systems on the basis of water quality.

Bail tests were conducted at a standard rate of 20 igpm (90 l/min) for two hours on each of the test holes. Three major pumping tests were carried out with durations of 69.5 hrs, 131 hrs, and 96 hrs, at pumping rates of 226 igpm (1,026 l/min), 155.6 igpm (706 l/min), and 152 igpm (690 l/min), respectively. The recommended safe yield of the production wells at the same locations are: 35 igpm (159 l/min), 140 igpm (636 l/min), and 200 igpm (900 l/min), respectively. The respective average values for the coefficients of apparent transmissibility for the three test sites are 1,960 igpd/ft, 3,850 igpd/ft, and 6,175 igpd/ft, based on data taken after 24 hours of pumping. The maximum values for the transmissibility coefficients have been found in bedrock adjacent to buried preglacial (glacial?) river valleys. Extended pumping at the two major production wells may have adverse affects on water levels in private farm wells in an area of approximately 10 square miles.

The town of Olds spent in capital layout approximately $1.29 per thousand gallons of water for exploration and subsequent installations of equipment between 1946 and 1964. If groundwaters described here are to be used at the maximum possible rate for the next 20 years, expenditures are reduced to $0.058 per thousand gallons of water. If, however, the present population of 3,000 remains constant for the next 20 years the capital expenditures for groundwater at Olds will be $0.209 per thousand gallons of water.

## INTRODUCTION

The town of Olds is a central Alberta farming community with a population of 3,000. It is located between the cities of Red Deer and Calgary, 4 miles west of Provincial Highway No. 2 (Fig. 1). The town's name became a familiar sight to Alberta newspaper readers in 1964 because of a serious water shortage.

Since its first public-supply wells were drilled and installed in 1946, the town has faced an almost continuous problem of water shortage due to the marginal amounts of groundwater which the wells could supply. From time to time the situation was eased by the drilling of new wells which, however, seemed all to be of temporary value. Alternate solutions to groundwater were considered also. In order, for instance, to help the town through periods of peak consumption, water was piped overland from Barrie Lake into gravel pits 2 miles west of the town (Fig. 5). The water was then withdrawn from the artifically recharged gravels by shallow supply wells constructed in the same gravels. This solution was not satisfactory, however, due to winter ice-conditions in the shallow lake, the necessity of strong chlorination in the summer, and the possibility of lowering the level of the lake. A plan to install a filtration and treatment plant at the Little Red Deer River approximately 12 miles west of Olds and to pipe the river water to the town was also contemplated. This plan had to be abandoned because the low minimum flow of the river in the fall might have created problems during extended dry spells. A short test-drilling program in the terraces of the Little Red Deer River proved a limited amount of stored water under abnormal pressure conditions, and also that no direct recharge from the river was taking place. The only solution—and the most costly—seemed then to be to construct a pipeline to a point on the Red Deer River (Fig. 3) approximately 18 miles from the town. When the situation became so critical that the trucking of approximately 18,000 igpd of water from the Little Red Deer River was necessitated by the end of 1963, the Town Council of Olds decided to make a final effort to find groundwater before giving its approval to the costly Red Deer River project.

In January 1964 the writer commenced work by drilling three test holes for groundwater in an area approximately 3 miles southeast of the town. The results obtained from this work were encouraging enough to warrant further testing on an enlarged scale. Drilling was carried out in a 17.5 square-mile area southeast and northeast of Olds, during the period between April and September, 1964. It is estimated that the total potential of the tested area is approximately 575 igpm, based on continuous pumping for 20 years, and as a result of this program a pipeline was constructed to the southern part of the area. This field has been supplying Olds since November, 1964.

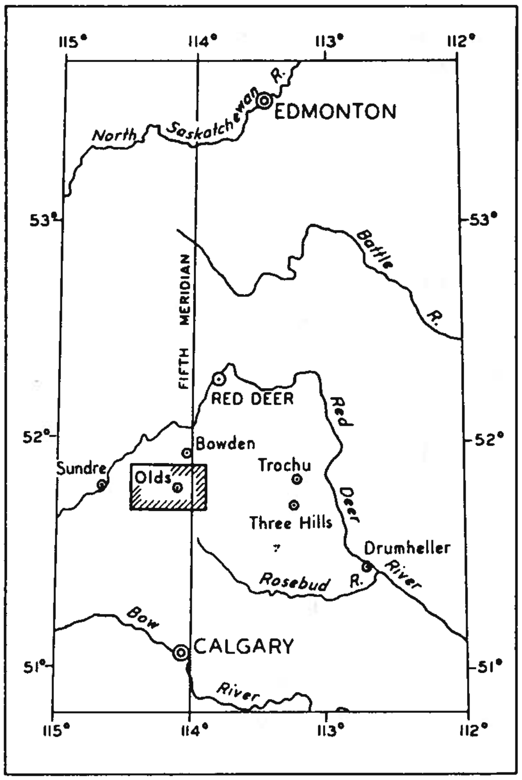


*FIGURE 1. Location of the Olds area.*

There are several reasons for the publication of the work outlined above. These are as follows.

(1) All available information pertaining to groundwater in the area has been compiled, and is either published with this report or filed at the Research Council.

(2) Shortcomings in the current techniques for obtaining, compiling, and using groundwater data in Alberta are exposed by the present case history, and it is hoped that authorities at all levels of government will recognize the economic importance of, and encourage, high-quality, systematic studies of the groundwater resources of the province.

(3) In connection with the production tests some new techniques were successfully applied. Standardization of the testing procedures has been established and it is felt that these procedures can be applied in many other parts of Alberta.

(4) The geologic work of the program revealed not only important water-bearing properties of the Paskapoo strata, but it also uncovered some important new sedimentologic and lithologic data on that formation.

(5) The report presents an application of theoretical considerations of the natural movement of groundwater to a practical problem.

(6) The use of water-well data in reconstructing and presenting the natural regime of groundwater is demonstrated.

## Acknowledgments

The author is thankful to Professor Dr. Ir. R. W. van Bemmelen, State University Utrecht, The Netherlands, for his interest and valuable suggestions in connection with the present report.

The author is grateful to Mr. M. A. Carrigy, Research Council of Alberta, who identified the Olds tuff by X-ray and microscopic analysis and also who checked the correlation among the samples collected from the various test holes.

Mr. C. E. Noble, Provincial Analyst, carried out the chemical analyses of the water samples.

Mr. R. Clissold, field assistant, carried out the well survey, collected water samples, assisted in supervising and performing the drilling, bail-testing, and pump-testing operations, and prepared maps and diagrams.

The author wishes to express his thanks to Mr. B. Meyer, Research Council of Alberta, who attended to the installation, maintenance and repair of the automatic water-level recorders during the pump tests, even under adverse weather and living conditions.

The author wants to express his great appreciation to Miss D. C. Cunliffe, and Mr. H. Weiss, both of whom spent many extra hours in typing the manuscript and preparing the illustrations, respectively, and without whose co-operation several deadlines could not have been met.

Mr. Roy Forrester, drilling contractor, and his personnel are responsible for the excellent quality of the drilling and testing operations; their interest and co-operation went far beyond usual obligations.

Some of the costs of the test-drilling program were divided equally between the Federal and Provincial Governments under the terms of the Federal Agricultural Rehabilitation and Development Act (ARDA). Support in 1964 was through ARDA project 9023. This assistance is gratefully acknowledged.

## GENERAL REVIEW

The topics discussed in this section are those thought to be important in providing background information both specifically for the Olds project, and for the current problems in groundwater investigations in Alberta.

### Systems of Numbering, Location, and Elevation of Wells

Due to the variety of the sources from which information was obtained during the program a master well-numbering system had to be designed. In this report reference is made to any individual well by the designation of "Olds Well No." (Appendix A). There are two groups of wells under this title. The first group includes flowing seismic shot-holes only, which are numbered from s1 through s38. The second group comprises water wells and test holes regardless of the type of information obtained from them. The wells in this group are numbered from 1 through 279. Numbers may be missed in both groups due to the fact that some wells, culled from different sources, received two different numbers; or when, except for a report of existence, no information was available; or when information was found to be unreliable.

Locations of the wells are reported always with the maximum accuracy possible. The locations are given either as the smallest land-survey unit of area within which the well is known to be situated or with reference to the corner of a land-survey unit. According to the system of survey of lands used in the Province of Alberta, a "Township" (Tp) is an area 6 miles square, containing 36 sections, each 1 mile square (Fig. 2). A "Section" (Sec.) is divided into 16 Legal Subdivisions (Lsd.).

The location of a well is often not known to a greater accuracy than a "quarter section" (¼).

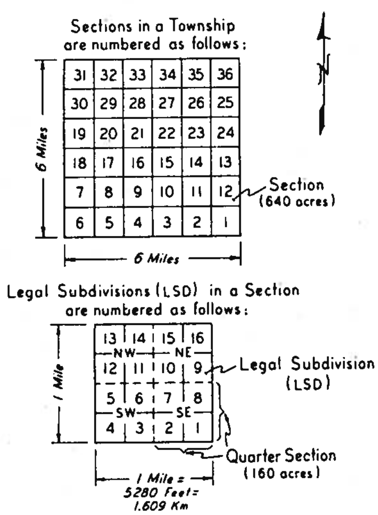


*FIGURE 2. System and terminology of the land-survey units in Alberta.*

Townships are numbered northward from the international boundary with the United States (forty-ninth parallel of latitude). Ranges are numbered westward from each principal meridian (Mer.). The fourth meridian is at 110°00′ longitude west of Greenwich; fifth meridian at 114°00′; and sixth meridian at 118°00′.

Topographic elevations are expressed in feet above mean sea level. Elevations for the wells have either been surveyed or estimated from a base-map with 25-foot contours.

## Physiography

### *The Town of Olds*

Olds is located in section 32, township 32, range 1, W. 5th Mer., at an altitude of 3,415 feet, at longitude 114°06′ west and latitude 51°47′ north. Its population was 2,940 in January, 1965. The main livelihood of the people is farming, commerce, and services. The major industry is an oil refinery close to town.

### *Topography*

The area of study is bounded by longitudes 113°54′ and 114°26′ west, and latitudes 51°42′ and 51°54′ north. The area comprises townships 32 and 33 between range 28, west of the 4th meridian and range 3, west of the 5th meridian. The area occupies an elevated portion of the Central Alberta Plains near the eastern edge of the Rocky Mountain Foothills. The west half of the area is hilly with a maximum elevation of 3,675 feet, and with slopes up to 250 feet per mile. The altitude of the general surface reaches an areal low of about 3,325 feet, 2 miles due west of Olds. The town is situated on a broad and elongated topographic high, the apex of which is slightly concave to the east and has a north-to-south trend. East from the top of this high, referred to for the purposes of the present report as the "Olds High", the surface is flat and slopes evenly southeast at a rate of approximately 40 feet per mile, as far east as Lonepine Creek. The elevation of the southeast corner of the map-area is approximately 3,125 feet. An exception to the direction of the general slope and the even character of the surface east of Olds is found in the northeast corner of the map-area, where the major gradient descends southward and tributaries to the Lonepine Creek are deeply incised. Farther east, beyond the map-area, the land is almost flat for a distance of approximately 2 to 3 miles and then rises again. Thus, the topographic profile of the area east of Olds may be pictured as that of a huge saucer, with a length of its west flank approximately 7 miles, and with a bottom, the center part of which is elevated very slightly, approximately 3 miles in width. Fitting into the corners where the flanks and bottom meet are the two main forks of the Lonepine Creek.

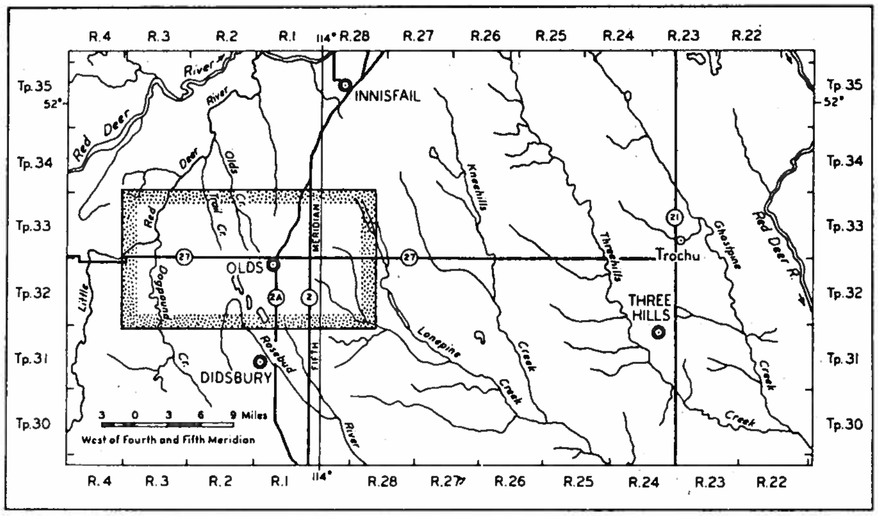


*FIGURE 3. Map showing surface drainage.*

## *Drainage*

The area of study is well drained by a large number of intermittent streams which form a dense and efficient network. The Little Red Deer River in the northwest corner of the area is the only truly perennial stream, although even it is reported to have been dry twice during the last thirty years. The other major drainage system, that of the Lonepine Creek, displays characteristics that are typical for each stream between Olds and the Red Deer River, east of the area (Fig. 3). Stream flow in the Lonepine Creek responds very quickly to snow melt and rain stroms. The flow is very variable, ranging from as high as 3,000 cfs during times of peak flow (Mr. R. K. Deeprose, Water Resources Branch, personal communication) to zero during the fall minimum flow. This is the time when only stagnant, discontinuous bodies of water can be found in the deepest depressions of the stream bed. During winter the stream bed is completely frozen.

The only impounded bodies of surface water of any significance are found west-southwest of Olds in the headwaters area of the Rosebud River. These lakes (Innis Lake, Barrie Lake, Copeley Lake, Johnson Lake) occupy shallow depressions in glacial gravels and derive their water partly from precipitation and partly from groundwater. They all have well-defined outlets.

The Olds High is an absolute water divide for the small intermittent streams. The drainageways are all directed in a radial manner away from these hills. Those creeks flowing to north, northwest, and west enter the Little Red Deer River. Waters flowing to the southwest and south are part of the Rosebud River system, and Lonepine Creek collects all surface runoff between southeast and northeast.

### *Climate, Vegetation and Soil*

The climate of the Olds area is humid continental. The annual averages for precipitation over 30 years are: rainfall 12.56 inches (320 mm), snowfall 50 inches (127 cm), combined precipitation 17.56 inches (447 mm). The mean summer, winter, and annual temperatures are: 58°F (14.4°C), 14.7°F (—9.6°C), and 37.1°F (2.8°C), respectively (Alberta, Industrial Development Branch, 1962). The months with the most precipitation are June (3.31 inches), July (2.61 inches) and August (2.41 inches). There are approximately 100 frost-free days in the area, during the period from late May to early September. The length of the growing season is approximately 175 days.

The area of study occupies the northern tip of a narrow extension from the south of grassland (prairie) plant-communities into the vegetational belt of the Aspen Parkland along the Foothills (Bird, 1961, Map 1). Whereas the natural vegetation would be the mixture of rich grasses with poplars and willows, extensive farming has changed the vegetation of the area completely. A high percentage of the land is arable and large fields of wheat, rye, barley, and oats cover the area.

The main soil type of the area is chernozem (Wyatt *et al.*, 1943; Peters and Bowser, 1957, p. 15). These soils are developed on glacial or alluvial material under a grassland vegetation in moderately well to well-drained locations. They are characterized by a dark surface and accumulation of lime in the subsoil. From an agricultural point of view the soils at Olds are rated as good to very good arable.

## A Critical Review of Basic Information Available for Groundwater Studies in Alberta

### *Information Required for Groundwater Studies*

Normally, the following types of information are needed to carry out a good quality, quantitative study of groundwater: geographical, geological, meteorological, chemical, and technical.

Geographical information includes topographic maps on an appropriate scale, exact locations, and exact (surveyed) elevations of the observation points. In order to establish the local stratigraphic succession, the groundwater geologist needs clean samples of the formations with accurately recorded depths, good descriptions of the lithology in water wells and other holes, preferably cores, and various types of mechanical logs. A calculation of the amount of water that can possibly infiltrate into the ground, to be recovered later, is feasible only if records of precipitation, evaporation, soil-moisture changes, and temperature are taken. The chemical studies, which are playing an increasingly more important role in groundwater investigations, should be based on water analyses reporting at least the main cations and anions separately. And the last, but by no means the least important, group of information includes the water-level measurements indispensable for groundwater engineering. Some of these are: nonpumping water levels at different points and at different depths at the same point, records of water-level fluctuations in wells uninfluenced by pumping, extended production tests with accurate and systematic measurements of production rates, and water levels both in the producing well and in its surroundings. Unless the above information is at his disposal, a geologist or an engineer cannot be expected either to assess an area's groundwater potential or to find the safe yield of a well.

*Sources of Information*

In Alberta there are numerous potential sources of information pertaining to different aspects of groundwater hydrology. These sources include water-well drillers' reports, well owners' reports, seismic shot-hole data, structural test holes of oil companies, reports by consulting engineering firms, well-water analyses of the Provincial Analyst and local Health Units, and the surveys of the Geological Survey of Canada and the Research Council of Alberta.

*Quality of Information*

Unfortunately, much of the above information is either inaccurate or incomplete as far as groundwater is concerned. In other cases the quality of the information is inadequate due to lack of interest or lack of skill. Also, there is much confusion in terminology and in the reporting of observations.

There are three major difficulties in obtaining accurate geographical information. First, the lack of large-scale (at least 1:50,000) topographic maps for many areas of the province. Whereas it is realized that this problem is mainly one of time, without these maps accurate locations and elevations require the services of a skilled surveyor. Second, the inaccuracy of reporting well locations. Even if the location of a well is known to the nearest legal subdivision, this may involve an error of over 1,300 feet. Most wells, however, are reported only with reference to the quarter section in which they are situated. Third, topographic elevations are either not known at all due to the uncertainty in the location, or, in fewer cases, are roughly estimated, or, very seldom, they are surveyed. Even the Research Council can very rarely afford to have its groundwater test holes located accurately.

In connection with the geology, the groundwater geologist must rely in most cases on water-well drillers' reports, owners' reports, or seismic shot-hole logs. Unfortunately, many compilers of these reports lack a geological background and their descriptive terms are often more confusing than helpful. For instance, it is very difficult to judge the drift-bedrock contact from a report in which "shale" is logged for clay, and "gravel with sandstone" is found at a greater depth. In some cases water-well logs can only have been made up after the day's work was done, or before the report was submitted, and in others no logs were made at all. From well owners one may be able to find only that the "stream is coming from the rock". In one particular case, approximately 35 miles east of Olds the writer constructed a drift-isopach map, using seismic shot-hole reports. During the field-check of the isopach map, one of the few bedrock outcrops of the area was found where the shot-hole log recorded 75 feet of drift! Logging techniques are restricted to electric logging, in most cases to SP (spontaneous potential) and one resistivity measurement. The quality of the few logs that are taken does not allow any kind of quantitative interpretation because of the lack of pertinent supplementary information such as mud resistivity and mud-temperature. Even the structural test holes of oil companies are not designed to be of help in finding fresh-water zones, nor to be used to calculate porosity of the water-bearing formations or salinity of the formation waters.

The taking of meteorological measurements is generally beyond the scope of groundwater programs, mainly because there is usually no time to establish records during one project. It is only hoped that a denser network of meteorologic recording stations will gradually be developed in Alberta.

The available chemical analyses of groundwater are carried out for health purposes. These analyses include the bare minimum of information and no separate determinations for Ca, Mg, Na, K, Si, $SO_4$ are made. The reports of water analyses do not usually give the name of the owner and the land locations, with the result that thousands of the analyses filed are useless.

Water-level measurement is another weak point in the general data. Errors are introduced early by the low-quality measuring techniques. During drilling and testing, water levels are either guessed, or measured from the "wetted portion of the drill stem", measured with a weight hanging in the hole on a line of twine, sometimes estimated by the time a falling stone needs to reach the surface of the water. Once a well is in use (this is the case when surveys are taken) it is the owner's memory, or the number of strokes a jack pump needs to lift the water above the ground that is used as an indication for the depth to the water. After drilling is finished no effort is made to obtain a recovered water level. This practice may introduce several tens of feet of error in the depth figure. Also, here the terminology used by many is very inadequate. In connection with pump or bail tests, after a well is completed, drawdown values are reported simply by "to bottom" or "none". Neither is it unusual to find in a report "drawdown 100 feet" whereas the water column in the well is, for example, 60 feet. In this case it is not hard to find out that the report meant: "drawdown *to* 100 feet"; but if the water column had been over 100 feet this error could not have been discovered. "Depth to water" is often interpreted as "depth of the water in the well", or "drawdown" as "depth to pumping level". Due to the inaccurate concepts and measuring techniques, "stabilized" water levels are too quickly announced. In the first year of the present writer's practice, during a pump test on Olds Well No. 24 water levels were reported to have been stabilized. He estimated the safe yield on this basis at 240 igpm, which was more than adequate to warrant construction of a 2-mile long pipeline, at approximately $5.50 per foot. The yield of the well, however, dwindled to 6 igpm in less than three years. Discharge is not measured at all, or only very roughly estimated. It is seldom that a barrel and watch are used, and flumes, weirs and flowmeters are practically unknown.

### *Consequences of the Low Quality of the Available Information*

The poor practices as outlined in the foregoing paragraphs have already resulted in many thousands of dollars of unwarranted expenditures over the province. Some of the worst types of mistakes, for which ready references are available, are the following: (1) an area or a location with a good potential is not recognized despite "testing"; (2) a good aquifer in a hole is overlooked and is cased off; (3) the potential of an aquifer is overestimated and costly installations—pump, screen, pipeline—are set up only to find out in a short time that money was wasted; (4) every new or renewed project in an area has to secure its own information since no previous data can be used. This last aspect is less direct than the others but is most expensive and is felt particularly strongly by groundwater geologists in their consulting work, when trying to solve problems of small consumers—farmers, small towns, and so on—who cannot afford a test program. These people could be helped, most of the time, if information in the area was available and reliable. This not being the case, however, the advice that can be given is nothing more than the outlines of a very primitive test program.

*Comparison of Available Information in the East and West Half of the Present Map-Area*

Without going into the details of the economics of the Olds project at this point, attention is drawn to the distribution of knowledge over the Olds map-area. Exploration costs (drilling, testing, professional expenditures) west of the town have been estimated by the town's office to be approximately $200,000. For the same type of work the costs of the present program totalled up to approximately $50,000. In addition, approximately $600,000 was spent in the west half on technical installations (pumps, pipes, etc.) which finally had to be abandoned, due to lack (real or visualized) of water. Even if the 1964 program had failed to locate a sufficient amount of water, a definite picture of the groundwater hydrology would have been obtained for an area over two townships, for $50,000. Also, possible future projects, geologic or hydrologic, would be able to make use of the information.

*Recommendations for the Improvement of Obtaining and Collecting Data*

These recommendations may be divided into three groups: (1) those which require education of the public; (2) those which are concerned with the water-well drillers; (3) those dealing with groundwater data.

(1) Efforts should be made by organizations, public or private, concerned with groundwater, to make certain that the public understands that groundwater costs money to produce. The more refined and detailed the required picture of the groundwater regime is to be, the more costly it becomes. And along with the growing industrialization of the country and increasing population density, the need for more refined knowledge of the groundwater occurrences, qualities and amounts is unavoidable. Increasingly greater emphasis will be laid on quality of water, accurate yield estimates will have to be available in cases of water appropriation, areas of influence must be defined in order to settle law suits, and industries will move into areas only where known reserves of water are guaranteed. For these reasons groups or persons sponsoring groundwater exploration should not be reluctant to comply with procedures and expenditures insisted upon by professionals. They should realize that observation wells are no luxury, that continuous records of discharge and water levels are the basis for future work whilst they also safeguard against unexpected depletion problems.

Distribution of pamphlets, the arranging of television and radio broadcast programs, and preparation of articles dealing with water regularly for the newspapers, would definitely help in making the public realize that sound management of groundwater is imperative and economical although, like other natural resources, it requires adequate financing.

(2) Persons wanting to start in the business of water wells should be required to take compulsory specialized education. Familiarity with different types of equipment (rotary, cable tool), operating different tools, logging techniques, measuring water levels and discharge rates, geology, and groundwater hydrology should be the main items on their curricula. Both the Northern Alberta Institute of Technology and the Southern Alberta Institute of Technology are excellently suited to teach such courses.

Water-well drillers should be treated in the same way as oil-well drillers and made to comply with government regulation in making up and submitting information concerning every well they construct. Informed water-well drillers are the foundation needed to develop Alberta's groundwater resources. Otherwise the data supplied can be so misleading that it is thwarting, rather than aiding in this development.

(3) The following suggestions are made regarding the data concerning groundwater.

(a) The location of every water well should be reported by means of *distances* along meridian and parallel with reference to a nearby section corner, instead of reporting the *area* (¼ Sec., or Lsd., or Sec.) in which it is situated.

(b) Industrial and public wells should have surveyed elevations.

(c) Samples of rock cuttings from water wells should be taken, submitted to and processed by a government organization.

(d) The government should have personnel and equipment to take electric logs of every industrial and municipal well. Well drillers should be encouraged to do the same in private wells.

(e) Bail tests and pump tests should be standardized and made compulsory. Different standards should be used for low-yield (up to 5 igpm), medium-yield (from 5 to 25 igpm), and high-yield (over 25 igpm) requirements. Bail tests, pump tests without observation well, and pump tests with one or more observation wells, respectively, are suggested as the appropriate techniques for the above groups.

(f) Water samples for chemical analysis should be taken, submitted to and analysed by a government organization, keeping the requirements of groundwater work in mind. An analysis that is detailed enough for hydrologic purposes can always be used to judge the suitability of the water from a health point of view. It is, however, not true the other way around.

In conclusion, it seems obvious enough that an efficient development of Alberta's groundwater resources can only be hoped for if, instead of the present struggle with scarce and low-quality information, people involved primarily with groundwater provide themselves with first-grade data and do not rely on the by-products of other disciplines.

## A Summarized History of Groundwater Investigations at Olds

### *Work Prior to 1964*

Exploration, aimed at locating a sufficient amount of groundwater for the planned public water-distribution system for Olds, started in January 1946. The contractor was Western Water Wells of Calgary. How long the supply wells that were constructed at the time lasted is not known. Their locations were northeast and west of the town. There are further records of at least five different drilling companies which worked for the town before 1959. The results were similar each time: the wells seemed to produce a sufficient amount of water for the then approximately 2,000 people of the town for several months or a few years, and only when they started to pump air was the difficulty realized. Being constantly in an emergency situation the town could not wait until a new reserve was found, but the first promising new well was taken into use. Despite this policy, water rationing during times of peak consumption was not unusual.

The town contacted the Research Council of Alberta first in 1959. According to the Council's advice, which could be based only on information as outlined previously, wells were drilled in the gravel pits west of town. These wells lasted approximately a year, after which the Research Council was contacted again. This time wells were not drilled at the locations suggested, and a pump test was run in such a manner that a gross misjudgment of the yield resulted.

Being aware of the difficulty the town was facing, and trying out some theoretical assumptions, a 700-foot deep test hole was drilled and equipped with an automatic FM water-level recorder by the Research Council in 1961 (Olds Well No. 147). In the following year approximately 40 test holes were drilled around the town.

After having done groundwater investigations near the town, Haddin, Davis & Brown Co. Ltd., Consulting Engineers, investigated the possibility of induced infiltration of the Little Red Deer River, some 12 miles west of Olds, in 1963. It was found that no artificial recharge was feasible, and also that costs of the installation and operation of a surface-water plant at the same site could be high. Besides this, the unknown flow characteristics of this river made the prospects of a continuous supply quite dim. Estimated costs of a similar installation at the (Big) Red Deer River, some 18 miles away were prohibitive. Basic capital expenditure was estimated in 1964 at $650,000 plus an additional $85 per day for operation and maintenance.

*Work During 1964*

In December, 1963, the Research Council was contacted by the town for advice. Drilling operations started east of town in January, 1964, with Olds Well No. 177. After an encouraging pump test on Olds Well No. 178, the water of which was trucked to town (Fig. 4), an extended test program was decided upon. The purpose of the investigations was extended also. Instead of aiming at locating a sufficient amount of water only, the potential of the area east of the Olds High was to be determined. According to the estimates of the present report a total of 575 igpm may be safely withdrawn from this area.

Information for the whole map-area has been compiled and either reported here or filed with the Research Council.

The official opening of the Olds water system utilizing this new supply took place on December 4, 1964 (Olds Gazette, 1964, p. 1).

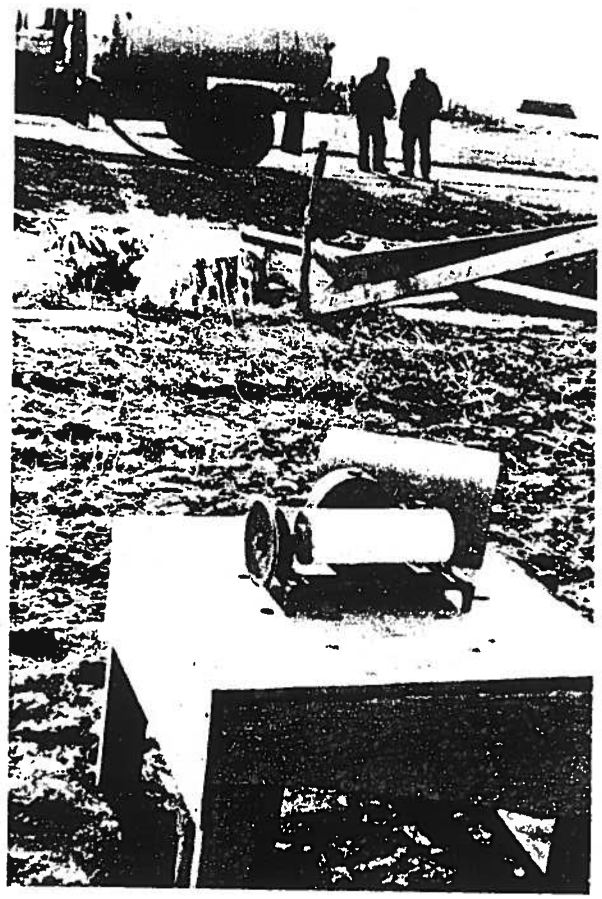

*FIGURE 4. Loading water for town supply during pump test 1; foreground: water-level recorder on observation well 15 feet from pumping well.*

# GEOLOGY

## Introduction

In connection with a study of the groundwater regime in a given area, which is aimed at obtaining either general or specific information, a knowledge of the geology is indispensable. The formations or rock units that are of prime importance in a search for groundwater in the Olds area are very little known. The reason for this is threefold. First, due to the virtual lack of outcrops in the area no geological mapping is feasible. Second, the major agent for subsurface geological work in Alberta, the oil industry, is uninterested in these relatively shallow formations because they are generally devoid of oil or gas. Third, the great majority of seismic shot-hole drillers and of water-well drillers in the province either are inadequately skilled to take and record pertinent information or fail to comply with government regulations to submit information obtained during the course of their work. However, from the few investigations that have been carried out a general picture of the near-surface strata in the Olds area may be established.

In the following paragraphs this general picture is summarized. Subsequently an account and the results of the geological work carried out for this report on the Olds area are given.

## General Information

Structurally, the area of study is located on the eastern flank and close to the centre of the Alberta syncline (Allan and Sanderson, 1945, p. 30), and the regional dip is westward at between 35 and 40 feet to the mile (J. D. Campbell, pers. comm.). The two rock units relevant for the purposes of the present study comprise the consolidated sandstones, siltstones, and claystones of the Paskapoo Formation of early Tertiary age, and the unconsolidated deposits of Quaternary ice-sheets, rivers, and lakes. For the sake of convenience the previously mentioned sediments are commonly referred to as the "bedrock" and "drift", respectively. In his paper, summarizing mainly the results of previous investigations, Webb (1954) describes the Tertiary sediments as having been deposited during the orogenic uplift of the Rocky Mountains (Laramide revolution), west of the Alberta Syncline: "The rejuvenated erosion in the west caused rapid accumulation of fresh-water sediments on the east across the present foothills and spreading far east on the plains." (*ibid.*, p. 24). In the Olds area a thickness of 800 to 1,200 feet may be inferred for the Paskapoo Formation from previous estimates, but thicknesses of over 6,000 feet have been reported elsewhere (Allan and Sanderson, 1945, p. 95).

The most comprehensive accounts of the lithology and its depositional environment of the Paskapoo beds to date have been given by Parks (1916, p. 191) and by Allan and Sanderson (1945, p. 96). According to these authors the Paskapoo Formation consists of soft, grey, argillaceous sandstones, some conglomerate and soft shales, and clays. Local, thin lenses of woody coal also occur. The beds are irregular and lenticular; grain size, lime content and porosity are variable; mud galls and cross-bedding are common. The little cementing material is mainly carbonate and the amount of clay in the sandstones is commonly less than 6 per cent. The sandstones weather to a buff color and have a "pepper and salt" appearance. The main minerals of the sandstones are quartz, constituting the bulk of the Paskapoo sandstones, and small amounts of feldspars, usually highly decomposed. Shale, limestone, chert, and quartzite fragments are also important components.

The fauna of the Paskapoo Formation consists mainly of freshwater and terrestrial gastropods. The genera are long-ranging but, according to Sanderson (Allan and Sanderson, 1945, p. 98): "It is believed that when the varietal differences are sufficiently well known this fauna will be of use stratigraphically. At present it can only be used as an index of the past environment." The remains of a few mammals have been used to date the Paskapoo Formation as of early Eocene age.

Due to the long-ranging nature of most of the 85 species of plants that are described from the Paskapoo Formation, the flora cannot yet be used for stratigraphic subdivision.

Allan and Sanderson (*ibid.*, p. 96) interpret this formation as comprising: "the deposits of large rivers which had strong flow at their heads and which deployed upon a great, incompletely drained plain. . . . No doubt large, temporary, shallow lakes were formed many times over, but none were of permanent basin type, or of important depth, and were probably always subject to rapid obliteration in dry seasons." It will be seen later that this manner of sedimentation, with minor modifications, has an important bearing on the type of occurrence and movement of groundwater in the area.

The Central Plains region of Alberta is generally covered by lacustrine, fluvial, and glacial deposits of the Pleistocene and Recent epochs. These deposits consist of clays, silts, sands, gravels, and boulders. They may fill up preglacial valleys, or cover extended flat areas without displaying significant local relief, or form strongly accentuated rolling and "knob and kettle" type topography. Their texture varies from mixed to well-sorted clean sands and gravels. The glacial deposits were derived from the Cordilleran and the Keewatin ice sheets, originating in the Rocky Mountains and the Keewatin district of the Northwest Territories, respectively

(Stalker, 1960, p. 3). Deposits brought in by the Cordilleran ice sheet consist mainly of sandstone, quartzite, limestone, and dolomite, whereas the bulk of the material of Keewatin origin comprises granites, gneisses and schists of the Precambrian Shield; both types of deposits also include considerable amounts of local bedrock.

Because the general character of the previously existing information precluded the establishment of the hydrogeologic conditions at Olds with the required details, it was decided to pay as much attention to the geological phase of the program as was allowed by time and funds.

## Scope and Techniques of the Present Work

The geological investigations carried out during 1964 were designed to establish the hydrogeologic conditions that govern the occurrence and movement of the groundwater in the area east of Olds. The western boundaries of the area of actual test drilling were determined by theoretical considerations, more fully explained in the chapter on "Occurrence and Natural Movement of Groundwater". The locations of the north, east, and south boundaries were controlled mainly by economic factors. Owing to the fact that the test holes were considered as potential production wells, all testing had to be done close enough to the town so that construction of a possible pipeline was still economically feasible. Figure 5 shows the location and extent of the area of test drilling. Chip samples were taken at 5-foot intervals in 19 test holes, covering an area of approximately 17.5 square miles. The depths of the test holes varied between 200 feet and 690 feet. Sampling encompassed the range of topographic elevation from 2,555 feet to 3,297 feet above mean sea level, making possible the construction of geologic cross sections as deep as 742 feet in places. Drilling was done by two "22-W Bucyrus-Erie" cable-tool rigs. Whenever a progress of 5 feet in the drilling was made, drill cuttings were removed from the hole by bailing mud off the bottom until no cuttings appeared. Subsequently 0.5 to 1 foot was drilled and the newly obtained drill cuttings were removed with the bailer and caught in a 100-mesh screen. Then the samples were washed, bagged and shipped to the laboratory of the Research Council of Alberta, where, after final washing and drying they were described and stored. The description of the samples was based on an examination under approximately 15-power magnification. The colors of the rocks were designated by means of the "Rock-Color Chart", distributed by the Geological Society of America (1951). This chart is based on the color system and notation of the Munsell Color Company. In the grain-size determinations the Wentworth Grades were used (Lahee, 1952, p. 38). Additional mineralogical and X-ray analysis of the "Olds tuff" was carried out by Mr. M. A. Carrigy. The lithological logs of the rocks penetrated are given in Appendix B.

Besides the above-mentioned test holes, use was also made of the field description of the lithology at Olds Well No. 147, of water-well driller's logs, and of a report of consulting engineers. The available descriptions of the lithology in water wells, as submitted by drillers, are presented in Appendix D*. Seismic shot-hole logs were used in contouring the surface of the bedrock in the northeast corner of the map-area.

**Paskapoo (Porcupine Hills?) Formation**

*Lithology*

Examination of the drill cuttings verified the descriptions of the lithology of the Paskapoo Formation by Parks (1916) and by Allan and Sanderson (1945). Laminated, lacustrine siltstone beds alternate with thick layers of claystone and argillaceous and silty sandstone, this latter varying in grain size from very fine to medium (1/16-1/2 mm). Only in one test hole, No. 178, was coarse-grained sandstone (up to 1 mm in grain size) found. The clastic strata are mostly poorly cemented, and the amounts of carbonate may vary from sample to sample. However, thin bands of very hard sandstones, marl and chert are not uncommon. All siltstones and sandstones have a "pepper and salt" appearance.

Despite the general agreement between the previously existing and the present concepts regarding the lithology of the Paskapoo Formation there are two major characteristics in the development of the formation at Olds that make it markedly different from the same stratigraphic unit as described at other localities.

Firstly, prior to the present investigations no appreciable amounts of coal were reported to be present in the formation in Central Alberta. Allan and Sanderson (1945, p. 97) mention " . . . local, thin lenses of woody coal . . . " and the "Geological Map of Alberta" lists "thin coal" in the Paskapoo (Canada, Department of Mines and Technical Surveys, 1951). Also, one of the accepted bases for separating the Paskapoo Formation from the immediately underlying Upper Cretaceous Edmonton Formation is its lack of coal seams (Allan and Sanderson, 1945, p. 32). Contrary to these observations, each test hole of the present program has penetrated several coal seams, having thicknesses up to 4 and possibly 5 feet. Many of the seams contain coal with a high degree of carbonization, whereas some of them may be termed "woody". The roof and floor of the coal beds are usually claystone or fine siltstone but coal may occur embedded in the sandstone layers also (as in Olds Well No. 178). The zones containing the

* Appendix not included with published report. Copies are available on request.

greatest number of freshwater gastropods and lamellibranchs are everywhere associated with coal seams, suggesting that these are autochthonous coals. The seams appear to have considerable areal extent, and an attempt at correlation is made in figure 6.

The other aspect of the Paskapoo Formation at Olds, which is strikingly different from previous descriptions, is its high montmorillonite content across the entire sampled section. Most of the strata penetrated at Olds contain some montmorillonite, and pure bentonite beds are fairly common. Many layers of siltstone and sandstone possessing basically good water-conducting characteristics are rendered poor aquifers owing to their high content of montmorillonite.

### *The Olds Tuff*

During the course of the study a distinctive bed of a light-colored rock was discovered which could be identified in 14 test holes, and was also present in Olds Well No. 185, drilled during a previous test program. According to M. A. Carrigy, the rock is a devitrified volcanic tuff. Its main mineral constituents are: volcanic glass shards, twinned feldspars, high-temperature quartz (cristobalite) in a felsitic ground mass which has altered to montmorillonite; heavy minerals present include apatite, epidote, biotite, hornblende, and pyrite. Figure 7 is a photomicrograph of this tuff showing well developed tricuspate shards (S). These shards, which are collapsed bubbles of molten rock left behind by the escaped gas, are diagnostic of volcanic ash.

By visual examination or under a low magnification the tuff appears much like a very fine siltstone. Its color is light greenish-grey or pale bluish-grey, the fresh surface having a dull waxy luster. Incorporated flakes of biotite lie parallel to the bedding, these commonly reaching a size of 0.5 mm in diameter and euhedral in habit. The rock is slightly indurated, varying from soft to medium hard. Its fracture is conchoidal, and some of the samples show fine but well-developed lamination. Occasionally rock chips are found with biotite flakes assuming a common direction, and giving the rock a schistose appearance. It disintegrates easily both in dilute hydrochloric acid and in water, but it does not swell. Its only reaction to acid is a slight color change, usually toward a pale yellowish-green blue.

The thickness of the tuff bed varies from less than 1 foot to at least 20 feet in Olds Well No. 195. Its apparent continuity makes it possible to use the tuff bed as a structural marker bed in the Olds area (Fig. 6).

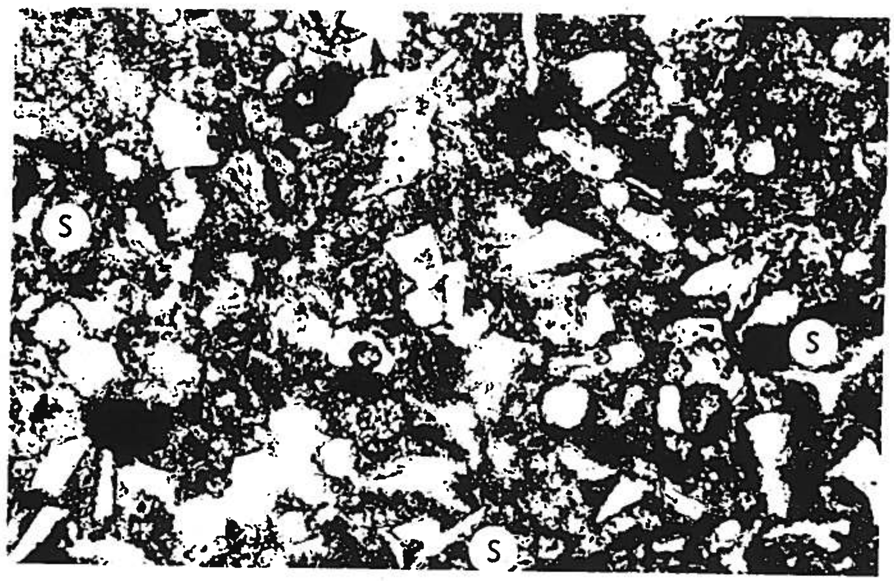


*FIGURE 7. Photomicrograph of the Olds tuff (magnification X 25; courtesy M. A. Carrigy).*

No other beds are known to be potentially useful for correlation in the Tertiary rocks in Central Alberta. The tuff bed in question displays characteristics that make it suitable for this purpose in the Olds area, and for this reason it is referred to as "the Olds tuff" in this report.

### *Stratigraphy*

During the course of the present study no investigations were carried out that would aid in the establishment of age of the formations tested. However, from works already cited it seems fairly certain that these sediments are of early Tertiary age. There may be some doubt as to whether the strata at Olds belong to the Paskapoo Formation or to the Porcupine Hills Formation, which, according to the recent investigations of M. A. Carrigy (personal communication) have marked mineralogical differences despite their similar age and visual appearance. He feels that the boundary between the two formations is located in or near the area of the present study. Both formations might, therefore, be present here. Since further inquiry in this matter is beyond the scope of the present study, the formations at Olds will continue to be referred to as Paskapoo, realizing, however, that future studies might prove the name Porcupine Hills Formation to be more correct.

Correlation of lithologic units within the area seems possible with the aid of the Olds tuff and of coal seams.

Four major lithologic units are present in the "south field" of the test area (south of Highway 27) (Fig. 6). Here the lower part of the cross section consists of a silty claystone unit, approximately 200 feet in thickness. A 40-foot thick sandstone layer is recorded in the lowest portion of this claystone unit in Olds Well No. 192, and the same sandstone is believed to attain a thickness of over 100 feet at Olds Well No. 147. The top of the clay unit is marked by a 3-foot thick layer of coal, above which the second unit, an 80- to 100-foot thick siltstone stratum is found. Near the top of this siltstone unit, coal seam-shell bed associations mark the beginning of a sharp transition into the third unit, a 90- to 120-foot thick sandstone layer, which is best developed in Olds Wells Nos. 187, 188, and 192. In several holes, a coal seam-shell bed and other carbonaceous matter are found near the top of this bed, which is overlain everywhere by the Olds tuff. The uppermost bedrock unit is a siltstone. This siltstone has a thickness of approximately 300 feet in Olds Well No. 195, but is absent 2 miles south of this well, due to the presence of a buried channel between Olds Wells Nos. 189 and 192.

It must be made clear that the unit designations such as claystone, sandstone, siltstone, do not imply a clean, homogeneous mass of rock. They indicate, rather, the bulk of the material that makes up the unit. Within these units, lenses, truncated beds, and other discontinuous bodies of the other two main rock types may be present.

In the north field—the area north of Highway 27—a corresponding stratigraphic subdivision of the rock units could not be made. The Olds tuff and several coal seams appear to continue north, therefore the disappearance of the sandstones must be attributed to a facies change. The lowest, or claystone unit does not change much toward the north, but is, however, somewhat more silty than in the south field. The sandstone unit is replaced by siltstone, whereas thick sandstone layers begin to appear above a regionally continuous coal seam-shell bed—in the upper part of the highest siltstone unit at the most northerly point of observation in Olds Well No. 200. It is concluded that the facies change takes place within an area approximately 1 mile wide immediately south of Highway 27.

Available information outside of the area of test drilling was deemed insufficient to warrant a more detailed description of the bedrock.

### *Interpretation of the Bedrock Strata*

The results of the present investigation seem to confirm the interpretation of the Paskapoo strata as given by Allan and Sanderson (p. 18 of present report). In the Olds area, however, the shallow depressions contained large swamps which under a humid climate gave rise to the extensive coal beds. During the deposition of these layers, volcanoes, associated with the Laramide orogeny, were still very active, covering the whole area with their ash, this being the source material for the great quantities of montmorillonite found mixed with the local sediments. One of these ash beds, the Olds tuff, remained particularly well preserved. It overlies a claystone-siltstone complex with coal seam-shell bed pairs, and it appears to be thickest toward the centre of a depression. Structure contours on the top of the Olds tuff (Fig. 8) show the position of this depression. Whereas there is the possibility that this broad depression might be part of a major basin the nature of its origin is uncertain. Excepting one instance, no evidence was found in support of a tectonic origin of the basin. Therefore, the feature may be attributable to either erosion or differential compaction or both. That one particular feature, however, strongly suggests the possibility of a fault in the area. This feature (see p. 41) is a complete hydraulic discontinuity, less than a few hundred feet in width, extending in an east-west direction between Olds Wells Nos. 189c and 189d. To the west it seems to decrease in importance between Olds Wells Nos. 178 and 187 (Fig. 16); its extent to the east is unknown. Such a narrow, sharply defined, impermeable boundary, having highly permeable materials on *both* sides, can hardly be explained by anything else but a fault. In the case of even a small displacement of one bedrock block against the other, the soft, plastic material of the bentonitic sandstones, siltstones, and clays, smeared between the surfaces of the faulted blocks could form a most effective, very local, impermeable barrier.

Since the end of the Laramide orogeny, the slow subsidence of the Alberta syncline ceased and the region was uplifted. It is not known how much of the bedrock has been eroded away and in what direction the preglacial drainage took place. It is obvious, however, that the last preglacial streams to cut into the surface of the Paskapoo Formation had a similar distribution pattern to that of today; that is, a drainage to the southeast in the area east of the town of Olds. At this time the elongated north-south bedrock high originated, on top of which Olds is presently situated. This elevated part of the bedrock functioned as a major water divide immediately prior to glaciation. Figure 9 shows the topography of the bedrock superimposed on the contours of the present-day surface. This map presents the major preglacial (glacial?) drainage channels in the Olds area. None of these channels is known to the writer to have been reported previously and they are not included with the latest bedrock-topography maps of Alberta (Farvolden, 1963, p. 65).

