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INVESTIGATION OF GROUND WATER CONDITIONS IN THE BOTTINEAU AREA BOTTINEAU COUNTY, NORTH DAKOTA

S.W.C.C. PROJECT NO. 738

By
Larry L. Froelich, Geologist

NORTH DAKOTA GROUND WATER STUDIES

NO. 52

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NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 STATE CAPITOL, BISMARCK, NORTH DAKOTA

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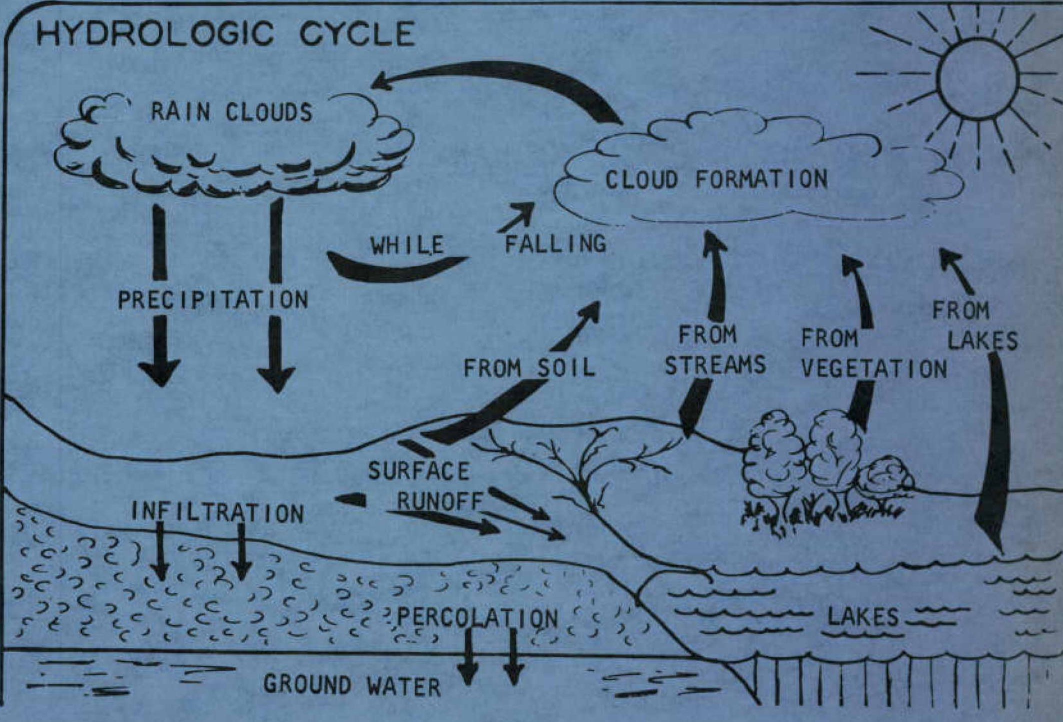

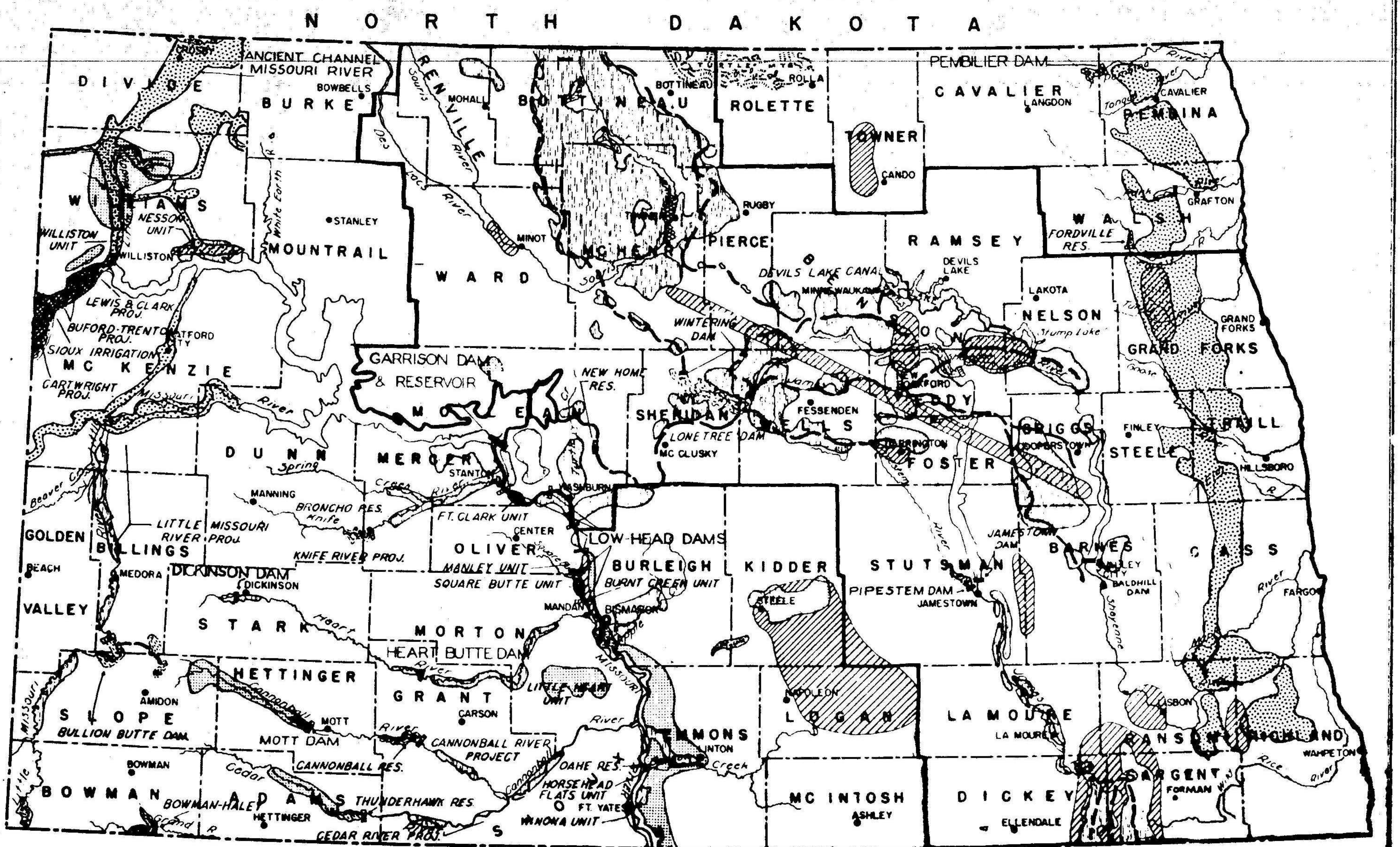

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

WATER RESOURCES DEVELOPMENT PLAN

LANDS UNDER IRRIGATION

AREAS CONSIDERED IRRIGABLE

AREAS BEING INVESTIGATED

PROPOSED FOR INVESTIGATION

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INVESTIGATION OF GROUND WATER CONDITIONS IN THE BOTTINEAU AREA, BOTTINEAU COUNTY, NORTH DAKOTA

INTRODUCTION

Scope and Purpose of the Investigation

The Bottineau City Council at its November 1957 meeting unanimously passed a resolution requesting the State Water Conservation Commission to place the city of Bottineau on its schedule for a ground-water survey. However, at the January 1958 council meeting it was decided to postpone the survey until more funds were made available. The matter was not considered again until June 1961 at which time the city council again requested assistance from the State Water Conservation Commission regarding the city water supply. Necessary requirements were fulfilled and the investigation began in the latter part of May 1962 and continued throughout the month of June 1962. The purpose of the investigation was to delineate potential ground-water aquifers capable of yielding a future satisfactory supply of water for the city of Bottineau, which is now solely dependent on ground water for its municipal supply.

The investigation consisted of a partial well inventory and collection of water samples for chemical analysis from selected wells within the Bottineau area. Thirty-four test holes were drilled with the State-owned rotary drilling machine to supplement information gained from soils surveys, aerial photographs, topographic maps, and other acquired data. The entire project was under the general supervision of C. P. Nelson, Investigation Engineer, North Dakota State Water Conservation Commission. Test drilling and other field work was under the direct supervision of Roger W. Schmid, Geologist, and the writer. Test drilling was done by Lewis and Lanny Knutson. Chemical analyses were performed by the North Dakota State Laboratories, Bismarck. Special thanks are due to Alex Gilles for his fine cooperation and information on the waterworks facilities of the city.

Previous Investigations

A general study of the geology and ground-water resources of Bottineau County was made by Simpson (1929, p. 79-88, 279) in which he includes records and chemical analyses of several wells in the Bottineau area. Abbott and Voedisch, (1938, p. 48) made an investigation of the municipal water supplies of North Dakota and their report includes well descriptions and chemical analyses of water from four Bottineau city wells. The area described by Lemke (1960) does not include Bottineau, but his report does contain information regarding geology of the area.

The North Dakota State Department of Health made a survey of the water quality of the city of Bottineau water supply in February 1961. Their report contains analyses of five of the eight city wells and an analysis of a sample taken from the distribution system at the Bottineau Armory.

Location and General Features of the Area

The Bottineau Area, as described in this report, is 9 by 11 miles in size and includes portions of Twp. 161, 162 and 163N., and Rge. 75 and 76W. in the northeastern portion of Bottineau County. It is included in the Souris River Valley and Turtle Mountains physiographic divisions of the Drift Prairie physiographic province of Simpson (1929), (fig.1).