Attention is drawn to the remarkably deeply incised valleys in the eastern part of the map-area. These short, ravine-like channels suggest that a badland-type topography preceded the deposition of the draft. In the

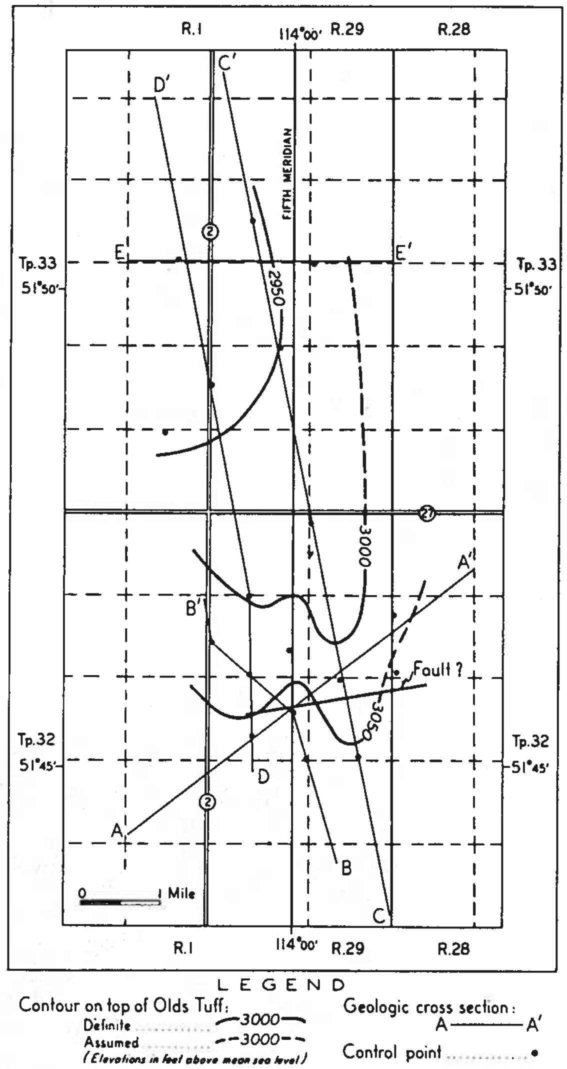


*FIGURE 8. Topographic elevation contours on the top of the Olds tuff.*

slightly indurated and bentonitic rock types of the Paskapoo Formation this topography must have resulted in landslides of large areal extent cutting deeply into the steep edges of the valleys. Such landslides are still common in Alberta, and figure 10 shows the plan view, cross-sectional sketch, and a photograph of one slump which was reported by Mr. J. Shpychka. The slide occurred in NE ¼, Sec. 8, Tp. 55, R. 8, W. 4th Mer., approximately 6 miles north of Myrnam in April, 1963, and was visited by the author shortly after. There is a close similarity between the configuration of the bedrock channels at and immediately east of Olds Well No. 192,

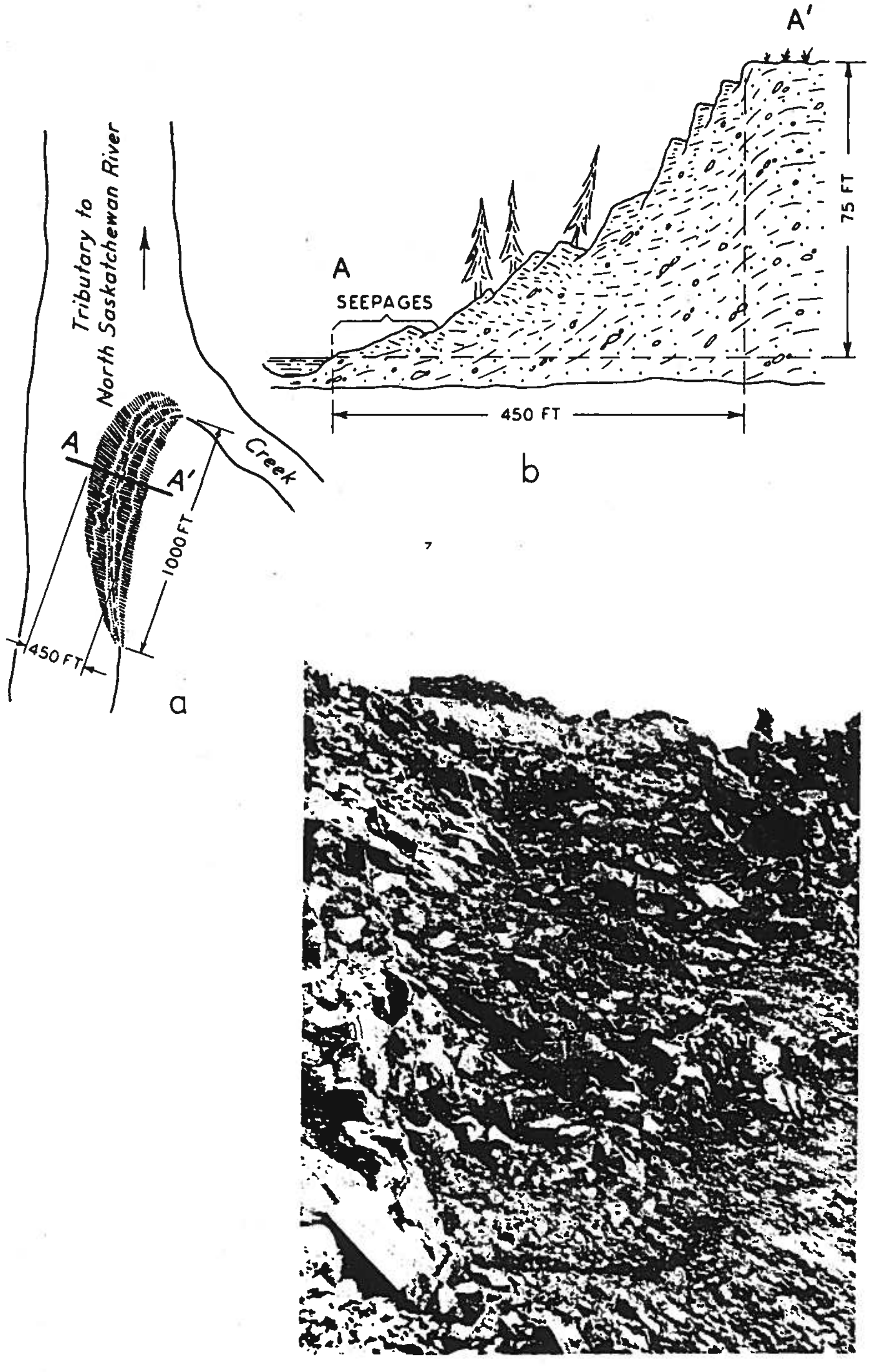


*FIGURE 11. Plan view, cross section, and photograph of a recent landslide.*

and the topographic environment of the recent slump as presented on the sketches of figure 10. The strongly caving character of certain zones in various wells indicates that weakness due to disturbance of the rocks by slides may exist in the area. Particular difficulty in drilling owing to the above phenomenon was experienced, as in Olds Wells Nos. 192 and 194. Production tests in pumping wells commonly indicate a high initial permeability which decreases in time to the average value obtained for the formations in question. This phenomenon was particularly well demonstrated during the tests on Olds Wells Nos. 172 and 189. Both wells are located close to the center but on the side of a buried channel. A similar observation, with similar explanation was brought to the attention of the author by Mr. L. Gray, Groundwater Geologist of the Manitoba Water Control and Conservation Branch (personal communication). The strong tendency of the Paskapoo rocks to slide was noted also by Allan and Sanderson (Allan and Sanderson, 1945, p. 30).

### Drift (Pleistocene)

No detailed investigation of any kind was carried out on the Quaternary deposits of the area during the present program. Although the surficial deposits have not been studied in detail, much of the area was mapped by Allan (1943) and that part of the area east of the fifth meridian was mapped by Stalker (1956) on a scale of 4 miles to 1 inch. The unconsolidated sediments comprise mainly till, on which lie scattered small esker ridges of gravel, sand and silt.

The drift consists of soft, unconsolidated blue, grey, or yellowish-grey clays, silt, fine to coarse sands, displaying a full range of roundness and sphericity, commonly having pitted and cobble-marked surfaces, boulders, and till. Much reworked bedrock material is incorporated in the drift, the amount increasing approaching the bedrock, so much so that identification of the drift-bedrock contact can be difficult.

The main minerals found in the drift include quartz, feldspar (commonly decomposed), biotite, hornblende, pyroxene, calcite, dolomite, gypsum, chert, pyrite, and coal. Pieces of limestone, ironstone, claystone, siltstone, sandstone, quartzite, and various metamorphic and igneous rocks make up a great percentage of the drift. The gross chemical and mineralogical composition is thus distinctly different to that of the bedrock.

Locally the drift contains layers of well-sorted, clean sand and silt of unknown areal extent. These layers or lenses probably represent fluvioglacial drainageways, and they may be interconnected. The thickness of the drift varies considerably within the area of study. Figure 11 is an isopach map of the drift, constructed for those parts of the area where available control warranted contouring. For the rest of the area, drift thicknesses at isolated points are also shown on figure 11. According to the isopach map, the thickness of the drift varies from less than 25 feet to over 175 feet. Water-well reports show that the unconsolidated material may be absent along the higher parts of the main water divide at the centre of the map-area. The drift attains its greatest thicknesses in the buried valleys. In each test hole the top zone of the drift was found to be oxidized. The oxidized zone is recognized by a yellowish-grey color, contrasting with the bluish-grey or grey hue of the fresh drift. The thickness of this zone was observed to vary between 5 and 25 feet.

## Summary and Conclusions

The present geological work is concerned with the early Tertiary Paskapoo Formation (bedrock), and with the Quaternary unconsolidated deposits which are usually referred to as drift.

The author has accepted and confirmed the major features of the lithology and sedimentary environment of the Paskapoo Formation, as interpreted by Allan and Sanderson (1945). According to this interpretation, this rock unit consists of subaerial floodplain and lake deposits, with randomly arranged lenses, and discontinuous beds of sandstones, siltstones, and claystones. In addition to this general picture, the present study revealed a number of features, unreported until now.

(1) The existence of a volcanic ash layer, called here "the Olds tuff", varying in thickness from less than 1 foot to at least 20 feet, and appearing potentially suitable for use as a marker in the Tertiary strata.

(2) The occurrence of several coal seams in the Paskapoo Formation at Olds, a feature previously thought to be characteristic of the underlying Edmonton Formation in Central Alberta. The coal seams appear to be of sufficient areal extent to be of use in correlating within the formation.

(3) The occurrence of abundant montmorillonite, which was thought to be typical of the Edmonton Formation and was used (Allan and Sanderson, 1945, p. 32) as a "physical criterion" for distinguishing between the two formations.

(4) A broad depression within the Paskapoo Formation, partly filled by the Olds tuff.

(5) The existence of several buried bedrock channels, consisting mainly of deeply incised and short valleys. The tendency of the soft, argillaceous, bentonitic rock types of the Paskapoo Formation to form badlands, the commonly encountered difficulty in drilling due to strongly caving material, and the high permeability values obtained from the early parts of production tests, which values decrease to an average for the formation on an extended test, suggest that landslides were taking place along these channels in preglacial times. In the disturbed environment of these slides the permeability for water of rocks is above the average for undisturbed material of the same type.

(6) The possibility of faulting in the area, as indicated by a complete hydraulic discontinuity between Olds Wells Nos. 189c and 189d.

## OCCURRENCE AND NATURAL MOVEMENT OF GROUNDWATER

### Introduction

#### *General*

The type, the place, and the array of the factors controlling the occurrence and natural movement are important points of consideration in any study of groundwater. A knowledge of the occurrence is needed for outlining areas of continuous bodies of groundwater. It is of great assistance in matters of well design, such as optimum well depth, available drawdown, screen setting, method of completion, and so on. Also, the choice of the appropriate model to approximate groundwater motion in a given area depends on the conditions of occurrence. The established picture of groundwater motion provides, in its turn, the hydraulic framework for that area. It can be used for locating areas with the most favorable conditions of fluid potential (high available drawdown) and for finding the source and route of contaminants. To a great extent this motion is responsible for the variations in the chemical quality of groundwater, and it has a strong influence on the moisture contents and chemical character of soils, and thus, on the vegetation.

#### *Definition and Terminology*

In this report the terminology and definitions outlined by Meinzer (1923) are adhered to. A few concepts, however, have been either newly developed or modified since that time. Those used in this chapter are defined below.

A *flow system* is a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region; they can be intersected anywhere by an uninterrupted surface across which flow takes place in one direction only; *area of downward flow* is that part of the flow system in which the saturated flow of groundwater is directed away from the water table; *area of upward flow* is that part of the flow system in which the saturated flow of groundwater is directed toward the water table; *a local flow system* has its area of downward flow at a topographic high and its area of upward flow at a topographic low that are located adjacent to each other; *a regional flow system* has its area of downward flow at the main water divide and its area of upward flow at the bottom of the drainage basin; *confined flow system* is one the potential distribution of which is *not* affected by the potential distribution of the overlying water table; *unconfined flow system* is one the potential distribution of which is affected by that of the overlying water table; *recharge area* is an area where water is absorbed which eventually reaches a part of the aquifer that is in the zone of saturation (Meinzer, 1923, p. 46) (under certain conditions both areas of downward flow and areas of upward flow may become recharge areas); *discharge area* is an area where water is removed from the zone of saturation (also, both areas of downward flow and areas of upward flow may become discharge areas at certain times).

### *Outlines of the Present Work*

Owing to the scarcity and poor quality of the information in the west half of the map-area, this report deals with the occurrence and natural movement of groundwater in the area east of the Olds High only. In the attempt to solve the town's water-shortage problem this area was selected for exploration on the theoretical grounds that the expected constancy or increase of the hydraulic head with well depth in areas of upward flow would provide for relatively high available drawdowns, thereby increasing the safe yield of the wells, even if geologic conditions were not more favorable than in areas where previous attempts failed to locate a sufficient supply of groundwater. The following field operations, relevant to the present chapter, were carried out during the test program: water-level measurements at different hole depths during drilling; daily and weekly water-level measurements in completed test holes; continuous water-level recording on Olds Well No. 147; bail testing; pump testing; surveying of private wells in the area; topographical surveying of test holes; geological sampling. On the basis of the above information the following maps and diagrams have been constructed: a map showing the nonpumping water levels (Fig. 12), cross sections of groundwater hydraulics (Fig. 15), a map showing the distribution of areas of downward flow and upward flow (Fig. 16), and maps showing changes in water levels due to and during pumping (Figs. 17, 18, and 19).

## Outlines of the Theoretical Background

A few years ago a mathematical model for groundwater motion in a certain type of environment was developed by the writer in a succession of papers and discussions (Tóth, 1962a, b; 1963a, b). According to van Bemmelen (1961, p. 454): "The functional validity of a working hypothesis is not a priori certain, because often it is initially based on intuition. However, logical deductions from such a hypothesis provide expectations (so called prognoses) as to the circumstances under which certain phenomena will appear in nature. Such a postulate or working hypothesis can then be substantiated by additional observations or by experiments especially arranged to test details. The value of the hypothesis is strengthened if the observed facts fit the expectation within the limits of permissible error." Since the Olds case history presents a good opportunity to test the applicability and practical usefulness of Tóth's theory in the light of van Bemmelen's "prognosis-diagnosis" method, the mathematical model is briefly reviewed below:

The distribution of the fluid potential in a drainage basin is derived from Hubbert's general expression (1940, p. 802):

$$\phi = gz + \int_{p_0}^{p} \frac{dp}{\rho} \qquad (1)$$

where $\phi$ = fluid potential, g = acceleration due to the earth's gravity field, z = elevation above a standard datum, $p_0$ = pressure of the atmosphere, p = pressure in the flow region at any point, and = density of water.

This equation has been solved for the case of a drainage basin, of which the geometric, geologic, and hydrologic environment may be characterized as follows:

(1) the basin is underlain by an impermeable boundary;
(2) the two valley flanks are parallel and symmetrical relative to the stream;
(3) the water table is a subdued replica of the topography;
(4) the strata are homogeneous and isotropic in the basin;
(5) climatologic conditions are uniform over the entire basin.

For the general case, in which the configuration of the water table is a harmonic function, the following equation is obtained for the potential distribution (Tóth, 1963b, p. 4798):

$$\phi = g\left\{ z_0 + \frac{c's}{2} + \frac{a'}{sb'}(1 - \cos b's) + 2\sum_{m=1}^{\infty}\left[\frac{a'b'(1 - \cos b's \cdot \cos m\pi)}{b'^2 - \frac{m^2\pi^2}{s^2}} + \frac{c's^2}{m^2\pi^2}(\cos m\pi - 1)\right]\frac{\cos\frac{m\pi x}{s}\cosh\frac{m\pi z}{s}}{s\cosh\frac{m\pi z_0}{s}}\right\} \qquad (2)$$

where a′, b′, c′, $z_0$ and s are geometric parameters of the drainage basin, x is the horizontal distance of any point in the flow region from the valley bottom, and m ≐ 1 - - - ∞ are integers.

The potential distribution is simplified when the water table is linear. Using the same notation, it is described by (Tóth, 1962a, p. 4381):

$$\phi = g(z_0 + \frac{cs}{2}) - \frac{4gcs}{\pi^2} \sum_{m=0}^{\infty} \frac{\cos\left[(2m+1)\frac{\pi x}{s}\right] \cosh\left[(2m+1)\frac{\pi z}{s}\right]}{(2m+1)^2 \cosh\left[(2m+1)\frac{\pi z_0}{s}\right]} \quad (3)$$

Numerical calculations have also been carried out to find the distorting effect of relatively high-permeability lenses on the potential distribution, both in the lens and in the surrounding low-permeability, homogeneous material (Tóth, 1962a, p. 4386).

The relevant major consequences of the above-outlined model, which constitute the "prognosis" in the "prognosis-diagnosis method" of van Bemmelen (1961, p. 454), are as follows.

(1) The groundwater regime of a drainage basin which satisfies the environmental conditions of the theoretical model consists generally of flow systems of different order (Fig. 13).

(2) The greater the relief of the water table, the more developed are the flow systems associated with the local features of it.

(3) As a result of the local systems, areas of downward flow and upward flow alternate across the valley. "This means that the origins of waters obtained from closely located places may not even be related. Rapid change in chemical quality may thus be expected." (Tóth, 1963b, p. 4808).

(4) The fluid potential, if measured in a vertical bore hole, decreases with depth in an area of downward flow, and it either decreases or remains unchanged, or increases in an area of upward flow. At this point it is imperative to make clear that the potential is measured in the vertical direction, that is, with reference to a co-ordinate system associated with the *earth's gravity field.* The flow lines, being orthogonal to the equipotential lines, will thus be directed downward relative to the *horizontal* if the potential decreases vertically downward. Despite their relative downward direction, however, the flow lines may still be intersecting the water table if their slope is less than that of the water table (Fig. 14). Therefore the flow is said to be directed "upward" relative to the *water table,* that is, in the co-ordinate system associated with it.

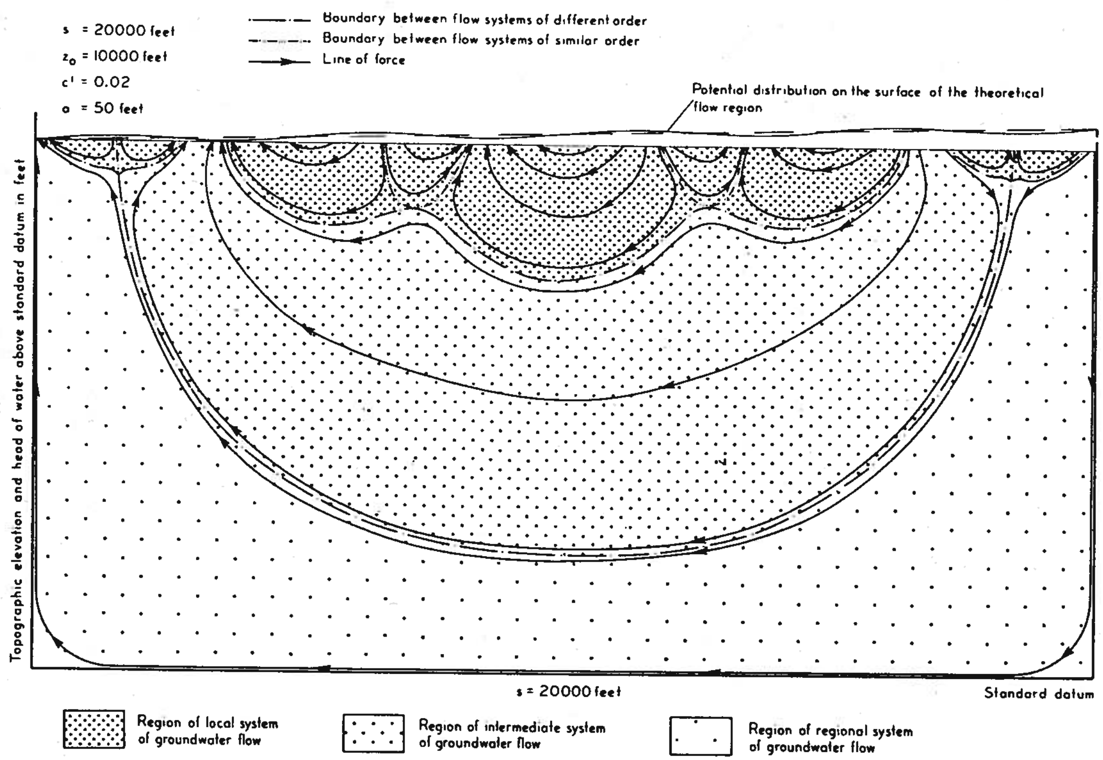


*FIGURE 13. Theoretical flow patterns and boundaries between different flow systems (after Tóth, 1963b, Fig. 3).*

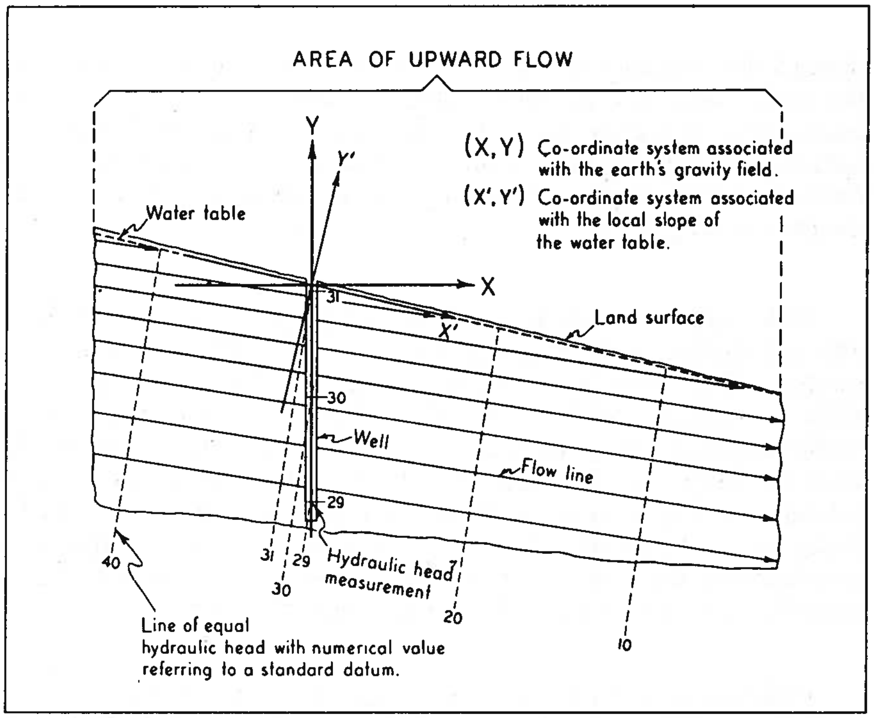


*FIGURE 14. Possible relation between the slope of the water table, that of the flow lines, and the earth's gravity field, resulting in decreasing hydraulic head with increasing well depth in an area of "upward" flow.*

(5) "The effects on the potential distribution of zones that differ in permeability from the matrix material are represented by anomalously low or high pressures, which are observed locally." (Tóth, 1962a, p. 4386).

(6) The presence of flowing wells is not necessarily an indication of confined conditions but may be the result of the natural potential distribution in the area of upward flow of an unconfined flow system.

## Occurrence of Groundwater

Groundwater in the Olds area occupies both original and secondary interstices of the rocks. Original interstices are those voids that came into existence during and by the processes which created the rock. The capability of the formation to transmit water due to communication between original interstices is referred to as intergranular permeability. The secondary interstices found at Olds comprise fracturing by ice movement, by landslides, fracturing of coal beds, and possibly by tectonic movements. Water moves through the secondary interstices by virtue of the fracture permeability of the rocks. This type of permeability was found to exist only in rocks fractured by ice and in coal in the Olds area. There is reason, however, to believe that landslides and possibly tectonic movements contributed to the fracturing of the bedrock. These reasons are discussed in more detail in the chapter on geology.

Unfortunately, a visual examination of the drill cuttings affords very little information about the permeability in most cases. This is due to the varying and generally high amounts of montmorillonite contained by the rocks in question. Well-sorted and coarse-grained sandstones are commonly rendered poorly permeable by authigenic montmorillonite (Olds Well No. 187). On the other hand, badly caving, fine-grained siltstones (shales) are known to be good "producers" in several holes, as in Olds Wells Nos. 192 and 194. For these reasons, on the basis of the present investigations, occurrence of groundwater cannot be associated with any particular rock type or geologic feature in the Olds area.

Observations as to the location of aquifers must, therefore, be related to depth, and left to the driller. His judgment is influenced by his previous experience and is guided by phenomena such as: first appearance of water, abrupt change in head, clearing up of the drilling mud, a decrease in the rate of lowering of the water level during mud bailing, and so on. These indications naturally become less useful as the depth of a hole increases. Also, a driller estimates occurrence of water in the practical terms used locally—in terms of human consumption. Quantities less than, for instance, ½ igpm mean "no water" to him, even though the rocks might be saturated and, in the strict sense, capable of transmitting water. For the reasons mentioned above also, the depth estimates of aquifers are only moderately reliable, except that the first zone of high production is seldom missed, and the second zone is quite certain. On this basis it is found that in approximately 50 per cent of all holes the first high-production zone is at the drift-bedrock contact. The first productive zone is commonly found in relatively clean sand and gravel lenses of the drift in areas of great drift thickness, whereas bedrock is the first producer where the drift is thin.

According to the driller's observations, the yield of the holes generally increases with increasing well depth, and in two cases (Olds Wells Nos. 147 and 178) this has been proven. Production zones in Olds Well No. 147 were sealed off at different depths. The lower sections, therefore, could be investigated without water from higher zones entering the hole. In Olds Well No. 147 water was found to be present at the following depths: 78 feet, 114 feet, 130 feet, 170 feet, 230 feet, 360 feet, and 495 feet. In hole No. 178 two separate bail tests were performed. During the first test the depth of the hole was 180 feet, and 290 feet during the second. Production of the well was definitely increased by the addition of the lower 110 feet (Olds Well No. 178, Fig. 37).

Also it must be mentioned that dug wells, construction ditches, dugouts, and other shallow excavations in the area collect water at depths of 10 to 20 feet. A comparison of the topographic elevations of the first and second water occurrences observed in different holes shows that these waters cannot belong to one or a few well-defined and separated strata. Also the depths of occurrence vary between 20 and 155 feet.

From the observations outlined above it is concluded that groundwater in the Olds area does not occur in preferred lithologic, stratigraphic or topographic zones. The permeability distribution is random and it is controlled by features that are local in character and in importance. These features are: the absence or presence in small amounts of montmorillonite associated with relatively coarse grained clastic rocks; the presence of clean lenses of sand and gravel in the drift; fracturing in the bedrock due to either ice action, or landslides, or tectonic movements. Groundwater forms a hydraulically continuous body in the strata which contain lenticular pockets of greater than average permeability. The presence of these lenses is most probable in channels of the bedrock topography.

A discontinuous distribution of high-permeability portions of the Paskapoo Formation has also been shown in the Pembina area by Farvolden (1961). However, while recognizing some exceptions, Farvolden attributes this feature to a relatively great thickness and high porosity of the sandstone members in the areas of high permeability. Whereas the association of relatively high permeability areas with the presence of sandstone strata was not corroborated by the present study, the similarity of the phenomenon is noteworthy and it should be considered in the planning of future groundwater-exploration programs in the Paskapoo Formation.

## Movement of Groundwater

### *Basic Concept*

Since, according to observations, no continuous, confined aquifers are recognized in the Paskapoo Formation, treating the movement of groundwater within the concepts of unconfined flow seems not only more proper than using a model of confined movement but also necessary. The basic difference between the two types of flow is that the mutual directions of the flow lines of a confined system are determined by the aquicludes of the water-bearing stratum and several of these systems may exist close to one another with independent fluid-potential distributions, whereas the unconfined flow distribution is controlled by the local topography and each point within the regime of flow is hydraulically interrelated.

*Flow Systems of Groundwater in the Area of Study*

The first step in constructing the flow systems was the preparation of the map of nonpumping water levels (Fig. 12, in pocket). This is not a piezometric map, for the contours do not represent an imaginary pressure surface of any particular aquifer. Nor is this a water-table map, for hydraulic heads of different zones were used in its construction. Also, it should be noted that different hydraulic heads are measured at different depths in several wells, as in Olds Wells Nos. 187 and 192. At these wells the nonpumping water levels do not form one unique surface; the configuration of this surface varies with depth. Since water levels vary with depth in most wells, a water-level map does not have a specific physical meaning. It is an indication only of the general direction of the groundwater movement. Cross sections which present the potential distribution with depth are necessary to understand the flow characteristics.

In constructing the hydraulic cross sections $H_1$-$H'_1$, $H_2$-$H'_2$, $H_3$-$H'_3$ (Fig. 15) field measurements of the water levels were used. In areas where observations were scarce, use was made of the previously outlined theory of groundwater motion. Application of this theory is justified also by the presence of three areas of flowing wells (Fig. 12) which, in the absence of a confining layer, indicate extended areas of upward flow instead of a line sink at the bottom of the valley. This feature is an important consequence of the above theory. In the cross sections the equipotential lines are based on field measurements, and the flow lines are constructed taking into account the nonorthogonality of equipotential and flow lines due to exaggerated vertical scale, as demonstrated by van Everdingen (1963).

Section $H_1$-$H'_1$ presents a relatively simple case. It dissects the northern part of the area, which is a simple slope west of the Lonepine Creek.

The orientation of the section is similar to that of the general flow. Slightly more than half of its surface is occupied by flowing wells, indicating an area of upward flow. Measurements indicate an even spacing of the equipotential lines. The area is easily divided into areas of downward flow and upward flow. The depth of the flow system cannot be located on the basis of existing information. The system is regional in that it connects the main divide and the main depression of a drainage basin, but it has also the characteristics of a local system, for the water divide and the valley bottom are adjacent. Its maximum length is slightly less than 4 miles. The system is designated by IA, the Roman numeral indicating the system's regional character and A meaning the northern part of the entire regional system originating on the Olds High. Assuming the generally accepted values of $P=10$ igpd/ft$^2$ for the average permeability of the sediments in question, $p=0.2$ for porosity, and $\frac{\partial\phi}{\partial x} = 0.008$ ft/ft for the average hydraulic gradient at the midline area, an approximate velocity of the groundwater of $v=0.065$ ft/day is found in this system.

Cross section $H_2$-$H'_2$ trends north-northwest. At its north end it dissects a marked local high in the nonpumping water levels, which coincides with a less pronounced topographic high. Approximately 1 mile south of this local water divide is found the north end of a flowing-well area that ends abruptly immediately south of Olds Well No. 189. Farther south the water-level contours indicate a mainly easterly direction of motion, and water levels here are over 40 feet lower than in the area at Olds Well No. 189. Combination of the water-level map and cross section $H_2$-$H'_2$ suggests a local flow system with its area of downward flow on the local high along Highway 27. The main direction of the flow is south but it splits into a southeast and southwest branch against an impermeable boundary just south of Olds Well No. 189. This local system is superimposed on the upward-moving part of the east-southeasterly directed regional system. Hypothetical water levels of the regional system are indicated with dashed lines in this area (Fig. 12). South of the impermeable boundary the area of upward flow of the same regional system is found, with the area of downward flow of a local system superimposed on it (see details in connection with cross section $H_3$-$H'_3$). The total length of local system 3-4 (Fig. 16) along the cross section under consideration is approximately 2 miles, and its depth varies between 400 and 500 feet. The velocity of the local flow varies between approximately 0.003 ft/day and 0.065 ft/day between the areas of downward and upward flow, respectively.

The third cross section, $H_3$-$H'_3$ dissects the south part of the area in an east-west direction. Judging by the general lack of good producing wells on the Olds High, the relatively close spacing of the equipotential lines in the west end of the section is due to the low permeability of the formations. To the east, in Olds Well No. 187 an anomalous drop of almost 30 feet in the water level is observed between the well depths of 185 feet and 235 feet. A drop, similar in character but of only 13 feet, is found between 136 feet and 187 feet in Olds Well No. 192. The water level rises slightly between 187 feet and the bottom of this well at 537 feet. The east part of the section ends in an area of flowing wells adjacent to the Lonepine Creek. The distribution of the potential outlined above has been explained by the presence of a lens with above-average permeability.

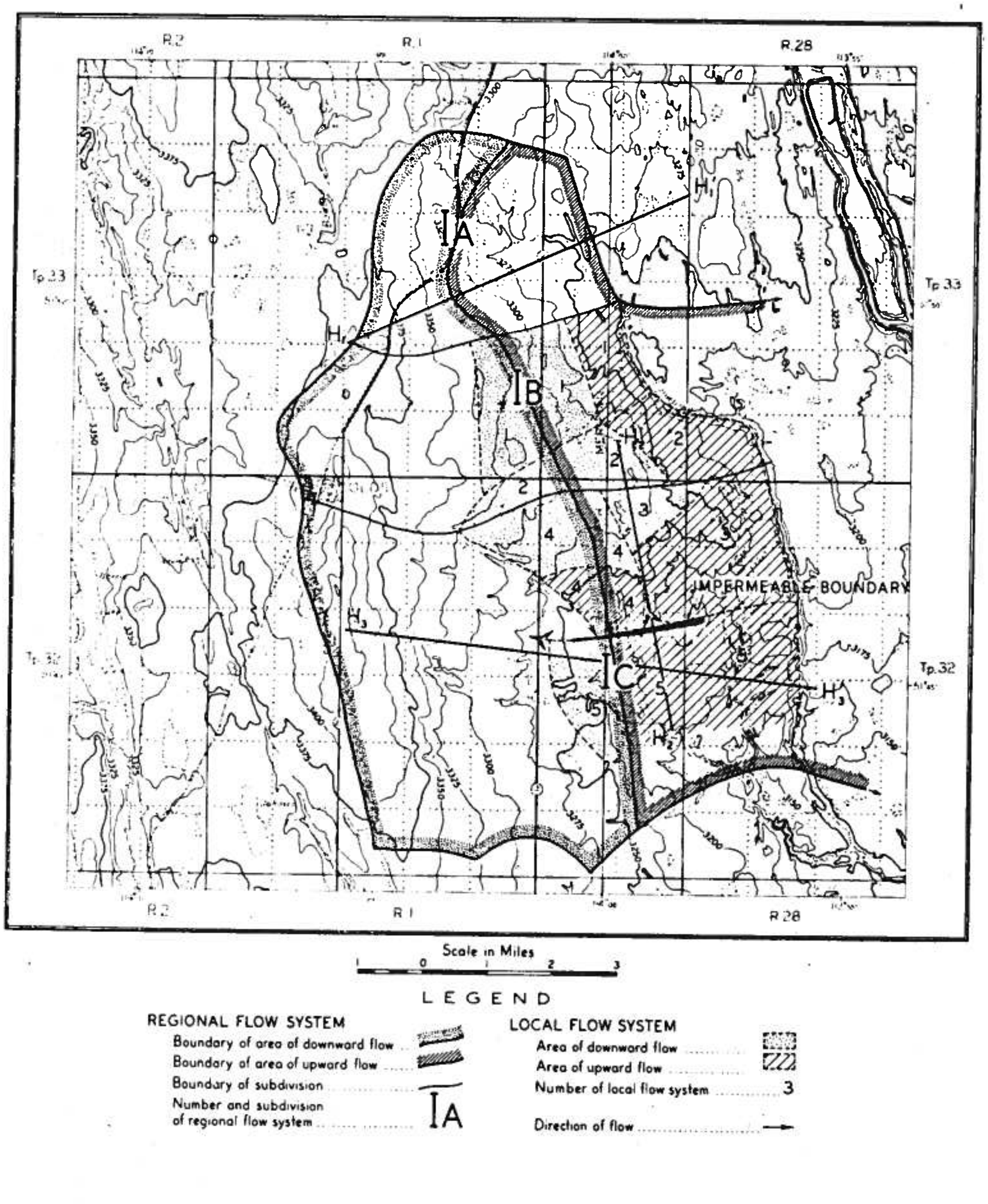


*FIGURE 16. Distribution of areas of downward flow and upward flow.*

The distorting effect of a highly permeable body on the otherwise homogeneous potential distribution was treated in detail by Tóth (1962a, p. 4384). It was shown there that within and around the "upstream" half of a lens the potential is less than its undistorted values, whereas within and around the "downstream" half, the potential is greater than its undistorted values. Near the center the potential retains its original magnitude. Upon construction of the hydraulic cross section by using the above theory and the water-level measurements in the surrounding area, it is found that the lens causes a local flow system to form. The length of local system 5 (Figs. 15 and 16) is approximately 3.5 miles, and its depth does not exceed 150 feet. Its western boundary is poorly defined owing to the gradual westward thinning of the system. The regional flow system should theoretically have an area of upward flow under local system 5. It, however, probably continues to move eastward under Lonepine Creek and reaches the water table just east of the map-area. This system IC may attain a length of 8 miles.

The distribution of the areas of downward and upward flow of the various flow systems is shown on figure 16. The most southerly area of flowing wells (Fig. 12) is thought to represent the area of upward flow of a short regional system with its area of downward flow situated on the extreme south portion of system IC, and beyond the south edge of the map-area. The length of this system is comparable to that of IA, and it merges with system 5.

*Two Anomalies*

During the course of the above discussion of the flow systems in the area, two anomalous features in the potential distribution were mentioned and explained. First, there was the sudden drop of water levels immediately south of Olds Well No. 189, associated with an area of flowing wells to the north and with an area of relatively low water levels and widely spaced contours to the south. The other anomaly was the abrupt lowering in the water levels at different depths of Olds Wells Nos. 187 and 192. The first anomaly was explained by supposing that an impermeable boundary exists between Olds Wells Nos. 189 and 189d; and the second was thought to be due to a high-permeability body connecting Olds Wells Nos. 187 and 192, and possibly to some of the flowing wells farther east. One purpose of the two extensive pumping tests, conducted separately on Olds Wells Nos. 189 and 192, was to prove or disprove the above conclusions.

Figures 17, 18, and 19 show the changes in water levels relative to the nonpumping levels, at specified times during the pumping period of the three production tests performed in the course of the present program (also see Table 1). The changes have been represented by arithmetic

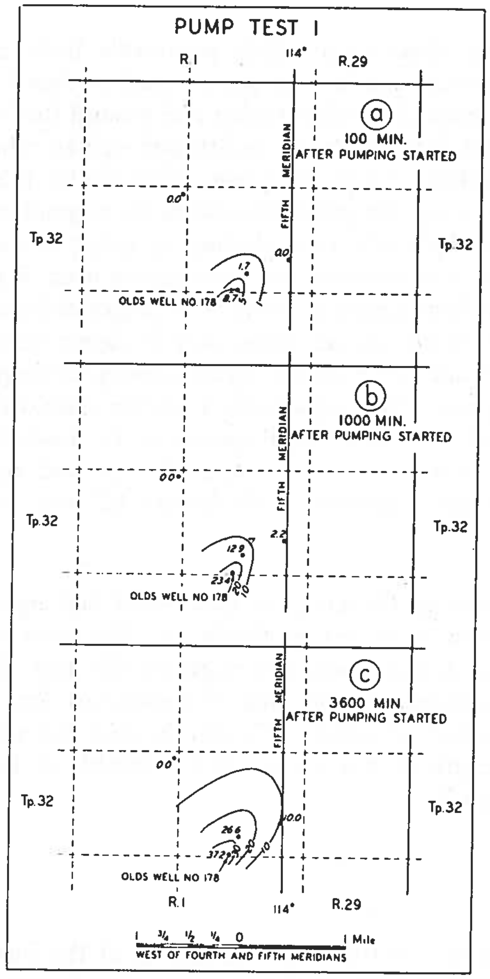


*FIGURE 17. Changes in water levels during pump test 1.*

contour intervals on figure 17 and by logarithmic intervals on figures 18 and 19 in order to show the full range of water-level variation. Positive and negative numbers indicate downward and upward change in water levels, respectively.

Figure 18 shows the development of the cone of depression at Olds Well No. 189 during pump test 2. Water levels fall to the west first, then to the north, and finally after 7,855 minutes of pumping it is observable over the entire semicircle north of the pumping well, at a radius of over two miles. To the south, however, no changes in water levels were observed in Olds Wells Nos. 189d, and 187, despite the short distance (approximately 0.5 miles) between Wells Nos. 189 and 189d. Also it is

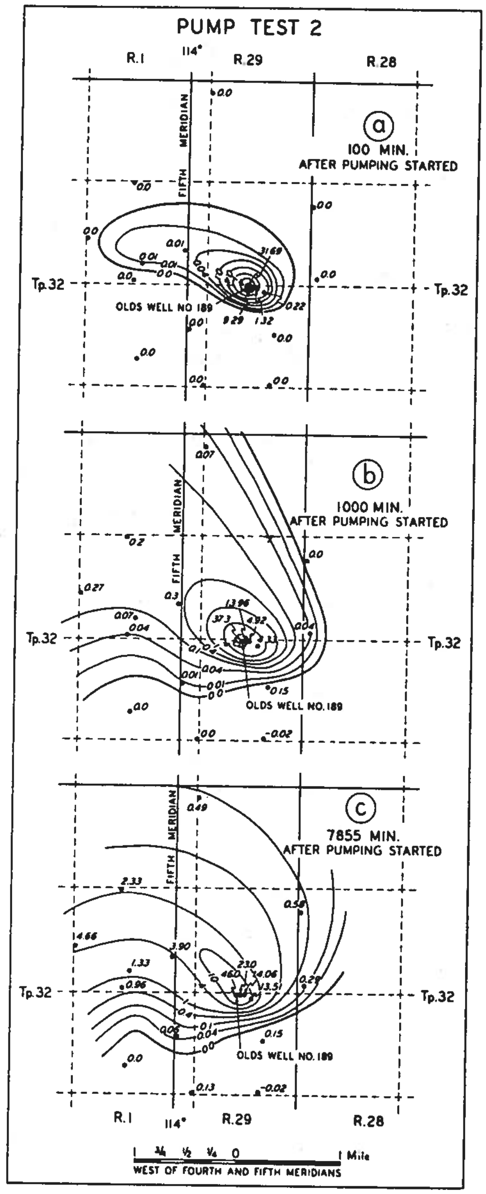


*FIGURE 18. Changes in water levels during pump test 2.*

clear that the major part of the depression follows along the north side of a bedrock channel, indicating an elongated and slightly curved area of high permeability. Recovery measurements indicate also (Table 1) that the area immediately south of Olds Well No. 189 does not communicate hydraulically with the area to the north.

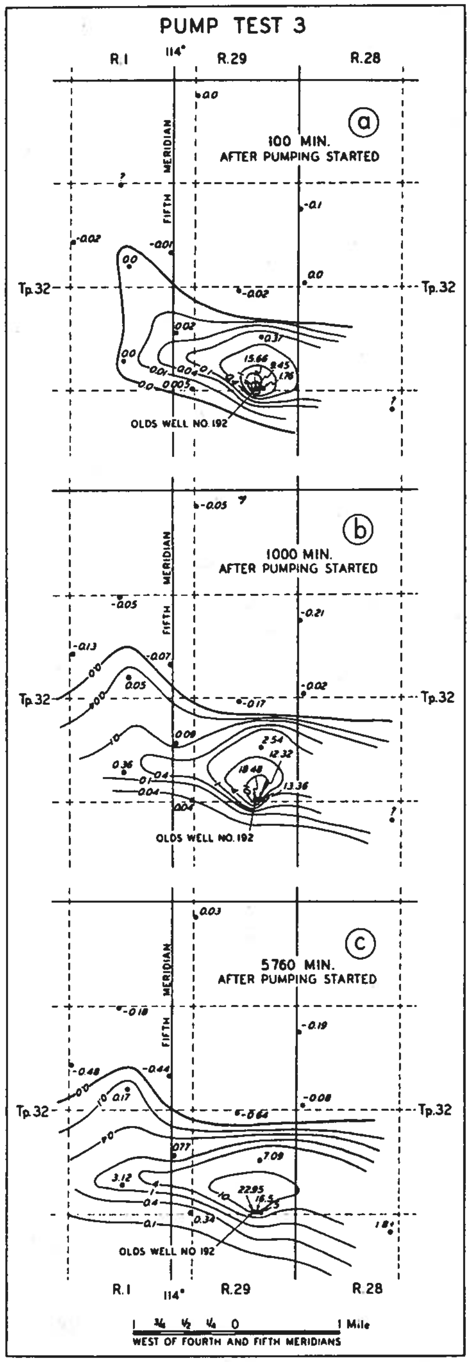


*FIGURE 19. Changes in water levels during pump test 3.*

Pump test 3 (Fig. 19, Table 1) provides an interesting follow-up experiment, proving that the south edge of the impermeable boundary is located north of Olds Well No. 189d. This narrows down the locality and extent of the impermeable zone to between the wells Nos. 189c and 189d and to a width less than 2,100 feet. It is seen from both figures 18 and 19 that in the area of well No. 178 the depression cone of each pumped well tends to invade the other area, thus indicating a decrease in the effectiveness of the impermeable boundary to the west.

Pump tests 2 and 3 thus prove conclusively the existence of a narrow, effective, east-west oriented impermeable boundary located between wells Nos. 189c and 189d. This boundary had been assumed to exist on the basis of the flow-system analysis.

Other important features of the water-level changes during pump test 3 are the elongated shape and east-west orientation of the cone of depression.

Declines of only 0.77 feet and 0.34 feet were measured in the water levels of wells Nos. 188 and 191, respectively, after 5,760 minutes of pumping. The distance between these wells and the pumping well (well No. 192) was approximately 0.9 miles and 0.6 miles, respectively. A decline of over 3 feet was recorded at the same time in well No. 187 located approximately 1.3 miles away from the pumping well (Fig. 19). These wells also responded readily to the cessation of pumping. During the pumping period of the test, water levels in each well between the impermeable boundary and Highway 27 continued to rise, except in well No. 178, which was located 150 feet away from a well continuously pumped for supplying the town. Water levels had not been measured at the flowing well, No. 244, during the last pump test, until its owner (Mr. Zimmerman) reported that the well stopped flowing. After 5,760 minutes of pumping the water level was 1.80 feet below the top of the casing, and it is estimated that it was at least 3 feet below its head prior to the test. The distance between wells Nos. 192 and 244 is approximately 1.3 miles.

Thus, pump test 3 conclusively proves the existence of a relatively highly permeable body, having an elongated shape, assuming an east-west direction, and connecting wells Nos. 187, 192, and 244, as was indicated by the analysis of the natural flow systems. The main part of this body is located alongside the south banks of a buried channel, but it seems to cross the channel to the east.

*Summary of the Groundwater Movement*

On summarizing the results of the flow-system analysis and of the practical experiments, the following picture of the groundwater regime can be established in the area east of Olds.

A regional flow system, I, originates along and immediately east of the Olds High. This system may be divided into three parts: IA, IB, and IC. The surfaces of the areas of downward and upward flow of system IA are adjacent. The same surfaces of the systems IB and IC are separated by local flow systems superimposed on the regional system. The upward flow of systems IB and IC reaches the water table along and directly east of the eastern parts of the map-area. Local systems 2, 3, and 4 owe their existence to topographic irregularity, whereas system 5 is caused by the separating effect of an elongated body of permeable rock surrounded by less permeable material. By analogy, system 1 is presumed to be similar to system 5, that is, to be caused by a lens of relatively high permeability.

Two anomalies in the water levels have been found, the first attributable to an impermeable boundary, and the second to a permeable lens. The impermeable boundary is approximately parallel to the direction of flow in system IC, separating it completely into two parts. The same impermeable boundary acts as a dam with respect to local systems 3 and 4, raising the water levels in these systems over the land surface. The body of increased permeability connecting wells 187, 192, and 244 causes anomalously low water levels at well 187, and this anomaly decreases and changes in level to the east. This body also gives rise to a local system, the area of upward flow of which is merging with that area of a short regional system coming from the southwest. These areas are represented by the third, that is, the southernmost area of flowing wells. The systems south of the impermeable boundary are all hydraulically connected, and they can exist separately only as long as the hydraulic conditions are not disturbed by pumping.

## Recharge and Discharge of Groundwater

For an analysis of the general recharge and discharge conditions in the Olds area the water-level records taken at Olds Well No. 147 since November 1961, and precipitation data between February 1961 and September 1964, have been used as a starting point (Fig. 20). The well hydrograph was obtained by a Leupold and Stevens FM automatic water-level recorder installed by the Research Council of Alberta. The recorder was serviced by a local man, who failed to collect a complete record. No complete records of precipitation exist for Olds, and for missing periods data from the closest weather stations were substituted. Due to the relatively uniform climate of the area no large errors, for the present qualitative purposes, are thought to have been introduced by the above substitutions.

The period of maximum precipitation in the area occurs during the months May, June, July, and August. This is also the time of the major water losses by evaporation and vegetative transpiration. The surplus water that can infiltrate gradually accumulates, raising the groundwater level slowly during the growing season and more rapidly after the first killing frosts. As a result a maximum in the groundwater levels is reached during the winter. Whereas a time lag of approximately one-half year is apparent between the rainy periods and maximum water levels, the effects of daily rainfall are also recorded by sharp peaks of short duration on the well hydrograph. For instance, the rain which fell in early May and between the 11th and 20th of June, 1964 is represented by relative maxima on the well hydrograph on the 6th of May and the 21st of June. Also, heavy rains on the 3rd and 4th of July, 1964, resulted in a well-pronounced rise in the water levels starting on the 3rd of July, 1964. This correlation between precipitation data and groundwater levels indicates a direct recharge of the groundwater regime by precipitation.

A rise in the water levels due to the early July rains was noticed in each test hole in which water-level observations were conducted, except in Olds Well No. 177 (Fig. 21). In the area north of the impermeable boundary the rise in the water levels ranged between 2 and 10 feet. A definite rise in the water levels of the wells south of the boundary was also observed, with a maximum of 0.6 feet at well 188.

The pumping tests proved that the wells are hydraulically interconnected, and the hydrographs show a direct recharge from precipitation (see also hydrograph of Olds Well No. 147 during pump test 2, Fig. 20). From the two observations it is concluded that the aquifers are replenished each time the precipitation exceeds evapotranspiration in the Olds area. The amount of this recharge, however, can not be estimated owing to the lack of data.

## Summary

In conclusion it may be stated that the elements of the groundwater regime in the area east of the Olds High are topographically controlled, geologically modified, and hydraulically connected unconfined flow systems, having extended areas of downward and upward flow. One regional system, consisting of three parts, and five local systems have been recognized. Anomalous water levels have been explained on the basis of the concepts of natural flow systems, and have been found by experiments to be caused (a) by a vertical impermeable boundary, and (b) by an extended body of relatively high permeability. The probability of the occurrence of bodies of high permeability is greatest along buried valleys on the surface of the bedrock. A direct exchange of water between the atmosphere and the zone of saturation is possible in the area in question.

# GROUNDWATER CHEMISTRY

## Introduction

The purpose of the investigation of groundwater chemistry in the Olds area was threefold: (1) to obtain detailed information regarding suitability of the groundwater in the Olds area for human consumption; (2) to establish an areal but detailed picture of the groundwater quality in a centrally located part of the province; and (3) to study the local relations among groundwater chemistry, geology, and flow systems.

Water-analysis reports were obtained from previous investigations and from a well-water survey carried out by the writer. Seven analyses could be used from various reports prior to 1964. Water samples were taken in 85 wells, in some instances from different depths, and after different lengths of pumping time, yielding a total of 102 analyses in the course of this investigation.

The water analyses were made by C. E. Noble, Provincial Analyst. Some of the analyses are similar to those standard in Alberta for health purposes; the majority, however, report the main cations and anions separately. Appendix C is a summary of the available water-analysis reports. The Provincial Analyst determined the following cations and anions: $Ca^{++} + Mg^{++}$; $Ca^{++}$; in some instances $Na^{+} + K^{+}$; $Fe^{++}$; $HCO_3^{-} + CO_3^{--}$; $Cl^{-}$; $NO_3^{-}$; the other components have been calculated from those determined.

## Areal Distribution of Chemical Constituents

### *Total Solids*

The distribution of the concentration of total solids is represented by contour lines with 500-ppm intervals (Fig. 22). According to figure 22 groundwaters north of Highway 27 and west of the Olds High generally contain less than 1,000 ppm of total-solid matter. Southeast of these boundaries the concentration is above 1,000 ppm and may reach values even over 2,000 ppm. Two low-concentration areas have been mapped here; the first, except for a northward-reaching tongue, lies along the south edge of the center part of the map, and the second is in the flowing-well area in the extreme southeast corner. However, not every flowing well contains water with low concentrations. Three wells are known, on the west side of the flowing-well area, the waters of which contain 1,500 ppm or more of total solids.

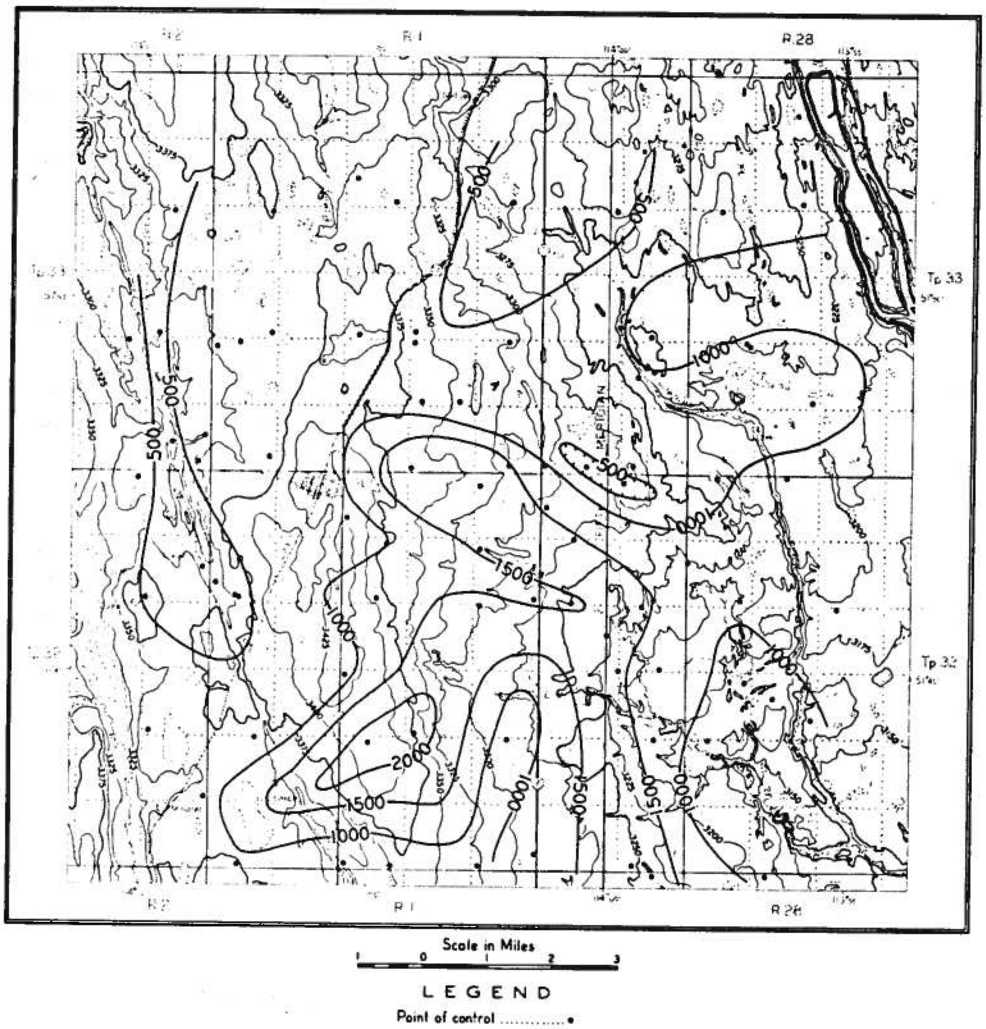


*FIGURE 22. Map showing areal distribution of total solids, in ppm.*

A general increase in total solids toward lower topographic elevations may be observed in the southeast part of the area, with the exception of the two low-concentration areas, mentioned above. In the north and west halves of the map-area this situation seems to be reversed due to the presence of the two topographically depressed areas with waters containing less than 500 ppm.

*Sodium and Potassium*

Sodium and potassium have, in most cases, not been determined separately. Figure 23 shows the areal distribution of the $Na^+ + K^+$ percentages of the total cations. From figure 23 it is seen that groundwaters containing more than 80 per cent of $Na^+ + K^+$ of their cations are predominant in the map-area. Two small areas are found with waters of less than 60 per cent $Na^+ + K^+$ content. One of these is the gravel-filled depression west of Olds. Samples of groundwater have been obtained here from shallow wells completed in the gravels, and the relatively small amounts of bedrock material included in these gravels explains the low $Na^+ + K^+$ content. The other area of low $Na^+ + K^+$ percentages, however, does not seem to be different from the other parts of the area, either topographically or geologically, and a reason for this feature has not been found. Nor is the apparent north-south lineation of the areal distribution of $Na^+ + K^+$ values understood. It might be pointed out that the plotted contour-lines tend to assume a direction at right angles to the flow-systems: the evidence is, however, too weak to warrant further discussion.

*Bicarbonate and Carbonate*

Figure 24 shows the areal distribution of $HCO_3^- + CO_3^{--}$ expressed as percentage of the total anions in epm. The only other major anion known to occur in the groundwaters of the Olds area is sulfate.

A strip of low relative $HCO_3^- + CO_3^{--}$ content divides the southern portion of the area in two parts. Bicarbonates and carbonates constitute more than 50 per cent of the anions in the north and west part of the map-area generally, and over large areas here they exceed 70 per cent and even 90 per cent. The waters in the gravels, west of Olds, stand out with their high relative content of $HCO_3^- + CO_3^{--}$.

*Chlorides*

Owing to the very small amounts of $Cl^-$ in the Olds groundwaters and to the possibility of analytical errors, a discussion of the distribution of this anion is hardly warranted. There are, however, two features which seem consistent enough to attribute their existence to some natural cause. One

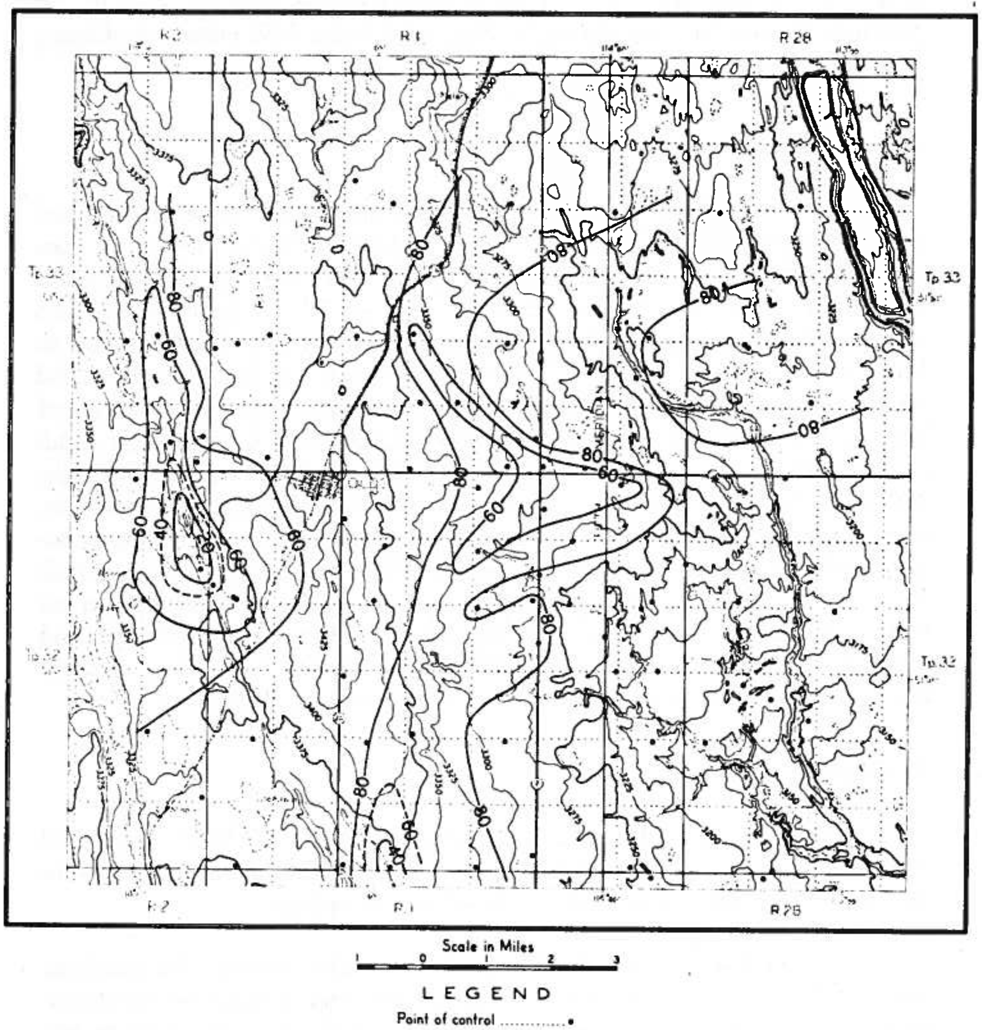


*FIGURE 23. Map showing areal distribution of sodium and potassium ions, in percentage of total cations.*

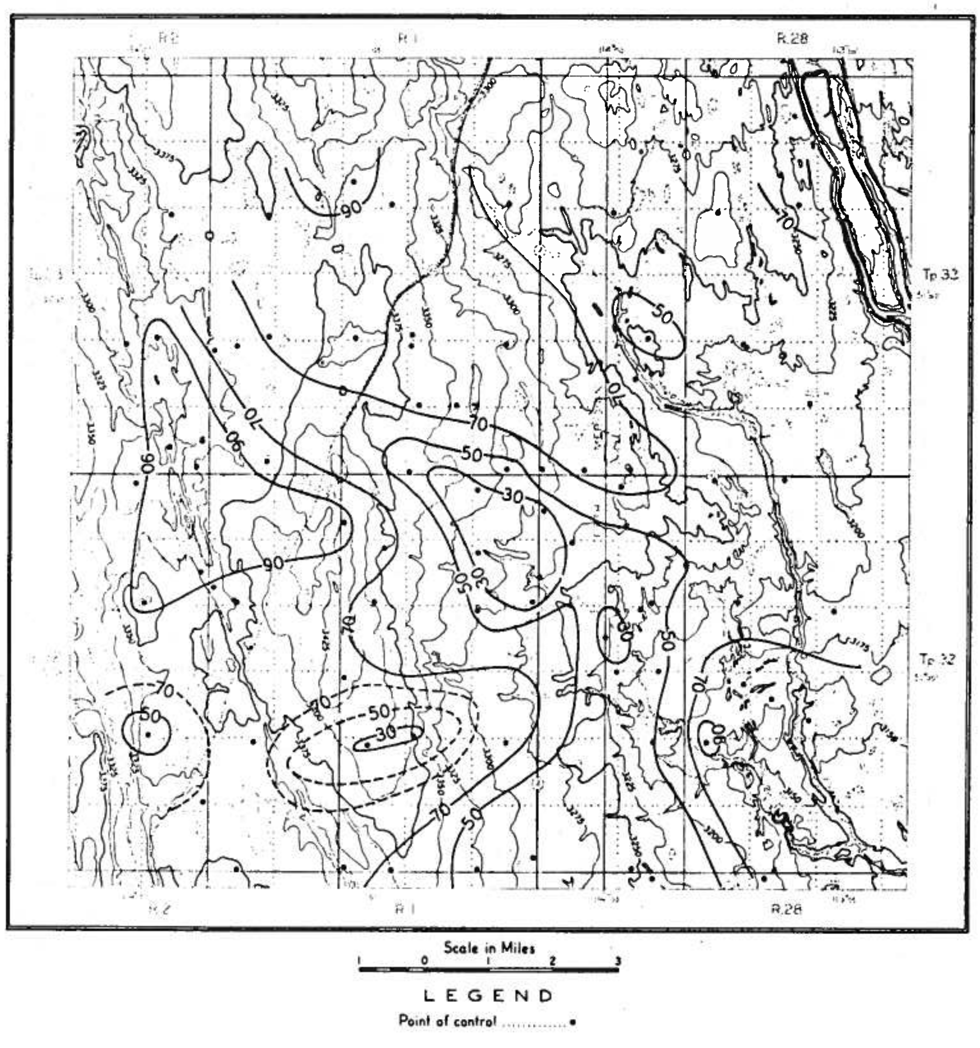


*FIGURE 24. Map showing areal distribution of carbonate and bicarbonate ions, in percentage of total anions.*

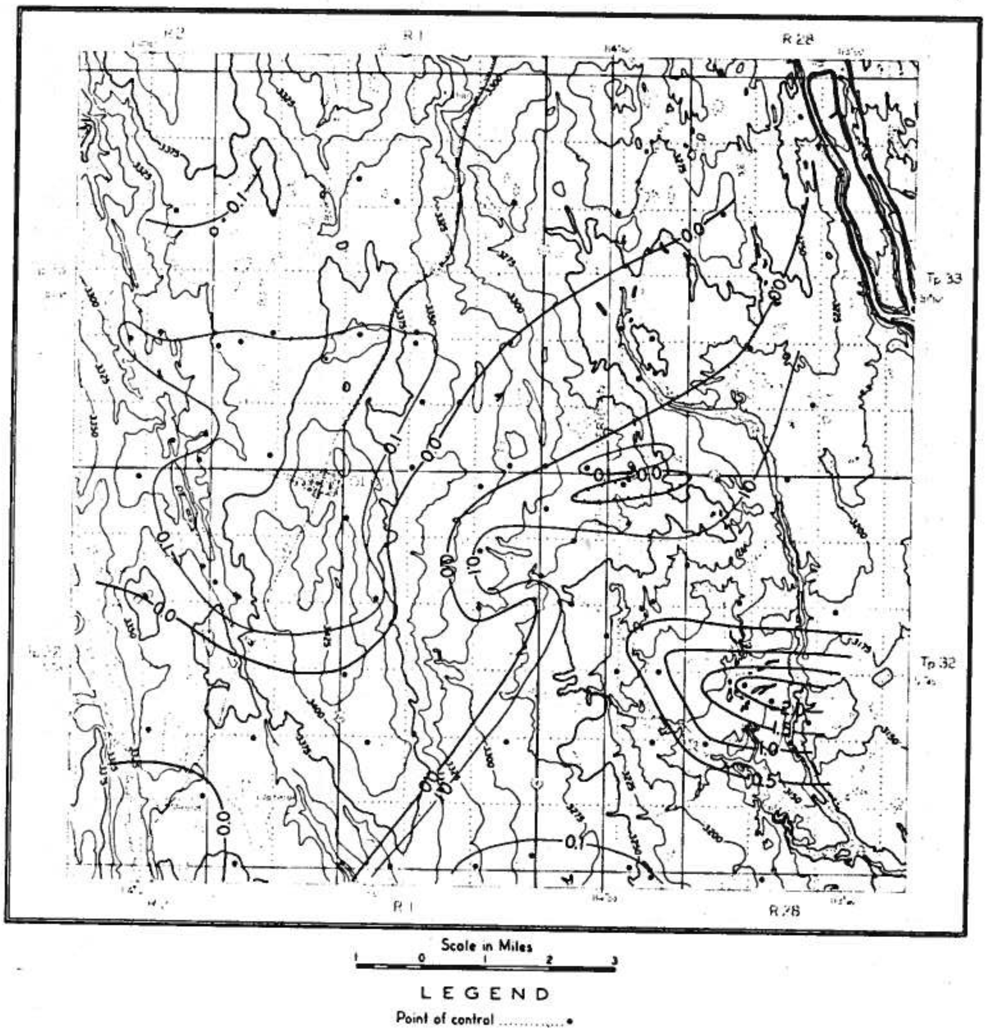


*FIGURE 25. Map showing areal distribution of chloride ions, in epm.*

of these features is a narrow area stretching across the map-sheet from northeast to southwest (Fig. 25). In this area chlorides are not found in the groundwaters. The other area worthy of mention is the northern part of the flowing-well area in the southeast corner of the map-area. Here the chloride content is higher than that commonly found in the Olds area, with a reported maximum value of 2.11 epm (75 ppm). It is observed that non-flowing wells (e.g. Olds Well No. 192) contain more than 0.5 epm $Cl^-$, and that flowing wells within the same area may have none at all. Except for the two areas mentioned here, the other waters contain $Cl^-$ in amounts between 0 epm and 0.5 epm (approximately 18 ppm). A gradual and definite increase in the $Cl^-$ content with increasing well depth was observed during the construction of Olds Well No. 147, but testing methods were not sufficiently accurate to warrant reporting absolute amounts.

*Calcium-Magnesium Ratio*

Four areas may be outlined on the map (Fig. 26) in which the groundwaters contain more $Ca^{++}$ than $Mg^{++}$. Over extended areas, however, groundwaters either lack both of these cations or have more $Mg^{++}$ than $Ca^{++}$, measured in epm. The major boundaries between areas of different calcium-magnesium ratios are approximately parallel to the flow lines of the groundwater system. Since the $Ca^{++}:Mg^{++}$ ratio is believed to change only slightly along short paths of groundwater movement, the above observation would indicate different original ratios of calcium and magnesium of the rocks in the areas of downward motion. Similar observations have been made and similar conclusions reached in the Hand Hills area of central Alberta (A. Vanden Berg, personal communication).

*Iron*

The iron content of the groundwaters at Olds is generally less than 1 ppm (Fig. 27). There are a few wells, however, which are noted for their high contents of iron. All of these occur east of the Olds High, on relatively elevated, but not on the highest, parts of the area of study. It is noted that the lowest areas are generally occupied by waters containing iron in traces only. Also, it is interesting to note that an area of low and one of high iron content are contiguous in the north part of the map-area, the dividing line between the two being Lonepine Creek.

**Analysis of Chemical Data in Terms of Flow Systems**

The maps which were discussed in the preceding paragraphs adequately represent the areal distribution of the major chemical constituents. They may be of use in inquiries into the expected quality of groundwater for

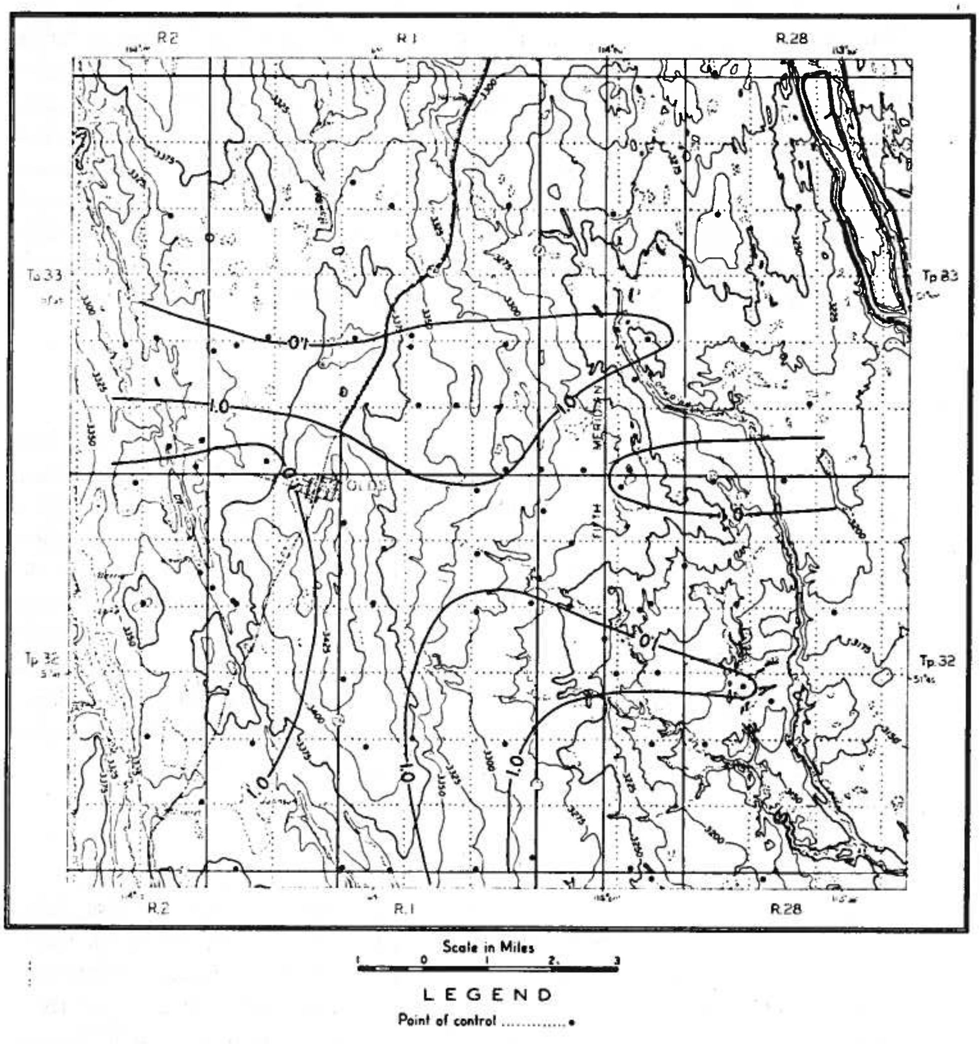


*FIGURE 26. Map showing areal variation in the calcium : magnesium ratio.*

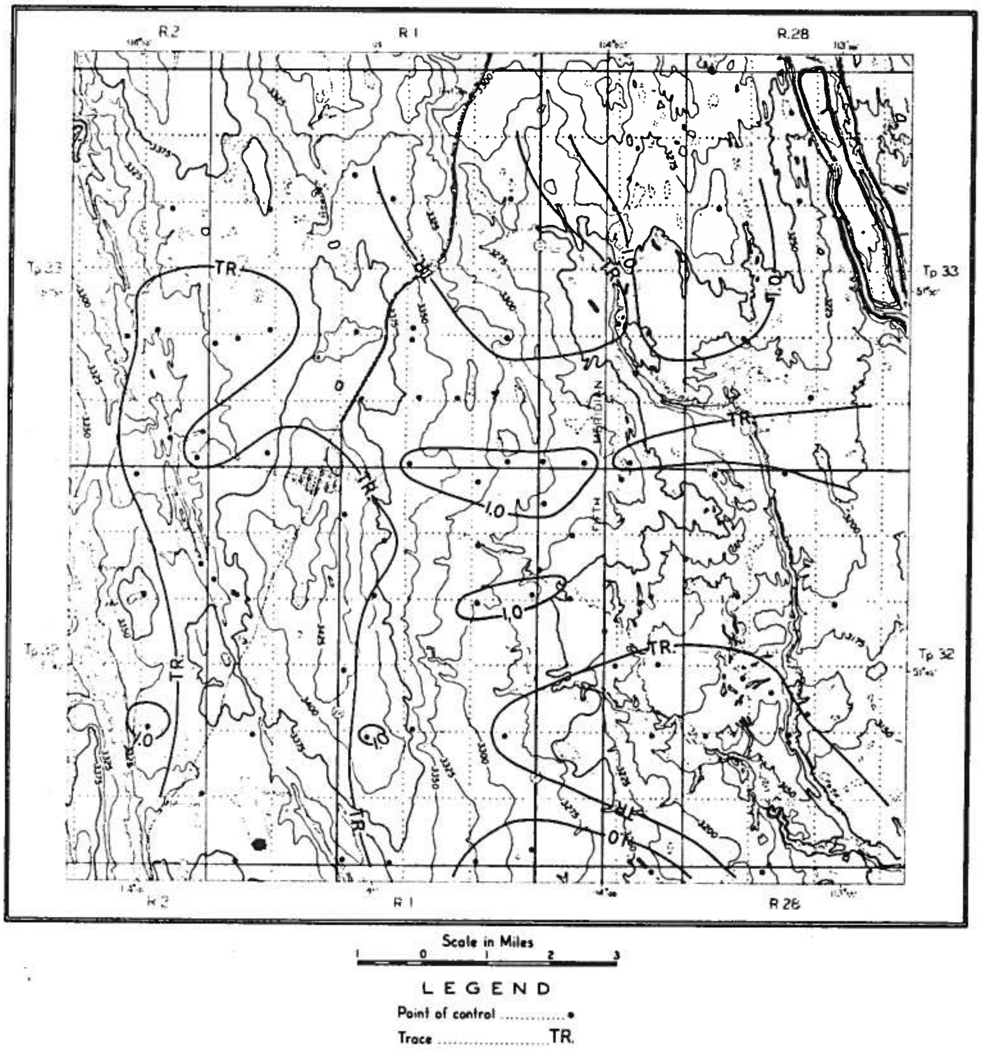


*FIGURE 27. Map showing areal distribution of iron, in ppm.*

possible future developments in different parts of the area of investigation, but they throw little light on the relations among water quality, geology, and movement of groundwater.

In an attempt to elucidate, at least partially, the mutual effects of the geology, movement, and quality, each water sample was identified as belonging to a particular flow system from its location on the map showing the distribution of the areas of downward and upward flow (Fig. 16), and the hydraulic cross sections (Fig. 15) were used to determine the vertical situation of the samples with reference to the flow systems. The analyses for each system were then plotted on trilinear diagrams (Piper, 1944), using different symbols for waters from areas of downward, and areas of upward flow. It was found that different systems may have similar types of water. The analyses of such systems have been brought together on the final diagrams.

Figure 28 shows the analyses of waters which are thought to occur in systems IA, IB, 1, and 2. These systems occupy the north part of the map-area. Marked differences may be observed between the anion facies of waters in areas of downward flow and upward flow. With two exceptions, the anions of the downward-flow area waters comprise 80 per cent or more $CO_3^{--}$ + $HCO_3^-$, whereas the upward-flow area waters are characterized by a narrow range of 60 to 70 per cent of $CO_3^{--}$ + $HCO_3^-$. Waters in areas of downward flow show a slight tendency to have a higher percentage of $Cl^-$, but the absolute amounts of $Cl^-$ are so small that no definite conclusion is warranted. Regarding the relative amounts of cations, no difference in the $Na^+$ + $K^+$ content between the waters of the different areas can be recognized. However, whereas waters in areas of downward flow generally have a calcium: magnesium ratio greater than 1, magnesium is predominant in areas of upward flow. The large spread in the relative amounts of the different cations in areas of downward flow may be indicative of a wide variation in the chemical composition of the rocks. The large original differences are then averaged out or diminished by the water moving through rocks of different composition before it is recovered in the area of upward flow.

In general, a tendency is apparent for the waters in the flow systems under consideration to shift their chemical character from a pure bicarbonate type toward the sulfate facies whilst moving to the areas of upward flow. This is easily understood when one considers that the available amount of $CO_2$, dissolved in the infiltrating rainwater and considerably increased in the root zone of the plants, is first used up to form bicarbonates in the downward-moving groundwater. The longer time the water spends underground, the slower the increase in the $CO_3^{--}$+ $HCO_3^-$ content becomes, and the more dominant the sulfate-ion percentage becomes. There is no practical limit to the accumulation of sulfates since it is available in readily

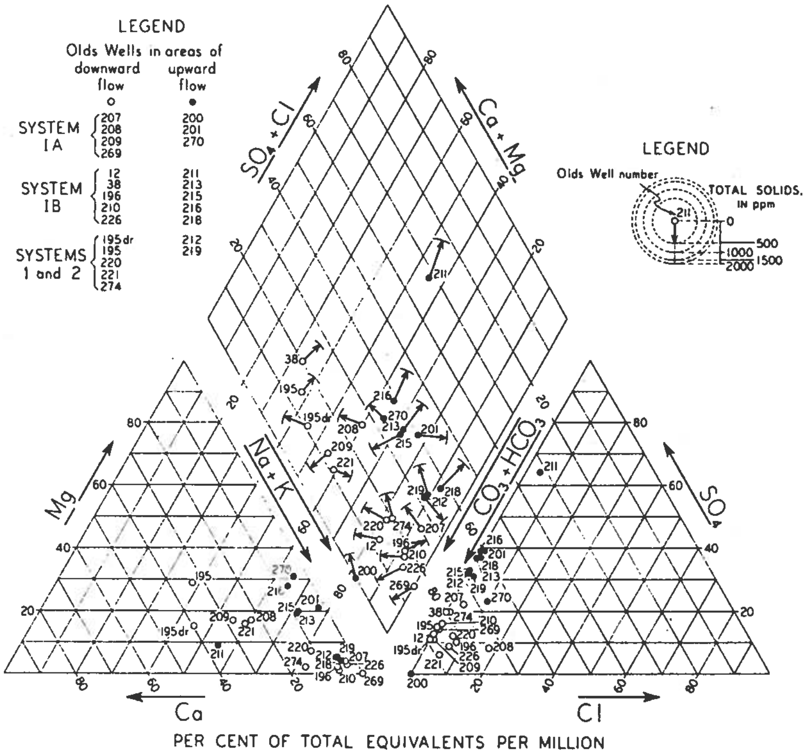


*FIGURE 28. Distribution of the water-quality in the flow systems IA, IB, 1, and 2. ("dr" refers to a well completed in drift.)*

soluble form in the bedrock of the area. Also, the increase in the relative amount of sulfates in the areas of upward flow is accompanied by an increase in total solids, indicating an addition of new mineral matter to the groundwater.

The waters which are attributed to the flow systems IC, 3, and 4 (Fig. 29) do not offer such a clear-cut picture of chemistry as was seen in systems IA, IB, 1 and 2. The total-solids content in this group is relatively high, averaging approximately 1,500 ppm. Except for a small group of four wells, the $CO_3^{--} + HCO_3^-$ percentage is between 20 and 60, with the high relative sulfate concentrations occurring predominantly in waters from areas of *downward* flow. The chloride portion of the anions is consistently below 5 per cent, regardless of the origin of the water sample. Regarding the cations, waters from both types of area are mainly sodium-potassium in character. The ratio of the relatively small amounts of calcium and magnesium averages very close to 1 both for areas of downward flow and of upward flow. The flow systems in question are rather complex and they cover a large area. The apparent uniformity of the

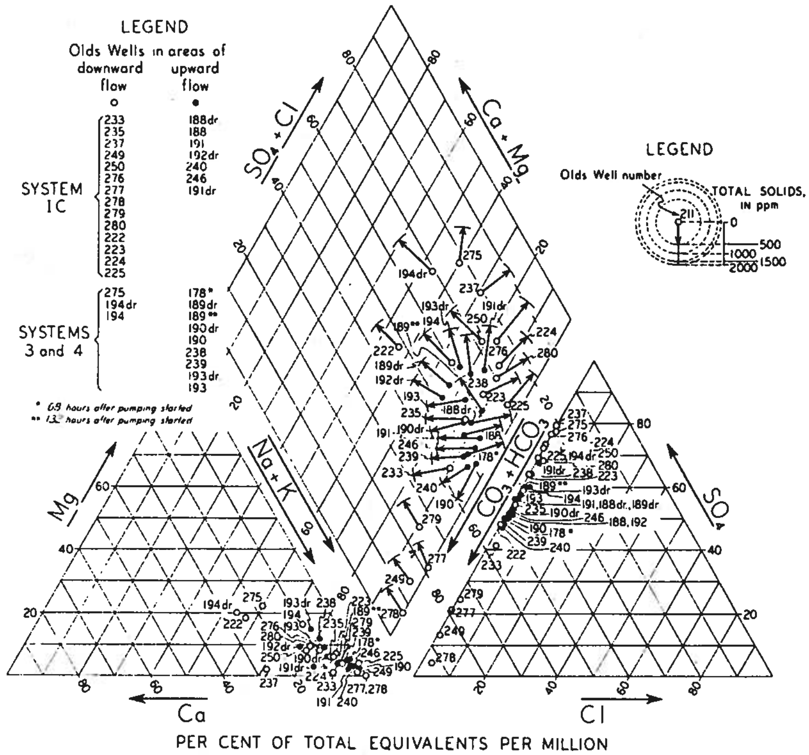


*FIGURE 29. Distribution of the water-quality in the flow systems IC, 3, and 4. ("dr" refers to a well completed in drift.)*

chemistry of the waters from the hydraulically different areas (areas of downward flow and upward flow) might, in part, be due to a failure to determine the locations of the individual sources properly with respect to the flow systems. It is reasonable, however, to assume that the homogenizing effect of long flow paths, as discussed in connection with the previous set of flow systems, might play an important role here. This assumption is supported by the generally high total-solids content of this group of waters. In a long system waters might follow a longer path and spend more time by travelling through the area of downward flow only, than do waters in short systems during both downward and upward flow. Concerning the short flow systems of this group, no conclusions can be drawn owing to the small number of analyses from areas of downward flow. The slight tendency toward an increasing proportion of bicarbonates, without an increase in the total solids might indicate a reduction-oxidation reaction between the sulfates and the abundant coal and other organic matter occurring in this area. A similar observation in Alberta was made by Meyboom (1960, p. 64), who explains a decrease in the sulfate concentration of the groundwater in the Milk River Sandstone by a reduction of calcium sulfate by methane.

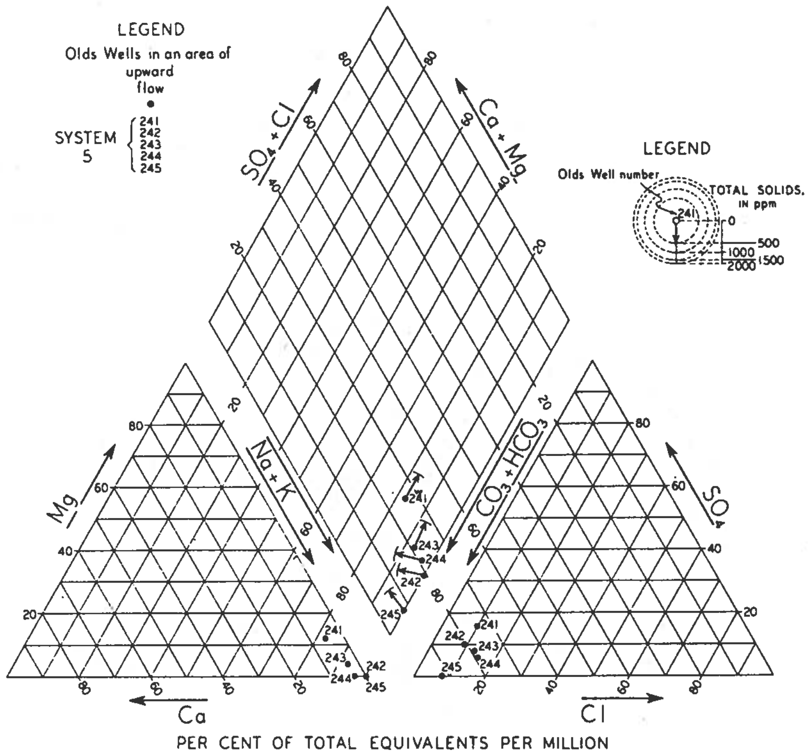


*FIGURE 30. Distribution of the water-quality in flow system 5.*

The generally different type of waters in these flow systems from that in systems IA, IB, 1 and 2, also suggests different chemical composition of the rock units in the two areas.

In figure 29 the four samples in the high $Na(HCO_3)$ range form a separate group. It is noteworthy that these waters occur either very close to the divide of system IC, or at the extreme south, where the boundary of another system is thought to be situated. The area of upward flow of this last-mentioned system merges with that area of system 5. The only difference noticed between the chemical character of the waters from areas of downward flow and areas of upward flow in the extreme southern end of IC and 5 (Figs. 29 and 30) is the definitely higher chloride content in the upward-moving waters. Apparently the only major change in the chemical quality of the groundwater in the extreme southern parts of the map-area along the flow lines is an increase in the chloride content.

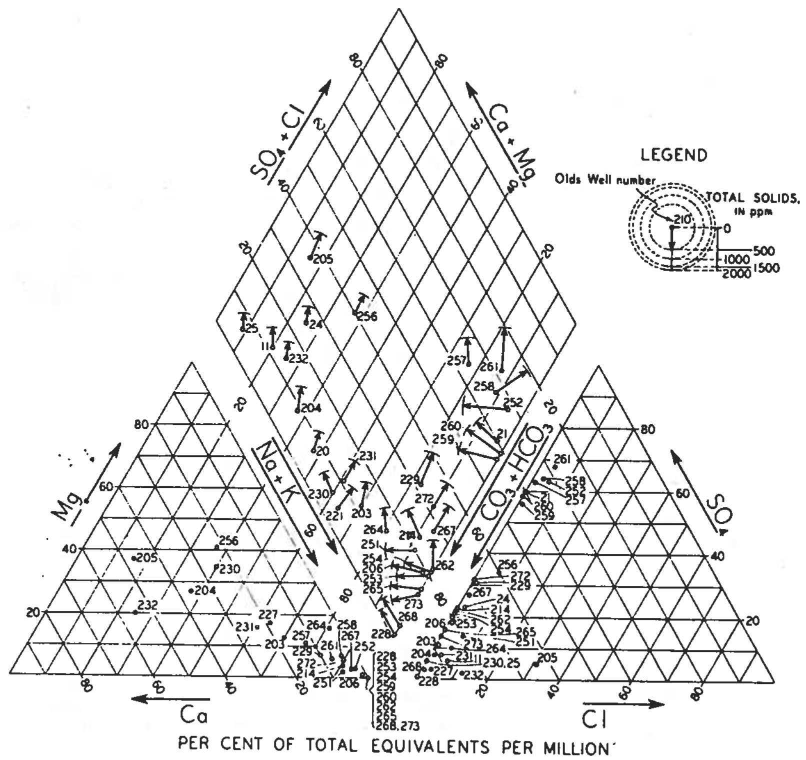


*FIGURE 31. Trilinear diagram showing water qualities outside of the area of described flow systems.*

Chemical analyses of waters from areas outside of those discussed above are shown in figure 31. Here, too, the same basic types of water occur but their detailed consideration within the flow-system concept is not possible because of insufficient information for the construction of flow systems.

## The Chemical Types of Groundwater

An inspection of figures 28, 29, 30, and 31 reveals that the majority of the water analyses are grouped around one or other of four centers of water quality. On the basis of this, each water sample was assigned to one of the four groups so defined. The average chemical qualities, and the limits of constituents for the groups are shown in figure 32. The same averages, calculated in equivalents per million, and the number of analyses used are also given in the pattern diagrams of figure 33.

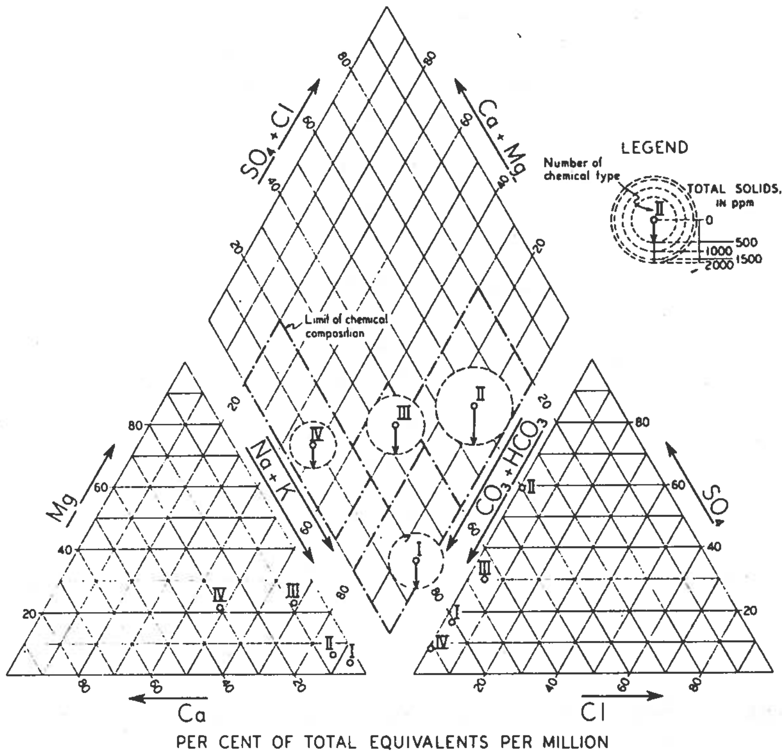


*FIGURE 32. Trilinear diagram showing the four main chemical types of groundwater in the Olds area, in epm.*

Most groundwaters in the Olds area belong to either group I or II (Figs. 32 and 33). Group I is characterized by an average of 830 ppm of total solids and a typical sodium-bicarbonate quality. This is the type of water that can be expected in most areas north of Highway 27, along the highest parts of the Olds water divide, and in the south and southeast parts of the map-area. Group II waters contain almost twice as much total solids as Group I waters, averaging 1,590 ppm. This is a sodium sulfate-bicarbonate type group, sulfates making up 60 per cent of the anions. This water is definitely inferior to that of the previous group, and it occupies mainly the area east of the Olds High and south of Highway 27 except the most southerly part of the map-area. Group III occupies an intermediate position between the other water types and is probably derived from Groups I and IV by being restricted to a relatively short flow system. The average of the total solids is 860 ppm. The major anions and cations are bicarbonates and sodium, but sulfate, and magnesium and calcium ions may total as much as 40 per cent. The chemical quality of group IV is typical of "young" groundwaters in the area, and as such it is found in areas of downward flow of short systems or in topographic depressions

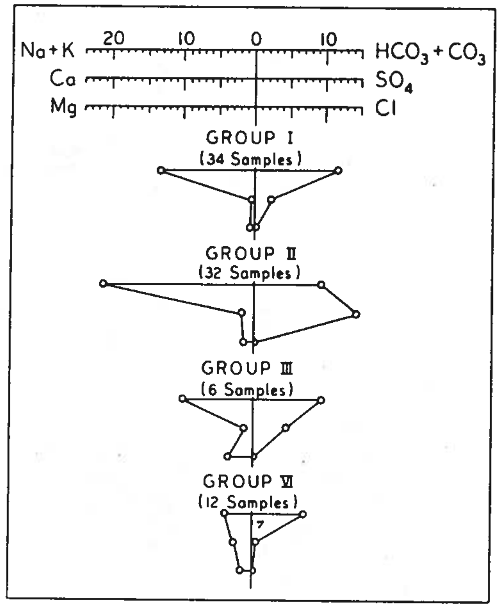


*FIGURE 33. Pattern diagram showing the four main chemical types of groundwater in the Olds area, in epm.*

where water from precipitation is collected and stored, as in the gravel pits. Whilst the total solids in this group average only 500 ppm, it has the highest percentage of bicarbonate anions, namely over 90 per cent. The alkali metals and alkali-earth metals are, on the average, equally represented. The $Ca^{++}$:$Mg^{++}$ ratio is slightly over 1. None of the four groups contains any appreciable amounts of chloride.

## Interpretation of the Chemical Results

The major cations in the groundwaters of the Olds area are $Na^{+}$, $Ca^{++}$, and $Mg^{++}$. These alkali and alkali-earth metals are derived from the weathering and solution of silicate minerals of igneous rocks, clay minerals, and nonsilicate sulfates and carbonates. The main silicate minerals that are found in the clastic sediments of the area are feldspars, pyroxenes, amphiboles, olivine, and micas. Montmorillonite is the chief representative of the clay minerals, and gypsum, anhydrite, calcite, and dolomite are the important nonsilicate sources of calcium and magnesium.

The bulk of the iron is probably derived from iron oxide and iron carbonate present in the Paskapoo sandstones, but also pyrite associated with the coal seams and other carbonaceous matter must be an important contributor locally.

The major anions in the area of study are bicarbonate ($HCO_3^-$) and sulfate ($SO_4^{--}$). Carbon dioxide, needed for the formation of $HCO_3^-$ and $CO_3^{--}$ in the groundwater, is derived from the air by rain, from decaying vegetation, and through the roots of assimilating plants. It accumulates in the soil and is washed down to the zone of saturation by the infiltrating water.

The sources of sulfates in the area are gypsum, anhydrite, and oxidized pyrite.

The very low amounts of $Cl^-$ in the Olds groundwaters suggest rain water for their source, besides strengthening the evidence for the continental origin of the bedrock in the area.

The chemical types of groundwater and their areal distribution near Olds are interpreted here as the result of chains of natural chemical reactions which take place in unconfined groundwater flow systems of different depths and lengths, moving through very fine to fine-grained argillaceous continental strata containing large amounts of montmorillonite and carbonaceous matter.