Topography is dependent upon the physiographic divisions; it ranges from gently undulating in the area once occupied by glacial Lake Souris to the

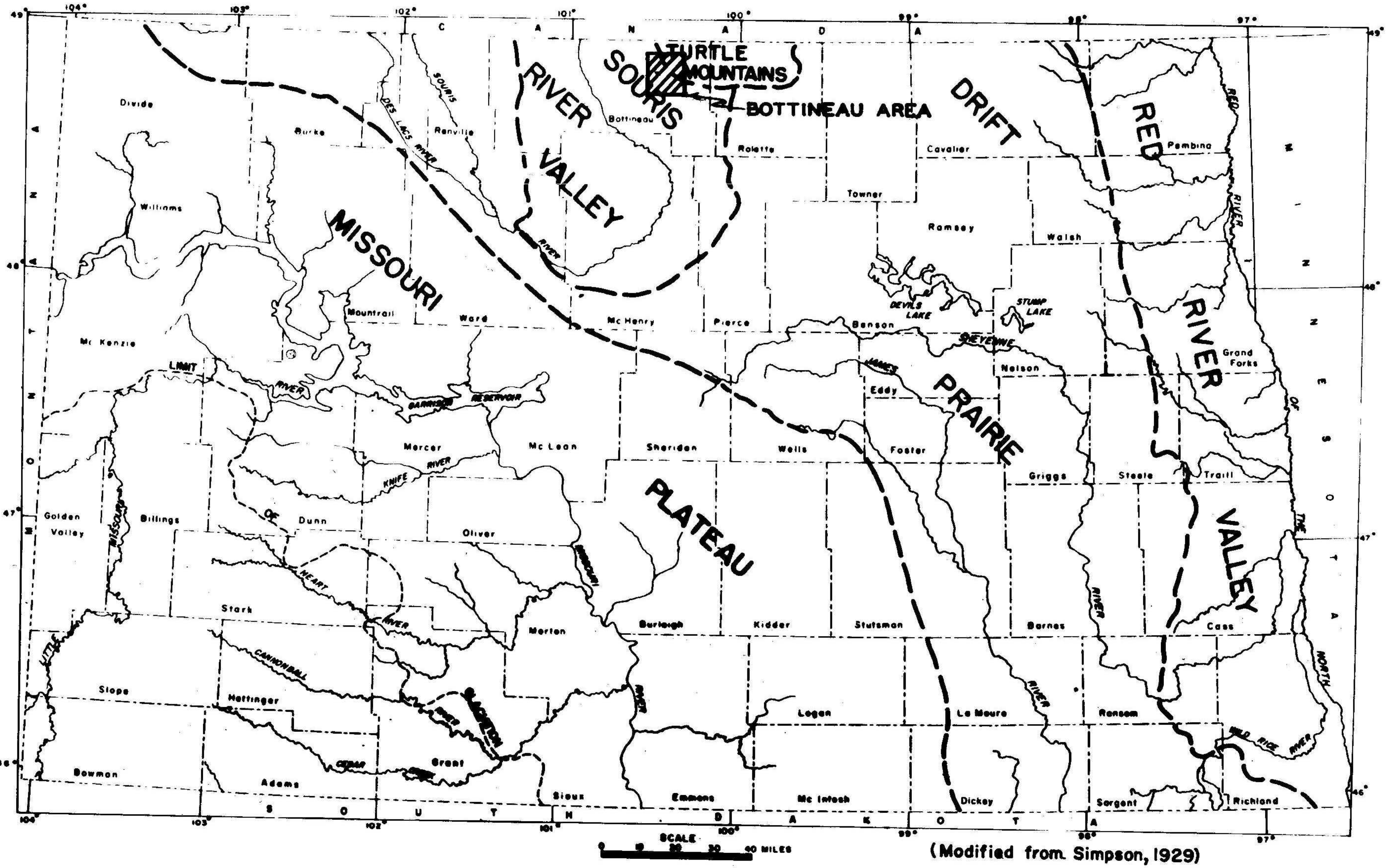

FIGURE I— MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF THE BOTTINEAU AREA rugged morainal expression of the Turtle Mountains. The flanks of the mountains are characterized by moderate to very steep slopes. Differences in surface elevation range from less than 1,520 feet above sea level in the southwestern part of the area to over 2,400 feet above sea level in the northwestern part, a difference of approximately 900 feet.

Each division also exhibits its own characteristic drainage pattern. Surficial drainage among the numerous lakes and peat bogs in the Turtle Mountains ranges from very poorly integrated to completely nonexistent. The majority of the lakes are elongated along an approximate north-south axis. The Souris River Valley division is drained by Oak Creek, Stone Creek, and several unnamed intermittent streams all of which have few tributaries. Integrated drainage patterns have not been developed in the areas between streams, and sloughs are common in lower portions of these areas. All drainage courses, with the exception of Oak Creek, which has its source in Lake Metigoshe, begin along the escarpment of the Turtle Mountains and trend in southwesterly direction coincident with the regional dip of the area. Some intermittent streams, beginning at the top of the escarpment, end abruptly in the permeable material along the flanks of the mountains. Others, beginning near the middle or base of the escarpment, have springs as their sources.

Bottineau, population 2,613 in 1960, is the only town in the area. It is located on State Highway No. 5 and served by a branch line of the Great Northern Railroad. Climatological data taken at the State School of Forestry in Bottineau through 1961 show the long-term mean temperature to be 37.8°F. Long-term mean precipitation at the same station was 16.35 inches per annum through 1961.

Present Water Supply

The waterworks facilities for the city of Bottineau consists of a series of eight free-flowing artesian wells located in the NE¼ of Sec. 7, Twp. 162N., Rge. 75W., along the base of the escarpment of the Turtle Mountains approximately three miles north of the city. Four of the eight wells are 40 feet in depth, one is 45 feet deep, one is 60 feet, and the remaining two are 80 feet deep. One of the 80 foot wells is equipped with a standby pump in case of emergency.

Water is collected in two reservoirs, each with a storage capacity of one million gallons, and is transmitted to the city through a 16-inch water line. An original 8-inch line remains in place for use in an emergency. One reservoir is in the NW¼,Sec. 7, Twp. 162N., Rge. 76W. and the other is in the NW¼, Sec. 18, Twp. 162N., Rge. 76W. Both are located with sufficient elevation so that pumping is not required to supply adequate water pressure for the city.

Bottineau does not have a master water meter installed in the main line so statistics are not available on the total volume of water supplied to the city. However, it is reported that approximately 3 million gallons of water are used per month during summer months and from 1½ to 2 million gallons per month during the remainder of the year. Three million gallons per month is equal to an average use of approximately 100,000 gallons per day. The eight flowing wells combined are normally capable of yielding at least 300,000 gallons per day. There is a seasonal diminishing of flow from the wells during the latter part of July and most of August when evaporation and transpiration losses are high. However, it is reported that during the unseasonably hot summer of 1961 when the total precipitation was 6.74 inches below normal, none of the eight wells ceased to flow, but the well with the standby pump was pumped for a period of two weeks to maintain an adequate supply in the reservoirs. This would indicate the city of Bottineau currently has a dependable water supply which is adequate for present needs. Additional demands may arise in the future depending upon how expansion of municipal facilities, development of irrigation farming under the Missouri-Souris project, and possibly the oil industry may affect the municipal and industrial growth of the area.

The major problem confronting the municipal water supply was defined in the report by the State Department of Health (1961). The results of their survey revealed that the city water supply was free of harmful bacteria but contained excessive amounts of dissolved carbon dioxide, iron, manganese, magnesium, and sulfates. Total hardness was also excessive and ranged from 745 ppm (parts per million) to 780 ppm; the recommended maximum limit is approximately 140 ppm. The State Department of Health recommended the city of Bottineau to give serious consideration to chemical treatment of the municipal water supply.

Well-Numbering System

The well-numbering system used in this report, illustrated in fig. 2, is based upon the location of the well in the federal system of rectangular surveys of public lands. The first numeral denotes the township north and the second numeral denotes the range west, both referred to the Fifth principal meridian and base line; the third numeral denotes the section in which the well is located. The letters a, b, c, and d designate respectively the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tracts). Consecutive terminal numerals are added if more than one well is located in a 10-acre tract. Thus, well 162-75-15daa is in the NE¼ NE¼ SE¼ Sec. 15, Twp. 162N., Rge. 75W.