The following are the main processes and factors which determine the chemical type of the groundwaters in the area: concentration of soluble salts; base exchange; differences in solubilities of salts; and sulfate reduction. By use of these concepts, the reasoning which leads to the above interpretation, and which is based to a great extent on Schoeller's work (1962, p. 351-376), may be outlined as follows.

Because of the fine-grained and argillaceous character of the sediments in the area their porosity is large; the permeability, however, is small. This condition results in a large surface of contact per unit volume between the rocks and the water, and also in low velocities. The larger the product (R) of this surface of contact and the time the water spends underground, the higher is the concentration of soluble salts that can be expected. R is generally large in the Paskapoo strata at Olds, which is the reason for the generally high total-solids content. Relatively low concentrations of total solids are found in waters of short flow systems, or in highly permeable sands and gravels occupying local depressions. The young age of these waters is demonstrated by their bicarbonate type. As these waters move toward the areas of upward flow, however, the relative amount of bicarbonates decreases, since the $CO_2$, which was available in the soil zone—that is, at an early stage—is used up to form bicarbonates, whereas sulfates continue to be available. The initial increase of bicarbonates, associated with low total solids, is shown in figure 34. Also, this illustration shows that a further increase in total solids has hardly any effect on the amount of bicarbonates.

In the long or the deep systems R is relatively large and, therefore, the total-solids content of these waters will be high as well. This is made up, however, mainly of sulfates, and the water type of group II originates. Due to the great length of their flow paths, these waters probably cross several coal seams, and a reduction of sulfates takes place between the areas of downward and upward flow (Fig. 29). The sulfate reduction results in the generation of free $CO_2$ which, in turn, renders the water acidic. If conditions are favorable, this acidic water may keep relatively high amounts of iron in solution. The areas of the highest iron content are, indeed, associated with areas of high sulfates (Figs. 24 and 27). (The contours for carbonates and bicarbonates in figure 24 represent also the distribution of sulfate concentration with a good approximation. The approximate relative amount of sulfate ions, in percentage of total anions, is obtained by subtracting the amounts of the carbonates + bicarbonates in figure 24, and those of the chlorides in figure 25, from 100.)

Since the chlorides are more soluble than the sulfates, wherever they are available the waters in the area of upward flow will contain relatively more $Cl^-$ than waters in the area of downward flow of the same system. This is the process to which is attributed the difference in the relative $Cl^-$ content between the waters in the downward and upward flow areas of the southeastern part of the map area.

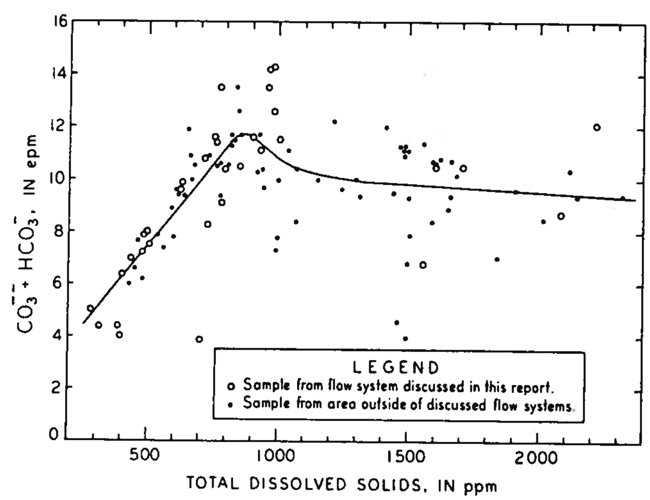


*FIGURE 34. Scatter diagram showing the amount of carbonate and bicarbonate as a function of the total dissolved solids.*

In groundwaters of the Olds area the investigated cations do not form marked patterns of areal distribution. This is probably due to the large quantities of sodium, both in the drift, which is reworked bedrock to a great extent, and in the bedrock. Locally, a limited amount of available sodium renders the downward-flow area waters relatively high in $Ca^{++} + Mg^{++}$, but, significantly, the waters in the areas of upward flow are all of the sodium type. Figure 35 shows that the relative amount of $Na^{+} + K^{+}$ increases rapidly in the young waters, after which stage it remains constant within the limits of error in the observation.

Finally it is pointed out that, according to figure 28, the amount of $Mg^{++}$ increases relative to that of $Ca^{++}$ in waters from areas of upward flow in the flow systems IA, IB, 1, and 2. Since $Mg^{++}$ is more soluble than $Ca^{++}$ this phenomenon may be expected within a flow system.

### Suitability of the Waters for Human Consumption

It is beyond the scope of the present paper to discuss the suitability of the different types of groundwater for various possible purposes, such as irrigation, industry, and so on. Only the aspects of direct human consumption will be discussed.

The chemical standards for water for human consumption depend very much on the quality of water that is available. Generally speaking, the groundwater in central Alberta is of medium quality, due to reasons discussed above. In table 2 limits suggested by the U.S. Public Health

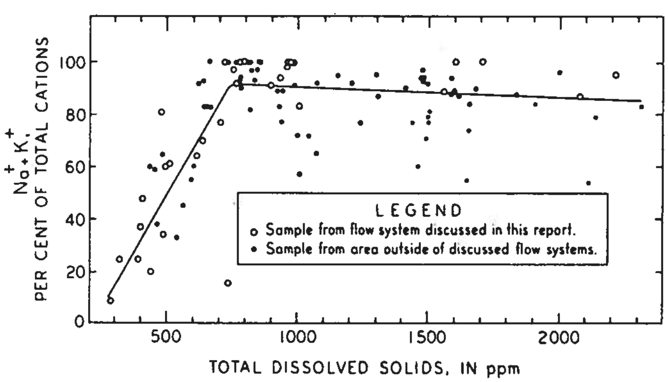


*FIGURE 35. Scatter diagram showing the relation between the relative amount of sodium and potassium and the total dissolved solids.*

Service (1961) and those used by the Alberta Public Health Units are given (in parts per million):

**Table 2. Chemical Quality Standards of the U.S. Public Health Service and Alberta Public Health Units**

| | U.S. Public Health Service | Alberta Public Health Units |
|---|---|---|
| Total solids | 500 | 1,600 to 2,000 |
| Sulfates | 250 | 400 for municipal supply<br>800 for private supply |
| Chlorides | 250 | 435 |
| Sodium | | 700 |
| Nitrates | 45.0 | 10 |
| Iron (+Mn together) | 0.3 | 0.3 Fe only |

According to Alberta Public Health Standards most groundwaters in the Olds area are acceptable for human use. There is, however, a marked difference between the water quality in the areas north of Highway 27, west of Olds, and in the south-southeast part of the map-area, on the one hand, and in the areas with total solid contents over 1,000 ppm on the other. Since construction of wells with favorable production characteristics seems to be possible in areas of good-quality waters, preferred development of the aquifers in these areas for supplies for public consumption is suggested here.

**Summary**

The study of the chemistry of groundwater in the Olds area has been based on water samples collected by the writer and analyzed by the Provincial Analyst. Groundwater in the area of study is generally suitable for human consumption but there are extensive areas to the north and to the south-southeast, which would be preferable for development for human use, owing to the good quality of groundwater.

Three basic types of water may be distinguished in the area. These are: (1) sodium bicarbonate, (2) sodium sulfate-bicarbonate, and (3) calcium-magnesium bicarbonate. A fourth type is thought to be the result of a mixing of types 1 and 3. There are strong indications that the pattern and nature of the distribution of the chemical constituents is controlled by the natural motion of groundwater. The changes in the water quality from areas of downward flow toward areas of upward flow for short systems is characterized by: a slight increase in total solids, a shift from strongly toward less pronounced bicarbonate type, and a decrease in both the $SO_4^{--}$:$Cl^-$ ratio, and the $Ca^{++}$:$Mg^{++}$ ratio. Groundwater in the areas of downward flow as well as in those of upward flow of long systems is highly loaded with total solids, except at or near the regional divide. Due to possible sulfate reduction in carbonaceous matter a shift from sulfate toward bicarbonate type might be apparent between waters in areas of upward and downward flow of long systems. In the areas of sulfate reduction high concentrations of iron may occur.

## GROUNDWATER EXPLORATION AND ENGINEERING

### Introduction

The groundwater exploration and aquifer-engineering activities which were carried out during the first nine months of 1964 had a dual purpose. Firstly, they were required to alleviate the immediate problem created by the failure of the town's water-supply wells and thus eliminate the necessity of bringing water by truck from a source 12 miles away at a cost of $200 per day. Secondly, they had to produce the type of information on the basis of which an assessment could be made of the groundwater potential in the Olds area in general, and of the feasibility of a permanent groundwater supply for the town of Olds, in particular. The operations were handicapped on the one hand by the emergency character of the problem creating a panicky atmosphere among officials, and, on the other hand, by the obvious hesitancy of the town council to provide the expenditures for exploration. Yet, definite answers were expected within a short time.

The original proposal of the Research Council of Alberta called for the completion of three test holes, regardless of the amount of water encountered in the first holes. If it were warranted, a pump test would then be conducted after the drilling of two additional observation wells. This proposal was accepted by the town, and after the pump test produced encouraging results the program entered its second stage, now on an enlarged scale.

During the second part of the program 15 test holes and 4 observation wells were drilled, and two major pump tests were conducted.

The actual program was divided into three phases: (a) planning; (b) exploration, which comprised test drilling and bail testing; and (c) engineering, the main facets of which were production tests and well completion.

In the following paragraphs a detailed description is given of the procedures outlined above with the emphasis on testing techniques believed to be adaptable to other parts of Alberta. An analysis of the economics of the present operations, compared to those of previous works, and recommendations close this chapter.

## Planning

No detailed planning could precede the exploration program at Olds because little information on groundwater was available and only two weeks elapsed between the first notice of the problem and the commencement of the test drilling.

The sites for the first three test holes (Olds Wells Nos. 177, 178, and 179) were decided upon on the basis of three points: (1) previous attempts to locate an adequate supply of water west and immediately northeast of town had failed, (2) the 700-foot deep test hole (Olds Well No. 147) drilled by the Research Council of Alberta in 1961 indicated favorable conditions of water occurrence, recharge (by continuous records of water levels), and hydraulic head in the aquifers approximately six miles southeast of Olds, and (3) theoretically, conditions of hydraulic head are favorable in areas of upward flow. The idea that the area east of Olds was an area of upward flow of groundwater was supported by local farmers' reports (for example, Mr. W. Hammer, personal communication, who reported that the crops are always good and "no dry years have been known on this land"). Good crops have been associated with "natural subirrigation" by King (1892, p. 28). In his early and clear-sighted paper he states: "It is a fact long established by practical experience that many low lands which require tile draining in order to bring them under cultivation, and lying adjacent to higher areas, become, when so treated, if adequately done, the most productive lands of the locality, and while there are several conditions which render them so the paramount one is the water supply naturally provided by the upward tendency of it under the low lands, coming from the supply of impounded water in the soil of the surrounding higher ground . . . ". Also, reports of the occurrence of flowing wells farther southeast seemed to confirm the basic concept.

The first three test holes were planned to be drilled as close to town as possible but in the area of theoretical upward flow. Besides this, they had to be drilled along roads in order to provide easy access for trucks hauling water to the town's water system, in case a usable quantity was found. When drilling and testing these holes, a geologic aspect was included with the considerations of planning for continued exploration. The presence of a bedrock channel was noticed with indications of relatively high permeability along its banks. Further drilling was planned mainly along the projected course of the channel where a favorable combination of high head and relatively high permeability could be expected. In the area north of Highway 27 locations for test holes were staked on the presumption that topographically similar features might be indicative of geologically similar conditions.

With respect to the actual drilling and testing operations, the specifications called for: cable-tool (percussion) equipment, lithologic sampling at 5-foot intervals, electric logging, chemical analyses of both drift and bedrock waters, water-level measurements before and after the day's drilling, bail tests at a standard rate of discharge with 2-hour bailing and 2-hour recovery periods, pumping tests of several days' duration with water levels being measured at least in two observation wells located at distances of 15 feet and 150 feet from the pumping wells. The diameter of the test holes was 8 inches in the drift and 6 inches in the bedrock. Seven-inch O.D. casing provided with a drive shoe was set by driving it into the first suitably tight formation in the bedrock, to prevent the loose drift material from caving into the hole, and to prevent the water in the drift from mixing with bedrock water in the hole. The depths of the holes depended on local conditions and were determined during drilling. The locations and elevations of the holes were surveyed.

## Exploration

### *Survey, Sampling, Logging, Water-Level Measurements*

The exploration activities followed very closely the procedures outlined in the plans. Electric logging, however, which was the self-assumed responsibility of the town of Olds, was called to a halt after the inadequacy of the obtained logs became apparent. Since no facilities for the examination of the lithologic samples could be provided in the field, the samples were shipped to Edmonton and described there which resulted in much lost time for the geologist who had to spend his time at the drill sites supervising. The results of the survey of the locations and elevations (carried out by the town of Olds), the lithologic sample descriptions, and the daily water-level measurements, for the test holes of this program are reported in Appendices A, B, D*, and E*.

### *Bail Tests*

The bail tests formed one of the most important phases of the exploration program. The calculated values for the coefficient of transmissibility at the test sites, while carrying a certain degree of inherent inaccuracy in their absolute magnitude, served as reliable indicators for the relative prospects of groundwater potential. The main reason for the inaccuracy in the absolute values is the fact that the mathematical formulas used in the calculation of the transmissibility coefficient are strictly valid only for

* Appendix not included with published report. Copies are available on request.

idealized geologic situations, which do not exist in nature. As soon as the strata have a lenticular distribution of permeability, the application of either confined or free water-table case formulas is not strictly correct. Moreover, the relative position of the lenses with respect to the discharging well adds an extra complicating factor in the flow distribution.

Bail testing is the periodic removal of constant amounts of water out of the well, with a long tubular container equipped with a foot valve. According to current methods of bail testing, recovering water levels are measured repeatedly after bailing has gone on for a given length of time. Mathematical formulas for this recovery method are available (Skibitzke, 1958; Lennox and Jones, 1964). In order, however, to obtain an idea of the reliability of the transmissibility values, the changes in the water levels were measured during the periods of both drawdown and recovery in the course of the present program. Time intervals and the water-level measurements for the bail tests are given in Appendix F*. The rate of bailing was kept at a constant 20 igpm in each case, by removing a volume of 10 imperial gallons of water each half minute. Water levels were measured with a combination of a steel tape and an electric tape. This combination was particularly useful during the period of bailing because the electric tape's touching the surface of the water in the well and the reading of the "depth to water" could be measured simultaneously, thereby avoiding a delay in lowering the next bailer. Figure 36 shows this procedure of water-level measurement during bailing. This technique becomes increasingly difficult to apply in cases of deep water levels because of the length of time the bailer is in the hole. The water-level measurements have been evaluated according to the Jacob, or "straight-line" method which is a modification of the Theis nonequilibrium equation (Cooper and Jacob, 1946). This method is quick, it enables the coefficient of transmissibility to be calculated from measurements taken in the discharge well without the use of observation wells; it may be applied to both drawdown and recovery curves; and as long as the measured points fall on a straight line on a semilogarithmic plot it is as accurate as other methods. The equation used in obtaining the transmissibility of the formations at the test sites is (Todd, 1959, p. 94):

$$T = \frac{264.Q}{s} \tag{4}$$

where: T = coefficient of transmissibility, in igpd/ft; Q = rate of bailing, in igpm; and s = drawdown difference in ft/log cycle. Figure 37 shows the bail-test data graphically. From the graphs and with equation (4) the transmissibilities for each test hole have been calculated. The bail-test results are summarized in table 3. In general, good agreement between the

* Appendix not included with published report. Copies are available on request.

*FIGURE 36. Photograph showing water-level measurements during bail test.*

drawdown and recovery measurements is apparent in figure 37. In certain cases the difference in slope is so small that one common curve, representing both measurements, could be assumed. Despite the scatter of the values in the drawdown measurements, these curves prove occasionally to be very useful guides in deciding which portion of the recovery curve should be used for the transmissibility determination (e.g. Olds Well No. 187, Fig. 37). Also, the general confidence in the results obtained increases when two independent sets of measurements yield consistent results.

For calculating the safe yield of the test holes for a period of twenty years, a rearranged form of equation (4) was used:

$$Q_{S_{20}} = \frac{T.H}{2110} \qquad (5)$$

where $Q_{S_{20}}$ = safe yield supplied from existing storage for twenty years, in igpm; H = total available drawdown, taken as the difference between the nonpumping level and the top of the aquifer, in feet.

In table 3 of the value of T for Olds Well No. 194 is definitely doubtful. This is due to the extremely low rate of drawdown and the consequent uncertainty of the measurements, as a result of bailing at only 20 igpm. Whereas the numerical value of 586,000 igpd/ft can not be

## Table 3. Summary of Bail-Test Results

| Olds Well No. | Date of bail test (1964) | Total depth at time of test (feet) | Length of open hole at time of test (feet) | Depth to top of main aquifer (feet) | Depth to nonpumping level (feet) | Available drawdown; H (feet) | Transmissibility; T (igpd/ft) | Approximate safe yield; $Q_{S_{20}}$ (igpm) |
|---|---|---|---|---|---|---|---|---|
| 177 | January 20 | 245 | 102 | 143 | 28.5 | 114.5 | (1) 406 | 28 |
| | | | | | | | (2) 1,055 | 57 |
| 178 | I. January 25 | 180 | 99 | (1) 147 | 16.67 | 130.33 | 2,300 | 142 |
| | | | | (2) 86 | 16.67 | 69.33 | 2,300 | 76 |
| 178 | II. January 28 | 290 | 209 | (1) 147 | 28.40 | 118.6 | 10,560 | 593 |
| | | | | (2) 86 | 28.40 | 57.6 | 10,560 | 288 |
| 179 | February 7 | 330 | 154 | 176 | 16.5 | 160 | (1) 1,200 | 91 |
| | | | | | | | (2) 1,880 | 143 |
| 187 | May 25 | 320 | 228 | 205 | 70 | 135 | (1) 960 | 61 |
| | | | | | | | (2) 765 | 49 |
| 188 | June 4 | 300 | 239 | 91.72 | 71.50 | 20.2 | (1) 2,640 | 25 |
| | | | | | | | (2) 1,015 | 10 |
| 189 | June 5 | 385 | 242 | 143 | 4.36 | 139 | 51,800 | 3,400 |
| 190 | June 15 | 320 | 193 | 127 | 40.33 | 87 | 32 | 1.5 |
| 191 | June 15 | 295 | 126 | 69 | 18.62 | 50 | 10,550 | 250 |
| 192 | July 2 | 537 | 400 | 137 | 29 | 108 | 15,100 | 772 |
| 193 | June 26 | 380 | 204 | 176 | 53.55 | 122 | (1) 1,760 | 102 |
| | | | | | | | (2) 1,060 | 61 |
| 194 | July 10 | 400 | 297 | 103.60 | 32.22 | 71 | 586,000 | 19,700 |
| 195 | July 14 | 350 | 310 | 40.57 | 34.16 | 6 | 7,550 | 21.4 |
| 197 | August 15 | 515 | 415 | 101 | 18.75 | 75 | (1) 4,210 | 150 |
| | | | | | | | (2) 5,280 | 188 |
| 198 | August 18 | 285 | 264 | 85 | flowing | 85 | 15,100 | 606 |
| 199 | August 5 | 365 | 242 | 123 | 12.29 | 85 | 2,780 | 112 |
| 200 | August 19 | 305 | 279 | 100 | 26.88 | 70 | 9,270 | 307 |
| 201 | August 24 | 242 | 211 | 40 | 16.09 | 24 | (1) 13,200 | 150 |
| | | | | | | | (2) 5,280 | 60 |
| 202 | August 26 | 200 | | 135 | 73 | 62 | 1,458 | 19 |

Note: (1) and (2) indicate the different possible interpretation of the same bail test.

accepted, it is obvious that this well is one of the best prospective producers. Unfortunately, however, its water was one of the few waters in the area that do not qualify for municipal consumption in Alberta (Appendix C and Table 2). Among the other test holes in the area south of Highway 27 Olds Wells Nos. 178, 189, and 192 seemed to be the best prospects and these were extensively tested by means of thorough pump tests. In the area north of the highway Olds Wells Nos. 198, 200, and 201 may be expected to be equivalent to the best wells in the south field.

## Aquifer Tests

### *Selecting Test Sites, Preliminary Tests*

Owing to the urgency of the matter, aquifer testing had to start in the south field before the test holes in the north field were drilled. After an adequate supply was proven south of Highway 27, further detailed work in the north field was deemed unnecessary by town officials. For this reason, pumping tests are limited to the south field.

The wells that were to be pump-tested were selected on the basis of the comparative bail tests. Olds Wells Nos. 178, 189, and 192 were chosen for extensive testing. From the bail tests, transmissibilities for the formations at the above test holes were found to be 10,560 igpd/ft, 51,800 igpd/ft, and 15,100 igpd/ft, respectively.

In each case a preliminary pumping test was conducted prior to the main test. It consisted of continuous pumping for 6 to 10 hours, while discharge rates were increased at 1- or 1.5-hour intervals. Pumping rates, water levels, and barometric pressures were noted. The purposes of conducting a preliminary pumping test were: firstly, to determine the most appropriate pumping rate for the main test during which it should not be changed; secondly, to develop the well gradually; and thirdly, to establish the possible influence of barometric pressure changes on the water levels (this influence was found negligible). Unfortunately, the pump available for the second and the third tests was not capable of pumping at the optimum test rates, which were judged to be over 200 igpm. After the preliminary tests, the water levels in the wells were left to recover for several days, and after a complete recovery was made the main tests were started. These tests in Olds Wells Nos. 178, 189, and 192 are referred to as pump test 1, 2, and 3, respectively.

### *Pump Test 1*

The first pump test was conducted on Olds Well No. 178. The most important technical data obtained from this test are listed below.

Time of start and finish of pumping: March 2, 1:30 PM, March 5, 11:00 AM, 1964; duration of pumping: 69.5 hrs; depth of well: 325 ft; size of well: 6 inches; bottom of casing set at 81 ft; open hole from 81 ft to 325 ft; pump set at 150 ft; nonpumping water level: 32.91 ft; maximum depth to water during test: 70.38 ft; maximum drawdown: 37.49 ft; average pumping rate: 226 igpm; depth to the top of first important water occurrence in the bedrock: 86 ft; water levels observed in: pumping well and 5 observation wells, four of which were equipped with automatic water-level recorders (Fig. 17). The detailed water-level measurements of this test, both for the drawdown and for the recovery test, are included in Appendix E*.

The test results have been analyzed on the basis of the nonequilibrium equation of Theis (1935), by means of the graphical solutions given by Walton (1962). Several other methods were attempted, for example, the gradient method (Butler, 1957, p. 139), methods for determining specific yield (Ramsahoye and Lang, 1961, p. 41-46; Walton, 1962, p. 12), but that of Theis gave the most consistent results.

The same basic difficulty is encountered in trying to apply any kind of mathematical solution to geologic conditions: the complexity of the actual situation can not be described in a rational way. The strata are not: isotropic, homogeneous, of infinite areal extent, wholly confined or completely free. Indeed, there are indications that the rate of drawdown was influenced by gravity drainage, leakage, and barrier boundaries in a very complex manner. Yet, the end results of the analysis by the Theis concept seem to be quite satisfactory.

The time-drawdown relations are plotted on semi logarithmic paper for the pumping well (Olds Well No. 178), and on logarithmic paper for the observation wells (Fig. 38). The transmissibility was calculated by the straight-line method for the pumping well (Fig. 38). The time-drawdown curve in this hole can be approximated with a straight line for the first 12 minutes, after which it gradually declined until about 1,400 minutes of pumping, where it stabilized at a rate of 28.4 ft/log cycle.

The time-drawdown curves in the observation wells must be controlled by the same cause(s) which determine(s) the shape of that curve in the pumping well. The initial portions of the observation-well curves in figure 38 can be matched to the nonleaky artesian type curve. Later, however, the measured curves depart from the type curve, and they match it again approximately at 1,000 minutes after pumping started. Several features common to the five curves under discussion may be observed. First, the

* Appendix not included with published report. Copies are available on request.

transmissibility coefficients derived from the early parts of the curves are from 3 to 15 times as high as those obtained from the later parts. Second, the late "apparent transmissibilities" of the five graphs are in good agreement, ranging from 1,948 igpm/ft to 2,382 igpm/ft. Third, whereas the phenomenon of an increasing rate of drawdown after an initial match with the type curve is a definite indication of barrier-boundary conditions, the theoretically required integer ratios of the successive slopes (on the semilogarithmic plot), or of the drawdowns belonging to successive match points could not be recognized (Walton, 1962, p. 16; Wisler and Brater, 1959, p. 175). The general conclusion from the analysis of the time-drawdown curves is that the wells are located in formations of relatively high permeability which are adjacent to areas of lower-permeability material, and that the line of contact does not follow a simple pattern.

In order to verify the above conclusions, drawdown values obtained simultaneously at different observation wells for different lengths of pumping time were plotted against the square of the distances between the pumping well and these observation wells (Fig. 39). This method is known as the distance-drawdown method and is treated in detail by Walton (1962, p. 6). The nonleaky artesian type curve was fitted between pairs of wells and the transmissibility values were determined. Here again the "apparent transmissibility" seems to decrease with increasing length of pumping. Also, the cone of depression departs from the theoretically required exponential shape for homogeneous material by being flatter close to, and relatively steep farther away from, the pumping well.

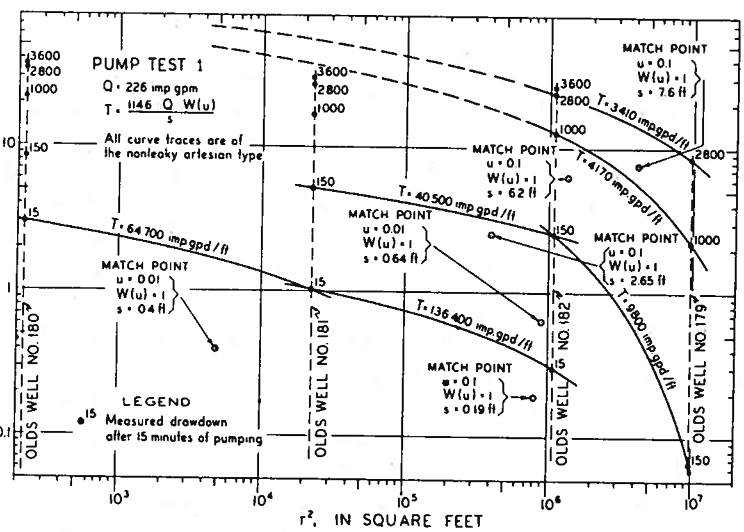


*FIGURE 39. Distance-drawdown graph for observation wells, pump test 1.*

The relationships among the coefficient of transmissibility, and the pumping time and the distance from the pumping well were further investigated by showing the calculated transmissibility values in relation to the two independent variables (Fig. 40). The end points of the horizontal straight lines indicate the times between which the nonleaky artesian type curve matches the actual time-drawdown graphs. The end points of the vertical lines represent the distances between the pumping well and the observation wells of those pairs that were used for transmissibility determinations by the distance-drawdown method. The numbers associated with the straight lines are the values of the transmissibility coefficient, in igpd/ft, obtained from that particular calculation represented by the line. In figure 40 it is seen that values of transmissibility obtained either by the time-drawdown or by the distance-drawdown method from data taken before approximately 1,000 minutes of pumping, are widely scattered, although generally high. Apparent transmissibility values, however, calculated from time-drawdown observations made towards the end of the test are in agreement within 20 per cent regardless of the distance from the pumping well. The transmissibilities obtained with the distance-drawdown method seem to be approaching the values of those from the time-drawdown method, but apparently a longer duration of pumping was needed to reach the established value of T. The vertical curve indicates the shortest duration of pumping that is required under the given conditions for the transmissibilities to converge to a common value. For the sake of convenience, this time may be stated as one day (1,440 minutes). This time would have to be increased at lower rates of pumping.

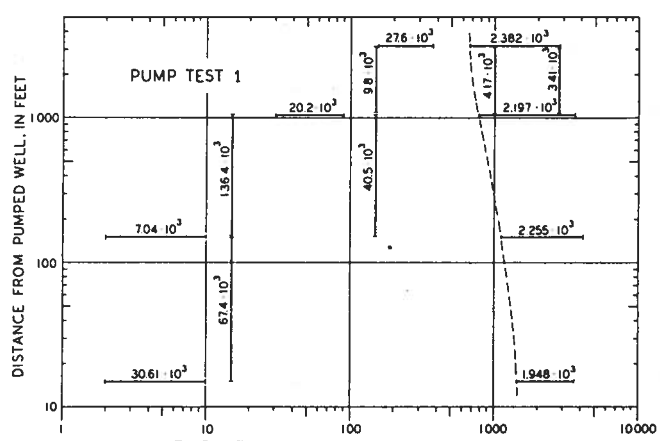


*FIGURE 40. Diagram showing convergence of calculated values of transmissibility with increasing length of pumping time.*

The third way of calculating the transmissibility was by applying Jacob's method for recovery data. No real straight-line relation was established in the recovery curves (Fig. 41). Whereas the recovery curve does not necessarily go through the zero point of drawdown, an extrapolation of the curve through this point seems to be the best possible approximation. As is seen in figure 41, very consistent values are obtained for the transmissibilities by this method but they are lower than those obtained from drawdown calculations.

On taking the average value for apparent transmissibility obtained from the late time-drawdown, and from the recovery calculations, T becomes 1,960 igpd/ft. On the basis of the available information this value can not be associated with any particular formation or part of a formation. It may be said, however, that the rate of drawdown after approximately one day of pumping at the location of Olds Well No. 178 will be the same as if the formations from the storage of which water is withdrawn had a combined transmissibility value of 1,960 igpd/ft. This value was used in the calculation of the safe yield. The rate of drawdown in Olds Well No. 178 stabilized at approximately 1,000 minutes of pumping, at 23 feet of drawdown, or approximately 56 feet below the surface (Fig. 38). In calculating the safe pumping rate at which the total available drawdown is used up by the end of the twentieth year (approximately $10^7$ minutes) it is sufficient to project the straight line of drawdown across the last four log cycles. The available drawdown should, of course, be calculated as the difference between the top of the first important occurrence of water and the *pumping level* at 1,000 minutes. On this basis available drawdown at 1,000 minutes of pumping is $H_{1000} = 86 - 56 = 30$ ft. In this way no errors are introduced into the estimates by not taking into account the early, unstabilized trend of the water levels. Upon reworking equation (4) for four log cycles, the following simple formula is obtained for the safe rate of production for 20 years at Olds Well No. 178:

$$Q_{S_{20}} = \frac{T.H_{1000}}{1056} \qquad (6)$$

Substituting 1,960 igpd/ft for transmissibility and 30 feet for $H_{1000}$, the safe yield is obtained:

$$Q_{S_{20}} = 56 \text{ igpm.}$$

By multiplying this value by a safety factor of 0.71, a pumping rate of 40 igpm is recommended.

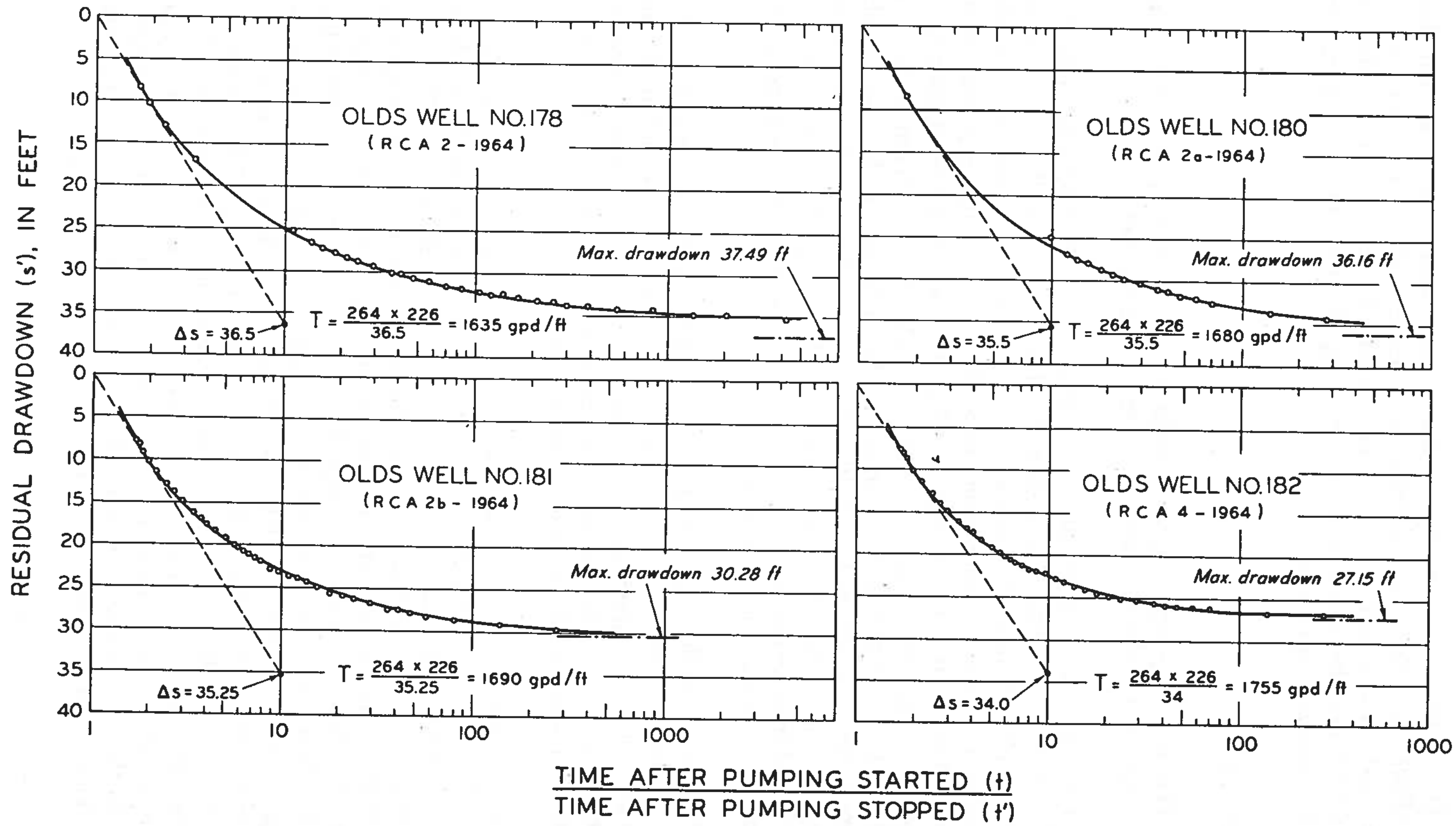


**FIGURE 41.** *Graphs showing recovery of water levels, pump test 1.*

Due to the wide range of the values obtained for the storage coefficient no effort was made to evaluate an average value. The calculations presented on the drawdown curves suggest, however, that a value of S=0.0001 may be accepted as representing the conditions of storage in the formations in question.

*Pump Test 2*

The second pump test was conducted on Olds Well No. 189. The most important technical data of this test are listed below.

Time of start and finish of pumping: July 22, 7:00 AM, July 27, 6:00 PM, 1964; duration of pumping: 131 hrs; depth of well: 380 ft; size of well: 6 inches; bottom of casing set at 143 ft; open hole from 143 ft to 380 ft; pump set at 140 ft; nonpumping water level: 4.09 ft above ground level; maximum depth to water during test: 42.25 ft below ground level; maximum drawdown: 46.34 ft; average pumping rate: 155.64 igpm; depth to the top of the first important water occurrence in the bedrock: 145 ft; water levels observed in: pumping well and 16 observation wells, five of which were equipped with automatic water-level recorders (Fig. 18). The detailed water-level measurements of the test, both for the drawdown and recovery periods, are included in Appendix E*.

The same method was used in the analysis of the test results as in test 1. Since, however, the interpretation of this test seemed to be in agreement with the previous one, and because of the exceptional urgency in obtaining results the distance-drawdown and recovery methods were not used to obtain coefficients of transmissibility.

A complication in the calculation of the drawdowns was introduced by the fact that the general rise in the water levels during the week of June 29 (Figs. 20 and 21), caused Olds Well No. 189 to flow (Fig. 42). This flow could not be checked after the installation of the pump in this well so that a pre-pump-test drawdown resulted at the nearest observation wells. The true nonpumping water levels were established by assuming that the drawdown resulting from the estimated 30 igpm flow was almost negligible at Olds Well No. 189c. The elevations of the water levels were measured and plotted on semilogarithmic paper (Fig. 43). The possibility of approximating the water levels with a straight line is an indication that the cone of depression caused by the natural flow at Olds Well No. 189 has an undisturbed, exponential surface near the well. It is, therefore, assumed that the undisturbed level at each well of the group was 3,228.00 feet above mean sea level. The differences between this and the actual

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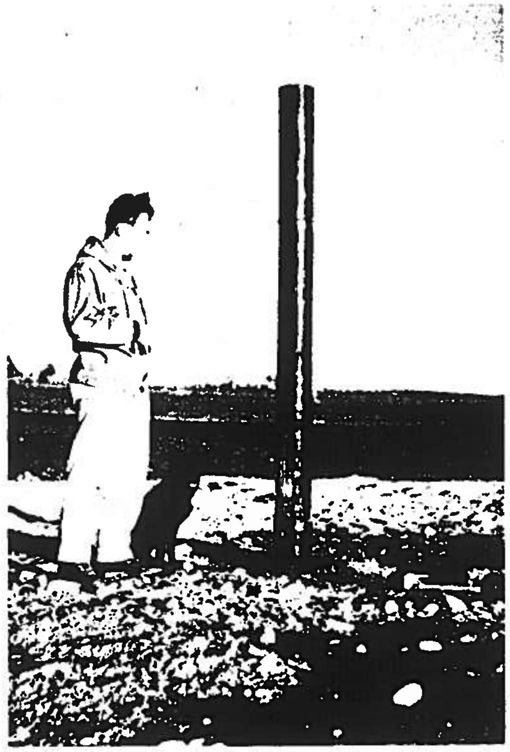

a

b

*FIGURE 42. (a) Casing of Olds Well No. 189a extended above ground to enable recording of water levels during pump test 2;*
*(b) Free flow of water at Olds Well No. 189.*

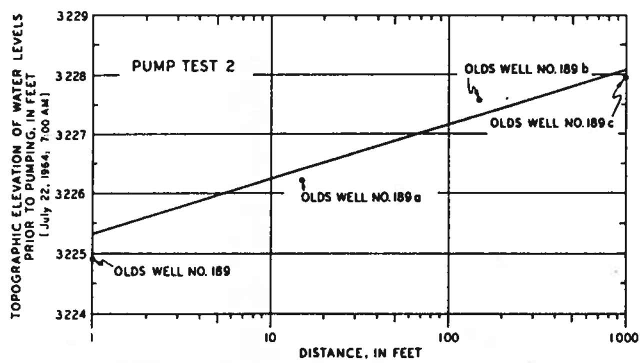


*FIGURE 43. Graph showing the cone of depression due to the free flow prior to pump test 2, on Olds Well No. 189.*

elevations have thus been applied as corrections to the measured drawdowns. (Also, from this preliminary "natural pump test" a value of 11,860 igpd/ft was obtained for the coefficient of transmissibility by the distance-drawdown method).

The corrected drawdowns for the pumping well were plotted against the time after pumping started on semilogarithmic paper (Fig. 44). Those for the four observation wells equipped with automatic water-level recorders were plotted on logarithmic paper (Fig. 44). These graphs show basically the same aquifer characteristics as those obtained from pump test 1, namely, high initial transmissibilities which decrease and converge gradually to a common, relatively low value. The average for the apparent transmissibilities, calculated for the late portions of the time-drawdown curves for Olds Wells Nos. 189, 189a, 189b, 189c, and 179 is:

$$T = 3{,}850 \text{ igpd/ft}$$

Attention is drawn to two noteworthy features on the time-drawdown graphs. One of these is the relatively flattened initial portions of the curves, which do not seem to fit any type curve, and which succeed very rapid drops in the water levels during the first minute. The flattened portions appear to decrease in length with increasing distance from the pumping well. This shape of the time-drawdown curve has been explained by gravity drainage from the zone of the drift-bedrock contact to that part of the formation which is actually being pumped (Fig. 44), but could also have been caused by the correction factor for the pre-test flows. The discussion of this phenomenon is beyond the scope of the present report, and for more details the reader is referred to Walton (1962, p. 7 and 35).

Another feature that may be observed on the graphs for the pumping well and the closest observation well (Olds Well No. 189a) (Fig. 44) is the occurrence of separately marked barrier boundaries. In the pumping well the slope of the first limb is less than it would be without the effect of gravity drainage. For this reason the slope of the second limb is more than twice as steep as that of the first limb. A ratio of 1:2 would prove the correctness of the assumption that the increase in the slope between the first and the second limb is due to a barrier boundary. However, if it is assumed that the slope of the first limb should be 3.25 ft/log cycle (i.e. half that of the second limb) then the slopes of the three limbs have the exact ratio of 1:2:3. In Olds Well No. 189a the drawdown values of the match points have a ratio of 1:1.92:3.08, which is accepted as a good approximation to the required 1:2:3, to be indicative of the presence of barrier boundaries. The distances between the observation well and the image wells have been computed in figure 44, according to the image-well theory (Walton, 1962, p. 16 and 47). The above distances have been found to be $r_{i1}$ = 670 ft and $r_{i2}$ = 9,675 ft. These values cannot be expected to be very accurate, and the locations of the boundaries cannot be constructed because of lack of similar calculations in at least two more observation wells. However, $r_{i1}$ is considered to be a very certain indication of the presence of the boundary immediately south of the pumping well, as was found also from the analysis of the change in water levels at every observation well (Fig. 18). The location of the distant boundary is uncertain, but it is believed to be associated with the bedrock high and the facies change approximately 2 miles north of the pumped well.

For the calculation of the safe pumping rate for 20 years, $Q_{S20}$, for Olds Well No. 189, a conservative available drawdown of 120 feet has been used. This was done partly in recognition of the possible rapid changes of the nonpumping levels at this site, and partly to take into account the unexplained large drop of the water level during the first minute of pumping. Using equation (4) the safe yield for Olds Well No. 189 is obtained:

$$Q_{S20} = \frac{3850 \cdot 120}{2110} = 219 \text{ igpm}$$

By applying a safety factor of approximately 0.68, a pumping rate of 150 igpm is recommended, if well 189 only is pumped. This restriction is necessary, since there is evidence that pumping of Olds Wells Nos. 178 and 189 is withdrawing water from the same area.

For the coefficient of storage widely ranging values have been obtained also from pump test 2. Considering the late portions of the time-drawdown curves only, it is observed that the calculated values for S are decreasing with distance from the pumping well. Since there is relatively little variation between the storage coefficients obtained for the distant wells (189c, and 179), the formations are assumed to react to pumping at the site of Olds Well No. 189, as though having a coefficient of storage of: S = 0.0004.

*Pump Test 3*

The third pump test was conducted on Olds Well No. 192. The most important technical data of the test are given below.

Time of start and finish of pumping: August 17, 6:10 AM, August 21, 6:10 AM, 1964; duration of pumping; 96 hrs; depth of well: 537 ft; size of well: 6 inches; bottom of casing set at 137 ft; open hole from 137 ft to 537 ft; pump set at 120 ft; nonpumping water level: 29.00 ft; maximum depth to water during test: 52.21 ft; maximum drawdown: 23.21 ft; average pumping rate: 152 igpm; depth to the top of the first important water occurrence in the bedrock: 129 ft; water levels observed in: pumping well and in 16 observation wells, four of which were equipped with automatic water-level recorders (Fig. 19). The detailed water-level measurements of this test, both for the drawdown and recovery periods are included with Appendix E*.

For determining coefficients of transmissibility and storage the straight line method and the nonleaky artesian type curve were applied to the pumping well and to observation wells 192a, 192b, and 189d, respectively (Fig. 45).

Similar to the results of the previous pump tests, the early portions of the time-drawdown curves yield high values for the coefficient of transmissibility. The later measurements indicate, however, that due to barrier-boundary conditions the formations behave hydraulically as those with relatively low transmissibility. The average apparent transmissibility is obtained from the late parts of the time-drawdown curves for Olds Wells Nos. 192 and 192a:

$$T = 6{,}175 \text{ igpd/ft.}$$

Each of the above-mentioned curves shows the presence of barrier-boundary conditions. The correctness of attributing the increase in the slope and departure from the type curve in the pumping well and the

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* Appendix not included with published report. Copies are available on request.

observation well to boundary conditions, (Fig. 45, Wells Nos. 192 and 192a, respectively) is supported by the fact that the ratios are approximately 2, both for the slopes of the straight lines and for the drawdowns of the match points.

The calculation of the storage coefficient seems to be unreliable, due to the large spread of the values. It seems reasonable to assume a value of 0.001 for the coefficient of storage to represent the way the formations react to pumping at the site of Olds Well No. 192.

The departure of the measured time-drawdown curve at Olds Well No. 192a was used to determine the distance of the barrier boundary from that observation well. By use of the theory of the image wells, this distance is calculated to be approximately 1,150 feet. This distance is within a thousand feet of that obtained for the impermeable boundary between Olds Wells Nos. 189 and 189d from contouring the changes in water levels in every observation well during this pump test, and from the analysis of the natural motion of groundwater (Figs. 19 and 15).

The presence of the same boundary is reflected by the deviation of the time-drawdown graph for Olds Well No. 189d from the type curve. Apparently, this well is located within a few hundred feet from the impermeable boundary and approximately one-half mile from the pumping well. This ratio of distances explains the slow initial rate of drawdown which quickly increases after the cone of depression reaches the boundary. Whereas the late part of this curve could not be used for determination of the formation constants, its early portion supplied new evidence for the high transmissibility of the material near the pumping well.

The high transmissibility of the surrounding material is supported by information obtained from Olds Well No. 192b. However, the time rate of drawdown in this well slows down more than is theoretically (i.e. by the type curve) expected after approximately 80 minutes of pumping (Fig. 45). This phenomenon might be caused by leakage from overlying formations into a confined aquifer, or by a recharge boundary, or by partial penetration of the observation well (Walton, 1962, p. 7). Since no other indication was recognized of the first two possibilities during the previous investigations, and since the depth of this observation well is only 152 feet, in contrast to the depth of 537 feet of the pumping well, the deviation of the observed time-drawdown curve from the type curve is explained here by partial penetration. According to Walton (1962, p. 7): "If the pumped well is open to the top of the aquifer and the observation well is open to the bottom of the aquifer, or vice versa, the observed drawdown in the observation well is smaller than for fully penetrating conditions."

The fact that the water levels in an observation well that fully penetrates a major zone of water occurrence, according to lithologic data and drillers' observations, show partial-penetration conditions during an extended pump test, is interpreted here as an indication that a large portion of the formation contributes water to the well, instead of the water being obtained from one or two major aquifers.

In view of the rather complicated nature and the small reward expected from calculating the formation coefficients from data of this partially penetrating well, these calculations have been omitted. References to these types of computation are found in papers by Hantush (1961a and b).

The safe pumping rate for a period of twenty year ($Q_{S_{20}}$) is calculated again with the straight-line method (Eq. 4). This method, in fact, involves the finding of the pumping rate associated with a straight line on the semilogarithmic plot the slope of which is such that the line connects the point of zero drawdown with the point where the total available drawdown intersects the line of 20 years (approx. $10^7$ minutes.) Using 100 feet for available drawdown and 6,175 igpd/ft for the coefficient of transmissibility, equation (4) yields for the safe pumping rate for twenty years:

$$Q_{S_{20}} = 293 \text{ igpm}$$

or upon application of a safety factor of approximately 0.68 the safe pumping rate becomes: 200 igpm.

## Areas Influenced by Pumping at Well Sites 189 and 192, and Summary of Pumping Tests

Due to the fact that the computed values for the storage coefficient vary greatly both with time and space, and that the shapes of the measured cones of depression are irregular, the calculating of future water levels at any location by the standard methods would be fictitious. Yet, an idea of the direction and extent of the future cone of depression has to be obtained in order to be able to estimate the effect of pumping at the above-mentioned well-sites on the surrounding farm wells.

In an attempt to solve this problem it has been assumed that the drawdown at any point within the area of influence is an exponential function of time, during continuous pumping and at constant pumping rate. If the cone of depression associated with a particular drawdown value of the pumping well is known, cones of depression belonging to any other value of drawdown of the well may be constructed. Drawdown values, from figure 18 along cross sections oriented north, west, and east, and radiating from Olds Well No. 189 were plotted on the logarithmic scale of semilogarithmic paper against distances measured from the pumping

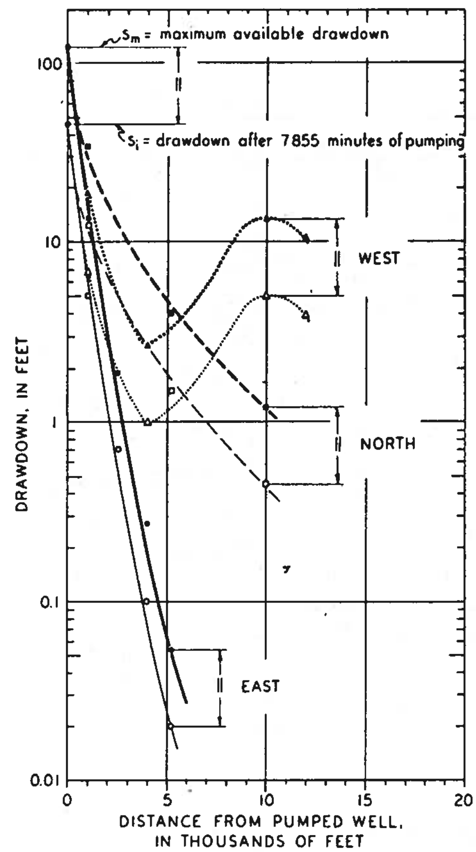


*FIGURE 46. Diagram showing method of finding maximum drawdowns in area of influence of Olds Well No. 189.*

well, for the time of 7,855 minutes after pumping started (Fig. 46). The logarithmic cross sections of the cone of depression were then shifted parallel with the drawdown axis by the amount of 120 — 46 = 74 ft at the pumping well. The available drawdown at Olds Well No. 189 is 120 feet, and 46 feet was the drawdown at this well at the time shown on figure 18. The new values of the cone of depression belonging to the maximum available drawdown in the pumping well were then replotted on to the three profiles and new contours were constructed (Fig. 47). The same procedure was applied to Olds Well No. 192. Figure 47 shows the amount and the areal extent of the cone of influence for the maximum available drawdowns at both pumping wells.

For practical purposes the area of influence is defined here as the area which is bounded by the contour line of 1-foot maximum drawdown due to pumping at Olds Wells Nos. 189 and 192. The water levels within this area will depend on the pumping level of the supply wells. Depending

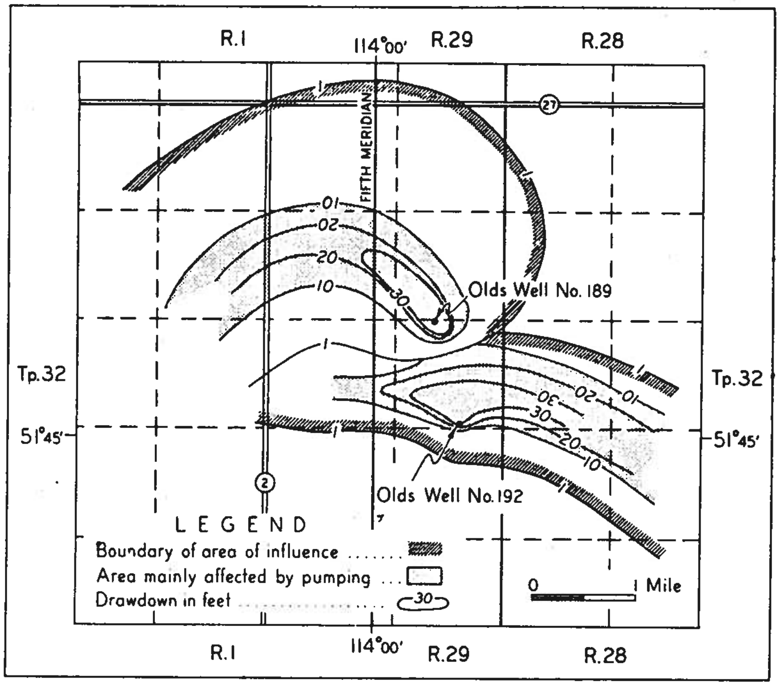


*FIGURE 47. Amount and areal extent of the cones of influence for the maximum available drawdowns for Olds Wells Nos. 189 and 192.*

on the unknown details of the future development of the cone of depression, existing wells within the outlined area may be more or less affected by pumping at the town's wells. No major interference is, however, expected outside the shaded area—less than 10 feet of predicted maximum drawdown. Wells situated within the area of greater than 10 feet of maximum drawdown might be seriously affected even by temporary increases in the pumping rates of the wells.

*Summary of Pumping Tests*

In order to assess the amount of groundwater that can be withdrawn from the investigated area south of Highway 27, and to find the safe rate of withdrawal, extended pump tests have been conducted on Olds Wells Nos. 178, 189, and 192. The tests are referred to as pump tests 1, 2, and 3. The dates and durations of pumping for tests 1, 2, and 3 are: March 2, 69.5 hrs; July 22, 131 hrs; and August 17, 96 hrs, respectively. Each test indicated barrier boundary conditions. A major, completely impermeable boundary with an east-west direction has been located between Olds Wells Nos. 189c and 189d. This barrier separates the areas influenced by pumping at Olds Well No. 189, and at Olds Well No. 192. Olds Wells Nos. 178 and 189, however, are hydraulically connected. The following average values of transmissibility characterize the rocks at, and immediately surrounding, Olds Wells Nos. 178, 189, and 192: 21,400 igpd/ft, 13,600 igpd/ft, and 15,400 igpd/ft. Due to factors not fully understood, a relatively uniform period of approximately one day of pumping was required during each test before the time rate of drawdowns for a second time conformed to the nonleaky artesian type curve. Since this means that time rates of drawdown were stable for at least two days in each test, transmissibilities obtained from these portions of the curves were used to determine the safe yields of the wells. Average values of apparent transmissibility obtained from the late parts of the time-drawdown relations for pumping tests 1, 2, and 3 are: 1,960 igpd/ft, 3,850 igpd/ft, and 6,175 igpd/ft, respectively. The following approximate values for the storage coefficient may be assumed to be representative for wells placed in the area of influence of the above pumping wells, respectively: 0.0001, 0.0004, and 0.001. Using the final values for the transmissibilities, and the following available drawdowns: 30 feet, 120 feet, and 100 feet, the safe rates of continuous pumping for twenty years are estimated to be: 40 igpm, 150 igpm, and 200 igpm for Olds Wells Nos. 178, 189, and 192, respectively, if the wells are pumped separately. Interference is expected to develop between the first two wells only, for Well No. 192 is effectively separated from the north area by the barrier boundary. Taking interference into account, the following pumping rates are recommended:

Olds Well No. 178 (RCA 2-1964): 35 igpm
Olds Well No. 189 (RCA 7-1964): 140 igpm
Olds Well No. 192 (RCA 10-1964): 200 igpm

The area in which the water levels are expected to be influenced by pumping at the well sites in question is outlined in figure 47. Data available for Olds Well No. 178 have not been deemed sufficient to be used in constructing the above map. Since, however, Wells Nos. 178 and 189 obtain water from the same strata the area outlined in figure 47 is not expected to be significantly modified by moderate pumping (not in excess of the recommended rates).

It is possible to increase slightly the total rate of water production in the area in question by drilling additional wells. It is recommended, however, that until several years of records of production and water level are available, the total rate of water withdrawal should not exceed 375 igpm.

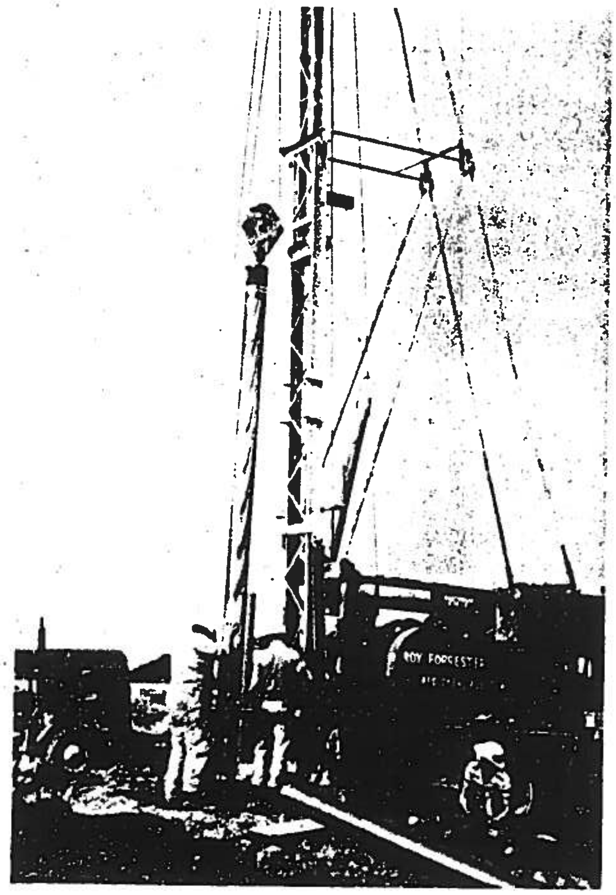

*FIGURE 48. Installation of screen at Olds Well No. 189.*

## Design of the Production Wells

Since the details of the design and of the completion of the production wells are the driller's responsibility, only the guiding principles of the recommended well construction are outlined below. Construction of production wells was considered for sites 178, 189, and 192. (In fact, production wells 178 and 189 have been in operation since November 1964—Fig. 48.)

Owing to the occurrence of groundwater over great portions of the well profile, open-hole completion is recommended below the drift-bedrock contact. To protect the pumps from possible cavings of the otherwise consolidated bedrock material the wells should be provided with large-opening screens.

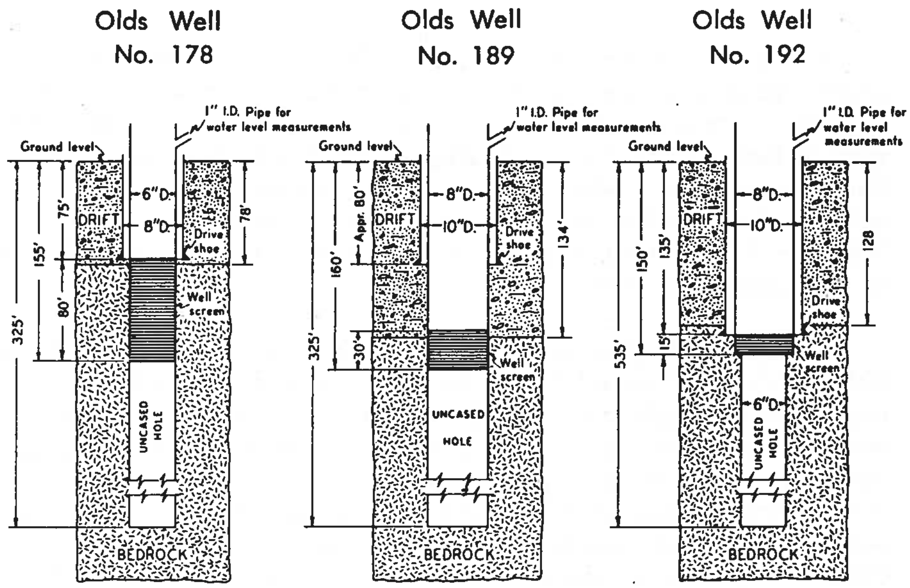


*FIGURE 49. Proposed construction of production wells at Olds.*

More specifically the following specifications are recommended for each well:

*Production Well at the Site of Olds Well No. 178*

Well depth: 325 ft; 8" O.D. surface casing set at 75 ft below ground surface; 6" I.D., 80 ft long, 120 mesh, stainless steel screen, top set at 75 ft below ground level; the top of the pump cylinder should be set at 145 ft (Fig. 49).

*Production Well at the Site of Olds Well No. 189*

Well depth: 380 ft; 8" O.D. surface casing set at 130 ft below ground level; 8" I.D., 30 ft long, 120 mesh, stainless steel screen, top set at 130 ft; the top of the pump cylinder should be set at 150 ft (Fig. 49).

*Production Well at the Site of Olds Well No. 192*

Well depth: 535 ft; 8" O.D. surface casing set at 135 ft below ground level; 8" I.D., 15 ft long, 120 mesh, stainless steel screen, top set at 135 ft; the top of the pump cylinder should be set at 140 ft (Fig. 49).

### Approximate Cost of Groundwater at Olds

An estimate of the cost of water at Olds prior to 1964 can be approximated only, as the town has not made the relevant financial details available. During the period of several months, however, which the writer spent in that town meeting town officials and consulting engineers, certain figures regarding expenditures on water were mentioned consistently. It is believed, therefore, that the estimates given below are good approximations. The costs of the present program are better known; however, some figures are not based on invoices.

During the 17-year period between 1947 and 1964 an estimated $200,000 was spent on test drilling, pump testing, and other operations that may be called exploration. In addition to this, $600,000 was spent on technical installations to transport the water to the town, such as pumps, water mains, and so on (distribution system in the town not included). If the average population of Olds was 2,000 during these 17 years, and the consumption of water was 50 gallons per day per capita, then an amount of 620 million gallons of water was consumed during the same period. Using the above estimates, the following unit prices are obtained.

| | |
|---|---|
| Exploration costs: | $0.3 per thousand gallons of water |
| Total (exploration and installation—distribution system not included): | $1.3 per thousand gallons of water. |

These expenditures provided the town with a marginal supply of water, which failed by the end of 1963, thus new spending was unavoidable. Except for one engineer's report concerning the prospects of groundwater at one site on the Little Red Deer River, no geologic, hydraulic, or chemical information useful in possible future investigations resulted from these expenditures.

Exploration costs during the 1964 program (consulting fees not paid by the town included) totalled $50,000. Construction of wells, water mains, pumps, and so on cost approximately $180,000. If the three recommended production wells were used at full capacity (375 igpm) for the period of 20 years, total production would be 3,950 million gallons. With these figures the following unit prices are obtained.

| | |
|---|---|
| Exploration costs: | $0.013 per thousand gallons of water |
| Total (exploration and installation—distribution system in town not included): | $0.058 per thousand gallons of water. |

If, however, the present population of Olds of approximately 3,000 is maintained for the next twenty years, using an average consumption of 50 igpd per capita, initial investments would be spent to produce 1,100 million gallons of water. The unit prices in this case would be as follows.

| | |
|---|---|
| Exploration costs: | $0.045 per thousand gallons of water |
| Total (exploration and installation—distribution system in town not included): | $0.209 per thousand gallons of water. |

The same exploration has resulted in the discovery of the groundwater reserves north of Highway 27, which could be developed into a supply of approximately 200 igpm. Lithologic, hydraulic, and chemical data have been obtained and recorded in such a manner that they can be either used in possible future work, or reanalyzed.

In the light of the above comparisons, it would seem that systematic, high-quality and well-supervised search for groundwater deserves preference, from the point of view of provincial economy, to the current hit-and-miss type of exploration.

## Recommendations for Further Exploration, Development, and Management of the Groundwater Resources in the Olds Area

The state of knowledge of the groundwater resources in the Olds area may be considered under three categories. The recommendations are grouped according to these categories.

(1) The south field of the area of the present study—the area south of Highway 27 and east of Highway 2.

This area has received the most attention during the investigation, and the recommendations of management of the groundwater resources here are based on field tests.

The construction of three production wells is recommended in this area at the test sites of Olds Wells Nos. 178, 189, and 192. These wells may be pumped continuously at the following respective rates: 35 igpm, 140 igpm, and 200 igpm. These rates should not be exceeded for any extended period of time. Observation wells, equipped with automatic water-level recorders, should be constructed at a distance not exceeding 20 feet from each production well. Water levels in the observation wells, daily amounts of water production, and pumping rates should be obtained and recorded for each production well. The main load of production should be divided initially between Olds Wells Nos. 189 and 192 in proportion to their estimated safe yields. The most advantageous ratio of production may be decided upon later from the analysis of the production and the water-level records. Sharing the load between the wells is advantageous for two reasons: (1) since the two wells are withdrawing water from hydraulically unconnected areas, relatively small lowering of the water levels in both areas of influence will prevent private wells (mainly farm wells) from being seriously affected; (2) on extended pumping Olds Well No. 192 is expected to produce water from local system 5, the chemical quality of which water is superior to that of Olds Well No. 189, thus a desired quality will result from mixing the two waters. The production well at test site 178 should be used mainly for standby purposes.

(2) The north field of the area of the present study.

On the basis of observed occurrences of water and the bail tests it is estimated that groundwater at a rate of 200 igpm may be safely withdrawn from storage for a period of twenty years in this area. Development of these resources for human consumption is desirable because of the high chemical quality of the groundwater. Prior to any development, however, careful pumping tests should be conducted taking into account the expected similarities with geologic and hydraulic conditions encountered in the south field. Test sites 198, 200, and 201 should be given preference for any possible future pump tests.

(3) Areas west of the south and north fields of the present investigation.

Despite the apparent failure of previous investigations, it is felt that wells with moderate yield (10-30 igpm) may be developed here. Renewed exploration should start in this area with a careful well survey, and with the collection and interpretation of chemical analyses of samples of the groundwater. Having tentatively located areas of downward and upward flow, test drilling in the latter areas should be conducted with cable-tool equipment following the procedures outlined in this paper.

If a new test program in any part of the area of the present study is decided upon, the possibility of the occurrence of potable water at greater depths should also be investigated. It is expected that wells over 1,500 feet in depth might still penetrate fresh-water zones at Olds.

## SUMMARY AND RECOMMENDATIONS

### Summary

In this report an attempt has been made to compile and interpret data pertaining to the groundwater regime in an area of approximately 250 square miles. A comparatively detailed picture of the hydrogeologic conditions and groundwater resources was possible over an area of approximately 90 square miles in the east half of the map-area. This was obtained mainly by means of an intensive test-drilling program conducted in 1964. No comprehensive interpretation of the few data in the western half of the area was feasible. Most of the information, however, is contained in this report, up to the end of 1964. The type and availability of all known information is listed in Appendix A.

*Resources*

According to the results of the investigation, groundwater may be withdrawn from storage at a safe rate of 375 igpm for a period of twenty years in the area south and east of provincial Highways 27 and 2, respectively—the south field of this report. Existing information did not warrant the calculation of the amounts of natural recharge and discharge of groundwater in either this or other parts of the area of study, thus it was not possible to produce a groundwater budget.

Only a limited amount of testing was carried out in the area north of provincial Highway 27 and east of the Olds High, which is referred to as the north field of this report. Based on bail-test results and on probably analogous hydrogeologic conditions with the south field, the development of 200 igpm for a twenty-year period out of storage seems possible in the north field.

Previous experiences show that water wells with moderate production (10-30 igpm) may be developed in the western part of the area. Any such attempt, however, should be preceded by thorough investigations. For the above estimates groundwater occurrences averaging approximately 400 feet and not exceeding 700 feet in depth have been considered. It is theoretically possible, however, that additional sources of potable groundwater are situated at greater depths.

*Chemistry*

Regarding chemical quality, the majority of the groundwaters at Olds belong to either the sodium bicarbonate, or the sodium sulfate, or, locally, the calcium-magnesium bicarbonate types. With very few exceptions the waters meet Alberta Public Health Standards. The total solids content of analyzed water samples varies between 288 ppm and 2,314 ppm, averaging 830 ppm, 1,590 ppm, and 500 ppm, for the above-mentioned chemical groups, respectively. The areas of different types of water, particularly with respect to the total solids content, are well separated. Development of good-quality water for human consumption, therefore, can be and should be preferred. Such areas are the southeastern corner of the map-area, and the north field. Although the formations in which Olds Well No. 192 is completed contain second-class water, since they are hydraulically connected with formations of the southeast area, the quality of water produced at Olds Well No. 192 is expected to improve on sustained pumping.

*Flow Systems*

Based on theoretical considerations, one regional flow system, consisting of three parts, and five local flow systems have been outlined in the area east of Olds. The correctness of the above subdivision has been substantiated partly by the apparent differences between certain characteristics of the water chemistry in areas of postulated downward and upward flow of groundwater, partly by the general distribution of the measured fluid potentials, and partly by the prediction of the causes of two anomalies in the nonpumping water levels. In this connection the report presents methods for construction and representation of natural systems of groundwater flow.

*Geology*

The program has revealed certain new features of the lithology and structure of the formations east of Olds. A volcanic ash bed, referred to as the Olds tuff, has been discovered which seems to offer the possibility of being the first stratigraphic marker bed to be found in the Tertiary formations in Central Alberta. Contrary to the generally accepted views, the Paskapoo (Porcupine Hills?) strata at Olds contain many beds of bentonite and coal. Due to the apparent large areal extent of the coal seams, they may also be useful for correlation purposes. A new set of preglacial (glacial?) buried valleys has been discovered. A hydrogeologically important feature thought to be associated with these channels is the relatively large increase in permeability alongside the buried valleys. The observed permeability increase is attributed to fracturing and chemical weathering due to landslides and increased circulation of water on the banks of the old channels. The possibility of tectonic features occurring in the Tertiary formations has been suggested by the presence of a narrow, well-defined impermeable barrier between Olds Wells Nos. 189c and 189d. The formations on both sides of the boundary have relatively high and comparable coefficients of transmissibility, whereas the barrier has proven to be an effective hydraulic divide. This feature is attributed here to the presence of an east-west oriented tectonic fault.

*Engineering*

The major new techniques and methods applied during the test program and thought to be applicable in other parts of Alberta are: standardized comparative bail tests with water levels being measured also during the period of bailing; measurements of nonpumping water levels as a function of well depth by taking readings of depth to water twice a day, namely before drilling starts and after drilling stops; pumping tests of several days' duration have proven to be necessary due to the marked changes in the time rates of drawdown after one day of pumping.

**Recommendations**

Whereas specific recommendations regarding various aspects of groundwater exploration and management in the Olds area have been given in the appropriate chapters, a summary of the general suggestions is presented here with a view to obtaining a better understanding, and improving the methods and techniques of the development, of the groundwater resources in Alberta. These suggestions are based partly on the general experience of the writer, but mainly on the recognition of the costly shortcomings of the methods and techniques applied during the past 17 years at Olds.

Minimum-standard specifications for work in the testing procedure for groundwater supplies, drilling and constructing water wells should be formulated and enforced. Systematic studies of the groundwater resources should be carried out continuously with the emphasis on areas potentially suitable for municipal or industrial development. Representatives of large consumers of groundwater (municipalities and industries) should seek professional advice in their search for water, and they should ask well ahead of time to allow for the collection and interpretation of existing information, which is the basis of soundly (economically) planned test programs. Test programs should not be curtailed for the sake of unwarranted savings. A few hundred dollars gained by not constructing an observation well might easily result in wasting ten times that amount of money on the construction of a pipeline that will soon be useless due to depletion of the well. Also, a pump test which is too short may be found to supply misleading results. And finally, without possessing information to his satisfaction, a consultant should not give advice in matters of groundwater development, since both his reputation and the consumer's money are at stake.

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# APPENDIX A: SCHEDULE OF WATER WELLS IN THE OLDS AREA

## Abbreviations Used

| | |
|---|---|
| s | surveyed elevation |
| m | map elevation |
| Dr | drilled well |
| Dg | dug well |
| M | municipal well |
| D | domestic well |
| S | stock well |
| I | industrial well |
| th | test hole |
| obs | observation well |
| Q | yield of well |
| DD | drawdown |

| Olds Well No. | Location: Distance in feet | Lsd. corner or 1/4 | Sec. | Tp. | R. | West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 330S | NE | 30 | 33 | 2 | 5 | 3,270s | | flowing | 3,270+ | | | | Dr | 45 | Shot hole | | | | | | 1953 | | |
| S2 | 10N & 3,780W | NE | 9 | 32 | 2 | 5 | 3,375s | | flowing | 3,375+ | | | | Dr | | " | | | | | | 1956 | | |
| S3 | 5,100S | NE | 31 | 33 | 2 | 5 | 3,270m | | flowing | 3,270+ | | | | Dr | 60 | " | | | | | | 1956 | | |
| S4 | 2,660S | NE | 17 | 33 | 2 | 5 | 3,270s | | flowing | 3,270+ | | | | Dr | | " | | | | | | 1956 | | |
| S5 | 2,540S | NE | 17 | 33 | 2 | 5 | 3,271s | | flowing | 3,271+ | | | | Dr | | " | | | | | | 1956 | | |
| S6 | 4,720S | NE | 29 | 33 | 2 | 5 | 3,250s | | flowing | 3,250+ | | | | Dr | | " | | | | | | 1956 | | |
| S7 | 195W & 55N | NE | 20 | 33 | 2 | 5 | 3,252s | | flowing | 3,252+ | | | | Dr | | " | | | | | | 1956 | | |
| S8 | 2,640W & 2,640S | NE | 13 | 33 | 1 | 5 | 3,260m | | flowing | 3,260+ | | | | Dr | 60 | " | | | | | | 1959 | | |
| S9 | 2,640W & 2,640S | NE | 24 | 33 | 1 | 5 | 3,252m | | flowing | 3,252+ | | | | Dr | 60 | " | | | | | | 1959 | | |
| S10 | 55E & 3,670S | NE | 17 | 32 | 2 | 5 | 3,390s | | flowing | 3,390+ | | | | Dr | | " | | | | | | 1958 | | |
| S12 | 3,780 | NE | 9 | 32 | 2 | 5 | 3,375s | | flowing | 3,375+ | | | | Dr | 15 | " | | | | | | 1958 | | |
| S13 | 55N & 855W | NE | 12 | 32 | 29 | 4 | 3,179s | | flowing | 3,179+ | | | | Dr | | " | | | | | | 1958 | | |
| S14 | 10E & 2,565S | NE | 17 | 33 | 2 | 5 | 3,274s | | flowing | 3,274+ | | | | Dr | | " | | | | | | 1958 | | |
| S15 | 1,760S | NE | 26 | 33 | 1 | 5 | 3,246s | | flowing | 3,246+ | | | | Dr | 60 | " | | | | | | 1958 | | |
| S16 | 3,520W | NE | 12 | 33 | 1 | 5 | 3,266s | | flowing | 3,266+ | | | | Dr | 44 | " | | | | | | 1958 | | |
| S17 | 3,520W | NE | 24 | 33 | 1 | 5 | 3,252s | | flowing | 3,252+ | | | | Dr | 55 | " | | | | | | 1958 | | |
| S18 | 2,715W & 10N | NE | 20 | 33 | 2 | 5 | 3,253s | | flowing | 3,253+ | | | | Dr | 60 | " | | | | | | 1958 | | |
| S19 | 1,370W & 10S | NE | 1 | 33 | 29 | 4 | 3,206s | | flowing | 3,206+ | | | | Dr | | " | | | | | | 1958 | | |
| S20 | 10E & 1,896N | SE | 17 | 32 | 2 | 5 | 3,397s | | flowing | 3,397+ | | | | Dr | | " | | | | | | 1959 | | |
| S21 | 10S & 1,690W | SE | 27 | 33 | 2 | 5 | 3,291s | | flowing | 3,291+ | | | | Dr | | " | | | | | | 1959 | | |
| S22 | 522E | NW | 20 | 33 | 2 | 5 | 3,334s | | flowing | 3,334+ | | | | Dr | | " | | | | | | 1959 | | |
| S23 | 10N & 1,375E | NE | 5 | 32 | 28 | 4 | 3,108s | | flowing | 3,108+ | | | | Dr | | " | | | | | | 1959 | | |
| S24 | 65E & 3,760 | NE | 17 | 32 | 2 | 5 | 3,390s | | flowing | 3,390+ | | | | Dr | | " | | | | | | 1958 | | |
| S25 | 55N & 1,575W | NE | 12 | 32 | 29 | 4 | 3,185s | 60 | flowing | 3,185+ | | | | Dr | 60 | " | | | | | | 1958 | | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S26 | 3,395W & 4,630S | NE | 12 | 32 | 3 | 5 | 3,488s | 70 | flowing | 3,488+ | | | | Dr | 70 | Shot hole | | | | | | 1958 | | |
| S27 | 200S & 660W | NE | 3 | 32 | 3 | 5 | 3,440s | 60 | flowing | 3,440+ | | | | Dr | | " | | | | | | 1958 | | |
| S28 | 10E & 3,960 | NE | 32 | 33 | 3 | 5 | 3,498s | 45 | flowing | 3,498+ | | | | Dr | | " | | | | | | 1958 | | |
| S29 | | NE | 15 | 33 | 1 | 5 | 3,289s | 50 | flowing | 3,289+ | | | | Dr | | " | | | | | | 1958 | | |
| S30 | 10E & 2,224S | NE | 34 | 32 | 3 | 5 | 3,371s | | flowing | 3,371+ | | | | Dr | | " | | | | | | 1960 | | |
| S31 | 10E & 1,896N | SE | 17 | 32 | 2 | 5 | 3,397s | | flowing | 3,397+ | | | | Dr | | " | | | | | | 1960 | | |
| S32 | 780N & 2,610E | SW | 22 | 33 | 1 | 5 | 3,330s | | flowing | 3,330+ | | | | Dr | | " | | | | | | 1960 | | |
| S33 | 10N & 970W | NE | 9 | 33 | 3 | 5 | 3,305s | | flowing | 3,305+ | | | | Dr | | " | 10 | | | | | 1960 | | |
| S34 | 10N & 2,550E | NW | 9 | 33 | 3 | 5 | 3,306s | | flowing | 3,306+ | | | | Dr | | " | | | | | | | | |
| S35 | 10N & 2,555E | NW | 9 | 33 | 3 | 5 | 3,307s | 60 | flowing | 3,307+ | | | | Dr | | " | | | | | | | | |
| S36 | Lsd. 4 | SW4 | 16 | 32 | 2 | 5 | 3,381.4s | | flowing | 3,381+ | | | | Dr | 60 | " | | | | | | Sun Oil Co. 1961 Sept. | | |
| S37 | | SE2 | 29 | 33 | 2 | 5 | 3,238.6s | | flowing | 3,239+ | | | | Dr | 60 | " | | | | | | Sun Oil Co. 1961 Sept. | | |
| S38 | 3,000W | NE | 10 | 32 | 2 | 5 | 3,337s | | flowing | 3,337+ | | | | Dr | | " | | | | | | July 30/63 | | |
| 1 | | SE | 5 | 33 | 1 | 5 | 3,420m | 200 | 35 | 3,385 | 52 | 3,368 | 5 5/8 | Dr | 52-56 103-108 | M | 8.3 | 97 | 29 | 440 | 3 | Western Water Wells 1946 Jan. | Driller's report; pump test | |
| 2 | | SE | 5 | 33 | 1 | 5 | 3,430m | 81 | 35 | 3,395 | 6 | 3,389 | 5 5/8 | Dr | 51-68 | M | 10 | 28 | 19.5 | 226-600 | 3 | Western Water Wells 1946 Feb. | Driller's report; pump test | |
| 3 | | SE | 32 | 32 | 1 | 5 | | 229 | | | | | 5 5/8 | Dr | | M | | | | | 2 | Western Water Wells 1946 Feb. | | |
| 4 | | SE | 5 | 33 | 1 | 5 | 3,425m | 60 | 35.5 | 3,390 | 26 | 3,400 | 6 1/4 | Dr | 50-56 | M | ~20 | 14 | 17.5 | 914-636 | 4.5 | Western Water Wells 1946 Feb. | Driller's report; pump test | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | Pump, bail or production test: DD | Pump, bail or production test: hrs. | Pump, bail or production test: T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | NE | 5 | 33 | 1 | 5 | 3,385m | 108 | 43 | 3,342 | 26 | 3,359 | 6 1/4 | Dr | 51– 57<br>102–103 | M | 10 | 12.5 | 19.5 | 905 | 3 | Western Water Wells | Driller's report | |
| 6 | | NE | 32 | 32 | 1 | 5 | 3,415m | 143 | | | 32 | 3,383 | | Dr | 61– 62 | M | | | | | | | Driller's report | |
| 7 | | NE | 30 | 32 | 1 | 5 | 3,405m | 100 | 7 | 3,398 | 16 | 3,389 | | Dr | 16– 21 | M | | | | | | Western Water Wells 1946 Oct. | Driller's report | |
| 8 | | SW | 4 | 33 | 1 | 5 | 3,395m | 78 | 15.5 | 3,370 | 21 | 3,374 | | Dr | 48– 56 | M | 20 | 55 | 1/2 | | | Western Water Wells 1946 Oct. | Driller's report | |
| 9 | | NE | 4 | 33 | 1 | 5 | 3,385m | 80 | | | 18 | 3,367 | | Dr | | M | | | | | | Western Water Wells 1946 Oct. | Driller's report | |
| 10 | | NE | 4 | 33 | 1 | 5 | 3,375m | 80 | 19.6 | 3,355 | 17? | 3,358 | | Dr | 17– 21<br>37– 39<br>63– 65 | M | ~50 | 19 | 68 | 1820? | | Oct. 1946 | Pump test | |
| 11 | | SE | 4 | 33 | 2 | 5 | 3,385m | 150 | 18 | 3,317 | 52 | 3,273 | 6 1/4 | Dr | 56–100 | M | 60 | 18 | 10 | | | Kinsella | Driller's report; pump test; chemical analysis | |
| 12 | | SW | 10 | 33 | 1 | 5 | 3,370m | 110 | 26 | 3,344 | 20 | 3,350 | | Dr | 39– 80 | M | 60 | 20 | 48 | | | Kinsella | Driller's report; pump test; chemical analysis | |
| 13 | | SE | 10 | 33 | 1 | 5 | 3,345m | 104 | | | | | | Dr | 39– 70 | | | | | | | | | |
| 14 | | SE | 18 | 32 | 1 | 5 | 3,300m | 160 | 25 | 3,355 | 40 | 3,340 | 5 | Dr | 40–130 | D&S | 3 | | | | | Leonard 1958 Aug. | Driller's report | |
| 15 | | NW12 | 30 | 32 | 2 | 5 | 3,525m | 120 | 10<br>65 | 3,515<br>3,460 | 20 | 3,505 | 5 1/2 | Dr | 35– 45<br>90–112 | I | 7<br>25 | 35 | 0.25<br>0.5 | | | Kinsella 1958 Aug. | Driller's report | |
| 16 | | NE16 | 24 | 33 | 2 | 5 | 3,360m | 60 | 24 | 3,336 | 26 | 3,334 | 5 | Dr | 47 | D&S | 4 | 20 | 0.5 | | | Lawson 1959 March | Driller's report | |
| 17 | | SE1 | 36 | 32 | 2 | 5 | 3,350m | 85 | 34 | 3,316 | 16 | 3,334 | 4 1/2 | Dr | 62 | D | 3 | 21 | 1.5 | | | Lawson 1959 March | Driller's report | |
| 18 | | NE9 | 36 | 32 | 2 | 5 | 3,350m | 150 | | | 28 | 3,322 | | Dr | 40– 90 | M | 6 | | | | | Kinsella 1959 summer | Driller's report | |
| 19 | | NW12 | 6 | 33 | 1 | 5 | 3,335m | 150 | | | 17 | 3,318 | | Dr | 62– 72 | M | 1 | | | | | Kinsella 1959 summer | Driller's report | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | | SW6 | 1 | 33 | 2 | 5 | 3,330m | 125 | 40 | 3,290 | 57 | 3,279 | | Dr | 49– 51<br>60– | M | 50 | 12 | 48 | | | Kinsella<br>1959<br>summer | Driller's report;<br>pump test;<br>chemical analysis | |
| 21 | | NW13 | 7 | 33 | 1 | 5 | 3,355m | 225 | 14 | 3,341 | 18 | 3,337 | 5 5/8 | Dr | 190–225 | M | 35 | | 0.5 | | | Kinsella<br>1961<br>spring | Driller's report;<br>pump test;<br>chemical analysis | |
| 22 | | NW | 24 | 32 | 3 | 5 | 3,490m | 45 | 8.5 | 3,481 | 20 | 3,470 | 12 | Dr | 41– 42 | D | 1 | | | | | Hall<br>1960 Oct. | Driller's report | |
| 23 | | NW | 24 | 32 | 3 | 5 | 3,500m | 360 | 10<br>15 | 3,490<br>3,355 | 28 | 3,462 | 5 1/2 | Dr | 42– 45<br>200–201 | D | 0.5 | | | | | Hall<br>1960 Oct. | Driller's report | |
| 24 | | SW | 30 | 32 | 1 | 5 | 3,340m | 110 | 5 | 3,335 | 18 or<br>100 | 3,322 or<br>3,240 | 6 | Dr | 16– 40<br>60–100 | M | 60 | none | 10 | | | Kinsella<br>1961 July | Driller's report;<br>pump test;<br>chemical analysis | |
| 25 | | NE9 | 25 | 32 | 2 | 5 | 3,340m | 70 | 20 | 3,320 | 44 | 3,296 | | Dr | 40– 44 | M | 72 | 2(?) | 7 days | | | Kinsella<br>1961 July | Chemical analysis;<br>pump test | |
| 26 | | NE | 25 | 32 | 2 | 5 | | 110 | 20 | | | | | Dr | 28– 32 | M | 65 | 2(?) | | | | Kinsella<br>1961<br>summer | Pump test | |
| 27 | | NW | 12 | 33 | 2 | 5 | 3,320m | 150 | 40 | 3,280 | 28 | 3,292 | | Dr | 125 | M | 2 | to bottom | 0.1 | | | Kinsella<br>1961 June | Driller's report | |
| 28 | | NE | 25 | 32 | 2 | 5 | 3,320m | 103 | 18 | 3,302 | 28 | 3,292 | 8 | Dr | 27– 28 | M | 45 | 2 | 0.2 | | | Kinsella<br>1961 | Driller's report | |
| 29 | | NE | 35 | 33 | 1 | 5 | 3,305m | 168 | | | 15 | 3,290 | | | | | | | | | | | | |
| 30 | | SE | 32 | 33 | 1 | 5 | 3,325m | 130 | 17 | 3,308 | 12 | 3,312 | 5 1/2 | Dr | 100–105 | | 2.5 | to bottom | 0.5 | | | | Driller's report | |
| 31 | | NE | 9 | 33 | 1 | 5 | 3,370m | 130 | 15 | 3,355 | | | 6 | | | D | | | | | | Lawson<br>1954 June | RCA survey | |
| 32 | | SW6 | 1 | 33 | 1 | 5 | 3,290m | 128 | 60 | 3,230 | | | | | 41– 48<br>50– 54<br>61– 97 | | | | | | | | | |
| 33 | | NW12 | 1 | 33 | 1 | 5 | 3,300 | 50 | 43(?) | 3,257 | 9 | 3,291 | | | | | good | | | | | 1904 | Driller's report | |
| 34 | | NE10 | 4 | 33 | 1 | 5 | | 130 | | | | | | | | | | | | | | | | |
| 35 | | NW13 | 4 | 33 | 1 | 5 | 3,380 | 60 | 4 | 3,376 | | | 4 | Dr | | | | | | | | 1955 | RCA survey | |