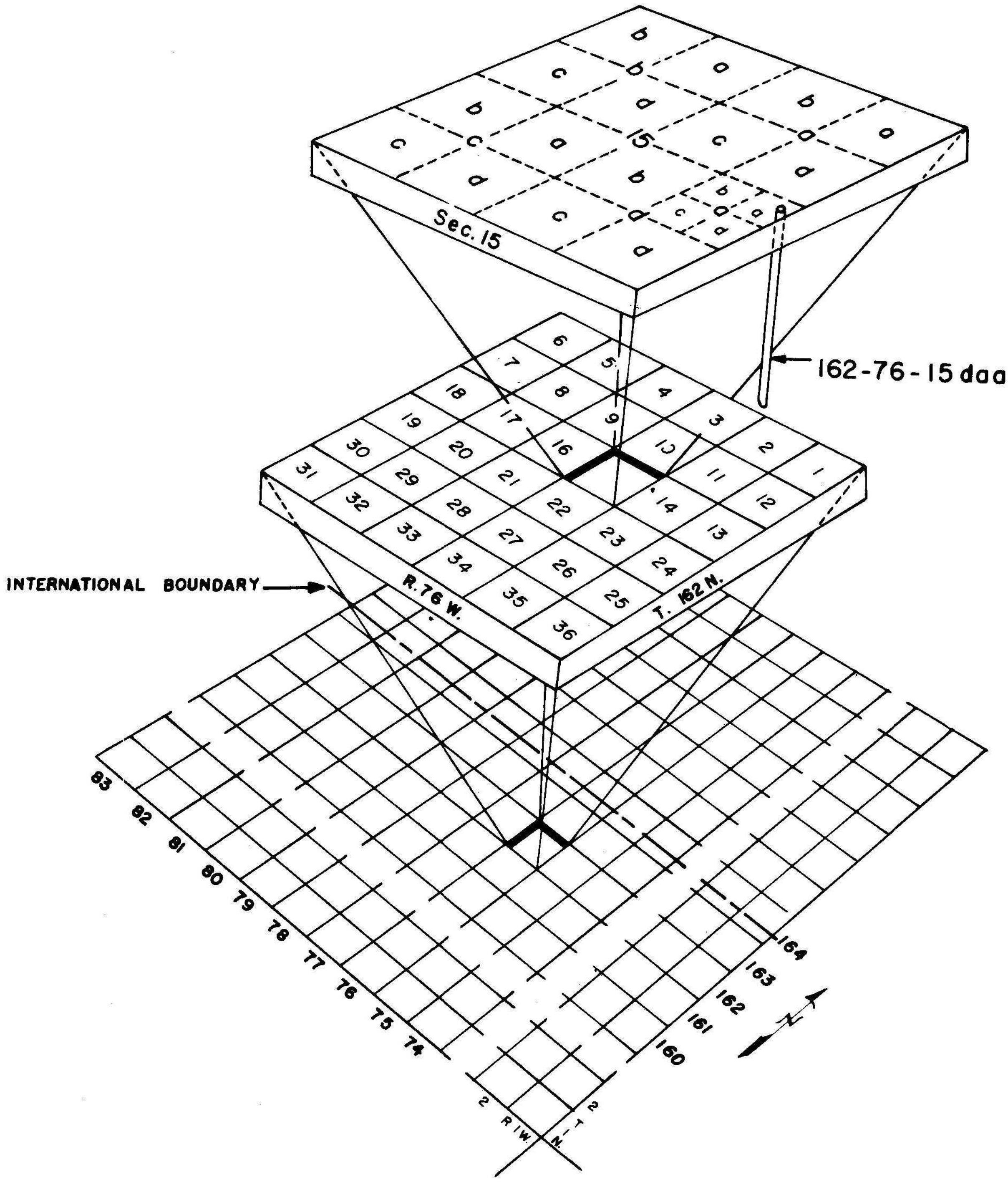

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

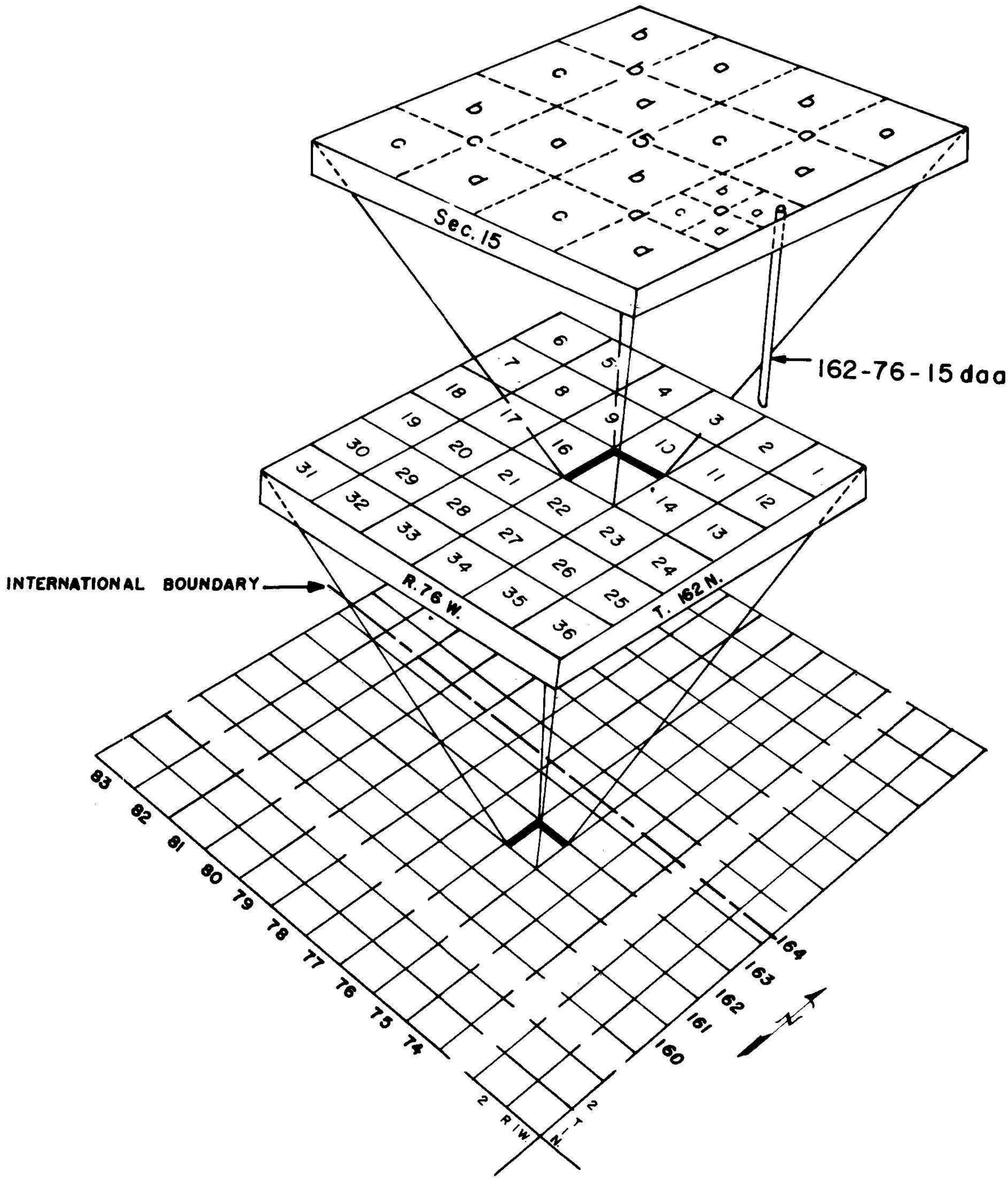

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

GEOLOGY AND OCCURRENCE OF GROUND WATER

Introduction

For the purpose of discussing the occurrence of ground water in the Bottineau Area, geologic formations have been grouped into three types: (1) alluvium, found in valleys of streams, (2) glacial drift, including the Turtle Mountains Moraine, the kame terrace, alluvial, and outwash deposits, the Souris River Ground Moraine, and glacial Lake Souris deposits, and (3) bedrock formations.

A summarized geologic history and certain hydrologic concepts are presented prior to the discussion of the occurrence of ground water as a means of introducing to the reader general geologic conditions in the area and explaining geologic and hydrologic terminology which will be used in the discussion.

Geologic History

Prior to glaciation, the region in and surrounding the Bottineau area probably resembled the unglaciated portion of present day southwestern North Dakota. Tertiary and Upper Cretaceous rocks controlled the topography and major drainage courses led north into Canada. The ancestral Turtle Mountains occupied an oval-shaped area of approximately 800 square miles. Tertiary rocks capped the majority of this area which in places may have protruded more than 600 feet above the surrounding terrain. Geologists are not in agreement concerning the origin of the ancestral Turtle Mountains and it is beyond the scope of this report to repeat the several theories. It will suffice, instead, to acknowledge the fact that there was a topographic high, prior to glaciation, in the area now occupied by the present Turtle Mountains.

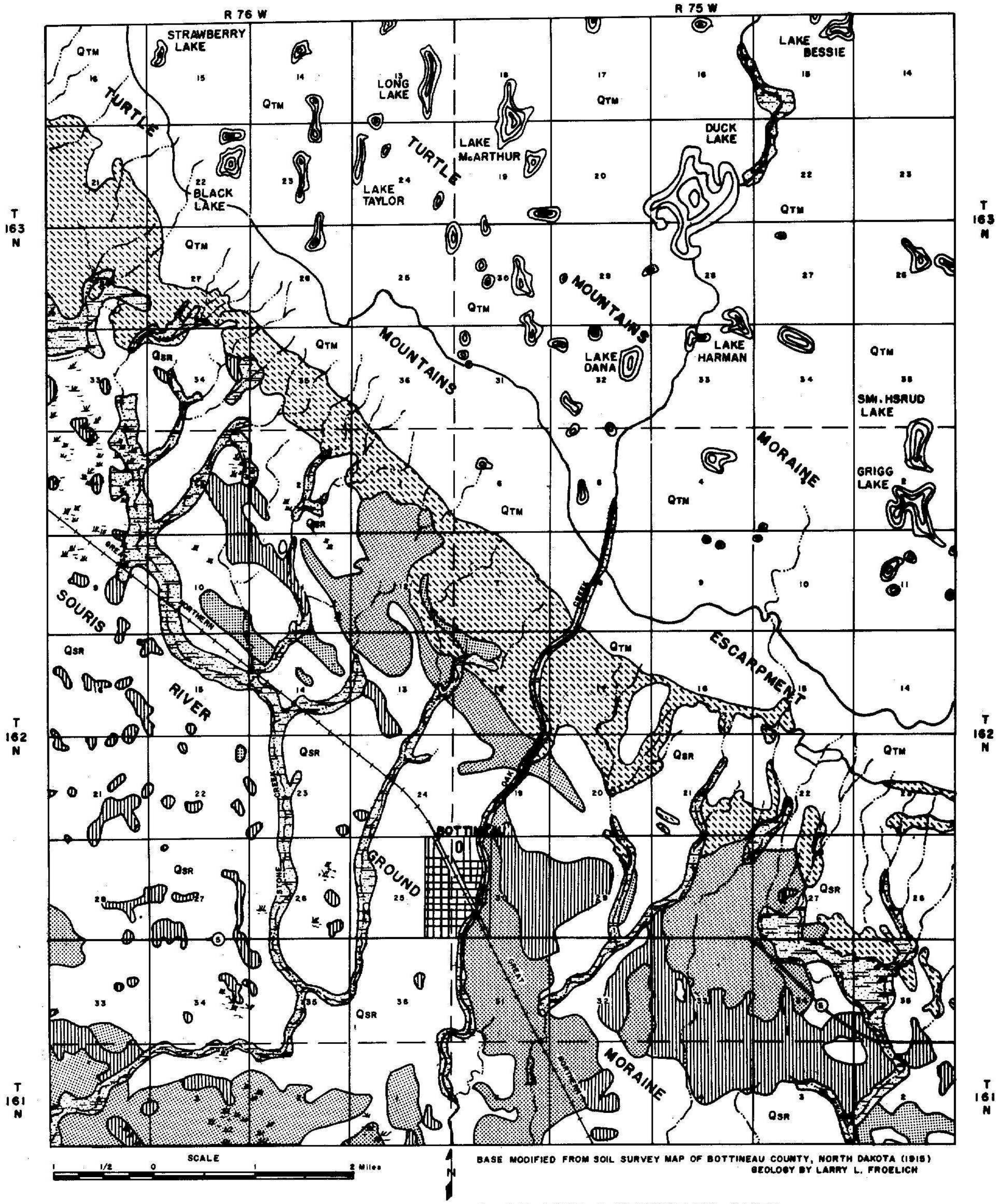

FIGURE 3--GEOLOGIC MAP OF THE BOTTINEAU AREA

EXPLANATION

QUATERNARY PERIOD

RECENT AGE

ALLUVIUM

Small to moderate quantities of water are recovered from local saturated sand and/or gravel deposits.

PLEISTOCENE AGE

QTM

TURTLE MOUNTAINS MORAINE

Sand and gravel deposits associated with the moraine yield small to large quantities of water, depending on saturated thickness of the deposits; numerous springs along escarpment.

QSR

SOURIS RIVER GROUND MORAINE

Small to moderate quantities of water are recovered from sands and gravels associated with the moraine; larger quantities nearer the escarpment.

KAME TERRACE, ALLUVIAL AND OUTWASH DEPOSITS

Consist of essentially sand and gravel capable of yielding small to large quantities of water; local thinning of deposits precludes development of shallow wells.

LAKE SOURIS DEPOSITS

LAKE SOURIS SANDS

Consist mainly of surficial deposits; locally recharge areas for underlying kame terrace, alluvial and outwash deposits; shallow wells yield small to moderate quantities of water.

LAKE SOURIS CLAYS AND SILTS

Consist of thin surficial deposits, essentially non-water-bearing.

During the Pleistocene Epoch approximately 20 percent of the earth's land surface was glaciated. This epoch lasted from about 1,000,000 to less than 10,000 years ago. During this time four major stages of glaciation passed over portions of that 20 percent of the land surface. The major stages are from oldest to most recent: Nebraskan, Kansan, Illinoian, and Wisconsin. Each major stage has been subdivided by glacial geologists into various substages. Lemke (1960, p. 42) has assigned all exposed glacial deposits of the Souris River area to the Mankato substage of the Wisconsin stage of Pleistocene glaciation.

At least three ice sheets have crossed over or shoved debris onto the ancestral Turtle Mountains. The latest advance to cover this high is presumably of Wisconsin age, but no attempt has been made in this report to differentiate genetic relationships of the material deposited by the ice advances and all the material will be considered as a single lithologic unit, hereafter called the Turtle Mountains Moraine.

During the waning stages of glaciation, as the ice mass began to thin, the Turtle Mountains Moraine acted as a buttress and the glacier was forced to flow around it. The Turtle Mounrains Moraine then became an "island", the sides or flanks of which were subjected to the continual smoothing effect of ice action. Beneath this ice mass the Souris River Ground Moraine was being deposited.

The ice on the Turtle Mountains Moraine began to melt first and meltwaters carried outwash onto the glacier surrounding the moraine. When the glacier finally began to retreat, the ice mass slowly moved away from the flanks of the Turtle Mountains Moraine, creating an avenue for meltwaters from both the glacier and the remaining ice on the moraine. Due to the large volume and high velocity of the meltwater much coarse sand and gravel were deposited in this avenue. With continued retreat of the glacier a gravelly terrace, or a kame terrace, remained on the south and west flanks of the Turtle Mountains Moraine. Outwash which had been deposited on the glacier was either redeposited on the Souris River Ground Moraine as collapse outwash or remained on the ice to be redeposited with the eventual melting of the ice. Meltwaters remained active for a length of time in the area between the moraine flanks and the margin of the glacier--eroding, reworking, and redepositing portions of the kame terrace, the outwash, and the Souris River Ground Moraine. The majority of the redeposition was in regions outside of the Bottineau Area, however.

As the glacier continued its northerly retreat, it blocked the natural drainage to the north and glacial Lake Souris was created due to the confinement of the glacial meltwaters. The maximum level attained by glacial Lake Souris approximated the 1600 foot contour above sea level (Fenneman, 1938, p. 583); this resulted in a shoreline in the immediate vicinity of Bottineau. A near-shore condition prevailed at this time with currents and wave action modifying the existing glacial and glaciofluvial deposits. Beaches, bars and spits composed mainly of sand were deposited along the margin of the lake, while clay and silt were taken into suspension and deposited in sheltered areas along the lake shore or carried into deeper portions of the lake.

The rising waters of glacial Lake Souris finally found a southern outlet and the lake waters eventually made their way southeast to glacial Lake Agassiz, or the present day Red River Valley. With continued retreat of the glacier, preglacial drainage was re-established and glacial Lake Souris was drained, leaving a gently undulating lacustrine plain mantled by Lake Souris clays and silts.

Wind, water, and mass-wasting agencies have continued to form and reshape portions of the topography in the Bottineau Area since the withdrawal of Lake Souris. Sandy tracts, as well as windblown silt or loess, are present in the area, especially on the slopes approaching the escarpment of the Turtle Mountains Moraine. These deposits are now more or less stabilized by vegetation, except of course, those areas under cultivation. Water,in the form of rain and snow, has produced numerous gullies along the escarpment as well as a poorly developed drainage pattern on the plain below. In places springs have deposited calcium, magnesium and manganese carbonates in the form of mounds and small terraces. Mass-wasting processes are evidenced by minor amounts of colluvium associated with the alluvium in the valleys and by the slumps and solifluction terraces on the slopes. Aerial photographs indicate what may be alluvial cones in certain areas along the escarpment.

Hydrologic Concepts

Essentially all ground water of economic importance is meteoric, or that water derived from precipitation. The water may enter the ground either by direct penetration or by percolation from streams, lakes and ponds. Practically all ground water is in the process of movement through the ground from the place of intake or recharge to a place of disposal or discharge. The rate of movement may vary in different areas, but velocities of a few tens to a few hundreds of feet a year are common under natural conditions.

Natural discharge of ground water may occur as direct evaporation from the soil surface, lakes, or ponds, as transpiration from plants, by seepage to streams, or by springs. Ground water may also discharge directly from one ground-water reservoir to another, or by slow percolation from one reservoir to another through a separating formation.

Any formation or stratum that will yield water to wells in sufficient quantity to be of importance as a source of supply is called an "aquifer". The water moving through an aquifer from recharge areas to discharge areas is considered as water in "transient storage". The amount of water that can be thus stored in an aquifer is dependent upon the porosity of the material composing the aquifer and upon the volumetric dimensions of the aquifer as a whole.

The capacity of an aquifer to yield water by gravity drainage may be much less than would be indicated by its porosity because part of the water may be held in the pore spaces by molecular attraction or surface tension between the water and the rock materials. The volume of water that will drain by gravity from a unit of the saturated aquifer expressed as a percentage of the volume of rock material, is called the "specific yield".

If the water in an aquifer is not confined by impermeable strata, the water is considered to occur under water-table conditions. If the aquifer is separated from the main ground-water reservoir by impermeable strata, a perched water-table condition may develop. In either case, water may be obtained from storage in the aquifer by lowering the water level, as in the vicinity of a well being pumped, which results in gravity drainage. However, if water is confined in the aquifer by an overlying impermeable stratum, so that the water in a well rises above the top of the aquifer under hydrostatic pressure, the water is said to occur under artesian conditions. In this case, if ideal artesian conditions prevail, water is yielded as the water level in the well is lowered, but the aquifer remains saturated and the water is yielded because of its own expansion and the compression of the aquifer due to lowered pressure rather than by gravity drainage. The water-yielding capacity is called the "coefficient of storage" and is very much smaller than the specific yield of the same material when drained by gravity. The coefficient of storage is defined as the volume of water that will be released from storage in each vertical column of the aquifer having a base one foot square, when the artesian level falls one foot.

If the pore spaces are large and interconnected, as they commonly are in sand and gravel, the water is transmitted more or less freely, and the material is considered permeable, but if pore spaces are very small or not connected, as they are in clay or silt, the water is transmitted very slowly or not at all, and the material is said to be impermeable.

Unconsolidated material such as sand and gravel is generally more permeable than consolidated rocks and, therefore, are considered more important as ground-water reservoirs. However, in some areas consolidated rocks are highly permeable and function as important reservoirs.

Alluvium

The valleys of the intermittent streams in the Bottineau Area, with the exception of Stone Creek, are generally narrow and shallow. Alluvium in the valley floors consists for the most part of thin deposits of silt or fine sand. Oak Creek, the only perennial stream in the area, has a narrow, shallow valley south of Bottineau, but north of the city it becomes progressively steeper until it reaches canyon dimensions in the escarpment. The alluvium is composed of fine to coarse sand north of the city up to the escarpment and silt or fine sand predominates south of the city and in the Turtle Mountains Moraine. The alluvium in the Oak Creek valley attains a thickness of more than 15 feet in only a few places.

Stone Creek differs from the other streams in the area in both its topographic expression and mode of origin. The most noticeable feature is the comparatively wide valley occupied by an underfit intermittent stream. Geologic evidence in the area indicates that whereas the other present day streams in the area are of recent age, with perhaps the exception of Oak Creek, Stone Creek probably represents a westerly continuation of the streams that deposited the sand and gravel below and along the escarpment. Stone Creek may have drained most of the western flank of the Turtle Mountains and at least the portion included in the Bottineau Area.

Test holes 1 and 19 show two alluvial deposits in the Stone Creek valley. The upper alluvium is light colored clay or silt and the lower alluvium consists of clay, silt, sand, and gravel. The total thickness of both is approximately 25 feet. The upper alluvium is the result of deposition by floods during spring runoff in recent time. The lower alluvium is much older and was deposited at the time glacial meltwaters occupied the Stone Creek valley.