| Olds Well No. | Location: Distance in feet | Lsd. corner or 1/4 | Sec. | Tp. | R. | West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 36 | | SE1 | 6 | 33 | 1 | 5 | | 300 | | | | | | | | | | | | | | | | |
| 37 | | NW12 | 6 | 33 | 1 | 5 | | 100 | | | | | | | 67- 72 | | | | | | | | | |
| 38 | | SE1 | 10 | 33 | 1 | 5 | 3,345m | 180 | 51 | 3,294 | 32 | 3,313 | 6 | Dr | 50- 51<br>75-100<br>110-130 | M | 36 | nil | 10 | | | | Driller's report; chemical analysis | |
| 39 | | SE1 | 2 | 32 | 1 | 5 | 3,290m | 120 | 70 | 3,220 | | | | | | | good | | | | | | RCA survey | |
| 40 | | NW12 | 2 | 32 | 1 | 5 | 3,330m | 240 | 60 | 3,270 | 110(?) | 3,220 | | | 190-196 | | | | | | | | Driller's report | |
| 41 | | NW13 | 2 | 32 | 1 | 5 | 3,325m | 90 | ~55 | 3,270 | | | | | | | poor | | | | | | RCA survey | |
| 42 | | NE16 | 2 | 32 | 1 | 5 | 3,290m | 95 | 30 | 3,260 | 21 | 3,269 | 5 | Dr | 56- 86 | S | 20 | 5 | 1 | | | Kinsella 1958 Sept. | Driller's report | |
| 43 | | SW4 | 6 | 32 | 1 | 5 | | 30 | | | | | | Dg | | | | | | | | | RCA survey | |
| 44 | | NE16 | 6 | 32 | 1 | 5 | | 131 | | | | | | | 100-105 | | | | | | | | | |
| 45 | | NE9 | 11 | 32 | 1 | 5 | 3,280m | 120 | 30 | 3,250 | 19 | 3,261 | 5 | Dr | 113-120 | D&S | 4 | 85 | 6 | | | Lawson 1960 | Driller's report | |
| 46 | | NW12 | 14 | 32 | 1 | 5 | 3,290m | 103 | 15 | 3,275 | 28 | 3,262 | 4 3/4 | Dr | 31- 32 | D | 2 | | 0.5 | | | Kinsella 1959 Nov. | Driller's report | |
| 47 | | NW12 | 14 | 32 | 1 | 5 | | 182 | | | | | | | 30- 36 | | | | | | | | | |
| 48 | | NE16 | 19 | 32 | 1 | 5 | 3,405m | 120 | 40 | 3,365 | | | 4 | | | | 3 | | | | | 1958 | RCA survey | |
| 49 | | SE1 | 21 | 32 | 1 | 5 | 3,375m | 70 | | | 15 | 3,360 | | Dr | | | 2.5 | | 0.5 | | | Lawson 1960 Nov. | Driller's report | |
| 50 | | NE16 | 28 | 32 | 1 | 5 | 3,365m | 300 | | | | | | | | | | | | | | | | |
| 51 | | NW14 | 29 | 32 | 1 | 5 | 3,405m | 24 | 20 | 3,385 | 20(?) | 3,385 | | Dg | 20 | | | | | | | | RCA survey | |
| 52 | | SE1 | 30 | 32 | 1 | 5 | 3,405m | 120 | 10 | 3,395 | | | 5 1/2 | Dr | | | 5 | | | | | 1949 | RCA survey | |
| 53 | | NE16 | 30 | 32 | 1 | 5 | | 375 | 70 | | | | | | | | | | | | | | | |
| 54 | | NW13 | 31 | 32 | 1 | 5 | 3,405m | 38 | 13 | 3,392 | | | | Dr | | | 5-6 | | | | | 1956 | RCA survey | |
| 55 | | SW5 | 32 | 32 | 1 | 5 | 3,395m | 22 | 16 | 3,379 | | | | Dg | | | 1.5 | | | | | | RCA survey | |
| 56 | | NW13 | 32 | 32 | 1 | 5 | 3,385m | 88 | 10 | 3,375 | | | | | | | | | | | | | | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | Pump, bail or production test: DD | Pump, bail or production test: hrs. | Pump, bail or production test: T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 57 | | NE15 | 32 | 32 | 1 | 5 | | 160 | | | | | | | 62- 68 | | | | | | | | | |
| 58 | | NE9 | 36 | 32 | 1 | 5 | 3,280m | 150 | | | 10 | 3,270 | | | 51- 55<br>60-100 | | | | | | | | | |
| 59 | | SW3 | 1 | 33 | 2 | 5 | | | | | | | | | | | | | | | | | | |
| 60 | | SE8 | 1 | 33 | 2 | 5 | 3,320m | 200 | | | 12 | 3,308 | | | 90-180 | | | | | | | | | |
| 61 | | SW4 | 2 | 33 | 2 | 5 | | 265 | | | | | | | | | | | | | | | | RCA observation well; water-level records |
| 62 | | SW3 | 12 | 33 | 2 | 5 | 3,325m | 130 | 20 | 3,305 | 35 | 3,290 | | | 30- 35<br>65- 75 | M | 2 | to bottom | 0.1 | | | Kinsella 1963 | | |
| 63 | | SW6 | 12 | 33 | 2 | 5 | 3,320m | 130 | | | | | | | 60- 62 | | | | | | | | | |
| 64 | | NW13 | 34 | 33 | 2 | 5 | 3,320m | 87 | 26 | 3,294 | 7 | 3,313 | 5 | Dr | 80- 87 | S | 10 | none | 3 | | | Johansen | Driller's report | |
| 65 | | SW3 | 5 | 32 | 2 | 5 | 3,445m | 50 | 0 | >3,445 | 11 | 3,434 | 3 3/4 | Dr | | D&S | 60 | 4 | 1 | | | Lawson 1959 April | Driller's report | |
| 66 | | NW13 | 5 | 32 | 2 | 5 | 3,440m | 68 | 12 | 3,428 | 10 | 3,430 | 4 3/4 | Dr | 63 | | 5 | 35 | 0.4 | | | Lawson 1959 April | Driller's report | |
| 67 | | NE9 | 19 | 32 | 2 | 5 | 3,465m | 275 | | | 17 | 3,448 | 4 3/4 | Dr | 42- 48 | D&S | 15 | 155 | 0.2 | | | Kinsella 1959 June | Driller's report | |
| 68 | | NW13 | 24 | 32 | 2 | 5 | 3,385m | 100 | 8 | 3,378 | | | | Dr | | | | | | | | | RCA survey | |
| 69 | | SW4 | 25 | 32 | 2 | 5 | 3,345m | 60 | 35 | 3,310 | | | | Dr | | | | | | | | | RCA survey | |
| 70 | | NE9 | 25 | 32 | 2 | 5 | | 200 | | | | | | Dr | 40- 41 | | | | | | | | | |
| 71 | | NE9 | 25 | 32 | 2 | 5 | 3,328m | 65 | 14 | 3,314 | 26 | 3,302 | 6 1/4 | Dr | 30- 32 | | 70 | 30 | 7 days | | | Lawson 1961 Aug. | Driller's report | |
| 72 | | NE10 | 25 | 32 | 2 | 5 | 3,355m | 102 | | | 23 | 3,332 | | Dr | 40- 41 | | | | | | | | | |
| 73 | | NE16 | 25 | 32 | 2 | 5 | | 200 | | | | | | Dr | 140-150 | | | | | | | | | |
| 74 | | NE16 | 25 | 32 | 2 | 5 | 3,320m | 65 | 14 | 3,306 | 26 | 3,294 | | Dr | 30- 32 | | | | | | | | | |
| 75 | | SE1 | 26 | 32 | 2 | 5 | 3,410m | 120 | 90 | 3,320 | | | | Dr | | | 1 | | | | | | | |
| 76 | | NW12 | 28 | 32 | 2 | 5 | 3,380m | 140 | 60 | 3,320 | 60 | 3,320 | | Dr | | D | | | | | | | Driller's report | |
| 77 | | NE16 | 34 | 32 | 2 | 5 | 3,360m | 150 | | | 26 | 3,334 | | Dr | | | | | | | | | | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 78 | | NE15 | 35 | 32 | 2 | 5 | 3,320m | 150 | | | 50 | 3,270 | | Dr | 45- 50 | | | | | | | | | |
| 79 | | NE16 | 35 | 32 | 2 | 5 | 3,320m | 150 | 35 | 3,285 | 45 | 3,275 | | Dr | 45- 50 | M | 2 | bottom | 0.1 | | | Kinsella 1961 | Driller's report | |
| 80 | | SE2 | 36 | 32 | 2 | 5 | 3,325m | 240 | 10 | 3,315 | | | | | 30- 35 | | | | | | | | | |
| 81 | | SE7 | 36 | 32 | 2 | 5 | 3,375m | 103 | 18 | 3,357 | | | | | 27- 27<br>35- 50<br>65- 90 | | | | | | | | | |
| 82 | | SE8 | 36 | 32 | 2 | 5 | 3,350m | 90 | 25 | 3,325 | | | 6 | | | | 5<br>good | | | | | | Driller's report | |
| 83 | | NW11 | 36 | 32 | 2 | 5 | | | | | | | | | | | | | | | | | | |
| 84 | | NW14 | 36 | 32 | 2 | 5 | 3,330m | 55 | 30 | 3,300 | | | | | | | 7.5<br>good | | | | | | RCA survey | |
| 85 | | NE16 | 36 | 32 | 2 | 5 | 3,355m | 150 | 25 | 3,330 | 35 | 3,320 | | Dr | 50- 60<br>120-130 | M | 10 | bottom | 0.2 | | | Kinsella 1961 March | Driller's report | |
| 86 | | NE16 | 36 | 32 | 2 | 5 | 3,350m | 85 | 38 | 3,312 | 17 | 3,333 | | | 64- 69 | | | | | | | | | |
| 87 | | SW | 30 | 32 | 1 | 5 | 3,345m | 25 | 5 | 3,340 | 20 | 3,325 | | Dg | 5- 6 | | | | | | | | RCA survey | |
| 88 | | NE | 31 | 32 | 1 | 5 | 3,373m | 88 | 8 | 3,365 | 12 | 3,361 | 5 | | | | good<br>could<br>not bail<br>below 30' | | | | | | RCA survey | |
| 89 | | SE | 26 | 32 | 2 | 5 | 3,400m | 140 | 80 | 3,320 | | | | | | | 1.5 | | | | | 1954 | RCA survey | |
| 90 | | NE | 36 | 32 | 2 | 5 | 3,355m | 100 | 34 | 3,321 | 16 | 3,339 | 4 1/8 | Dr | 62 | | 3 | | | | | Lawson | RCA survey | |
| 91 | | NE | 36 | 32 | 2 | 5 | 3,350m | 31 | 23 | 3,327 | | | | Dg | 29 | | | | | | | | RCA survey | |
| 92 | | NE | 31 | 32 | 1 | 5 | 3,385m | 60 | 6.5 | 3,378 | | | 6 | | | D | poor<br>7-hrs<br>pumping<br>dry | | | | | | RCA survey | |
| 93 | | NE | 31 | 32 | 1 | 5 | 3,385m | 51 | 8 | 3,377 | | | 6 | Dr | | D | " | | | | | | RCA survey | |
| 94 | | SE | 16 | 33 | 1 | 5 | 3,400m | 80 | 44 | 3,356 | | | 4 | Dr | | | good<br>>5 | | | | | 1949 | RCA survey | |
| 95 | | SE | 16 | 33 | 1 | 5 | | 55 | | | | | | | | S | poor | | | | | very old | RCA survey | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | | NE30 | 30 | 32 | 1 | 5 | | 160 | | | | | | Dr | | | | | | | | 1949 | RCA survey | |
| 97 | | SE | 16 | 32 | 1 | 5 | 3,395m | 75 | ~5 | ~3,390 | | | | Dr | | | | | | | | 1949 | RCA survey | |
| 98 | | NE | 17 | 32 | 1 | 5 | 3,435m | 35 | ~8 | ~3,427 | 15 | 3,420 | | Dg | | D | | | | | | | RCA survey | |
| 99 | | NE | 17 | 32 | 1 | 5 | | 110 | | | | | | Dr | | D | | | | | | 1947 | | |
| 100 | | SW | 30 | 32 | 1 | 5 | 3,335m | ~375 | 70.3 | 3,265 | | | 6 | Dr | | D | ±5 | | | | | | RCA survey | |
| 101 | | NE | 34 | 32 | 1 | 5 | 3,345m | 90 | ~40 | 3,305 | | | 6 | Dr | | D good | at 3 never dry | | | | | old | RCA survey | |
| 102 | | SE | 25 | 32 | 1 | 5 | | 144 | 31 | | | | 5 | Dr | 50– 55 | | 8 | 20 | 2 | | | Erickson & Vaugan 1962 Aug. | Driller's report | |
| 103 | | SE8 | 6 | 32 | 1 | 5 | 3,360m | 132 | 30 | 3,330 | 100 | 3,260 | | | | good | | | | | | 1919 | Driller's report | |
| 104 | | NW | 14 | 32 | 1 | 5 | 3,285m | 185 | 12 | 3,273 | 28 | 3,257 | 4 3/4 | Dr | 30– 32 | D poor | 1 | to bottom | 0.2 | | | Kinsella 1959 Nov. | Driller's report | |
| 105 | | NE16 | 28 | 32 | 1 | 5 | 3,375m | 62 | 20 | 3,355 | 30 | 3,345 | 4 3/4 | Dr | 47– 59 | D good | 25 | 15 | 15 | | | Kinsella 1959 March | Driller's report | |
| 106 | | SW | 30 | 32 | 1 | 5 | 3,350m | 100 | 7.5 | 3,342 | 44 | 3,306 | 8 | Dr | 16– 21 | M | 10 | | | | | Hadland 1946 Oct.6 | Driller's report | |
| 107 | | | 33 | 32 | 1 | 5 | | 78 | 15.5 | | 37 | | | Dr | 48– 56 | M | 20.5 | 55 | | | | Hadland 1946 Oct.29 | Driller's report | |
| 108 | | NE | 7 | 32 | 1 | 5 | 3,350m | 100 | 40 | 3,310 | 24 | 3,326 | 6 | Dr | 75– 88 | S | 30 | 26 | 0.4 | | | Kinsella 1962 June | Driller's report | |
| 109 | | SE | 6 | 32 | 1 | 5 | 3,360m | 90 | 11 | 3,349 | 14 | 3,346 | 4 3/4 | Dr | 60– 61 | | 2 | to bottom | 1 | | | Lawson 1962 May | Driller's report | |
| 110 | | NE10 | 17 | 32 | 1 | 5 | 3,425m | 70 | 25 | 3,400 | 8 | 3,417 | 5 | Dr | 30– 40 | D | 1.5 | to bottom | 0.75 | | | Lawson 1961 June | Driller's report | |
| 111 | | SE | 22 | 32 | 1 | 5 | 3,295m | 40 | 18 | 3,277 | 25 | 3,270 | 4 3/4 | Dr | 33 | D | | 12 | 0.75 | | | Lawson 1961 Nov. | Driller's report | |
| 112 | | NE | 32 | 32 | 1 | 5 | 3,420m | 153 | 23 | 3,397 | 11 | 3,409 | 4 3/4 | Dr | 70– 80 | D | 1 | to bottom | | | | Lawson 1962 Aug. | Driller's report | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Sec. | Tp. | R. | West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 113 | | NE9 | 1 | 32 | 3 | 5 | 3,520m | 380 | 60 | 3,460 | 36 | 3,484 | 4 3/4 | Dr | 148–154<br>312–318 | D | 7 | to bottom | 0.4 | | | Kinsella 1959 July | Driller's report | |
| 114 | | SE | 10 | 32 | 3 | 5 | 3,425m | 55 | +3 | 3,428 | 16 | 3,409 | 4 3/4 | Dr | 47– 48 | D | 1.5 flow | | | | | Lawson 1961 Oct. | Driller's report | |
| 115 | | NE | 10 | 32 | 3 | 5 | 3,500m | 40 | 13 | 3,487 | 9 | 3,491 | 5 1/2 | Dr | 37– 32 | D | 12 | 17 | 1 | | | Lawson 1961 Oct. | Driller's report | |
| 116 | | NW | 11 | 32 | 3 | 5 | 3,555m | 299 | 140 | 3,415 | 20 | 3,535 | | Dr | 200–202<br>260–275 | I | 1<br>7 | to bottom | 3<br>30 | | | Kinsella 1957 Sept. | Driller's report | |
| 117 | | NW | 14 | 32 | 3 | 5 | 3,480m | 195 | 41 | 3,439 | 15 | 3,465 | 4 3/4 | Dr | 160–175 | D | 4 | 90 | 0.5 | | | Lawson 1961 Nov. | Driller's report | |
| 118 | | SE8 | 17 | 32 | 3 | 5 | 3,420m | 21 | 13 | 3,407 | 9 | 3,411 | 4 1/4 | Dr | 16 | | 5 | 3 | 0.25 | | | Lawson 1961 Jan. | Driller's report | |
| 119 | | NW13 | 18 | 32 | 3 | 5 | 3,510m | 103 | 20 | 3,490 | 60 | 3,450 | 4 3/4 | Dr | 75– 77<br>93– 99 | D | 30 | 8 | 0.25 | | | Kinsella 1959 Mar. | Driller's report | |
| 120 | | SW | 18 | 32 | 3 | 5 | 3,490m | 155 | 4 | 3,486 | 120 | 3,370 | 4 3/4 | Dr | 137–145 | I | 25 | 40 | 0.25 | | | Kinsella 1960 June | Driller's report | |
| 121 | | NW | 19 | 32 | 3 | 5 | 3,565m | 124 | 37 | 3,528 | 58 | 3,547 | 4 3/4 | Dr | 104–114 | | 30 | 33 | 0.25 | | | Kinsella 1960 April | Driller's report | |
| 122 | | SW | 19 | 32 | 3 | 5 | 3,530m | 90 | 25 | 3,505 | 80 | 3,450 | 6 | Dr | 60– 80 | I | 35 | | 0.50 | | | | Driller's report | |
| 123 | | NW | 24 | 32 | 3 | 5 | 3,500m | 50 | 18 | 3,482 | 28 | 3,472 | 6 1/2 | Dr | 28– 30 | | 1/2 | | | | | Hall 1962 July | Driller's report | |
| 124 | | NW | 26 | 32 | 3 | 5 | 3,450m | 100 | 31 | 3,429 | 15 | 3,435 | 6 | Dr | 50– 70 | | 1 | | | | | Lawson 1962 Feb. | Driller's report | |
| 125 | | SE | 28 | 32 | 3 | 5 | 3,400m | 64 | 14 | 3,386 | 38 | 3,362 | 5 3/4 | Dr | 61 | | 15 | | 1.5 | | | Lawson 1960 July | Driller's report | |
| 126 | | SE | 28 | 32 | 3 | 5 | 3,400m | 63 | 11 | 3,389 | 52 | 3,348 | 6 1/4 | Dr | 61 | D&S | 10 | | 0.75 | | | Lawson 1960 Nov. | Driller's report | |
| 127 | | NE | 32 | 32 | 3 | 5 | 3,370m | 180 | 51 | 3,319 | 20 | 3,350 | 4 3/4 | Dr | 160–161 | | 4 | to bottom | 1 | | | Lawson 1962 Oct. | Driller's report | |
| 128 | | NW | 33 | 32 | 3 | 5 | 3,325m | 103 | 60 | 3,265 | 55 | 3,270 | 4 | Dr | 88–102 | | 20 | | 0.2 | | | Kinsella 1959 April | Driller's report | |
| 129 | | NW | 34 | 32 | 3 | 5 | 3,325m | 104 | 8 | 3,318 | 40 | 3,285 | 4 1/2 | Dr | | D | 10 | 15 | 0.6 | | | Lawson 1959 Nov. | Driller's report | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | | SW | 35 | 32 | 3 | 5 | 3,415m | 134 | 15 | 3,400 | 12 | 3,403 | 4 3/4 | Dr | 16– 20<br>115 | | 2 | to bottom | 1 | | | Lawson<br>1959 Sept. | Driller's report | |
| 131 | | NE15 | 21 | 33 | 3 | 5 | 3,275m | 9 | | | | | 3 1/2 | | 7– 8 | | | | | | | Water Resources Branch<br>1959 June 5 | Driller's report | |
| 132 | | NE | 9 | 33 | 1 | 5 | 3,380m | 95 | 19 | 3,361 | 19 | 3,361 | 4 3/4 | Dr | 64 | | 2 | 90 | 1 | | | Lawson<br>1962 April | Driller's report | |
| 133 | | NW13 | 7 | 33 | 1 | 5 | 3,355m | 215 | 33 | 3,322 | 13 | 3,342 | 4 3/4 | Dr | 207–210 | D | 5 | 147 | 0.5 | | | Lawson<br>1962 March | Driller's report | |
| 134 | | NE | 16 | 33 | 1 | 5 | 3,370m | 90 | 12 | 3,358 | 18 | 3,352 | 5 | Dr | 26<br>85 | D | 4 | 73 | 1 | | | Lawson<br>1962 April | Driller's report | |
| 135 | | NE15 | 26 | 33 | 1 | 5 | 3,285m | 176 | 33 | 3,252 | 20 | 3,265 | 4 3/4 | Dr | 162 | D | 5 | 67 | 0.7 | | | Lawson<br>1962 May | Driller's report | |
| 136 | | NE | 22 | 33 | 1 | 5 | 3,290m | 67 | 45 | 3,245 | 37 | 3,253 | 4 3/4 | Dr | 50– 55 | S | 18 | none | 0.25 | | | Kinsella<br>1960 March | Driller's report | |
| 137 | | NW11 | 5 | 32 | 28 | 4 | 3,175m | 102 | 27 | 3,148 | | | 5 | Dr | 63– 65<br>78– 85 | D | 8 | | | | | Western Water Wells<br>1947 Feb. 1 | Driller's report | |
| 138 | | 11 | 17 | 32 | 28 | 4 | 3,155m | 207 | flowing +7 | 3,162 | | | 5 | Dr | 185–206<br>cased to 185 | | abundant | | | | | Western Water Wells<br>1946 Aug. | Driller's report | |
| 139 | | 16 | 18 | 32 | 28 | 4 | 3,175m | 185 | flowing +5 | 3,180 | 164 | 3,011 | 5 | Dr | 164–185<br>cased to 166 | D&S | | | | | | Western Water Wells | Driller's report | |
| 140 | | 14 | 19 | 32 | 28 | 4 | 3,200m | 86 | 30 | 3,170 | 18 | 3,187 | | | | | good flow | | | | | | Driller's report | |
| 141 | | SE | 33 | 32 | 28 | 4 | 3,190m | 162 | unknown 35 | 3,155 | 118 | 3,072 | 5 | Dr | 90–100<br>142–160 | D | 9<br>35 | to bottom<br>none | 0.25<br>0.25 | | | Kinsella<br>1959 Jan. | Driller's report | |
| 142 | | SW | 30 | 33 | 28 | 4 | 3,280m | 70 | 25 | 3,255 | 26 | 3,254 | 4 3/4 | Dr | 58– 65 | S | 12 | | 30 | | | Kinsella<br>1960 | Driller's report | |
| 143 | | NW | 32 | 33 | 28 | 4 | 3,275m | 270 | 140 | 3,135 | 40 | 3,235 | 4 | Dr | 250–270 | | 10 | | | | | Kinsella<br>1954 Nov. | Driller's report | |
| 144 | | NE | 12 | 32 | 28 | 4 | 3,170m | 185 | 3 | 3,167 | 157 | 3,013 | 4 | Dr | 168–176 | | 25 | 125 | 0.4 | | | Kinsella<br>1962 May | Driller's report | |
| 145 | | NW | 21 | 33 | 1 | 5 | 3,360m | 360 | 22 | 3,338 | 22 | 3,338 | 4 1/4 | Dr | 40– 90<br>165–328 | S | 5 | 130 | 0.5 | | | McLaren<br>1961 | Driller's report | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | Pump, bail or production test: DD | Pump, bail or production test: hrs. | Pump, bail or production test: T | Q safe (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 146 | | SE1 | 15 | 33 | 1 | 5 | 3,337m | | flowing | 3,337+ | | | | | | | | | | | | | Chemical analysis | |
| 147 | | SW4 | 30 | 32 | 28 | 4 | 3,213s, 48 | 690 | 31 | 3, 183 | 120 | 3,094 | 8 | Dr | | RCA obs. | | | | | | Forrester 1961 Sept. | Driller's report; chemical analysis | |
| 148 | | 16 | 27 | 32 | 2 | 5 | 3,320m | 345 | | | 13 | 3,307 | 4 3/4 | Dr | | th #1 | | | | | | Gertsma 1963 Nov. | Driller's report; E-log (339') | Town project |
| 149 | | 14 | 27 | 32 | 2 | 5 | 3,330m | 150 | 8 | 3,322 | 19 | 3,311 | 4 3/4 | Dr | | th #2 | | | | | | Gertsma 1963 Nov. | Driller's report; E-log (148') | Town project |
| 150 | | 13 | 27 | 32 | 2 | 5 | 3,330m | 150 | | | 35 | 3,295 | 4 3/4 | Dr | | th #3 | | | | | | Gertsma 1963 Nov. | Driller's report; E-log (148') | Town project |
| 151 | | 1 | 33 | 32 | 2 | 5 | 3,330m | 75 | | | 53 | 3,277 | 4 3/4 | Dr | | th #4 | | | | | | Gertsma 1963 Nov. | Driller's report; E-log (60') | Town project |
| 152 | | 9 | 25 | 32 | 2 | 5 | 3,335m | 670 | | | 20 | 3,315 | 4 3/4 | Dr | | th #5 | | | | | | Gertsma 1963 Nov. | Driller's report; E-log (667') | Town project |
| 153 | | 5 | 30 | 32 | 1 | 5 | 3,340m | 100 | | | 13 | 3,327 | | | | expl. #2 | 12 | to bottom | 2.5 | | | Gertsma 1963 Nov. | Driller's report | Town project |
| 154 | | 12 | 30 | 32 | 1 | 5 | 3,335m | 25 | ~6 | ~3,330 | 13 | 3,322 | 12 1/4 | Dr | | expl. #1 | 12 | | | | | Gertsma 1963 Nov. | Driller's report | Town project |
| 155 | | NE | 24 | 32 | 29 | 4 | 3,215m | 87 | flowing | >3,215 | 79 | 3, 136 | | Dr | | | | | | | | 1920 | Driller's report | |
| 156 | | NW | 25 | 32 | 29 | 4 | 3,265m | 94 | flowing | >3,265 | ~60 | 3,205 | | Dr | | D&S good | | | | | | 1929 | Driller's report | |
| 157 | | SE | 33 | 32 | 2 | 5 | 3,330m | 37 | +1 flowing | 3,331 | 10 | 3,320 | 5 3/4 | Dr | 35- 36 | D&S | 8 | 3 | 2 | | | 1960 Nov. | Driller's report | |
| 158 | | 9 | 2 | 32 | 2 | 5 | 3,315m | 58 | 5 | 3,310 | 19 | 3,296 | 6 | Dr | 35- 55 | | 3 | 50 | 0.5 | | | Lawson 1961 | Driller's report | |
| 159 | | SE | 6 | 32 | 2 | 5 | 3,480m | 180 | 38 | 3,442 | 18 | 3,472 | 4 1/2 | Dr | 82-160 | | 2.5 | to bottom | 1 | | | Lawson 1962 | Driller's report | |
| 160 | | 6 | 24 | 32 | 2 | 5 | 3,365m | 61 | 54 | 3,311 | 14 | 3,357 | 4 1/2 | Dr | 57 | | 20 | 3 | 0.1 | | | Lawson 1961 Jan. | Driller's report | |
| 161 | | 16 | 25 | 32 | 2 | 5 | 3,330m | 150 | 25 | 3,305 | 7 | 3,323 | 4 3/4 | Dr | 35 | M | 5 | to bottom | 0.5 | | | Lawson 1961 Sept. | Driller's report | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 162 | | 14 | 25 | 32 | 2 | 5 | 3,335m | 70 | 20 | 3,315 | 44 | 3,291 | 8 5/8 | Dr | 42- 44 | M | 50 | 32 | 5 days | | | Lawson 1961 Sept. | Driller's report | |
| 163 | | NE | 35 | 32 | 2 | 5 | 3,320m | 106 | 20<br>15 | 3,305 | 18 | 3,302 | 6 | Dr | 60<br>85- 90 | I | 4 | to bottom | 0.35 | | | Kinsella 1962 Jan. | Driller's report | |
| 164 | | 12 | 28 | 33 | 2 | 5 | 3,265m | 90 | 20 | 3,245 | 38 | 3,227 | 5 1/2 | Dr | 87- 88 | D | 6 | 65 | 1.5 | | | Lawson 1960 | Driller's report | |
| 165 | | SE | 11 | 33 | 2 | 5 | 3,305m | 93 | 18 | 3,287 | 16 | 3,289 | 6 | Dr | 52 | | 1.75 | to bottom | 1 | | | Lawson 1962 Sept. | Driller's report | |
| 166 | | SW | 14 | 33 | 2 | 5 | 3,320m | 60 | 5 | 3,315 | 11 | 3,309 | 3 3/4 | Dr | 55 | | 15 | 15 | 0.3 | | | Lawson 1961 June | Driller's report | |
| 167 | | NW | 25 | 33 | 2 | 5 | 3,375m | 100 | 50 | 3,325 | 85 | 3,290 | 6 | Dr | 85-100 | | | | | | | Lawson 1962 April | Driller's report | |
| 168 | | 16 | 9 | 33 | 3 | 5 | rel: 102.75 | 86 | +3.94 flowing | | 85 | 3,233 | | Dr | 70- 75 | th #1 | | | | | | Kinsella 1962 summer | Report on the test program by Haddin, Davis & Brown Co. Ltd., lith log, compiled data of pumping tests, interpretations | Haddin, Davis, & Brown, Consulting Ltd., Little Red Deer Project. Top elev. for each test hole is taken as 3,310 ft. Elev. of water level for each hole is taken as 3,315 ft. Depth to bedrock for each hole is taken as 77 ft. |
| 169 | | 16 | 9 | 33 | 3 | 5 | rel: 100.00 | 75 | +10.80 flowing | | 68 | 3,233 | | Dr | 63- 65 | th #2 | | | | | | | | |
| 170 | | 16 | 9 | 33 | 3 | 5 | rel: 98.75 | 70 | +8.02 flowing | | 70 | 3,233 | | Dr | 68- 71 | th #3 | | | | | | | | |
| 171 | | 16 | 9 | 33 | 3 | 5 | rel: 104.45 | 90 | +0.43 flowing | | 85 | 3,233 | | Dr | 81- 85 | th #4 | | | | | | | | |
| 172 | | 16 | 9 | 33 | 3 | 5 | rel: 102.90 | 65 | +5.08 flowing | | 61 | 3,233 | | Dr | 60- 62 | th #5 | | | | | | | | |
| 173 | | 16 | 9 | 33 | 3 | 5 | rel: 101.60 | 68 | flowing | | 65 | 3,233 | | Dr | 59- 60<br>65- 68 | th #6 | | | | | | | | |
| 174 | | 16 | 9 | 33 | 3 | 5 | rel: 105.8 | 92 | +4 flowing | | 90 | 3,233 | | Dr | 85- 90 | th #7 | | | | | | | | |
| 175 | | 10 | 9 | 33 | 3 | 5 | rel: 104.2 | 94 | +5.11 flowing | | 90 | 3,233 | | Dr | 85- 90 | th #8 | | | | | | | | |

| Olds. Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 176 | | 1 | 16 | 33 | 3 | 5 | | | | | | | | | | D | | | | | | | | Pump test by Haddin, Davis & Brown Co. Ltd. shows that this well is in the same aquifer as wells #168 through #175. |
| 177 | 241S & 50W | NE | 26 | 32 | 1 | 5 | 3,292s | 245 | 28.5 | 3,264 | •140 | 3,152 | 7 | Dr | | th #1 | 20 | 28.50 | 2 | 1,055 | | Forrester 1964 Jan. | | |
| 178 | 2,640E & 15N | SW | 25 | 32 | 1 | 5 | 3,249s | 325 | 32.91 | 3,216 | 75 | 3,174 | 7 | Dr | | th #2 | 226 | 37.49 | 69.5 | 1,932 | | Forrester 1964 Jan. | | |
| 179 | 1,640N & 30W | SE | 25 | 32 | 1 | 5 | 3,238s | 330 | 17.64 | 3,220 | 170 | 3,068 | 7 | Dr | | th #3 | 20 | 14.30 | 2 | 1,880 | | Forrester 1964 Feb. | Driller's report; lith samples; pump test; daily water-level measurements and rate of pumping for town after RCA test was completed (wells 177–182) | |
| 180 | 2,655E & 15N | SW | 25 | 32 | 1 | 5 | 3,249s | 260 | 32.27 | 3,216 | 74 | 3,175 | 7 | Dr | | obs. #2a | | | | | | Forrester 1964 Feb. | | RCA observation and test holes |
| 181 | 2,790E & 15N | SW | 25 | 32 | 1 | 5 | ~3,248s | 260 | 31.54 | 3,216 | 70 | 3,178 | 7 | Dr | | obs. #2b | | | | | | Forrester 1964 Feb. | | |
| 182 | 2,893E & 1,035N | SW | 25 | 32 | 1 | 5 | 3,249s | 250 | 31.97 | 3,217 | 117 | 3,132 | 7 | Dr | | S obs. #4 | | | | | | Forrester 1964 Feb. | | |
| 183 | | 1 | 1 | 32 | 2 | 5 | 3,360m | 135 | 10 | 3,350 | 8 | 3,352 | 4 3/4 | Dr | | th #6 | 12<br>15 | 13<br>20 | 4<br>4 | - | | Gertsma 1963 Nov. | Driller's report; E-log | |
| 184 | South boundary of | 12 | 32 | 32 | 1 | 5 | 3,390m | | | | 10 | 3,380 | | Dr | | th #7 | | | | | | Gertsma 1963 Nov. | Lith samples | Town project |
| 185 | NE corner | 14 | 2 | 33 | 1 | 5 | 3,320m | | | | 15 | 3,305 | | Dr | | th #8 | | | | | | Gertsma 1963 Nov. | Lith samples | Town project |
| 186 | | SE | 4 | 33 | 1 | 5 | | 216 | | | | | | Dr | | th #6a | | | | | | Gertsma 1963 Nov. | Driller's log | Town project |
| 187 | 2,730E & 1,400N | SW | 24 | 32 | 1 | 5 | 3,241s | 320 | 42<br>71 | 3,190<br>3,170 | 90 | 3,151 | 7 | Dr | | th #5 | 20 | 33.59 | 2 | 960 | | Forrester 1964 May | | RCA test hole |
| 188 | 900W & 2,250S | NE | 23 | 32 | 29 | 4 | 3,217s | 302 | 25 | 3,192 | 108 | 3,109 | 7 | Dr | | th #6 | 20 | 21.81 | 2 | 2,640 | | Forrester 1964 June | | |
| 189 | 3,200W & 45S | NE | 24 | 32 | 29 | 4 | 3,224s | 380 | flowing | 3,224+ | 134 | 3,090 | 7 | Dr | | th #7 | | | | | | Forrester 1964 June | | |
| 189a | 3,185W & 45S | NE | 24 | 32 | 29 | 4 | 3,223s | 210 | 2.92 above gr | 3,226 | | | 7 | Dr | | obs. #7a | | | | | | Forrester 1964 July | | |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 189b | 3,035W & 45S | NE | 24 | 32 | 29 | 4 | 3,224s | 207 | 3.39 above gr | 3,227 | | | 7 | Dr | | obs. #7b | | | | | | Forrester 1964 July | | RCA observation well |
| 189c | 3,388W & 408S | NE | 24 | 32 | 29 | 4 | 3,228s | | 2+ above gr | 3,230+ | | | | Dr | | obs. #7c | | | | | | | | Abandoned stock well, used by RCA as observation well. |
| 189d | 1,880W & 2,550N | SE | 24 | 32 | 29 | 4 | 3,192s | | 30 | 3,162 | | | | Dr | | obs. #7d | | | | | | | | Abandoned stock well, used by RCA as observation well. |
| 190 | 15E & 1,900S | NW | 30 | 32 | 28 | 4 | 3,225s | 320 | 25 | 3,200 | 123 | 3,102 | 7 | Dr | | th #8 | 10 | 118 | 2 | 32 | | Forrester 1964 June | | RCA test hole |
| 191 | 45W & 15N | SE | 23 | 32 | 29 | 4 | 3,208s | 295 | 21 | 3,187 | 65 | 3,143 | 7 | Dr | | th #9 | 20 | 6.43 | 1.5 | 10,550 | | Forrester 1964 June | | RCA test hole |
| 192 | 2,000W & 15N | SE | 24 | 32 | 29 | 4 | 3,192s | 530 | 29 | 3,163 | 128 | 3,064 | 7 | Dr | | th #10 | | | | | | Forrester 1964 July | | RCA test hole |
| 192a | 1,985W & 15N | SE | 24 | 32 | 29 | 4 | 3,191s | 221 | 27 | 3,164 | | | 7 | Dr | | th #10a | | | | | | Forrester 1964 July | | RCA test hole |
| 192b | 1,850W & 15N | SE | 24 | 32 | 29 | 4 | 3,193s | 152 | 16 | 3,177 | | | 7 | Dr | | obs. #10b | | | | | | Forrester 1964 Aug. | | RCA observation well |
| 193 | 20E & 2,850S | NW | 25 | 32 | 1 | 5 | 3,280s | 380 | 42 | 3,238 | 172 | 3,108 | 7 | Dr | | th #11 | 20 | 4.75 | 2 | 1,060 | | Forrester 1964 June | | RCA test hole |
| 194 | 2,620W & 15S | NE | 25 | 32 | 1 | 5 | 3,276s | 400 | 33 | 3,243 | 90 | 3,186 | 7 | Dr | | th #12 | 20 | 0.1 | 2 | 586,000 | | Forrester 1964 June | | RCA test hole |
| 195 | 65E & 800S | NW | 36 | 32 | 29 | 4 | 3,297s | 350 | 36 | 3,261 | 15 | 3,282 | 7 | Dr | | th #13 | 20 | 1.86 | 2 | 7,550 | | Forrester 1964 July | | RCA test hole |
| 196 | 45E & 2,400S | NW | 12 | 33 | 1 | 5 | 3,293s | 402 | 31 | 3,262 | 35 | 3,258 | 7 | Dr | | th #14 | | | | <1 | | Forrester 1964 July | | RCA test hole |
| 197 | 700W & 45S | NE | 12 | 33 | 1 | 5 | 3,246s | 690 | 16 | 3,230 | 90 | 3,156 | 7 | Dr | | th #15 | 20 | 3.31 | 2 | 4,700 | | Forrester 1964 Aug. | | RCA test hole |
| 198 | 2,660W & 2,540S | NE | 24 | 33 | 1 | 5 | 3,238s | 285 | flowing 3+ above | 3,241+ | 19 | 3,219 | 6 | Dr | | th #16 | 20 | 0.85 | 2 | 15,100 | | Forrester 1964 Aug. | | RCA test hole |
| 199 | 75E & 90S | NW | 13 | 33 | 29 | 4 | 3,235 | 365 | 11 | 3,224 | 112 | 3,123 | 7 | Dr | | th #17 | 20 | 5.04 | 2 | 2,780 | | Forrester 1964 Aug. | | RCA test hole |
| 199a | 110E & 90S | NW | 13 | 33 | 29 | 4 | 3,235 | | flowing | 3,235+ | | | | Dr | | D | | | | | | | | |
| 200 | 2,340W & 45S | NE | 23 | 33 | 1 | 5 | 3,287s | 305 | 26 | 3,261 | 75 | 3,212 | 7 | Dr | | th #18 | 20 | 1.85 | 2 | 9,270 | | Forrester 1964 Aug. | | RCA test hole |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 201 | 1,900W & 45N | SE | 23 | 33 | 1 | 5 | 3,276s | 242 | 14 | 3,262 | 20 | 3,256 | 7 | Dr | | th #19 | 20 | 3.88 | 2 | 13,200 | | Forrester 1964 Aug. | | RCA test hole |
| 202 | | 1 | 2 | 33 | 1 | 5 | 3,310m | 200 | 60<br>73 | 3,250<br>3,237 | 33 | 3,277 | 7 | Dr | 135<br>185-200 | service station supply | 20 | 19.66 | 2 | 1,460 | | Forrester 1964 Aug. | | |
| 203 | | 16 | 11 | 33 | 2 | 5 | 3,300m | 200? | | | | | 6 | Dr | | S | | | | | | | RCA survey; chemical analysis | T=40°F |
| 204 | | 4 | 13 | 33 | 2 | 5 | | | | | | | | | | | | | | | | | RCA survey; April 1964; chemical analysis | |
| 205 | | 14 | 7 | 33 | 1 | 5 | 3,360m | 26 | | | 8 | 3,358 | | Dug | | D&S | | | | | | | " | T=43°F |
| 206 | | 1 | 18 | 33 | 1 | 5 | 3,370m | 65 | 12-20 | 3,355 | | | | Dr | | D&S | | | | | | | " | |
| 207 | | 4 | 16 | 33 | 1 | 5 | 3,405m | 165 | 17 | 3,388 | | | 6 | Dr | 97 | Dom | 3/4 | | | | | | " | |
| 208 | | 13 | 10 | 33 | 1 | 5 | 3,365m | 160 | 60? | 3,305? | | | 6 | Dr | | S | 3/4 | | | | | | " | T=41°F |
| 209 | | 4 | 15 | 33 | 1 | 5 | 3,360m | 80 | 30 | 3,330 | | | | Dr | | D | | | | | | | " | T=41°F |
| 210 | | 14 | 11 | 33 | 1 | 5 | | 90 | | | | | | Dr | | S good | | | | | | | " | T=38°F |
| 211 | | 3 | 13 | 33 | 29 | 4 | | 100 | | | | | | Dr | | D&S | | | | | | | " | Spring; T=36°F |
| 212 | | 6 | 12 | 33 | 29 | 4 | 3,225m | | flowing | 3,225+ | | | | | | | | | | | | | | |
| 213 | | 11 | 12 | 33 | 29 | 4 | 3,230m | 60 | 11 flowing | 3,219 | | | | Dr | | | | | | | | | " | T=40°F |
| 214 | | 4 | 13 | 33 | 29 | 4 | 3,225m | 100 | flowing | 3,225+ | | | | Dr | | S | 2 | | | | | | " | T=41°F |
| 215 | | 16 | 7 | 33 | 28 | 4 | 3,220m | 80 | 8 | 3,212 | | | 6 | Dr | | D&S good | | | | | | | " | |
| 216 | | 16 | 7 | 33 | 28 | 4 | 3,220m | | 8-9 | 3,212 | | | | Dug | | | | | | | | | " | T=38°F |
| 217 | | 1 | 8 | 33 | 28 | 4 | | | | | | | | | | | | | | | | | " | T=41°F |
| 218 | | 15 | 32 | 34 | 28 | 4 | 3,200m | 90 | 22 | 3,178 | | | 6 | Dr | | D&S good | | | | | | | " | sulphur smell |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 219 | | 14 | 31 | 34 | 28 | 4 | 3,225m | 60 | 16–20 | 3,207 | | | 6 | Dr | | | 10 | | | | | | | |
| 220 | | 4 | 1 | 33 | 28 | 4 | 3,275m | 74 | 22 | 3,253 | | | 6 | Dr | | D&S good | | | | | | | RCA survey; April 1964 | |
| 221 | | 2 | 1 | 33 | 1 | 5 | | 40? | | | | | | Dr | | D&S | | | | | | | " | |
| 222 | | 4 | 1 | 33 | 1 | 5 | 3,310m | 80 | 30–40? | 3,275? | | | | Dr | | D&S good | | | | | | | " | |
| 223 | | 2 | 2 | 33 | 1 | 5 | | | | | | | | | | | | | | | | | " | |
| 224 | | 13 | 35 | 34 | 1 | 5 | 3,330m | 105 | 57 | 3,273 | | | 6 | Dr | | D&S good | | | | | | | " | |
| 225 | | 4 | 3 | 33 | 1 | 5 | | 110 | | | | | 6 | Dr | | | | | | | | | " | |
| 226 | | 1 | 6 | 33 | 1 | 5 | | | | | | | | | | | | | | | | | " | T=38°F |
| 227 | | 1 | 1 | 33 | 2 | 5 | | | | | | | | | | | | | | | | | " | T=39°F |
| 228 | | 9 | 1 | 33 | 2 | 5 | 3,335m | 125 | 17 | 3,318 | | | 6 | Dr | | D&S | 6 | | | | | | " | |
| 229 | | 16 | 35 | 34 | 2 | 5 | 3,325m | 108 | 15 | 3,310 | | | | Dr | | D&S | 6 | | | | | | " | Sulphur smell |
| 230 | | 4 | 25 | 32 | 2 | 5 | 3,400m | 75 | 30 | 3,370 | | | 6 | Dr | | D&S | 5 | | | | | | " | Sulphur smell |
| 231 | | 3 | 30 | 32 | 1 | 5 | 3,350m | 60 | 2 | 3,348 | | | | Dr | 42 | S good | | | | | | | " | T=40°F; aquifer in gravel |
| 232 | | 3 | 30 | 32 | 1 | 5 | 3,350m | 20 | 0 | 3,350 | | | | | | | | | | | | | " | |
| 233 | | 2 | 28 | 32 | 1 | 5 | | 60 | | | | | 6 | Dr | | D&S good | | | | | | | " | |
| 235 | | 13 | 23 | 32 | 1 | 5 | 3,310m | 86 | 25 | 3,285 | | | | Dr | | D&S | | | | | | | " | |
| 236 | | 9 | 26 | 32 | 1 | 5 | | | | | | | | | | S | | | | | | | " | T=41°F |
| 237 | | 1 | 26 | 32 | 1 | | | | | | | | | | | Service station good | | | | | | | RCA survey; April 1964 chemical analysis | |
| 238 | | 2 | 25 | 32 | 29 | 4 | 3,225m | 80 | flowing | 3,225+ | | | | Dr | | D&S | 3/4 | | | | | | " | |
| 239 | | 1 | 30 | 32 | 28 | 4 | 3,200m | 105 | 15 | 3,185 | | | | Dr | | D&S | 44 | | | | | | " | Water became muddy on the night of the Alaska Earthquake |

| Olds Well No. | Location: Distance in feet | Location: Lsd. corner or 1/4 | Location: Sec. | Location: Tp. | Location: R. | Location: West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 240 | | 14 | 21 | 32 | 28 | 4 | 3,195m | 72 | 18 | 3,177 | | | 6 | Dr | | D&S | 8+ | | | | | | RCA survey, April 1964; chemical analysis | |
| 241 | | 8 | 17 | 32 | 28 | 4 | 3,130m | 117 | flowing | 3,130+ | | | 6 | Dr | | D&S | 2 | | | | | 1928 | " | T=40°F |
| 242 | | 15 | 8 | 32 | 28 | 5 | 3,130m | | flowing | 3,130+ | | | | | 50 | D&S | 2.5 | | | | | 1958 | " | T=40°F; seismic shot hole |
| 243 | | 14 | 17 | 32 | 28 | 4 | 3,155m | 207 | flowing | 3,162 | | | | Dr | | D&S | | | | | | | " | T=40.5°F |
| 244 | | 16 | 18 | 32 | 28 | 4 | 3,175m | 185 | flowing | 3,180 | 164 | 3,011 | | Dr | 5; 106; 164 | D&S | 1.5 | | | | | Western Water Wells | " | T=41°F |
| 245 | | 14 | 7 | 32 | 28 | 4 | 3,165m | 115 | 10 | 3,155 | | | 5 | Dr | ~105 | D&S | 15? | | | | | | " | |
| 246 | | 15 | 12 | 32 | 29 | 4 | 3,180m | | flowing | 3,185+ | | | | Dr | | | 3 | | | | | | " | T=41°F |
| 247 | | 1 | 13 | 32 | 1 | 5 | | | | | | | | | | school | | | | | | | " | T=41°F |
| 248 | | 14 | 12 | 32 | 1 | 5 | | | | | | | | | | abandoned | | | | | | | " | T=41°F |
| 249 | | 12 | 11 | 32 | 1 | 5 | 3,285m | 110? | 20? | 3,265 | | | | Dr | | D poor | | | | | | | " | T=41°F |
| 250 | | 4 | 15 | 32 | 1 | 5 | 3,370m | 113 | 53 | 3,317 | | | | Dr | | S | 10 | | 12 | | | | " | |
| 251 | | 15 | 7 | 32 | 1 | 5 | 3,360 | 100 | 30 | 3,330 | | | 7 | Dr | 75-85 | D | 26 | | | | | | " | |
| 252 | | 4 | 13 | 32 | 2 | 5 | 3,360m | 140 | 125 | 3,235 | | | 5 | Dr | | D&S poor | | | | | | | " | T=40.5°F |
| 253 | | 3 | 6 | 32 | 1 | 5 | 3,375m | 135 | 20 | 3,355 | | | 6 | Dr | | D&S poor | | | | | | | " | |
| 254 | | 4 | 4 | 32 | 1 | 5 | 3,330m | 68? | | | | | | Dr | | D&S | 1 | | | | | | " | |
| 256 | | 1 | 4 | 32 | 1 | 5 | | | | | | | | | | D | | | | | | | " | T=41°F |
| 258 | | 8 | 1 | 32 | 1 | 5 | 3,290m | 30 | | 3,260 | | | | | | good | | | | | | | " | |
| 259 | | 4 | 1 | 32 | 29 | 4 | 3,255m | 80 | flowing | 3,255+ | | | | Dr | | D&S | 1 | | | | | | " | |
| 260 | | 15 | 36 | 31 | 29 | 4 | 3,230m | 80 | flowing | 3,230+ | | | 6 | Dr | | D&S | | | | | | | " | Pump required in dry years |
| 261 | | 13 | 32 | 31 | 28 | 4 | 3,195m | 85 | 20 | 3,175 | | | | Dr | | S | 5 | | | | | | " | T=40°F |
| 262 | | 13 | 32 | 31 | 28 | 4 | 3,195m | 110 | 25-30 | 3,170 | | | 6 | Dr | | D | 20 | | | | | | " | |
| 263 | | 3 | 4 | 32 | 28 | 4 | | | | | | | | | | abandoned | | | | | | | " | T=40°F |

| Olds Well No. | Location: Distance in feet | Lsd. corner or 1/4 | Sec. | Tp. | R. | West of Mer. | Elevation (feet) | Depth of well (feet) | Depth to water (feet) | Elevation of water surface | Depth to bedrock (feet) | Elevation of bedrock (feet) | Well diameter (inches) | Type of well | Depth to aquifer (feet) | Use and supply | Pump, bail or production test: igpm | DD | hrs. | T | $Q_{safe}$ (igpm) | Driller and year | On RCA file | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 264 | | 14 | 24 | 33 | 2 | 5 | 3,350m | | 30 | 3,320 | | | 4 | Dr | | | 3 | | | | | | RCA survey, April 1964; chemical analysis | T=41°F |
| 265 | | 16 | 19 | 33 | 1 | 5 | | 190? | | | | | | | | D&S good | | | | | | | " | |
| 267 | | 1 | 12 | 32 | 2 | 5 | 3,360m | 48 | 20 | 3,340 | | | 6 | Dr | | very good | | | | | | | " | sulphur smell |
| 268 | | 5 | 28 | 33 | 1 | 5 | 3,355m | 150? | 50-60? | 3,300? | | | 6 | Dr | | good | | | | | | | " | T=40°F |
| 269 | | 1 | 28 | 33 | 1 | 5 | 3,355m | 90 | 70 | 3,285 | | | | Dr | | D&S good | | | | | | | " | |
| 270 | | 2 | 26 | 33 | 1 | 5 | | | | | | | | | | D&S | | | | | | | " | |
| 271 | | 16 | 23 | 33 | 29 | 4 | | | | | | | | | | D&S | | | | | | | " | T=41°F |
| 272 | | 15 | 19 | 33 | 28 | 4 | 3,275m | 80 | 15 | 3,260 | | | | Dr | 60 | D&S | 5 | | | | | | " | T=41°F |
| 273 | | 1 | 29 | 33 | 28 | 4 | 3,235m | 75 | 40? | 3,195? | | | | Dr | 50 | D&S | | | | | | | " | |
| 274 | | 8 | 2 | 33 | 1 | 5 | | | | | | | | | | D&S | | | | | | | " | |
| 275 | | 5 | 36 | 32 | 1 | 5 | 3,290m | 80 | 40? | 3,250? | | | 6 | Dr | | D&S | | | | | | | " | After Alaska Earthquake color of water was red for 2 or 3 days |
| 276 | | 14 | 9 | 32 | 1 | 5 | 3,415m | 100? | 40-50? | 3,370? | | | | Dr | | D&S | | | | | | | " | |
| 277 | | 13 | 16 | 32 | 1 | 5 | | 75? | | | | | | | | D&S good | | | | | | | " | |
| 278 | | 5 | 33 | 32 | 1 | 5 | | 220 | | | | | | | | D&S | | | | | | | " | |
| 279 | | 15 | 28 | 32 | 1 | 5 | 3,375m | 90 | 20 | 3,355 | | | 6 | Dr | | D&S good | | | | | | | " | |