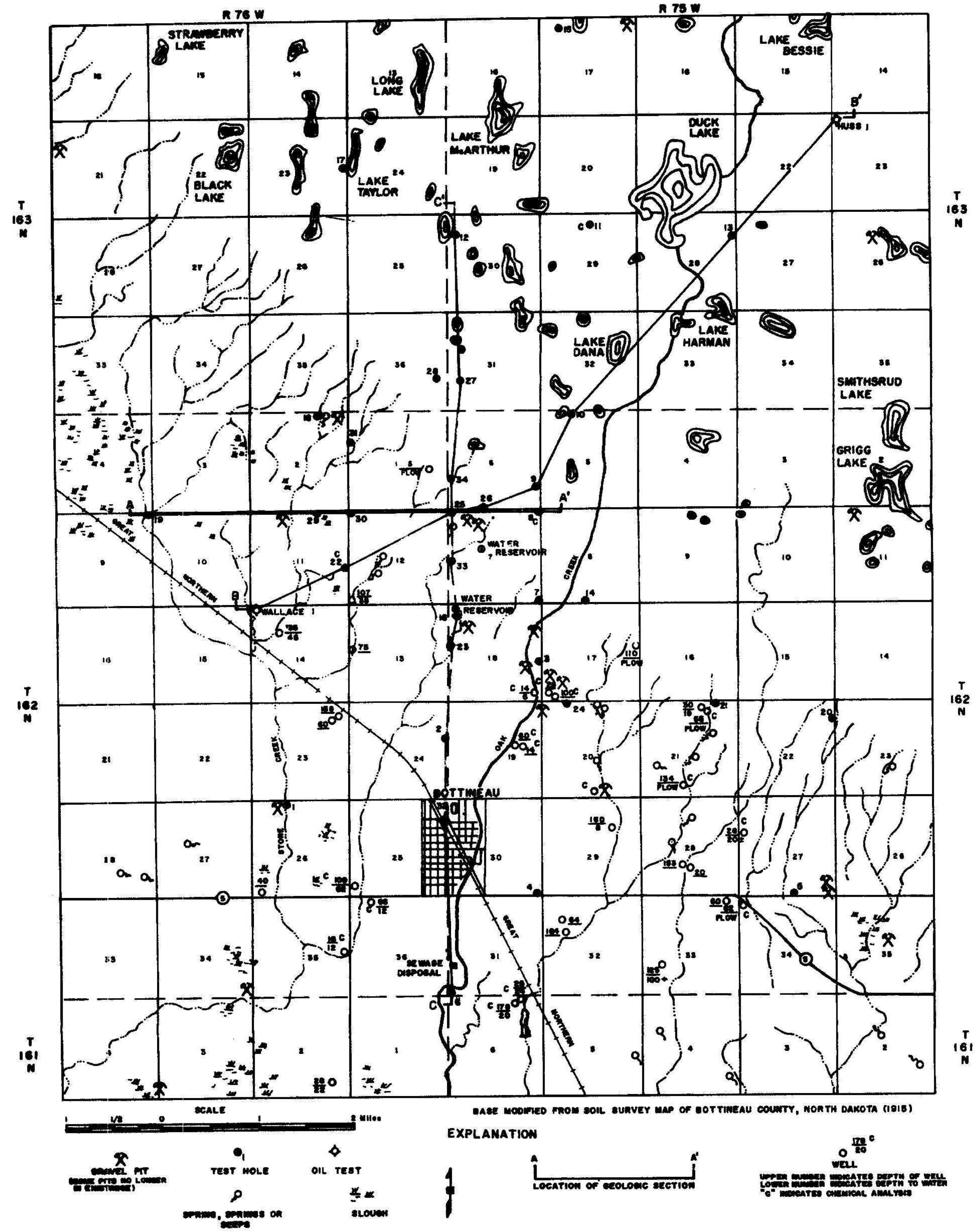

FIGURE 4--MAP OF THE BOTTINEAU AREA SHOWING THE LOCATION OF WELLS, TEST HOLES, GEOLOGIC SECTIONS, AND RELATED FEATURES

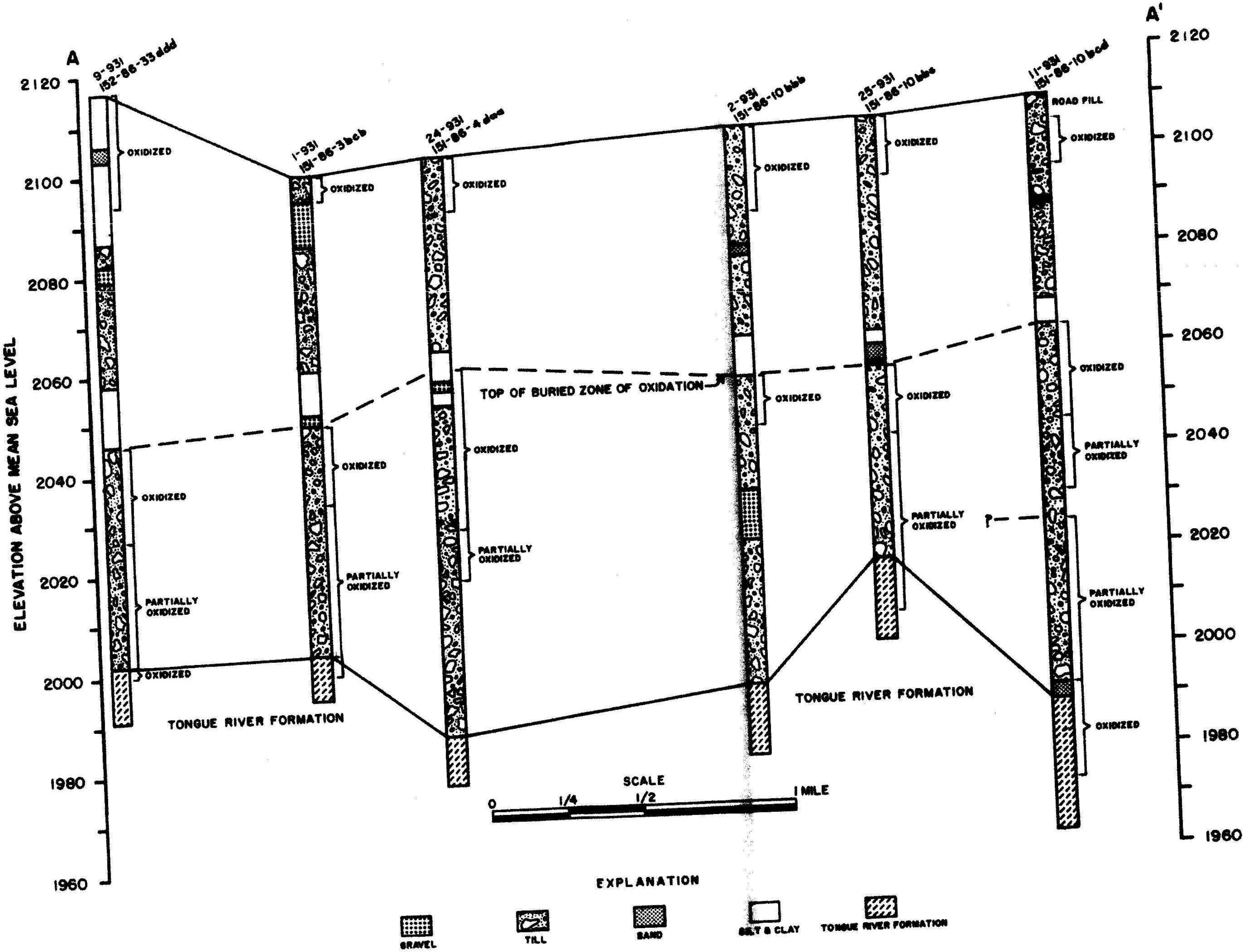

FIGURE 5--CROSS SECTION OF SELECTED TEST HOLES IN THE RYDER AREA

(LOCATION OF SECTION SHOWN IN FIGURE 4)

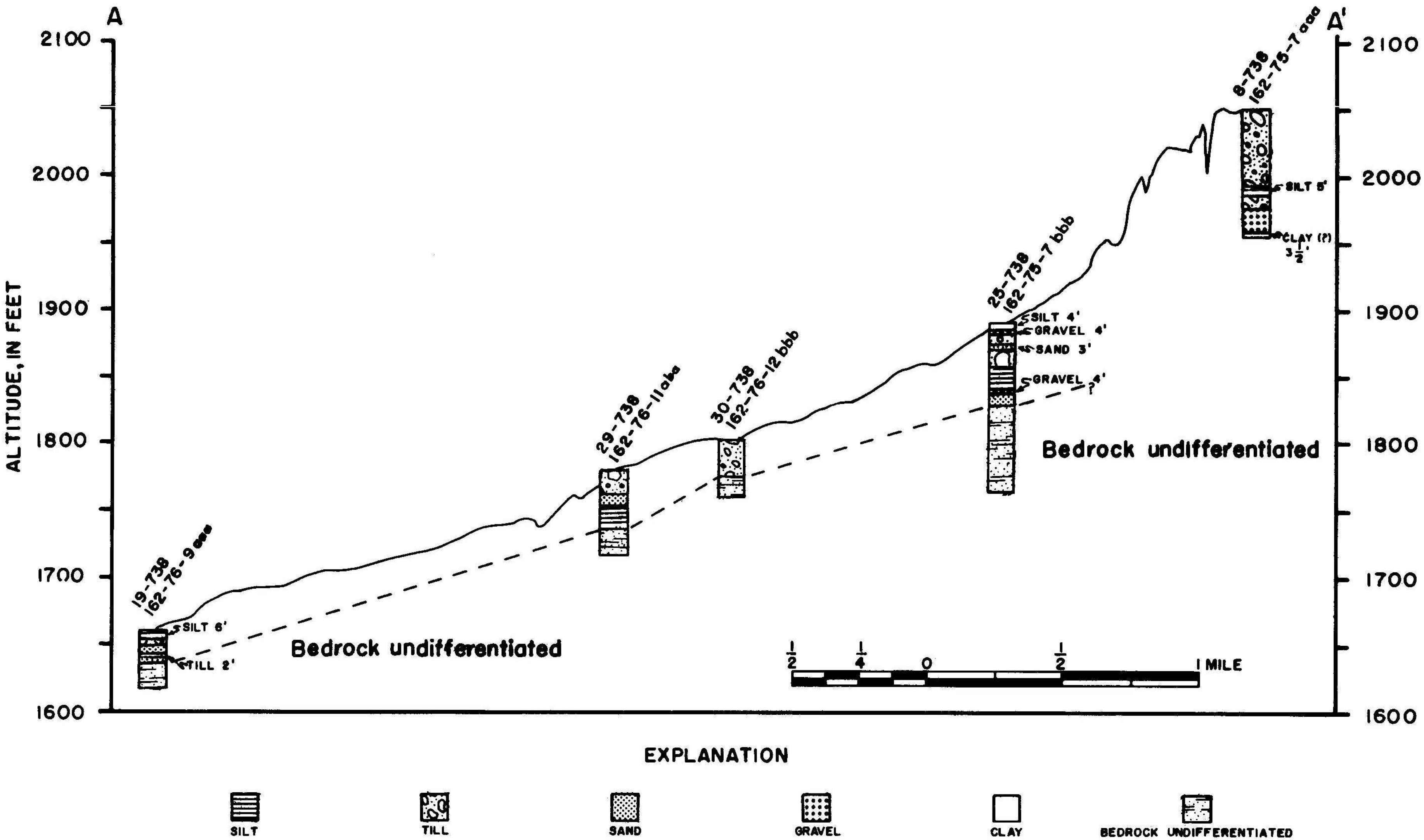

FIGURE 5a--GEOLOGIC SECTION A-A' IN THE BOTTINEAU AREA
(LOCATION OF SECTION SHOWN IN FIGURE 4)