# APPENDIX C:
# LIST OF CHEMICAL ANALYSES
# OF WELL WATERS

Appendix C

List of Chemical Analyses of Well Waters

| Olds well no. | Depth of well at time of sampling (feet) | Date of sampling | Total solids (ppm) | Ignition loss (ppm) | Na (epm) | K (epm) | Ca (epm) | Mg (epm) | Na+K Percentage of cations | Ca/Mg | Cl (epm) | $SO_4$ (epm) | $NO_3$ (epm) | Fe (ppm) | $HCO_3$ + $CO_3$ (epm) | $SO_4$ Per cent of total anions | $HCO_3$ + $CO_3$ Per cent of total anions | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 150 | - | 440 | 170 | Na+K = 1.59 | | Ca+Mg = 6.40 | | 20 | - | 0.48 | 0.45 | 0.06 | 1.2 | 7.00 | 6 | 88 | |
| 12 | 110 | - | 670 | 80 | Na+K = 9.56 | | Ca+Mg = 2.00 | | 83 | - | 0.08 | 1.48 | nil | 0.5 | 10.00 | 13 | 87 | |
| 20 | 125 | - | 406 | 120 | Na+K = 3.30 | | Ca+Mg = 3.60 | | 48 | - | nil | 0.50 | nil | 1.0 | 6.40 | | 93 | After 48 hrs. of pumping |
| 21 | 225 | Jan. 25/61 | 756 | 36 | Na+K = 28.19 | | Ca+Mg = 0.80 | | 97 | - | tr. | 17.33 | 0.06 | 0.8 | 11.60 | 60 | 40 | |
| 24 | 110 | July 20/61 | 320 | 94 | Na+K = 1.50 | | Ca+Mg = 4.40 | | 25 | - | 0.08 | 1.33 | 0.09 | 0.8 | 4.40 | 23 | 75 | After 24 hrs. of pumping |
| 25 | 70 | Aug. 17/61 | 288 | 122 | Na+K = 0.50 | | Ca+Mg = 4.80 | | 09 | - | tr. | 0.30 | nil | 0.8 | 5.00 | 6 | 94 | After 5 days of pumping |
| 38 | 180 | Nov. 27/56 | 540 | 144 | Na+K = 3.30 | | Ca+Mg = 6.60 | | 33 | - | nil | 2.00 | nil | 0.1 | 7.90 | 20 | 80 | |
| 178 | 325 | Mar. 3/64 | 1476 | 130 | 21.95 | nil | 0.43 | 0.87 | 94 | 0.49 | 0.11 | 11.18 | 0.01 | tr. | 11.28 | 48 | 48 | After 21.5 hrs. of pumping |
| 178 | 325 | Mar. 3/64 | 1496 | 146 | 21.95 | nil | 0.43 | 1.01 | 94 | 0.43 | 0.11 | 11.28 | 0.01 | nil | 11.47 | 50 | 50 | After 29.5 hrs. of pumping |
| 178 | 325 | Mar. 5/64 | 1484 | 140 | 22.21 | nil | 0.48 | 1.16 | 93 | 0.41 | 0.11 | 11.20 | 0.01 | tr. | 11.28 | 50 | 50 | After 68 hrs. of pumping |
| 178B | | May 23/64 | 1628 | 126 | Na+K = 22.00 | | Ca+Mg = 2.90 | | 88 | - | nil | 14.20 | nil | tr. | 10.70 | 57 | 43 | After 2 months and 3 weeks of pumping |
| 188 | 110 | May 27/64 | 1600 | 178 | Na+K = 21.35 | | Ca+Mg = 2.50 | | 89 | - | nil | 13.25 | nil | nil | 10.60 | 56 | 44 | Drift water |
| 188 | 300 | June 4/64 | 1556 | 134 | Na+K = 21.22 | | Ca+Mg = 2.60 | | 89 | - | 0.28 | 12.13 | 0.01 | 3.3 | 11.40 | 51 | 48 | Bedrock water after 2 hrs. of bailing |
| 189 | 134 | May 28/64 | 1440 | 192 | Na+K = 16.79 | | Ca+Mg = 5.00 | | 77 | - | 0.11 | 12.18 | nil | tr. | 9.50 | 56 | 44 | Drift water |
| 189 | 385 | June 5/64 | 1500 | 42 | 22.00 | nil | 0.91 | 0.98 | 92 | 0.93 | 0.28 | 12.73 | nil | nil | 11.10 | 53 | 46 | Bedrock water after 2 hrs. of bailing |
| 189 | 385 | July 23/64 | 1646 | 100 | 22.60 | 0.31 | 1.38 | 0.91 | 91 | 1.52 | 0.06 | 14.88 | nil | 3.9 | 10.34 | 58 | 41 | After 4 hrs. of pumping |
| 189 | 385 | July 23/64 | 1634 | 86 | 22.19 | 0.31 | 0.98 | 1.71 | 89 | 0.57 | 0.09 | 15.25 | nil | 5.5 | 10.35 | 59 | 40 | After 23.5 hrs. of pumping |
| 189 | 385 | July 25/64 | 1648 | 90 | 18.40 | 0.31 | 1.32 | 0.67 | 90 | 1.97 | nil | 15.30 | nil | 0.8 | 10.38 | 60 | 40 | After 72 hrs. of pumping |
| 189 | 385 | July 27/64 | 1686 | 104 | 22.85 | 0.31 | 1.67 | 0.82 | 90 | 2.04 | nil | 15.62 | 0.15 | 3.0 | 10.17 | 60 | 39 | After 132 hrs. of pumping |
| 190 | 120 | June 10/64 | 1310 | 104 | 17.82 | tr. | 1.43 | 1.17 | 87 | 1.22 | 0.4 | 10.80 | nil | 5+ | 9.40 | 53 | 46 | Drift water |
| 190 | 320 | June 15/64 | 1484 | 124 | 21.55 | nil | 0.25 | 0.45 | 97 | 0.56 | 0.17 | 11.15 | tr. | 0.6 | 10.90 | 50 | 49 | Bedrock water after 2 hrs. of bailing |
| 191 | 65 | June 9/64 | 1910 | 188 | 22.45 | nil | 3.88 | 2.71 | 84 | 1.43 | 0.14 | 19.88 | nil | tr. | 9.60 | 67 | 32 | Drift water |
| 191 | 295 | June 15/64 | 1594 | 90 | 22.98 | nil | 0.97 | 0.43 | 94 | 2.28 | 0.11 | 13.63 | nil | tr. | 10.70 | 56 | 44 | Bedrock water after 2 hrs. of bailing |
| 192 | 128 | June 18/64 | 1246 | 128 | 15.40 | tr. | 2.77 | 1.84 | 77 | 1.50 | 0.17 | 10.10 | nil | tr. | 9.64 | 51 | 48 | Drift water |
| 192 | 537 | July 2/64 | 1274 | 82 | 19.45 | tr. | 0.40 | 0.12 | 97 | 3.34 | 0.85 | 8.00 | nil | 0.6 | 11.10 | 40 | 56 | Bedrock water after 2 hrs. of bailing |
| 192 | 537 | Aug. 17/64 | 1126 | 78 | 17.48 | 0.20 | nil | nil | 100 | 0/0 | 1.33 | 5.78 | nil | tr. | 10.69 | 33 | 60 | After 2.5 hrs. of pumping |
| 192 | 537 | Aug. 19/64 | 812 | 48 | 13.72 | 0.20 | nil | nil | 100 | 0/0 | 2.54 | 0.53 | nil | 0.6 | 11.57 | 4 | 79 | After 48 hrs. of pumping |
| 192 | 537 | Aug. 20/64 | 810 | 64 | 10.82 | 0.10 | nil | nil | 100 | 0/0 | 2.54 | 1.02 | nil | nil | 10.58 | 7 | 75 | After 72 hrs. of pumping |
| 193 | 155 | June 20/64 | 1502 | 102 | 18.82 | tr. | 1.96 | 3.63 | 77 | 0.54 | nil | 14.85 | 0.43 | 0.4 | 9.32 | 60 | 38 | Drift water |
| 193 | 380 | June 26/64 | 1660 | 138 | 21.80 | tr. | 1.83 | 2.18 | 84 | 0.84 | 0.11 | 14.80 | nil | tr. | 10.70 | 57 | 42 | Bedrock water after 2 hrs. of bailing |
| 194 | 70 | June 30/64 | 2114 | 172 | 18.70 | tr. | 9.00 | 6.90 | 54 | 1.30 | 0.17 | 23.18 | nil | 0.2 | 10.39 | 69 | 31 | Drift water |
| 194 | 400 | July 10/64 | 1660 | 330 | 17.60 | tr. | 2.31 | 3.76 | 74 | 0.61 | 0.17 | 13.83 | nil | tr. | 9.38 | 59 | 40 | Bedrock water after 2 hrs. of bailing |
| 195 | 18 | July 7/64 | 562 | 222 | 3.78 | tr. | 3.35 | 1.25 | 45 | 2.68 | nil | 0.88 | nil | nil | 7.40 | 12 | 89 | Drift water |
| 195 | 350 | July 16/64 | 462 | 102 | 3.61 | tr. | 3.12 | 2.70 | 38 | 1.15 | nil | 1.33 | nil | tr. | 7.70 | 15 | 85 | Bedrock water after 2 hrs. of bailing |
| 196 | 350 | July 28/64 | 620 | 60 | 9.14 | 0.31 | 0.58 | 0.22 | 92 | 2.64 | nil | 1.25 | nil | nil | 9.48 | 10 | 82 | Bedrock water after 2 hrs. of bailing |

| Olds well no. | Depth of well at time of sampling (feet) | Date of sampling | Total solids (ppm) | Ignition loss (ppm) | Na (epm) | K (epm) | Ca (epm) | Mg (epm) | Na+K Percentage of cations | Ca/Mg | Cl (epm) | $SO_4$ (epm) | $NO_3$ (epm) | Fe (ppm) | $HCO_3$ + $CO_3$ (epm) | $SO_4$ Per cent of total anions | $HCO_3$ + $CO_3$ Per cent of total anions | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 199 | 100 | July 25/64 | 1302 | 150 | 15.87 | 0.31 | 2.82 | 1.57 | 79 | 1.80 | 0.06 | 10.34 | nil | nil | 10.03 | 51 | 49 | Drift water |
| 199 | 365 | Aug. 5/64 | 1152 | 78 | 17.50 | nil | 0.46 | 0.43 | 95 | 1.07 | nil | 6.65 | nil | 2.4 | 10.00 | 40 | 60 | Bedrock water after 2 hrs. of bailing |
| 200 | 305 | Aug. 19/64 | 654 | 78 | 9.18 | 0.41 | Ca+Mg = | 2.20 | 83 | - | nil | nil | nil | tr. | 11.90 | 0 | 100 | Bedrock water after 2 hrs. of bailing |
| 201 | 242 | Aug. 24/64 | 946 | 106 | 11.70 | 0.10 | 0.34 | 3.23 | 77 | 0.11 | nil | 6.33 | nil | 2.0 | 9.69 | 39 | 60 | Bedrock water after 2 hrs. of bailing |
| 203 | - | Apr. 20/64 | 634 | 84 | 6.44 | nil | 1.57 | 1.21 | 70 | 1.30 | 0.11 | 1.25 | nil | 0.6 | 9.90 | 11 | 88 | |
| 204 | - | Apr. 20/64 | 488 | 124 | 2.78 | nil | 2.67 | 2.02 | 37 | 1.32 | 0.06 | 0.70 | 0.06 | tr. | 7.90 | 8 | 91 | |
| 205 | 26 | Apr. 20/64 | 732 | 282 | 1.91 | nil | 5.58 | 4.40 | 16 | 1.27 | 3.30 | 0.35 | 0.56 | tr. | 8.30 | 3 | 66 | |
| 206 | 65 | Apr. 20/64 | 960 | 34 | 16.13 | nil | 0.24 | 0.25 | 98 | 0.96 | nil | 3.16 | nil | tr. | 13.50 | 18 | 81 | |
| 207 | 165 | Apr. 20/64 | 780 | 88 | 12.95 | nil | 0.48 | 0.51 | 93 | 0.94 | 0.42 | 2.75 | 0.14 | 0.4 | 9.40 | 22 | 74 | |
| 208 | - | Apr. 20/64 | 602 | 140 | 6.09 | nil | 2.31 | 1.79 | 60 | 1.29 | 1.52 | 0.88 | 0.38 | 0.4 | 7.80 | 8 | 74 | |
| 209 | - | Apr. 20/64 | 592 | 142 | 4.96 | nil | 2.54 | 1.54 | 55 | 1.64 | 0.06 | 1.10 | 0.02 | 3 | 8.90 | 11 | 88 | |
| 210 | 90 | Apr. 20/64 | 640 | 38 | 12.09 | nil | 0.73 | 0.17 | 93 | 4.23 | nil | 1.85 | 0.11 | tr. | 9.40 | 16 | 83 | |
| 211 | 100 | Apr. 20/64 | 1650 | 304 | 14.70 | nil | 9.54 | 2.37 | 55 | 4.02 | nil | 15.45 | nil | 0.4 | 8.90 | 64 | 32 | |
| 212 | spring | Apr. 20/64 | 944 | 100 | 16.43 | nil | 0.91 | 1.08 | 89 | 0.84 | nil | 4.90 | nil | 0.4 | 10.30 | 32 | 68 | |
| 213 | 60 | Apr. 20/64 | 1000 | 186 | 13.40 | nil | 1.70 | 3.58 | 72 | 0.48 | nil | 5.88 | nil | 0.6 | 10.00 | 37 | 63 | |
| 214 | 100 | Apr. 20/64 | 900 | 84 | 16.81 | nil | 0.97 | 0.62 | 91 | 1.56 | nil | 3.40 | nil | tr. | 11.60 | 23 | 77 | |
| 215 | 80 | Apr. 20/64 | 1046 | 216 | 12.7 | nil | 1.82 | 4.24 | 72 | 0.43 | nil | 5.53 | nil | 5 | 11.10 | 33 | 67 | |
| 216 | - | Apr. 20/64 | 1072 | 214 | 12.7 | nil | 1.46 | 5.41 | 65 | 0.27 | nil | 6.75 | nil | tr. | 10.40 | 39 | 61 | |
| 218 | 90 | Apr. 20/64 | 1210 | 94 | 22.62 | nil | 1.09 | 0.80 | 92 | 1.36 | 0.17 | 7.33 | nil | 0.4 | 12.20 | 37 | 62 | |
| 219 | 60 | Apr. 20/64 | 924 | 74 | 16.94 | nil | 0.97 | 0.52 | 89 | 1.87 | 0.06 | 4.78 | 0.09 | tr. | 10.30 | 31 | 67 | |
| 220 | 74 | Apr. 20/64 | 820 | 110 | 13.61 | nil | 1.09 | 0.93 | 82 | 1.17 | 0.26 | 1.78 | 0.61 | tr. | 11.70 | 12 | 82 | |
| 221 | - | Apr. 20/64 | 458 | 138 | 4.52 | nil | 1.22 | 1.88 | 59 | 0.65 | 0.28 | 0.43 | 0.07 | 1.4 | 6.60 | 6 | 89 | |
| 222 | 80 | Apr. 20/64 | 1008 | 252 | 8.70 | nil | 2.91 | 3.57 | 57 | 0.81 | nil | 7.1 | 0.06 | 4.0 | 7.80 | 48 | 52 | |
| 223 | - | Apr. 20/64 | 1590 | 182 | 21.30 | nil | 1.58 | 1.40 | 88 | 1.13 | nil | 14.65 | nil | 3.2 | 8.40 | 64 | 36 | |
| 224 | 105 | Apr. 20/64 | 1842 | 196 | 23.56 | nil | 1.58 | 1.62 | 88 | 0.97 | nil | 19.13 | nil | 2.8 | 7.00 | 73 | 27 | |
| 225 | 110 | Apr. 20/64 | 2016 | 230 | 24.54 | nil | 0.97 | 0.03 | 96 | 32 | 0.06 | 19.17 | nil | 2.2 | 8.50 | 69 | 31 | |
| 226 | - | Apr. 20/64 | 780 | 129 | 11.92 | nil | 0.43 | 0.38 | 94 | 1.13 | 0.46 | 1.15 | 0.31 | nil | 10.60 | 9 | 85 | |
| 227 | - | Apr. 20/64 | 614 | 162 | 6.44 | nil | 2.12 | 1.53 | 64 | 1.39 | 0.18 | 0.35 | nil | 3 | 9.60 | 3 | 95 | |
| 228 | 125 | Apr. 20/64 | 778 | 48 | 13.61 | nil | nil | nil | 100 | 0/0 | 0.06 | 0.15 | nil | 0.4 | 13.50 | 1 | 99 | |
| 229 | 100 | Apr. 20/64 | 1004 | 92 | 13.86 | nil | 1.70 | 1.19 | 83 | 1.43 | 0.08 | 5.23 | nil | tr. | 11.50 | 31 | 68 | |
| 230 | 75 | Apr. 20/64 | 496 | 120 | 5.09 | nil | 2.12 | 1.27 | 60 | 1.67 | nil | 0.50 | nil | 0.8 | 8.00 | 6 | 94 | |
| 231 | 60 | Apr. 20/64 | 510 | 134 | 5.05 | nil | 1.94 | 1.34 | 61 | 1.45 | 0.23 | 0.68 | nil | tr. | 7.50 | 8 | 89 | |
| 232 | 20 | Apr. 20/64 | 390 | 220 | 1.22 | nil | 2.67 | 0.93 | 25 | 2.87 | 0.33 | 0.10 | 0.28 | 0.3 | 4.40 | 2 | 86 | |
| 233 | 60 | Apr. 20/64 | 1416 | 182 | 18.96 | nil | 0.31 | 1.89 | 90 | 0.16 | 0.31 | 8.95 | 0.36 | 0.3 | 12.00 | 41 | 57 | |
| 235 | 86 | Apr. 20/64 | 1620 | 196 | 20.62 | nil | 1.70 | 1.47 | 87 | 1.16 | 0.08 | 13.08 | 0.02 | 3 | 10.80 | 54 | 45 | |
| 237 | - | Apr. 20/64 | 1494 | 304 | 13.65 | nil | 5.09 | 0.39 | 71 | 13.02 | nil | 15.23 | nil | 3.6 | 4.00 | 79 | 21 | |

| Olds well no. | Depth of well at time of sampling (feet) | Date of sampling | Total solids (ppm) | Ignition loss (ppm) | Na (epm) | K (epm) | Ca (epm) | Mg (epm) | Na+K Percentage of cations | Ca/Mg | Cl (epm) | $SO_4$ (epm) | $NO_3$ (epm) | Fe (ppm) | $HCO_3$ + $CO_3$ (epm) | $SO_4$ Per cent of total anions | $HCO_3$ + $CO_3$ Per cent of total anions | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 238 | 80 | Apr. 20/64 | 1508 | 188 | 17.83 | nil | 1.46 | 2.72 | 81 | 0.54 | 0.08 | 14.13 | nil | 0.2 | 7.90 | 64 | 36 | |
| 239 | 105 | Apr. 21/64 | 1078 | 94 | 15.12 | nil | 0.49 | 0.81 | 92 | 0.61 | 0.22 | 7.88 | nil | 0.5 | 8.40 | 48 | 51 | |
| 240 | 72 | Apr. 21/64 | 1300 | 70 | 18.21 | nil | 0.31 | 0.71 | 95 | 0.44 | 0.14 | 9.13 | 0.06 | nil | 10.00 | 47 | 52 | |
| 241 | 117 | Apr. 21/64 | 930 | 104 | 13.50 | nil | 0.79 | 2.00 | 83 | 0.40 | 1.72 | 2.49 | nil | 0.4 | 11.70 | 16 | 74 | |
| 242 | - | Apr. 21/64 | 860 | 64 | 14.35 | nil | nil | nil | 100 | 0/0 | 1.30 | 1.40 | nil | tr. | 11.70 | 10 | 81 | |
| 243 | 207 | Apr. 21/64 | 838 | 58 | 13.57 | nil | 0.43 | 0.57 | 93 | 0.76 | 2.01 | 1.10 | nil | tr. | 11.50 | 8 | 79 | |
| 244 | 183 | Apr. 21/64 | 824 | 54 | 13.78 | nil | 0.43 | 0.07 | 97 | 6.54 | 2.11 | 0.85 | nil | tr. | 11.30 | 6 | 79 | |
| 245 | 115 | Apr. 21/64 | 660 | 30 | 11.82 | nil | nil | nil | 100 | 0/0 | 0.90 | nil | nil | tr. | 10.90 | 0 | 92 | |
| 246 | - | Apr. 21/64 | 1484 | 36 | 22.27 | nil | 0.67 | 0.73 | 94 | 0.92 | 0.23 | 12.45 | nil | tr. | 11.10 | 52 | 47 | |
| 249 | - | Apr. 21/64 | 848 | 44 | 14.22 | tr. | 0.25 | 0.16 | 97 | 1.56 | 0.14 | 1.95 | nil | tr. | 12.60 | 13 | 86 | |
| 250 | 113 | Apr. 21/64 | 2146 | 146 | 26.20 | tr. | 4.31 | 2.78 | 79 | 1.55 | nil | 23.70 | 0.06 | 0.4 | 9.40 | 72 | 28 | |
| 251 | 100 | Apr. 21/64 | 768 | 94 | 12.60 | nil | 0.85 | 0.33 | 92 | 2.58 | nil | 1.95 | 0.86 | tr. | 11.40 | 14 | 80 | |
| 252 | 140 | Apr. 21/64 | 2214 | 114 | 32.08 | tr. | 0.67 | 0.13 | 95 | 5.16 | nil | 20.88 | 0.06 | 2.6 | 12.10 | 63 | 32 | |
| 253 | 135 | Apr. 21/64 | 982 | 94 | 15.69 | tr. | nil | nil | 100 | 0/0 | nil | 3.10 | nil | tr. | 12.60 | 20 | 80 | |
| 254 | - | Apr. 21/64 | 796 | 50 | 13.14 | nil | nil | nil | 100 | 0/0 | nil | 2.75 | nil | nil | 10.40 | 21 | 79 | |
| 256 | - | Apr. 21/64 | 400 | 110 | 2.56 | tr. | 1.49 | 2.80 | 37 | 0.53 | 0.34 | 2.23 | 0.06 | 0.3 | 4.00 | 34 | 60 | |
| 257 | - | Apr. 21/64 | 704 | 78 | 8.31 | tr. | 1.39 | 1.12 | 77 | 1.02 | nil | 6.80 | nil | 5.0 | 3.90 | 63 | 36 | |
| 258 | - | Apr. 21/64 | 1560 | 144 | 19.39 | tr. | 0.87 | 1.53 | 89 | 0.57 | 0.06 | 13.90 | nil | 5+ | 6.80 | 64 | 33 | |
| 259 | - | Apr. 21/64 | 1604 | 66 | 26.01 | tr. | nil | nil | 100 | 0/0 | nil | 13.70 | 0.06 | 2.2 | 10.50 | 56 | 43 | |
| 260 | 80 | Apr. 21/64 | 1706 | 66 | 25.70 | tr. | nil | nil | 100 | 0/0 | nil | 15.30 | nil | 1.6 | 10.50 | 59 | 41 | |
| 261 | 85 | Apr. 21/64 | 2080 | 208 | 26.20 | tr. | 2.02 | 2.04 | 87 | 0.99 | 0.31 | 21.08 | 0.86 | 2 | 8.70 | 68 | 28 | |
| 262 | 110 | Apr. 21/64 | 856 | 74 | 10.79 | tr. | nil | nil | 100 | 0/0 | 0.31 | 2.93 | nil | 0.2 | 10.50 | 22 | 78 | |
| 264 | 60 | Apr. 21/64 | 480 | 64 | 6.79 | tr. | 0.23 | 1.36 | 81 | 0.17 | 0.42 | 0.85 | nil | 1.2 | 7.20 | 10 | 85 | |
| 265 | - | Apr. 21/64 | 984 | 36 | 16.95 | tr. | nil | nil | 100 | 0/0 | 0.06 | 2.65 | nil | 0.2 | 14.30 | 16 | 84 | |
| 267 | 48 | Apr. 21/64 | 938 | 78 | 14.40 | tr. | 0.46 | 0.43 | 94 | 1.07 | 0.14 | 4.15 | nil | nil | 11.10 | 27 | 72 | |
| 268 | - | Apr. 21/64 | 968 | 108 | 14.75 | tr. | nil | nil | 100 | 0/0 | 0.08 | 0.43 | nil | 0.6 | 14.20 | 3 | 96 | |
| 269 | 90 | Apr. 21/64 | 734 | 22 | 12.82 | tr. | nil | nil | 100 | 0/0 | 0.08 | 1.83 | nil | nil | 10.90 | 14 | 85 | |
| 270 | - | Apr. 21/64 | 484 | 78 | 5.61 | tr. | 0.34 | 2.74 | 65 | 0.13 | 0.08 | 3.13 | 0.81 | tr. | 6.20 | 23 | 67 | |
| 271 | - | Apr. 21/64 | 436 | 72 | 4.96 | tr. | 0.81 | 2.46 | 60 | 0.33 | 0.06 | 1.55 | 0.64 | 1.00 | 6.00 | 19 | 73 | |
| 272 | 80 | Apr. 21/64 | 786 | 36 | 12.03 | tr. | 0.52 | 0.88 | 90 | 0.59 | nil | 4.28 | 0.02 | 2.8 | 9.10 | 32 | 68 | |
| 273 | 75 | Apr. 21/64 | 720 | 20 | 12.61 | tr. | nil | nil | 100 | 0/0 | nil | 1.80 | nil | tr. | 10.80 | 14 | 86 | |
| 274 | - | Apr. 21/64 | 648 | 52 | 9.63 | tr. | 0.23 | 1.76 | 83 | 0.13 | nil | 2.30 | nil | 0.5 | 9.10 | 20 | 80 | |
| 275 | 80 | Apr. 21/64 | 1460 | 188 | 12.74 | tr. | 3.75 | 4.81 | 60 | 0.78 | 0.06 | 16.08 | 0.14 | 2.6 | 4.60 | 77 | 22 | |
| 276 | - | Apr. 21/64 | 2314 | 192 | 28.80 | tr. | 2.75 | 3.04 | 83 | 0.94 | nil | 29.93 | 0.14 | 1.6 | 9.40 | 76 | 24 | |
| 277 | - | Apr. 21/64 | 768 | 16 | 13.20 | tr. | nil | nil | 100 | 0/0 | nil | 2.85 | nil | tr. | 10.50 | 21 | 79 | |
| 278 | 220 | Apr. 21/64 | 804 | 28 | 14.35 | tr. | nil | nil | 100 | 0/0 | 0.20 | 0.78 | nil | tr. | 13.50 | 5 | 93 | |
| 279 | 90 | Apr. 21/64 | 992 | 56 | 15.58 | tr. | 0.69 | 0.80 | 91 | 0.86 | 0.00 | 4.08 | 0.32 | tr. | 7.30 | 24 | 75 | |
| 280 | 90 | Apr. 21/64 | 1498 | 154 | 17.89 | tr. | 1.96 | 2.82 | 79 | 0.69 | 0.28 | 15.35 | 0.06 | 0.6 | 6.80 | 68 | 30 | |

## Table 1. Changes in Water Levels of Selected Observation Wells during Pump Tests 1, 2, and 3

(a) Pump test 1, March, 1964. Pumping rate: 226 igpm.

| Time of drawdown measurements (minutes) | | s or s'* | Olds Well No. 177<br>RCA Well No. 1-1964 | 178**<br>2-1964 | 180<br>2a-1964 | 181<br>2b-1964 | 179<br>3-1964 | 182<br>4-1964 |
|---|---|---|---|---|---|---|---|---|
| 100 | after pumping started | s | 0.00 | 8.70 | 7.10 | 3.90 | 0.00 | 1.70 |
| 1,000 | after pumping started | s | 0.02 | 23.40 | 21.60 | 16.50 | 2.20 | 12.90 |
| 3,600 | after pumping started | s | 0.00 | 37.20 | 36.71 | 29.81 | 10.00 | 26.60 |
| 100 | after pumping stopped | s' | | 30.30 | 31.40 | 27.49 | 11.50 | 25.90 |
| 1,000 | after pumping stopped | s' | | 22.20 | | 19.26 | | 19.10 |
| 5,860 | after pumping stopped | s' | | 8.40 | 8.50 | 7.82 | 6.80 | 7.60 |

* s: drawdown, in feet; s': residual drawdown, in feet

** pumped well

*** possible change not measured

Note: minus sign indicates rise in the water level

(b) Pump test 2, July, 1964. Pumping rate: 155.64 igpm.

| Time of drawdown measurements (minutes) | | s or s'* | Olds Well No. 147<br>RCA Well No. 1-1961 | 178<br>2-1964 | 179<br>3-1964 | 182<br>4-1964 | 187<br>5-1964 | 188<br>6-1964 | 189**<br>7-1964 | 189a<br>7a-1964 | 189b<br>7b-1964 | 189c | 189d | 190<br>8-1964 | 191<br>9-1964 | 192<br>10-1964 | 193<br>11-1964 | 194<br>12-1964 | 195<br>13-1964 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | after pumping started | s | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 31.69 | 9.29 | 1.32 | 0.82 | 0.15? | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1,000 | after pumping started | s | 0.04 | 0.04 | 0.30 | 0.07 | 0.00 | 0.01 | 37.30 | 13.96 | 4.92 | 4.33 | 0.15? | 0.00 | 0.00 | −0.02 | 0.27 | 0.20 | 0.07 |
| 7,855 | after pumping started | s | 0.29 | 0.96 | 3.90 | 1.33 | 0.00 | 0.06 | 46.00 | 23.00 | 14.06 | 13.51 | 0.15? | 0.58 | 0.13 | −0.02 | 4.66 | 2.33 | 0.49 |
| 100 | after pumping stopped | s' | 0.29 | 0.96 | 3.94 | 1.35 | 0.00 | 0.07 | 15.49 | 15.01 | 13.18 | 12.78 | 0.15? | 0.76 | 0.11 | −0.03 | 4.71 | 2.37 | 0.49 |
| 1,000 | after pumping stopped | s' | 0.27 | 1.09 | 3.99 | 1.46 | −0.01 | 0.10 | 10.89 | 10.40 | 9.79 | 9.36 | 0.06? | 1.21 | 0.11 | −0.06 | 4.10 | 2.45 | 0.49 |
| 9,800 | after pumping stopped | s' | 0.13 | 0.20 | 1.41 | 0.31 | −0.11 | 0.13 | ? | 2.70 | 1.96 | 1.57 | 0.00? | 0.83 | 0.23 | −0.17 | 1.00 | 1.89 | 0.69 |

(c) Pump test 3, August, 1964. Pumping rate: 152 igpm.

| Time of drawdown measurements (minutes) | | s or s'* | Olds Well No. 147<br>RCA Well No. 1-1961 | 179<br>3-1964 | 182<br>4-1964 | 187<br>5-1964 | 188<br>6-1964 | 189b<br>7b-1964 | 189d | 190<br>8-1964 | 191<br>9-1964 | 192**<br>10-1964 | 193<br>11-1964 | 194<br>12-1964 | 195<br>13-1964 | 244<br>Zimmerman | 192a<br>10a-1964 | 192b<br>10b-1964 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | after pumping started | s | 0.00 | −0.01 | 0.00 | 0.00 | 0.02 | −0.02 | 0.37 | −0.10 | 0.005 | 15.66 | −0.02 | ? | 0.00 | flowing*** | 9.45 | 1.76 |
| 1,000 | after pumping started | s | −0.02 | −0.07 | 0.05 | 0.36 | 0.09 | −0.17 | 2.54 | −0.21 | 0.04 | 18.48 | −0.13 | −0.05 | −0.05 | flowing*** | 12.32 | 3.36 |
| 5,760 | after pumping started | s | −0.08 | −0.44 | 0.17 | 3.12 | 0.77 | −0.64 | 7.09 | −0.19 | 0.34 | 22.95 | −0.48 | −0.18 | 0.03 | 1.80+ | 16.50 | 5.00 |
| 100 | after pumping stopped | s' | −0.08 | −0.45 | ? | 3.17 | 0.77 | ? | 6.83 | −0.19 | 0.37 | 7.52 | −0.52 | −0.19 | 0.03 | 1.86+ | 7.61 | 3.68 |
| 1,000 | after pumping stopped | s' | −0.09 | −0.52 | 0.18 | 3.13 | 0.70 | −0.75 | 5.34 | −0.22 | 0.37 | 5.00 | −0.54 | −0.19 | 0.03 | 1.84+ | 5.27 | 2.32 |
| 6,000 | after pumping stopped | s' | −0.19 | −1.23 | −0.84 | 1.48 | 0.36 | −1.04 | 3.41 | −1.41 | 0.32 | 2.97 | −0.90 | −0.41 | 0.02 | 0.36+ | 3.33 | 1.26 |

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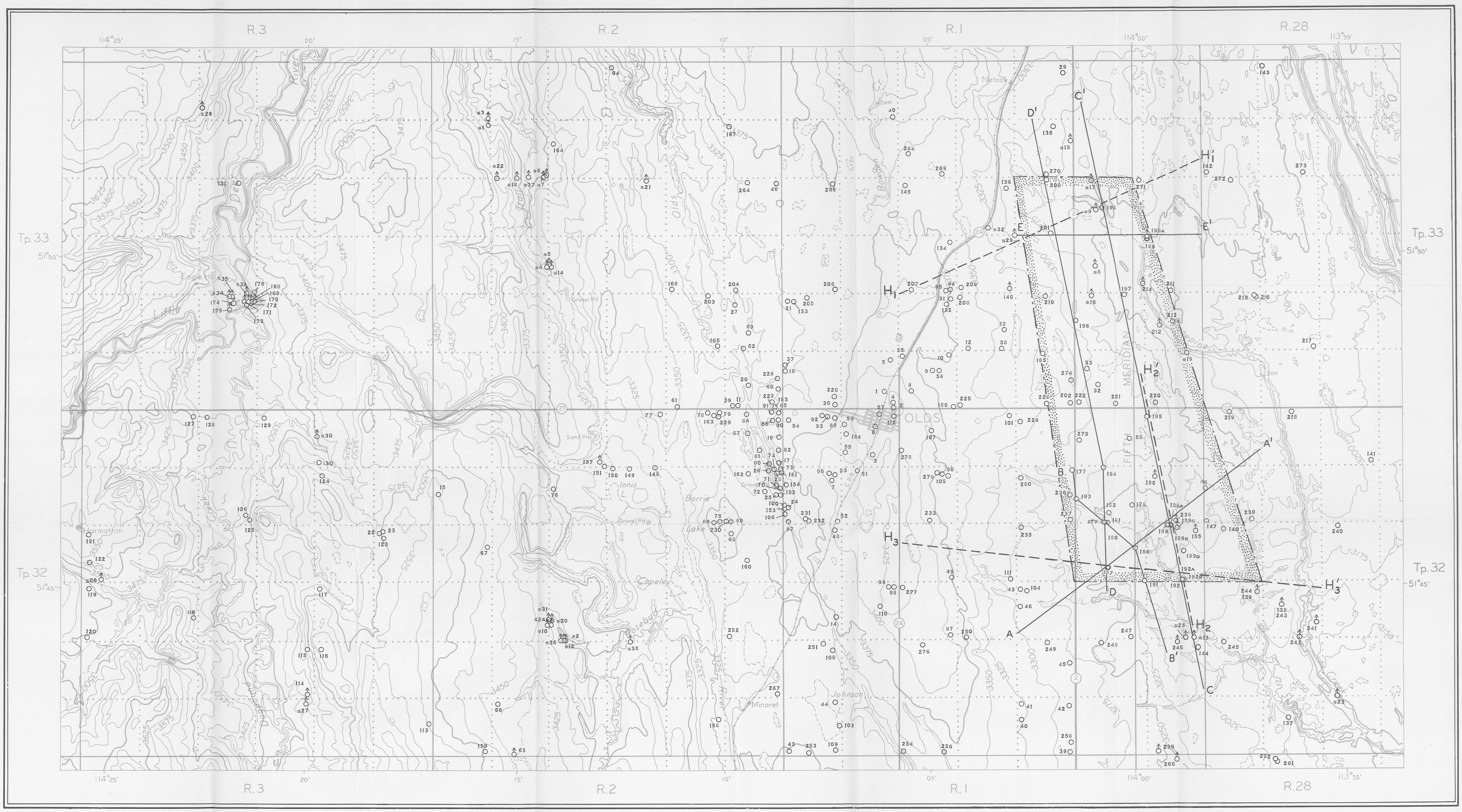



WEST OF FOURTH AND FIFTH MERIDIANS

Scale in Miles

1 0 1 2 3

FIGURE 5. MAP SHOWING LOCATIONS of OBSERVATION POINTS, GEOLOGIC and HYDRAULIC CROSS SECTIONS, LOCATION and EXTENT of R.C.A. TEST AREA.

## LEGEND

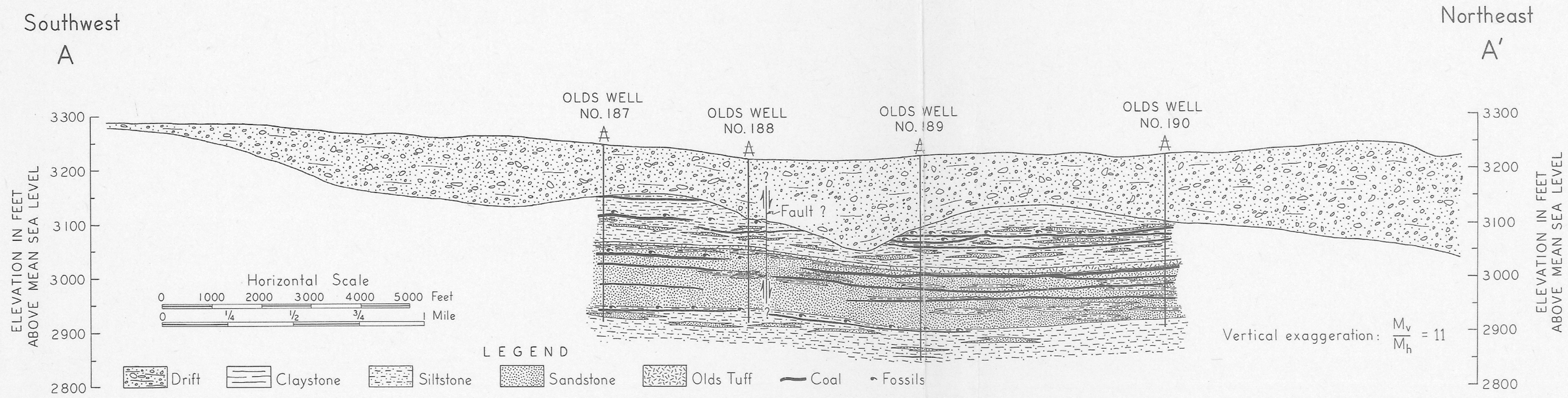
| | |
|---|---|
| "Olds Well" No. 247 | ○247 |
| Seismic shothole | ○s23 |
| Water level rises above ground surface | ↑○ |
| Geologic cross-section | A———A' |
| Hydraulic cross-section | $H_2$— — —$H_2'$ |
| Boundary of R.C.A. test area | |

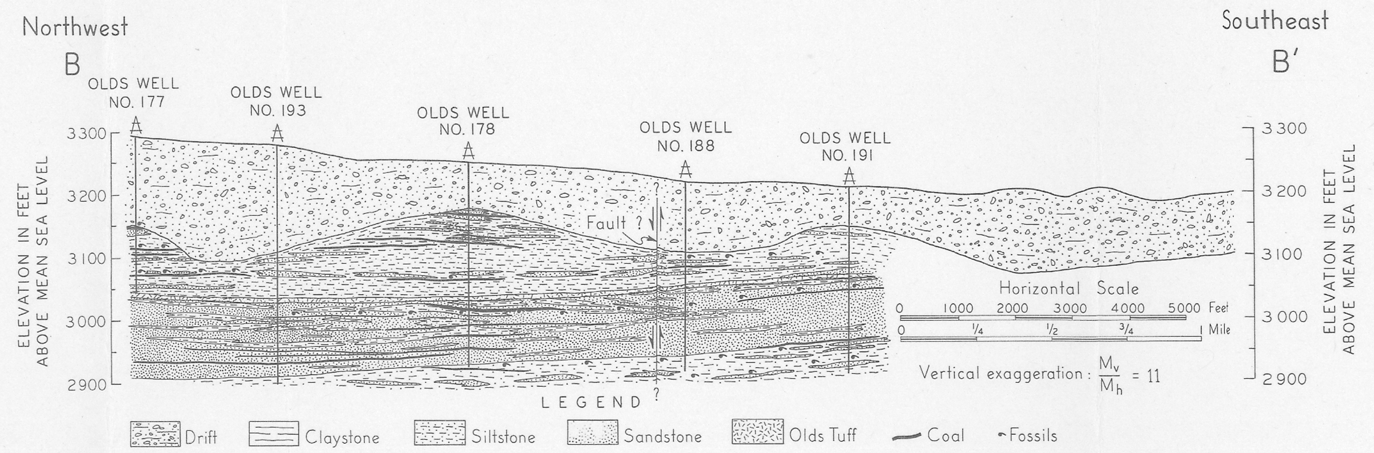
## REFERENCE

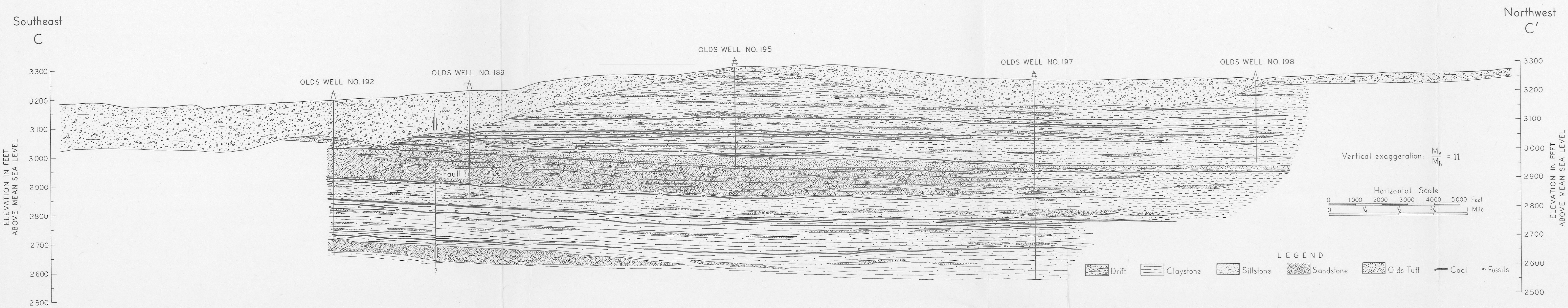
| | |
|---|---|
| Town | |
| Hamlet | |
| Post Office | |
| Township line | |
| Section line | |
| Highway | |
| Railway | Station |
| Stream | |
| Stream, intermittent or dry | |
| Lake, intermittent | |
| Surface contours: elevation | 3250 |
| depression | |

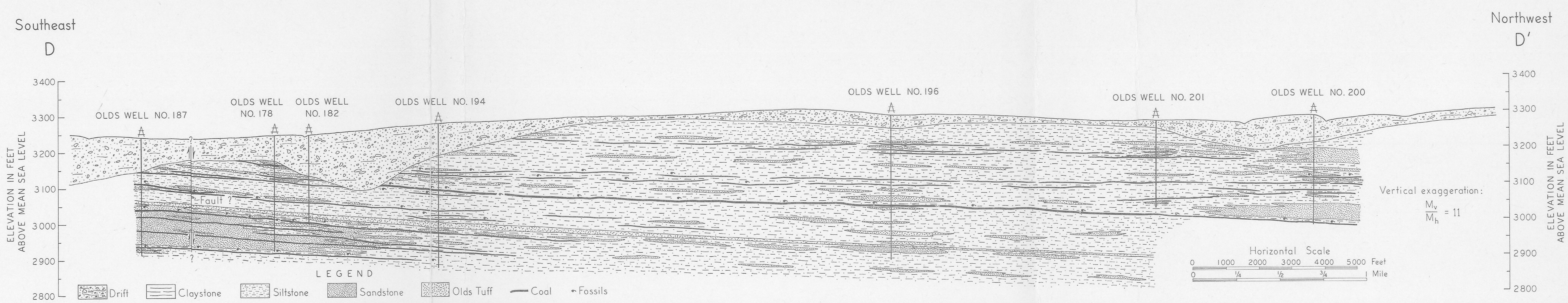
(Contour interval 25 feet)

All elevations in feet above mean sea level.



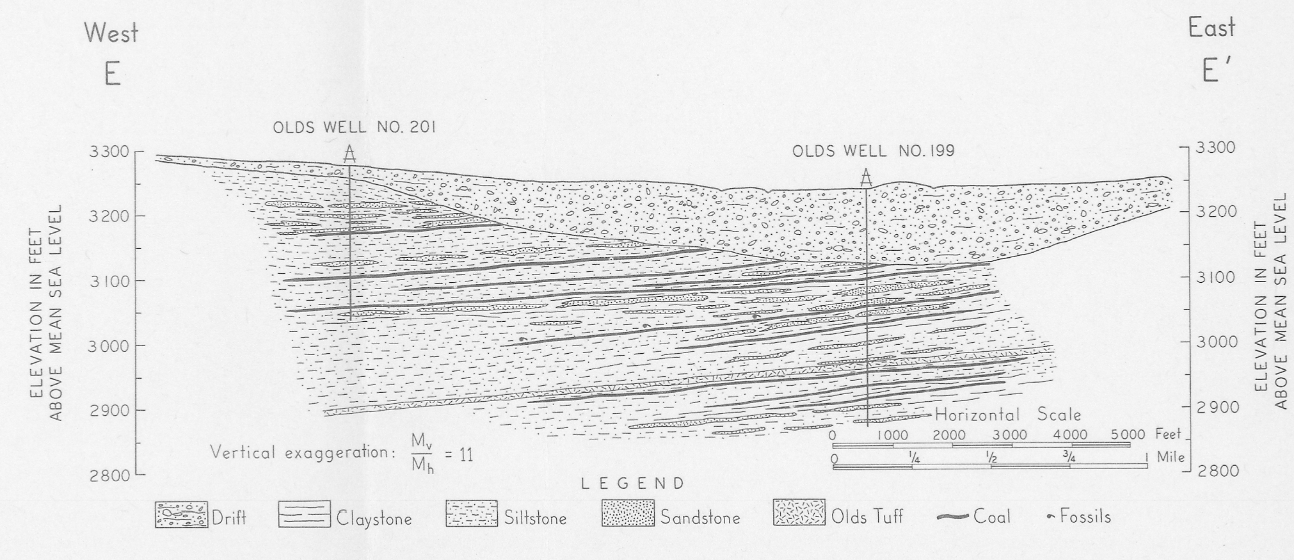




FIGURE 6. GEOLOGIC CROSS SECTIONS A-A′ to E-E′.

To accompany Research Council of Alberta Bulletin 17, by J. Tóth.

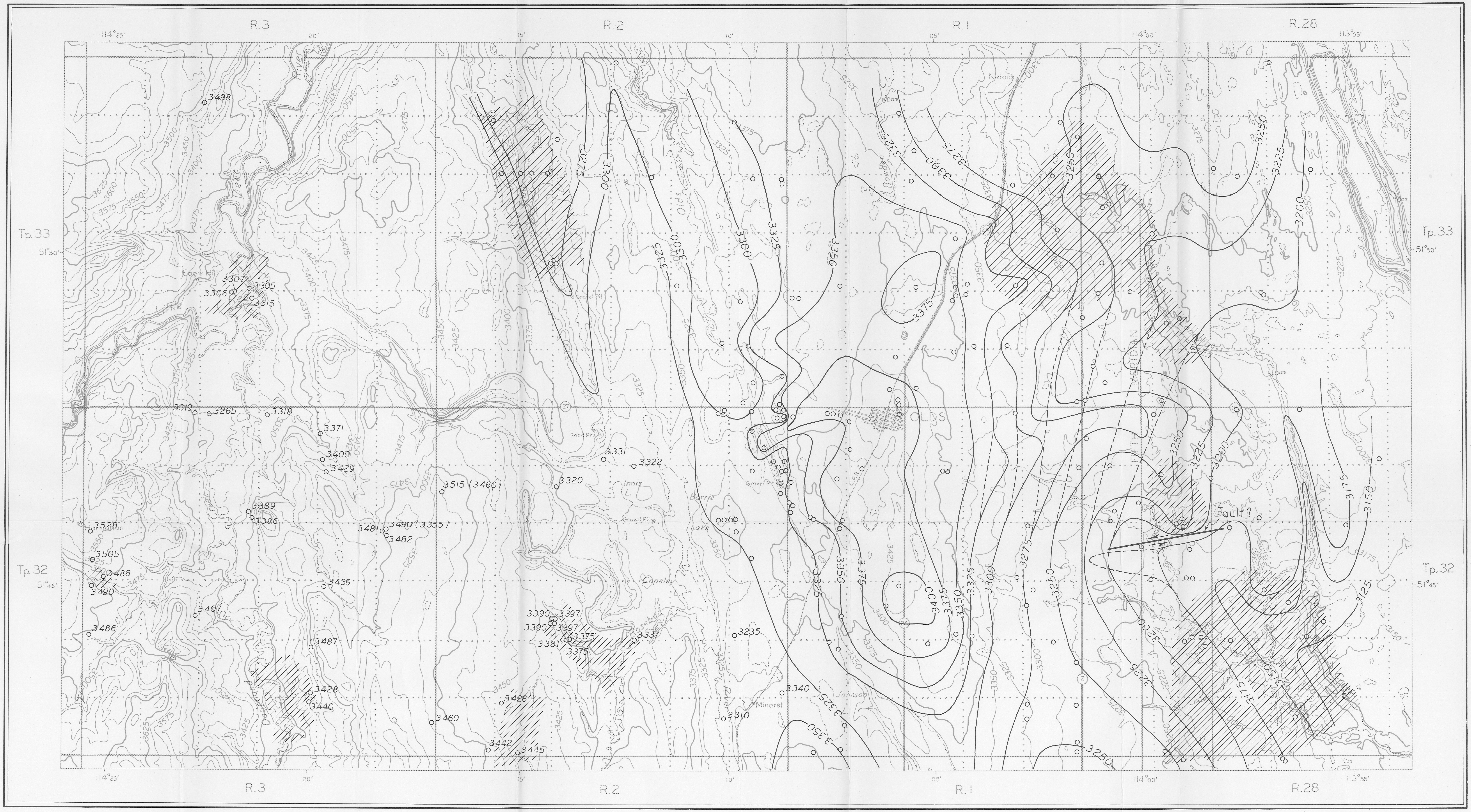



FIGURE 9. MAP SHOWING NON-PUMPING WATER LEVELS.

WEST OF FOURTH AND FIFTH MERIDIANS

Scale in Miles

1 0 1 2 3

LEGEND

Topographic elevation of nonpumping water levels (Contour interval 25 feet) — 3200 — Upper level / Lower level

Well location and topographic elevation of nonpumping water levels — 3515 (3460) Upper level / Lower level

Area of flowing wells

REFERENCE

Town

Hamlet

Post Office

Township line

Section line

Highway

Railway — Station

Stream

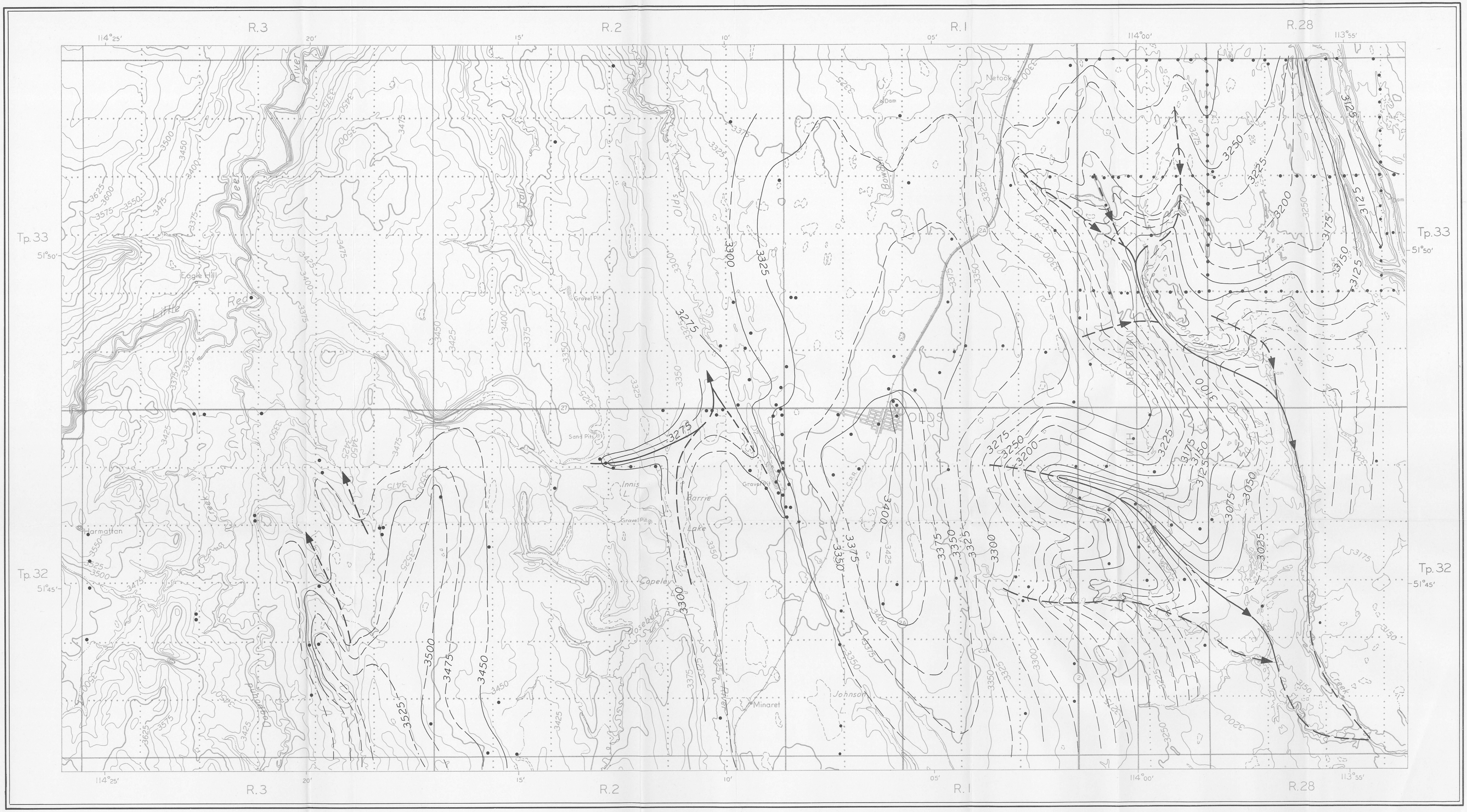
Stream, intermittent or dry

Lake, intermittent

Surface contours: elevation — 3250; depression

(Contour interval 25 feet)

*All elevations in feet above mean sea level.*




WEST OF FOURTH AND FIFTH MERIDIANS

Scale in Miles

1 0 1 2 3

## LEGEND

Bedrock contour:
- definite ........ 3300
- assumed ........ 3200

*(Contour interval 25 feet)*

Drainage channel on bedrock surface:
- definite ........
- approximate ........