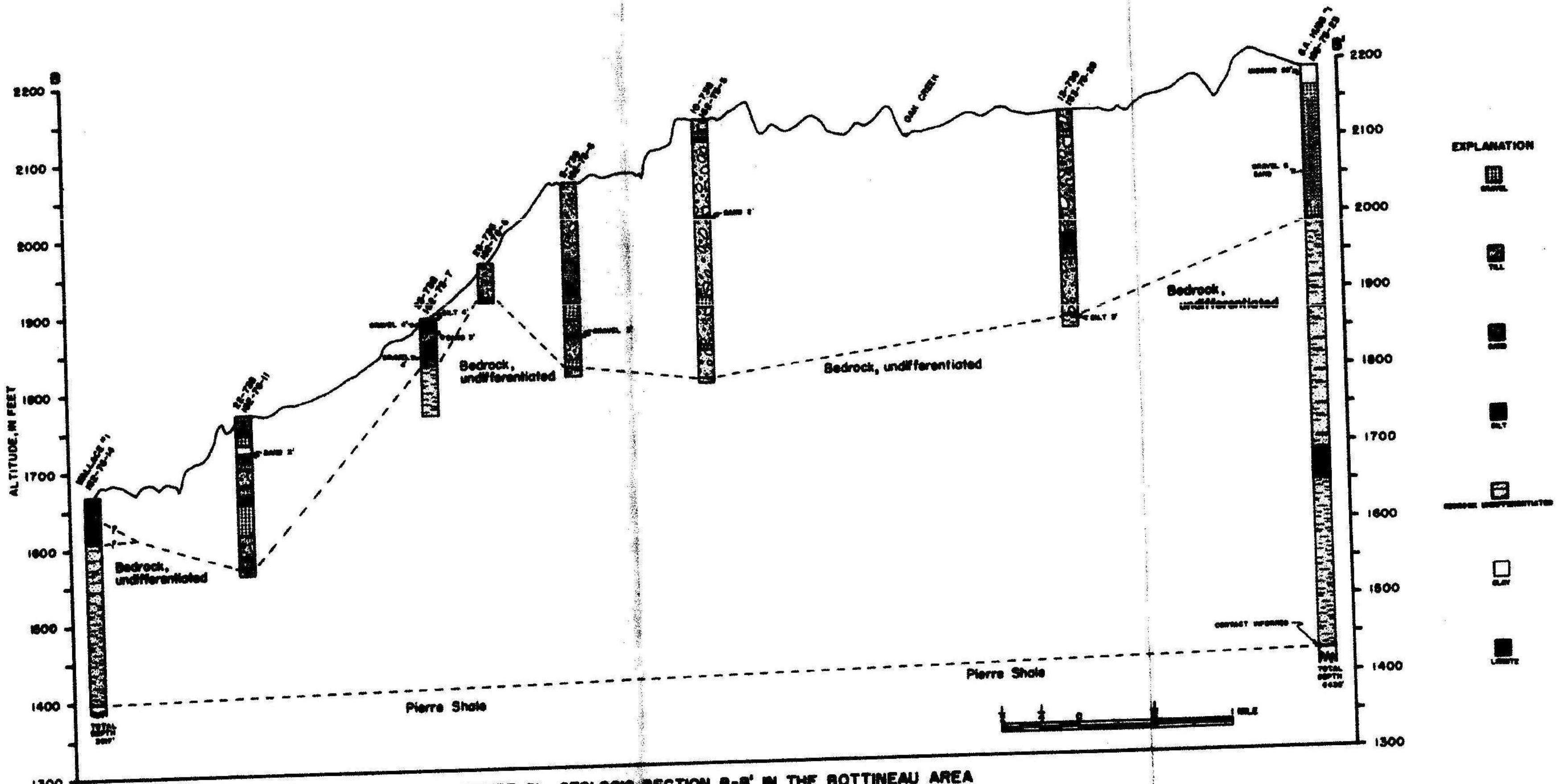

FIGURE 5b--GEOLOGIC SECTION B-B' IN THE BOTTINEAU AREA

(LOCATION OF SECTION SHOWN IN FIGURE 4)

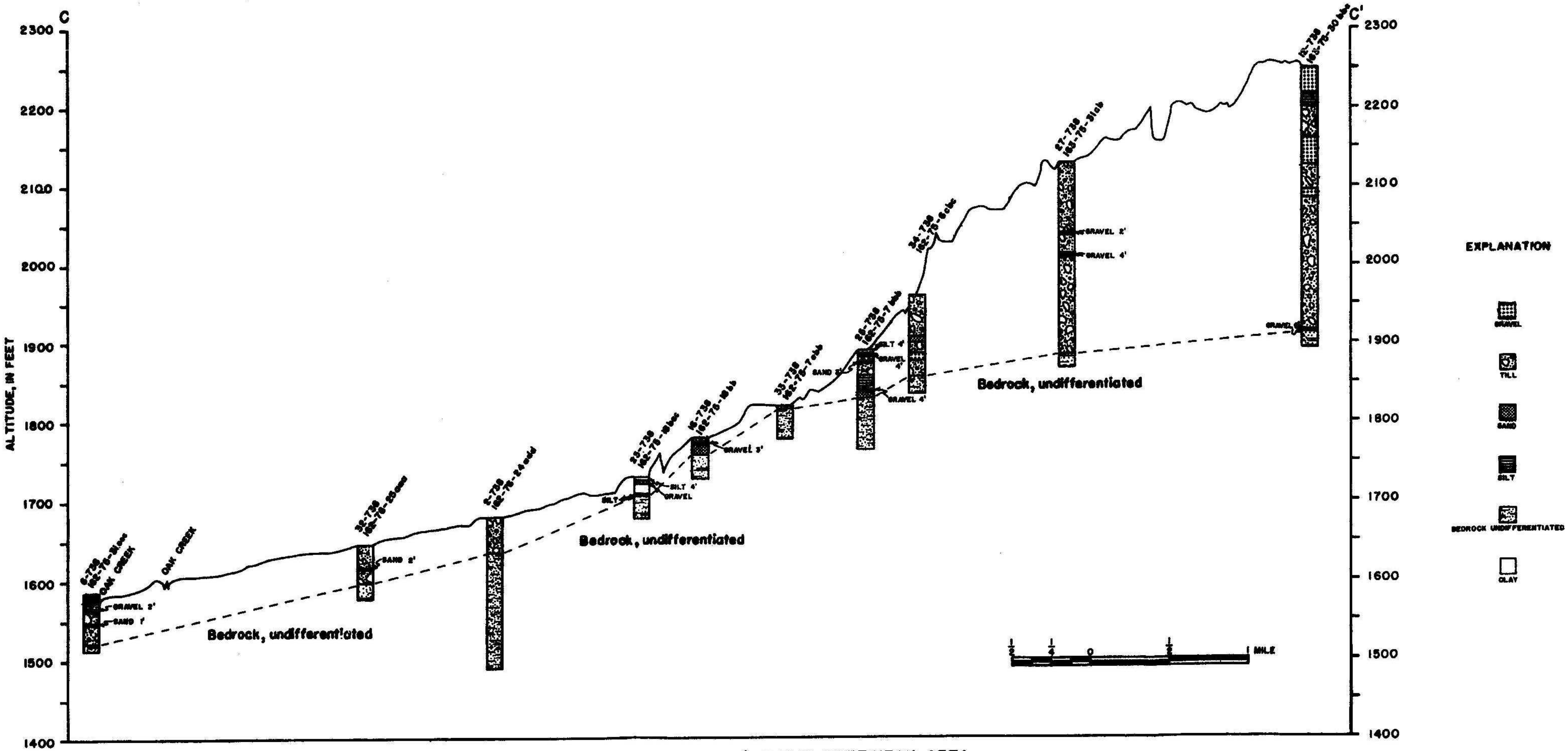

FIGURE 5c--GEOLOGIC SECTION C-C' IN THE BOTTINEAU AREA
(LOCATION OF SECTION SHOWN IN FIGURE 4)

Along a northwest-southeast trending line in the extreme southwestern corner of the Bottineau Area are a series of sand and gravel deposits, some of which are presently being mined. These deposits are probably material that has been transported by meltwater in Stone Creek. Stone Creek may have entered Lake Souris at this point and a deltaic or near-shore depositional environment existed or, more likely, the meltwater was restrained by stagnant ice in that area causing deposition of the sand and gravel with subsequent modification by Lake Souris waves and currents.

In general, the alluvium in stream valleys does not constitute a major aquifer in the Bottineau Area. However, small to moderate supplies sufficient for ordinary domestic and stock-watering demands can be obtained from sandy or gravelly portions of the alluvium that occur below the water table. At places where the streams have intersected the water table, springs and seeps are sometimes developed for stock-watering purposes. The sand and gravel in the southwestern corner of the Bottineau Area may contain a ground-water source that can be recharged by spring runoff from Stone Creek.