Control point ........

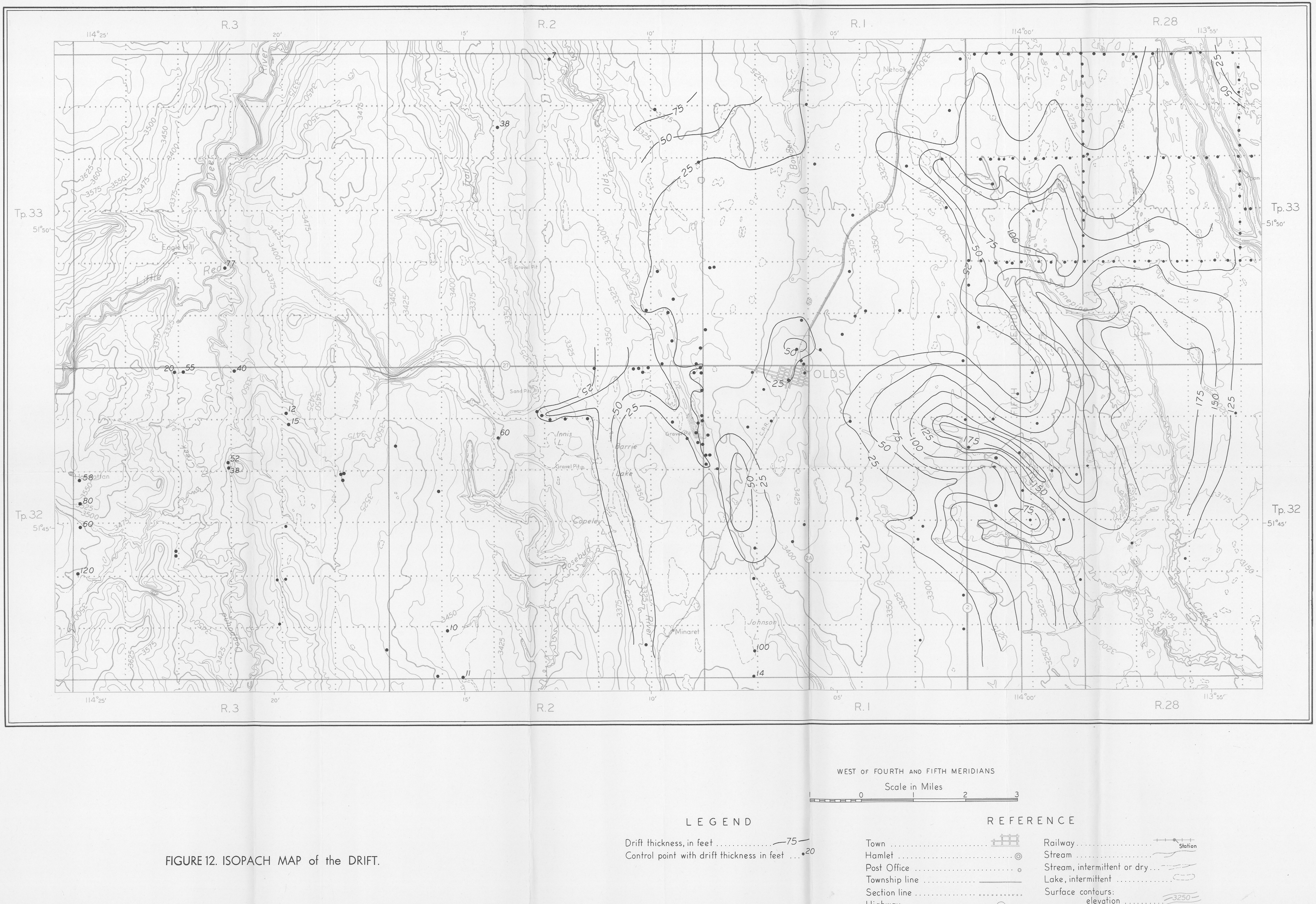
## REFERENCE

- Town ........
- Hamlet ........
- Post Office ........
- Township line ........
- Section line ........
- Highway ........
- Railway ........ Station
- Stream ........
- Stream, intermittent or dry ........
- Lake, intermittent ........
- Surface contours:
  - elevation ........ 3250
  - depression ........

*(Contour interval 25 feet)*

*All elevations in feet above mean sea level.*

FIGURE 10. BEDROCK TOPOGRAPHY MAP.




WEST OF FOURTH AND FIFTH MERIDIANS

Scale in Miles

1 0 1 2 3

FIGURE 12. ISOPACH MAP of the DRIFT.

LEGEND

Drift thickness, in feet ............. 75

Control point with drift thickness in feet ... •20

REFERENCE

Town ........................

Hamlet ........................

Post Office ........................

Township line ............

Section line ........................

Highway ................

Railway ................... Station

Stream ........................

Stream, intermittent or dry...

Lake, intermittent ............

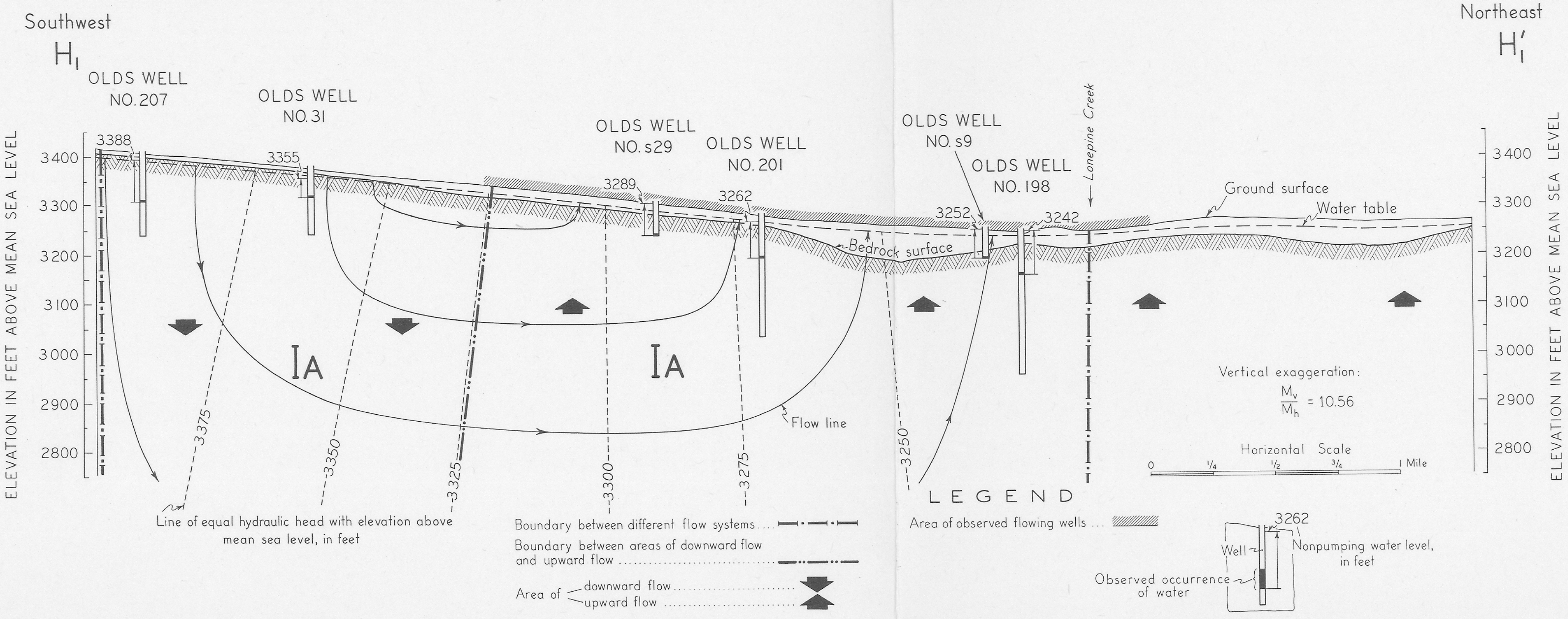
Surface contours:

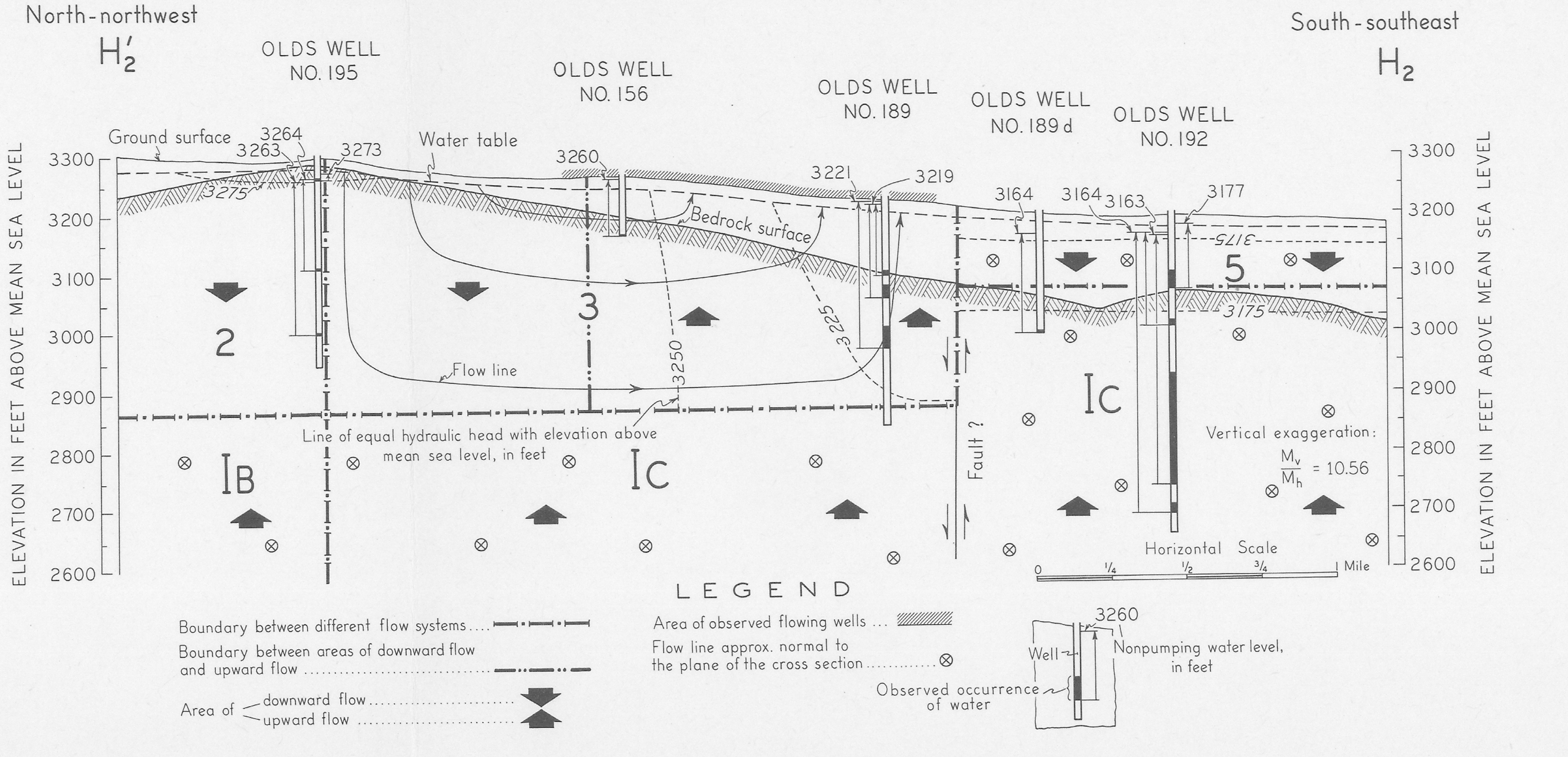
elevation ............ 3250

depression ..........

(Contour interval 25 feet)

*All elevations in feet above mean sea level.*



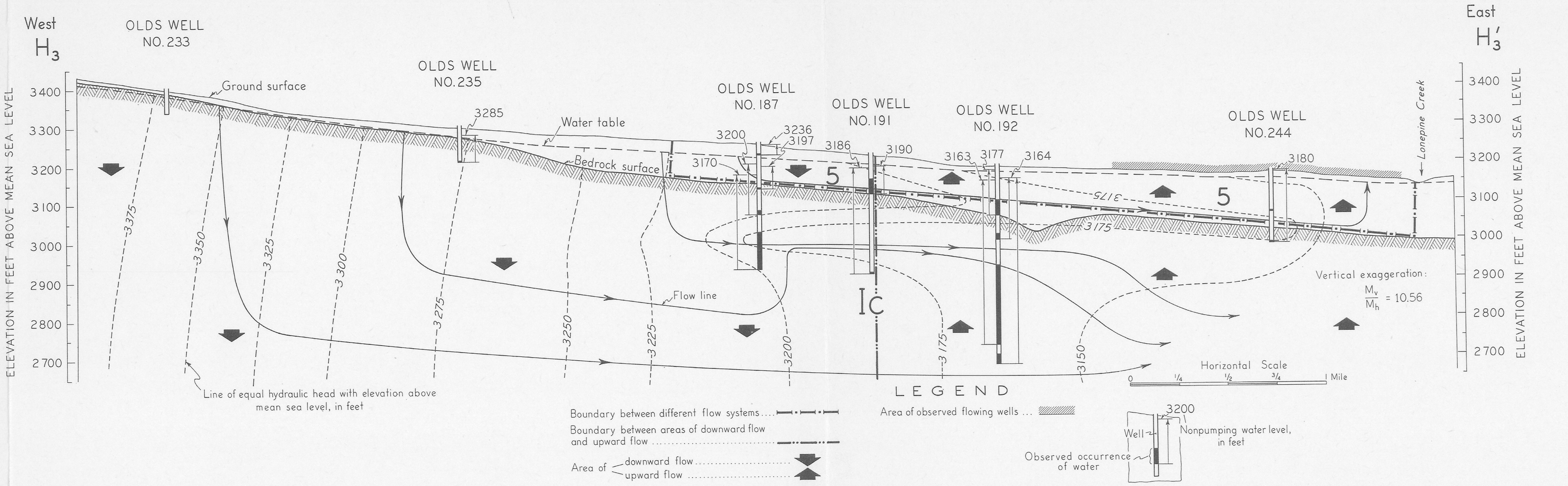




FIGURE 15. HYDRAULIC CROSS SECTIONS $H_1$-$H_1'$ $H_2$-$H_2'$ AND $H_3$-$H_3'$ In hydraulic cross section $H_3$-$H_3'$ the short bold arrows of regional system 1C indicate the generalized flow directions without the influence of the high-permeability lens.

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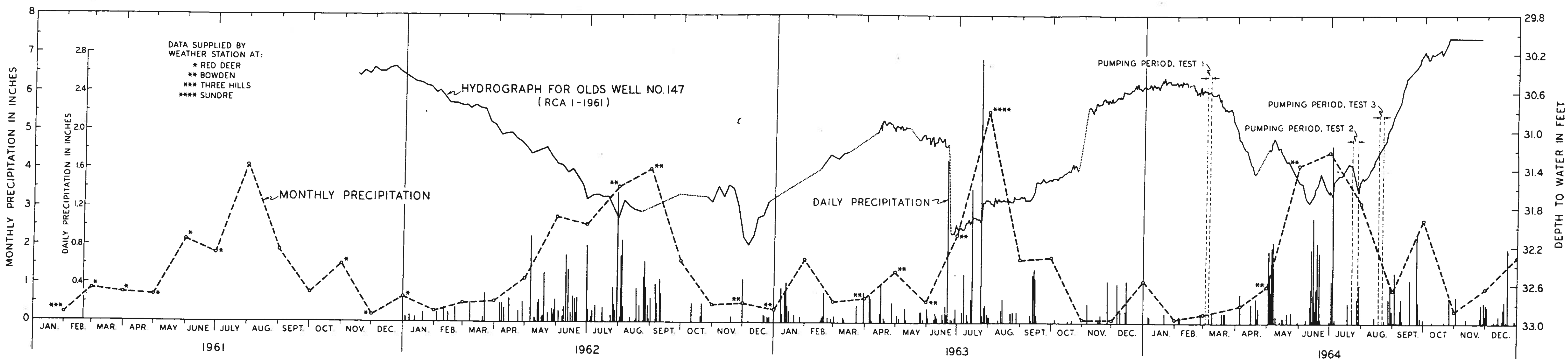


*FIGURE 20.*
*Monthly total and daily precipitation. and hydrograph for Olds Well No. 147.*

FIGURE 21.

WELL HYDROGRAPHS FOR OBSERVATION WELLS DURING THE TEST PERIOD.

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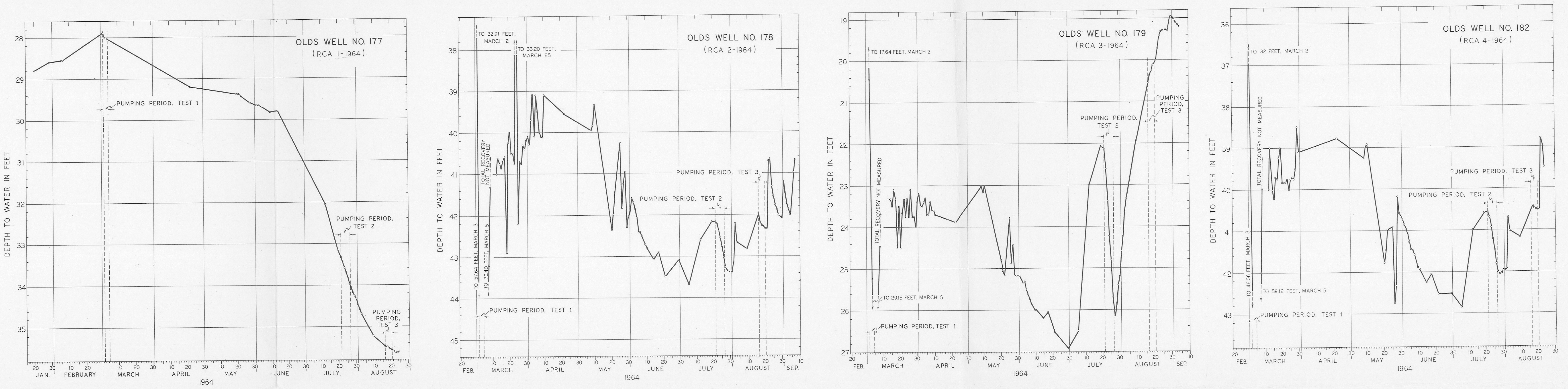


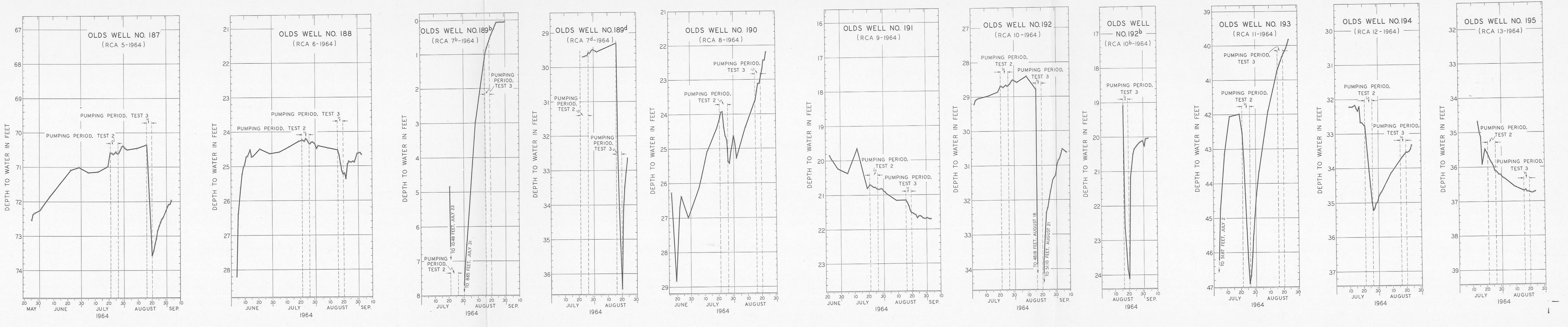

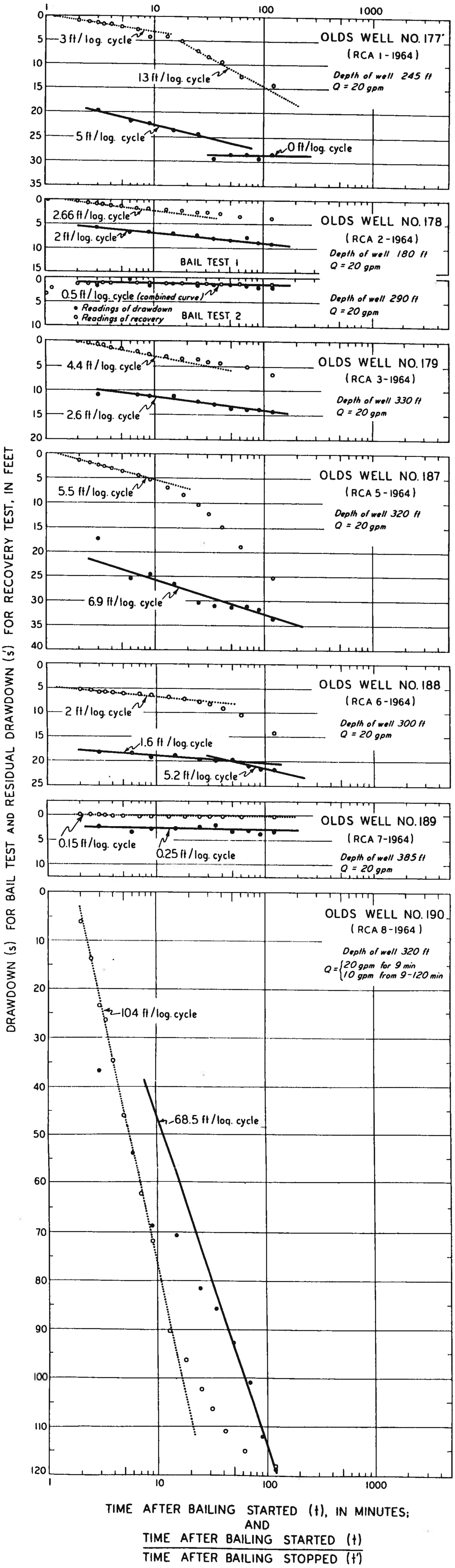


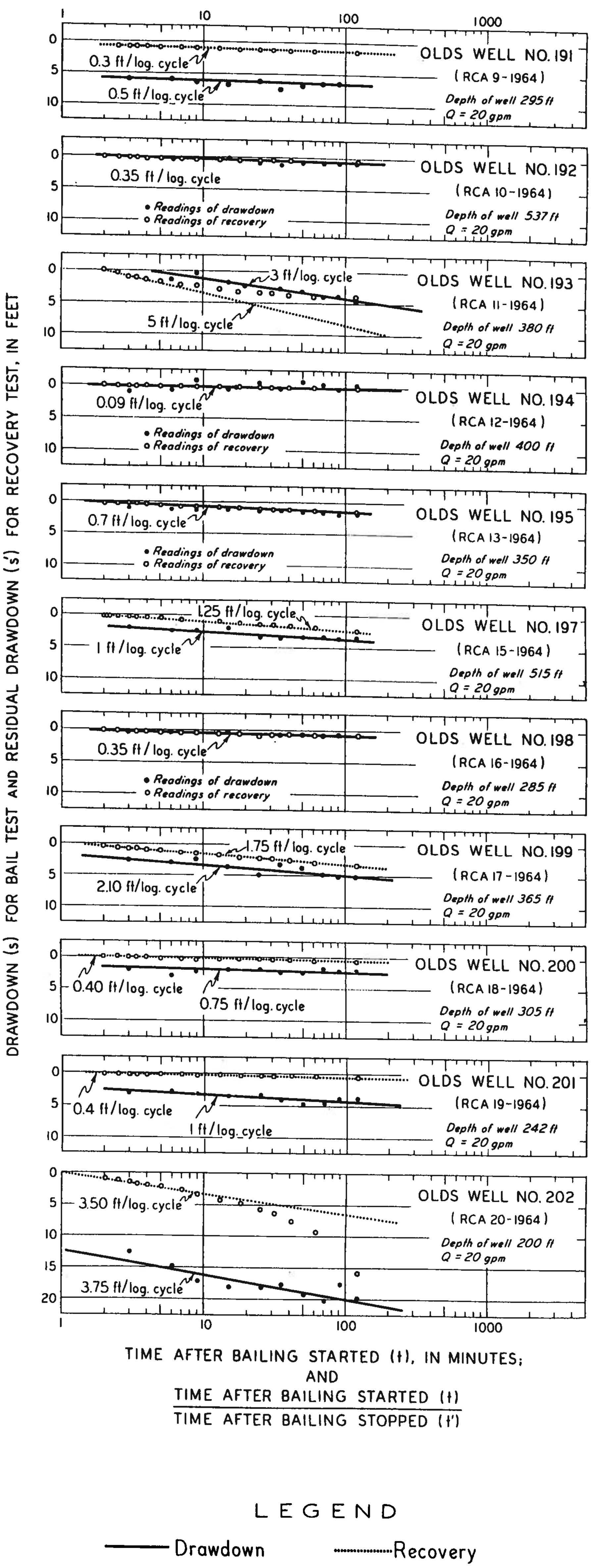


*FIGURE 37.*
*Graphs showing drawdown and recovery of water levels in test holes during bail tests.*

FIGURE 38.

TIME-DRAWDOWN GRAPHS, PUMP TEST 1.

A-Olds Well No. 178;
B-Olds Well No. 179;
C-Olds Well No. 180;
D-Olds Well No. 181;
E-Olds Well No. 182.

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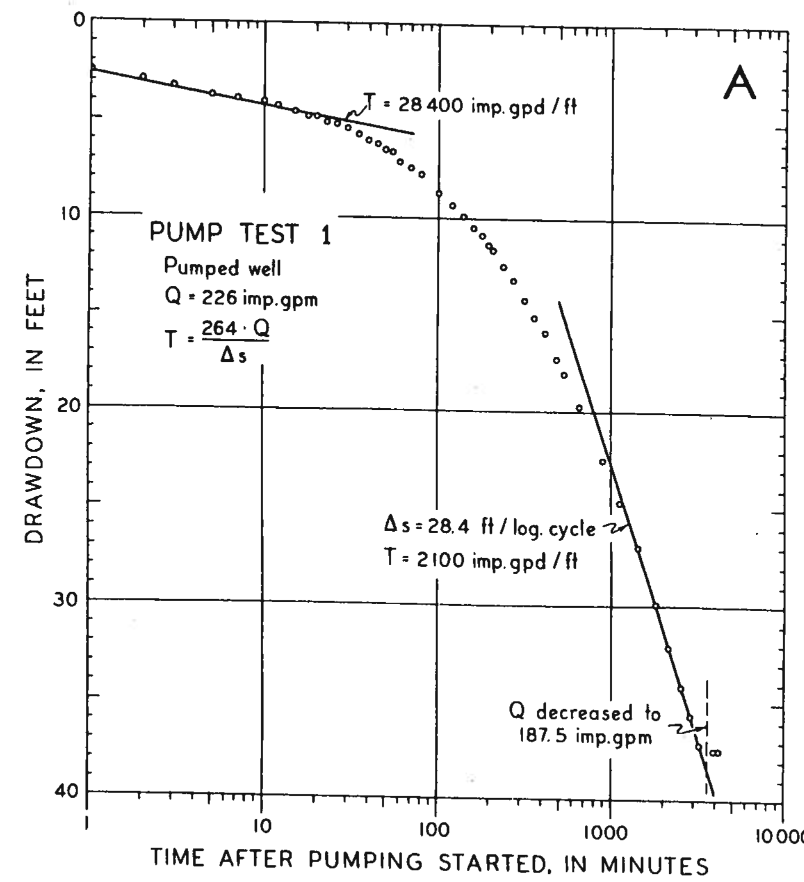
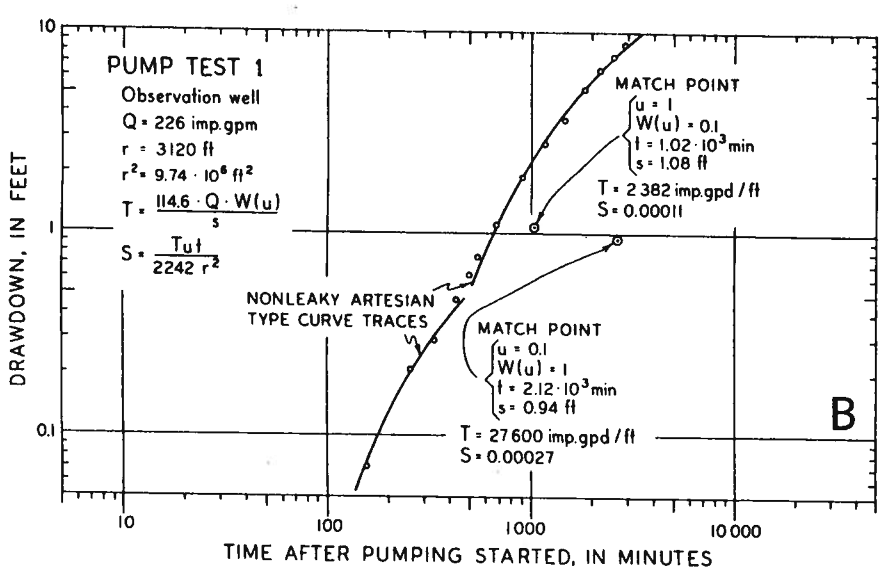
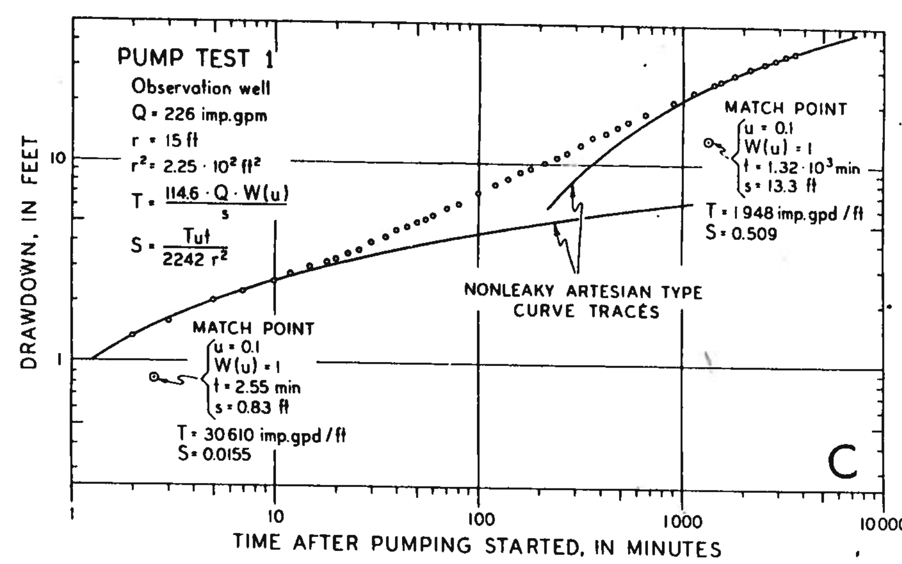
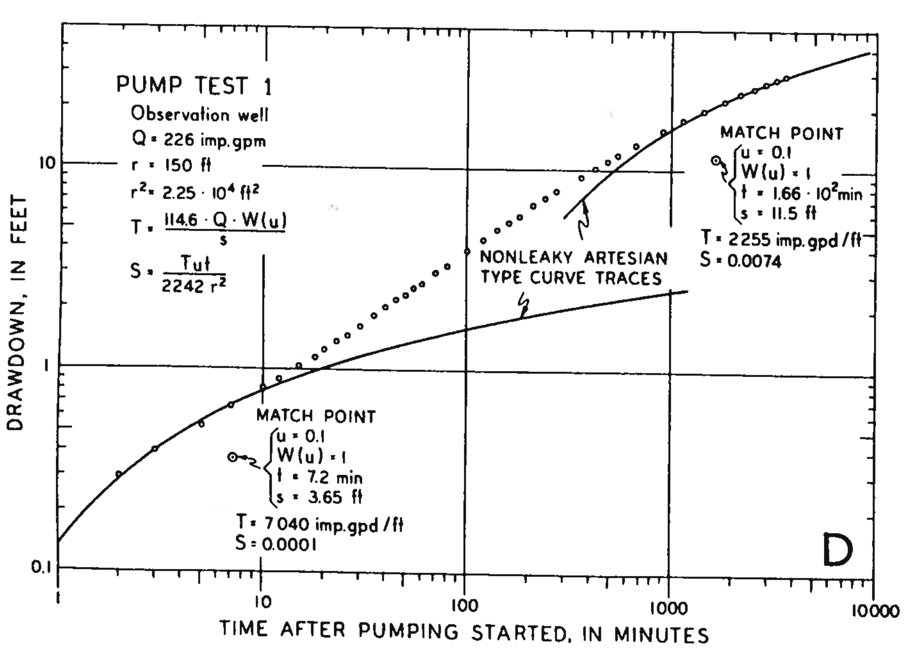
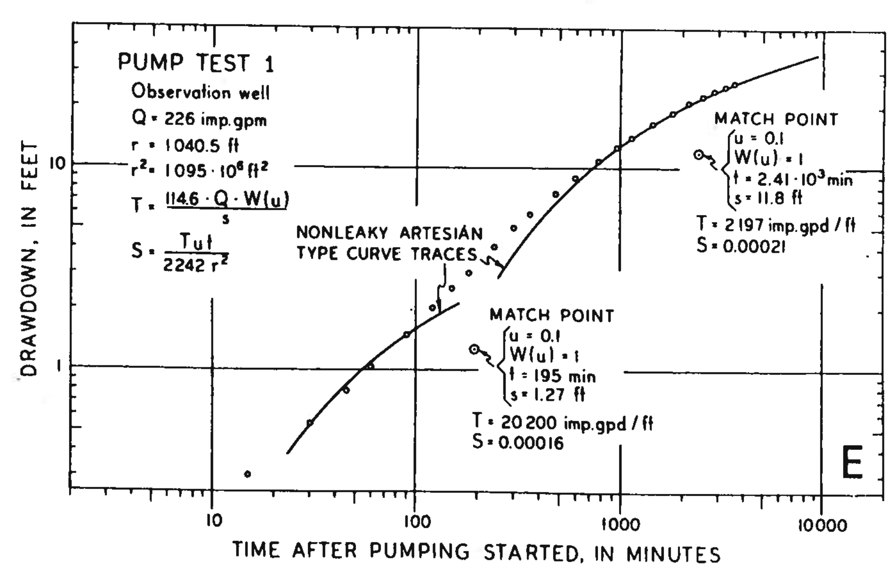
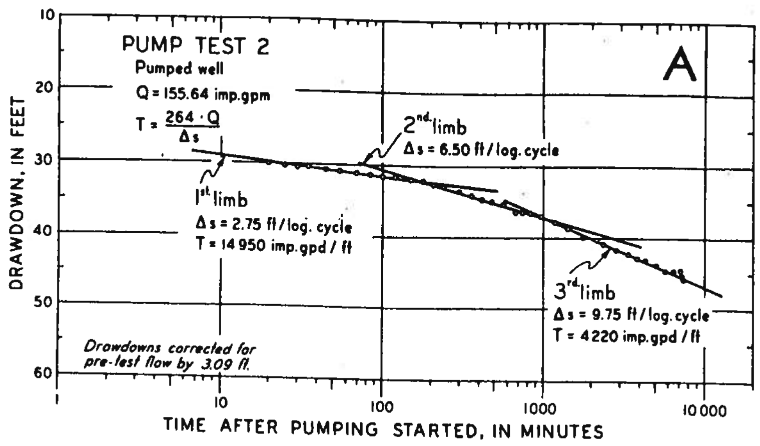


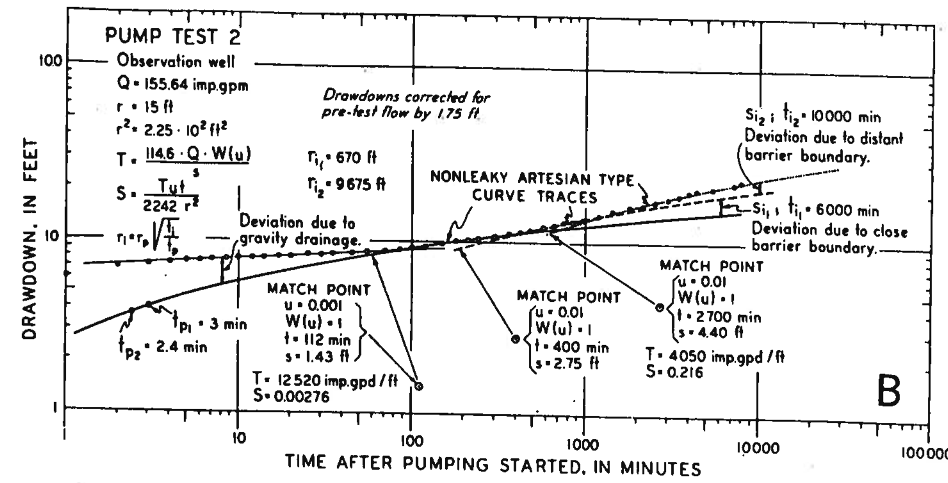



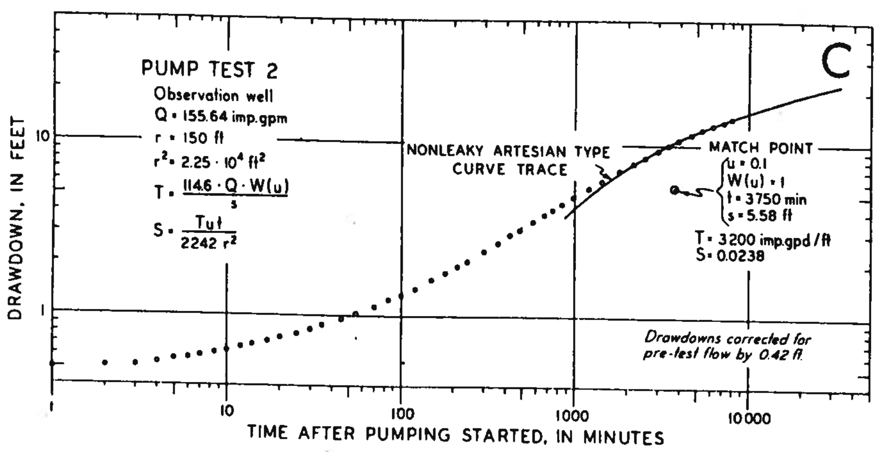



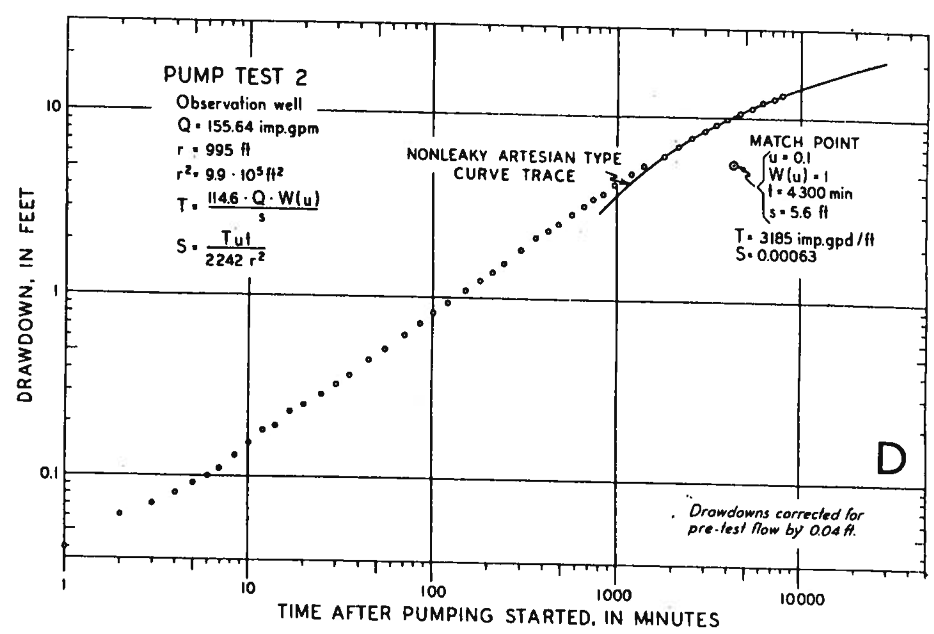





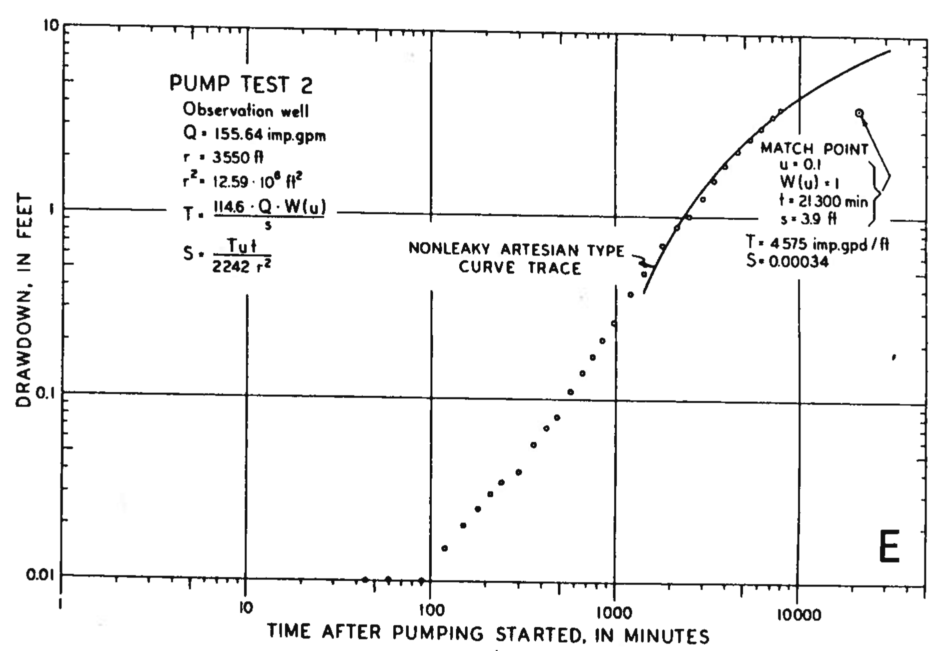




## FIGURE 44.

## TIME-DRAWDOWN GRAPHS, PUMP TEST 2.

A-Olds Well No. 189;
B-Olds Well No. 189a;
C-Olds Well No. 189b;
D-Olds Well No. 189c;
E-Olds Well No. 179.

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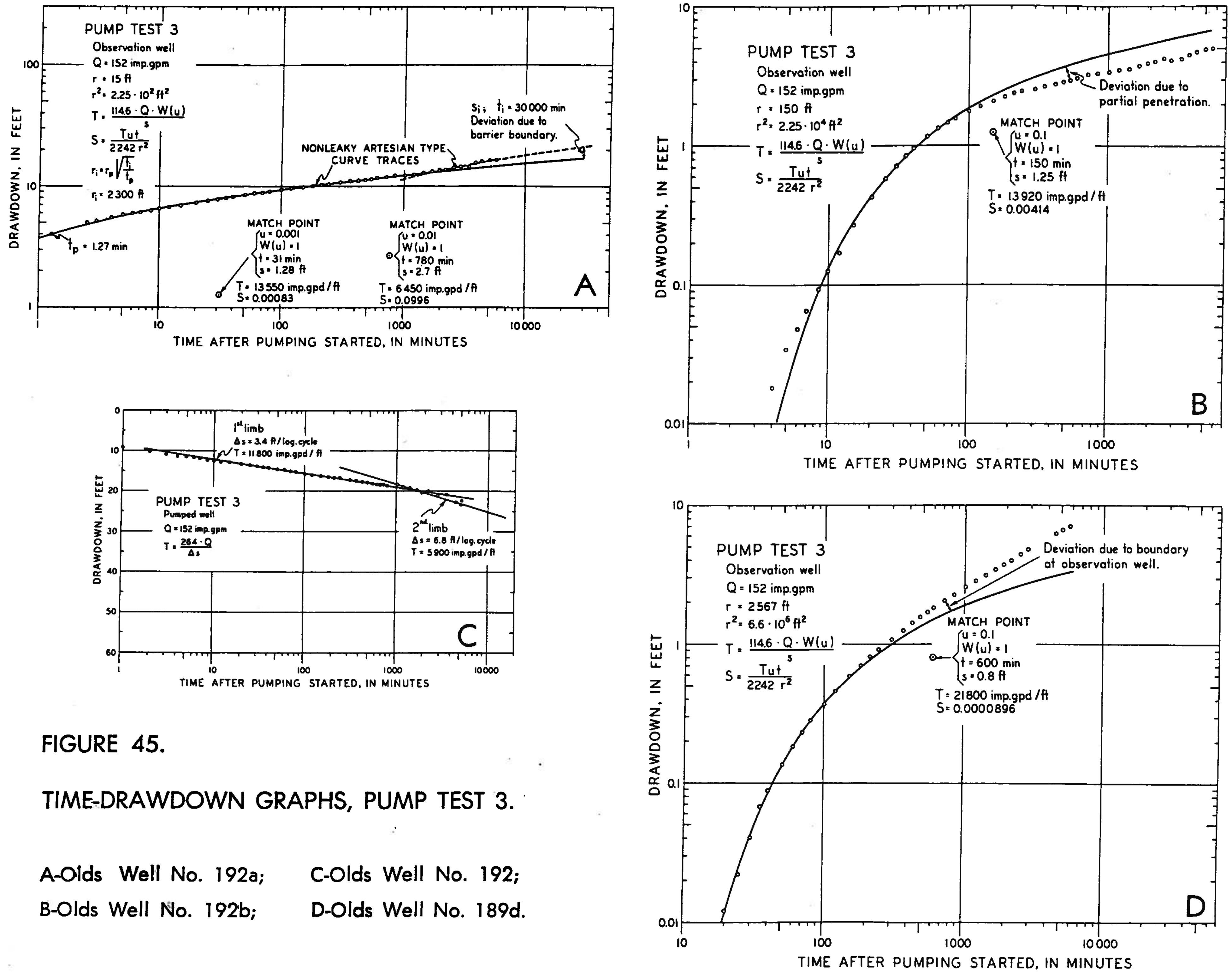


FIGURE 45.

TIME-DRAWDOWN GRAPHS, PUMP TEST 3.

A-Olds Well No. 192a; C-Olds Well No. 192;
B-Olds Well No. 192b; D-Olds Well No. 189d.

To accompany Research Council of Alberta Bulletin 17, by J. Tóth.


Appendix B: LITHOLOGIC STRIP LOGS of R.C.A. TEST HOLES.