Glacial Drift

Turtle Mountains Moraine - - - - Test drilling in connection with this study revealed an irregular bedrock surface beneath the glacial drift of the Turtle Mountains Moraine. This would indicate the ancestral Turtle Mountains may have been subjected to erosional processes for a considerable length of time before glaciation and were probably deeply dissected by narrow steep-walled valleys. Test drilling, however, did not definitely establish the presence of such valleys.

During the Pleistocene Epoch the surface of the ancestral Turtle Mountains was modified by the glaciers and pre-existing geologic sequences were masked. The first glacial advance completely covered the ancestral mountains.

Later glacial lobes lacked the massiveness of previous glaciers and although they did not override the Turtle Mountains, they did shove material onto the moraine as evidenced by the arcuate recessional moraines and intervening lakes in the western portion. The lineation of these ridges and lakes indicates that the direction of this later ice movement was from the west and northwest.

The principal material composing the Turtle Mountains Moraine is till. Till may be defined as that part of glacial drift consisting of material deposited by ice with little or no transportation by water. It is a generally unstratified, unconsolidated, heterogeneous mixture of clay, silt, sand, gravel, and boulders. In the Bottineau Area the till is mainly an olive gray clay or silt impregnated with limestone and granitic pebbles and/or boulders and is locally termed "blue clay", except for the upper zone of weathered and oxidized olive brown till which is termed "yellow clay". The till itself is very nearly impermeable and does not function as an aquifer.

During the Pleistocene Epoch there were at least four major and many minor advances and retreats of glaciers in North America and considerable thawing and melting occurred coincident with these advances and retreats. Melt-water streams sorted glacial material with which they came in contact and where free flowing, these streams deposited sand and gravel. Clay and silt were deposited in areas where the water was impounded or no longer had the capacity to carry material in suspension. Sorted deposits are found in the Turtle Mountains Moraine both at the surface and included within the till. The clays and silts are impermeable but the sand and gravels are important aquifers to residents of the area. Where exposed at the surface the sands and gravels may yield small, moderate, and in some instances, large quantities of water to wells. Small to moderate supplies are obtained from sand and gravel deposits included in the till; large quantities may be obtained if the deposits are hydraulically connected to a recharge area. If the deposits are not capable of being readily recharged, as is the case if they are completely surrounded by impermeable till, the aquifer may be dewatered by continuous pumping.

Test holes penetrating the drift in the moraine revealed several 20 and 30 foot sections of sand and gravel and every test hole disclosed at least one sand or gravel deposit before bedrock was reached. No flowing wells were encountered but artesian conditions are present in the deeper wells. The majority of private wells on the moraine are shallow, generally less than 40 feet deep.

The material in the Turtle Mountains escarpment is much the same as that in the moraine itself, and hence the escarpment is included as part of the Turtle Mountains Moraine. However, erosional processes along the escarpment have exposed many of the buried sand and gravel deposits resulting in numerous springs in the gullies. These springs could be a good supplementary source of water for the city of Bottineau especially because the present water system employs gravity drainage. Water samples can be obtained for chemical analyses and only those springs with suitable quality need be selected. However, before any springs are selected for development, they should be thoroughly investigated to determine their yield, storage capacity, probable source of recharge, and whether or not they continue to flow during summer months.

Private wells along the escarpment are similar to those in the moraine. The majority of wells are dug and are shallow. The deeper drilled wells obtain water under hydrostatic pressure from sand and gravel deposits within the till. Only two private wells were inventoried in the area composing the escarpment; both were flowing wells.

Souris River Ground Moraine- - - - - The Souris River Ground Moraine is the result of deposition of material beneath the ice as the glaciers passed over the region. In the Bottineau Area the surface of the ground moraine is characterized by gently to moderately undulating topography up to the Turtle Mountains escarpment.

The principal material composing the Souris River Ground Moraine, as in the Turtle Mountains Moraine, is till. Both tills are similar in lithology; however, the ground moraine does contain noticeably fewer deposits of sand and gravel. Where test drilling encountered these sand and gravel deposits they seldom, if ever, exceeded ten feet and were probably of limited extent laterally. A cover of stagnant ice over the ground moraine during thawing and melting periods on the Turtle Mountains Moraine may be one of the reasons for the scarcity of sand and gravel in the ground moraine.

The majority of shallow wells below the escarpment tap surficial aquifers that overlie the ground moraine. Where these surficial aquifers are absent, shallow dug or bored wells obtain water from sand and gravel lenses within the till of the ground moraine. Since infiltration into the wells occurs at such a very slow rate, large diameter wells are necessary. Many of these wells produce supplies barely adequate for ordinary domestic and stock uses. More recent wells have been drilled through the till and obtain their supply from the underlying bedrock.

Kame Terrace, Alluvial and Outwash Deposits - - - -The kame terrace, alluvial and outwash deposits are treated as one unit, in that, combined they constitute the major aquifer in the Bottineau Area. The kame terrace deposits are surficial and made up of material deposited by glacial meltwater streams between the escarpment and the receding ice front. Some of the alluvial and outwash deposits are also surficial but the majority of these deposits are buried and associated with the till of the Souris River Ground Moraine adjacent to the escarpment. The alluvial and outwash deposits are the result of meltwater streams emerging from the Turtle Mountains Moraine between the advance and retreat of the glaciers.

The kame terrace deposits consist mainly of permeable sand and/or gravel. A blanket of silt generally exists overlying the sand and/or gravel and locally lenticular silty deposits occur within them. The areas delineated as kame terrace, alluvial and outwash deposits on the geologic map (See figure 3) are for the most part kame terrace deposits. Where these deposits attain a saturated thickness of ten feet or more, moderately large quantities of water may be withdrawn without serious depletion of ground water in storage. The ground water in these deposits is not now being withdrawn in large quantities but millions of gallons of water are lost annually through evaporation, transpiration, and runoff from springs. Wells developed in these deposits are capable of immediate recharge at most places and may flow in certain areas.

The alluvial and outwash deposits consist of permeable sand and/or gravel associated with clay, silt and/or till. Recharge areas to many of these deposits are along the escarpment where they are exposed or overlain by the permeable kame terrace deposits. Due to the high recharge area and the slope of the escarpment, water contained in these deposits is under hydrostatic pressure and flowing wells are common.

Test hole 22 (figures 4 and 5b) contains material typical of the kame terrace, alluvial, and outwash deposits. Water did not flow from this particular test hole, but a properly developed well at this site should be capable of producing an adequate supply of water to meet the present demands of Bottineau. There is reason to suspect, although future exploration is needed to prove, that a preglacial valley exists in the vicinity of test hole 22.

Glacial Lake Souris Deposits-------Glacial Lake Souris deposits consist of thin patches of clay or silt and sand that mantle the Souris River Ground Moraine. The clay and silt occupy hollows and lower portions of the ground moraine whereas the sand is associated with the low ridges and rolling topography. The clay and silt are generally too thin and impermeable to constitute an aquifer in the Bottineau Area.

The sand deposits are the result of the wave action of Lake Souris producing beaches and near-shore depositional features. Wells penetrating these deposits usually obtain adequate supplies of water for domestic and stock uses. The sand deposits associated with the kame terrace, alluvial, and outwash deposits are more likely the result of wind action rather than fluvial processes. In many instances the sand deposits are immediately underlain by kame terrace deposits such as at test hole 22. In any event, these sand deposits are capable of constituting aquifers if significant saturated thicknesses are discovered. The sand is not as permeable as the sand and gravel in the kame terrace, alluvial, and outwash deposits, however, and the yield will be less.

Bedrock Formations

Exploratory oil tests in the Bottineau Area indicate the presence of geologic formations from the Tertiary, Cretaceous, Jurassic, Triassic, Mississippian, Devonian, Silurian, and Ordovician Systems. Precambrian granite was encountered at a depth of 6,422 feet in the G. A. Huss #1 (figure 4).

Tertiary rocks of Paleocene Age underlie the glacial drift in the Bottineau Area. The Tongue River Formation is believed to underlie the drift of the Turtle Mountains Moraine and the Cannonball Formation underlies the drift in the remainder of the area. The Tongue River Formation consists of variegated clay and shale with associated sand, carbonaceous material, and lignite. Because of the thickness of the drift on the moraine and the predominance of clay and shale, the Tongue River Formation is not considered a potential aquifer in the Bottineau Area. The Cannonball Formation consists, for the most part, of an unconsolidated, very fine to fine, light greenish gray sand with associated clay, silt, shale and sandstone strata. Many of the deeper wells in the Bottineau Area obtain water from the Cannonball sands. The water is generally of better quality than waters from glacial drift aquifers and northeast and east of Bottineau practically every well developed in these sands is a flowing well. The permeability of the Cannonball Formation is low and consequently several properly spaced wells would be required for a municipal supply.

In the stratagraphical sequence of North Dakota the Upper Cretaceous Hell Creek Formation is usually found below the Cannonball Formation. However, the Hell Creek Formation is not known to extend as far north as the Bottineau Area and is presumed to be absent. The Fox Hills Sandstone stratigraphically underlies the Hell Creek and is believed to be present in the extreme southern portion of the Bottineau Area. Test drilling did not prove its existence however. The sand of the Fox Hills resembles the Cannonball but is coarser-grained. If present in the Bottineau Area the Fox Hills sands may yield water more readily than the Cannonball sands. Essentially impermeable Cretaceous shales follow in the sequence and continue to depths of 1900 to 2000 feet. Ground-water exploration at this depth is unwarranted, unfeasible and uneconomical

TABLE 1 -- CHEMICAL

Analysed by State Laboratories, Bismarck
*Analysed by Public Health Laboratory, Bismarck

Location No.	Owner	Aquifer	Depth of well (ft.)	Date of collection	Total Solids	Fixed Solids
161-75-6aab1	Henry Beckman	Sand	25	5-14-62	4564	3766
161-75-6aab2	Henry Beckman	--	178	5-14-62	1852	1520
162-75-7aaa	Test hole 8-738	Gravel	94½	5-21-62	3608	3028
162-75-17add	George Laugsand	Gravel	110	6-14-62	1643	1441
162-75-17ccc1	Harold Amsbaugh	--	100 ≠	5-14-62	1479	1306
162-75-17ccc2	Harold Amsbaugh	--	28	5-14-62	998	771
162-75-18ddd	Richard Little	Gravel	14	5-14-62	1599	1334
162-75-19a1	Arvid Ring	--	60	5-14-62	1142	972
162-75-19a2	Arvid Ring	--	14	5-14-62	1127	917
162-75-20dcc	Joe Krzebetkowski	--	-	5-14-62	1262	1014
162-75-21ab2	Lewis Wagner	Sand	65(?)	6-14-62	1544	1378
162-75-21cda	Henry Kofoid	Sand	134	5-14-62	1188	1092
162-75-27bcb	Harold White	Gravel	28	5-14-62	1655	1524
162-75-34bbb	Bennie Schneider	Sand	62	5-14-62	1184	1016
162-76-11da	Test hole 22-738	Sand & Gravel	210	6-15-62	1359	1222
162-76-25ccc	Duane Garben	Gravel	100	5-14-62	1599	1285
*162-76-25d	Tap at Bottineau Armory	Sand & Gravel	-	2-15-61	1399	--
162-76-26ccc	Floyd McNey	--	40	5-14-62	2196	1830
162-76-35daa	W. G. Stewart	Sand	18	5-14-62	2384	1828
162-76-36bba	Dr. O. H. Curry	--	86	5-28-62	1702	1340
163-75-29abb	Test hole 11-738	Sand & Gravel	126	6- 4-62	710	569

1/ mmhos/cm - micromhos per centimeter

ANALYSES

Total hardness (as $CaCO_3$)	pH	Electrical conductivity (cell)	Alkalinity (as $CaCO_3$) Carbonates	Bicarbonates	Chlorides (Cl)	Sulfates (SO_4)	Iron (Fe)	Nitrates (NO_3)
		1/			Results in parts per million except as indicated			
1420	7.4@24°C	7131 mmhos/cm	Absent	608	163	2090	.6	61
30	7.6@24°C	3269 mmhos/cm	Absent	520	775	trace	.5	Absent
2280	7.2@25°C	5154 mmhos/cm	Absent	436	18	1834	.8	Trace
370	7.8@27°C	2414 mmhos/cm	Absent	452	14	767	3.0	Absent
30	7.9@24°C	2347 mmhos/cm	Absent	628	16	560	1.3	12
510	7.2@24°C	1487 mmhos/cm	Absent	300	32	348	.5	Trace
790	7.2@24°C	2230 mmhos/cm	Absent	376	42	687	.2	43
20	8.3@24°C	1891 mmhos/cm	Absent	568	153	211	.6	Absent
630	7.5@24°C	1565 mmhos/cm	Absent	276	22	482	.7	Trace
30	8.0@24°C	1982 mmhos/cm	Absent	532	60	408	1.4	Trace
60	7.6@27°C	2364 mmhos/cm	Absent	544	14	622	.8	Absent
50	8.2@24°C	1982 mmhos/cm	Absent	516	54	398	.1	Absent
460	7.5@24°C	2379 mmhos/cm	Absent	348	24	818	.3	Trace
30	8.2@24°C	1922 mmhos/cm	Absent	592	44	353	.8	Absent
260	7.9@30°C	2021 mmhos/cm	Absent	472	32	540	1.4	Absent
40	8.0@24°C	2798 mmhos/cm	Absent	580	574	trace	1.5	Absent
780	7.2@24°C	------	Absent	496	4	438	.2	Trace
150	8.4@24°C	3569 mmhos/cm	Absent	616	584	431	.9	24
1190	7.5@24°C	2776 mmhos/cm	Absent	404	62	1035	.1	61
70	7.6@25°C	3103 mmhos/cm	Absent	532	780	18	.8	Absent
508	7.4@25°C	1039 mmhos/cm	Absent	356	4	184	8.6	Trace

QUALITY OF WATER

Table 1 lists chemical analyses of the water obtained from 17 wells and 3 test holes in the Bottineau Area. An analysis performed by the Public Health Laboratory of a sample taken from the tap at the Bottineau Armory is also included so as to compare the quality of water of the present municipal supply with that of other waters present in the area. The analyses are given in parts per million--that is, in parts by weight of the constituents in 1,000,000 parts by weight of water.

In order that the reader may more easily understand the significance of these analyses, they will be evaluated in relation to standards of the U. S. Public Health Service for drinking water. The standards, adopted in 1914 to protect the health of the travelling public, were revised several times in subsequent years. The latest revision (1961), approved by the Secretary of Health, Education, and Welfare, is, in part, as follows:

TABLE 2 -- Drinking water standards of the U. S. Public Health Service

Iron (Fe)	.3 ppm
Sulfate (SO_4)	250 ppm
Chloride (Cl)	250 ppm
Nitrate (NO_3)	45 ppm
Dissolved solids	500 ppm

The hardness caused by the alkaline-earth equivalent in a water is called carbonate hardness and the remainder, noncarbonate hardness. The consumption of soap by water of a given hardness is normally the same whether the hardness is caused by carbonate or noncarbonate hardness. "Hardness of 0 to 15 ppm is negligible and is really an extremely soft water, from 15 to 30 ppm is very soft water, from 30 to 45 ppm is soft, from 45 to 90 ppm moderately soft, from 90 to 110 ppm is moderately hard, from 110 to 130 ppm is hard, from 130 to 170 ppm is very hard, and from 170 to 230 ppm is excessively hard. Waters from 250 to 500 ppm are too hard for many purposes and nearly always have to be softened by treatment on account of increased soap consumption and increased cost of plumbing repairs". (Bennison, 1947, p. 436).

Hydrogen-ion concentration in an aqueous solution or in water on the pH scale is represented by a number which is the negative logarithm of the hydrogen-ion concentration in moles per liter of solution. The pH range is from 0 to 14. A solution with a pH of 7 is said to be neutral. Progressive values below 7 denote increasing acidity, and progressive values above 7 denote increasing alkalinity.

Electrical conductivity, expressed in micromhos per centimeter, is a measure of the ability of a solution to conduct an electrical current. It is approximately proportional to the dissolved solids content.

Table 1 indicates that none of the analyses of water in the Bottineau Area conform to standards of the U. S. Public Health Service and most of the waters are of very poor or poor quality. The bedrock waters are perhaps the best in the area and would require the least amount of treatment. These waters are characterized by very soft to moderately soft water--20 ppm to 70 ppm (table 1). However, they do exceed the limits of the Public Health Service in dissolved solids, chlorides or sulfates or both, and generally iron content. A concentration of 1000 ppm of dissolved solids is permissible for drinking water and, therefore, most of the bedrock waters would be acceptable. The chlorides, sulfates, and iron would, however, require treatment. Nitrates are generally absent or low in the bedrock water.

CONCLUSION AND RECOMMENDATIONS

At present (1963) the municipal water supply of Bottineau is adequate for normal annual demands and the water is of fair quality, with the exception of the hardness content. Water softening processes would insure a more generally acceptable municipal supply.

Future growth and industrialization will require and probably depend on larger quantities of water of better quality. The potential aquifers in the Bottineau Area include the kame terrace, alluvial and outwash deposits overlying or associated with the Souris River Ground Moraine adjacent to the Turtle Mountains escarpment, the sand and gravel deposits of the Turtle Mountains Moraine, and the bedrock sands.

Large quantities of water may be obtained from the kame terrace, alluvial, and outwash deposits and the sand and gravel deposits in the moraine. These deposits contain a large volume of ground water in transient storage, are generally quite permeable, and transmit the water rather freely. The water is generally of objectional quality, however. The following test holes encountered aquifers capable of augmenting the present water supply: Test Hole 8,9,10,11,12,13,14,16,17,18,22,34, the Wallace #1 and the Huss #1 (see figure 4 and table 4). Other areas worthy of investigation are in the vicinity of gravel pits or where sand and gravel are exposed at the surface since these are the ground-water recharge areas. Springs and seeps should also be investigated for many millions of gallons of water are lost annually through discharge, evaporation, and transpiration.

Certain industries require very soft water. The bedrock sands in the Bottineau Area yield some of the softest waters in the State. It is believed bedrock waters could be recovered throughout the majority of the area. However, that portion of Whitteron Township (Twp. 162N. and R. 75W.) below the Turtle

Mountains escarpment should be of primary concern. Two test holes, 5 and 21, and the majority of private wells which penetrated the bedrock sands flowed or are presently flowing. The specific capacity of these wells is low, less than 10 gallons per minute, as a result of low permeability of the sands. Pumping would increase the yield and moderate supplies could be recovered from a single well. Properly spaced wells should be capable of supplying demands required by minor industries.

Because of the nature of the topography within the area of this study, it is worth comment in regard to the total potential ground-water supply and quality of water, that a dam and reservoir aimed at improving aquifer recharge might be beneficial. Study of the U. S. Geological Survey quadrangle maps covering the Oak Creek watershed between Lake Metigoshe and Bottineau indicates that such an impoundment, located in the SE¼ of Section 18, Township 162 North, Range 75 West, in conjunction with a flood retention dam located in the SE¼ of Section 33, Township 163 North, Range 75 West, could serve the dual purpose of cutting down on the peak flow of Oak Creek through and below Bottineau, and improving recharge into the kame terrace deposits through the permeable surface in Section 18, Township 162 North, Range 75 West.

It is not within the scope of this report to determine the feasibility of such an improvement, since evaluation of flood protection benefits, and costs of the flood-preventive structures would be an integral part of such a study. It is mentioned here only because of possible beneficial effect on ground-water supply.

Depth to water: Measured water levels in feet and tenths or hundredths; reported water levels in feet.

Type of well: Dr, drilled; Du, dug; Dv, driven; Bo, Bored; g.p.m., Gallons per minute

Location No.	Owner	Depth (feet)	Diameter (inches)	Type	Date completed
161-75					
161-75-6aa1	Henry Beckman	178	5	Dr	-
161-75-6aa2	Henry Beckman	25	-	--	-
161-76					
161-76-2dd	Angus Campbell	28	-	--	-
162-75					
162-75-5bab	Test hole 10-738	346½	4 3/4	Dr	5-28-62
162-75-6cbc	Test hole 34-738	126	4 3/4	Dr	6-27-62
162-75-6cd	Test hole 26-738	52½	4 3/4	Dr	6-19-62
162-75-6dda	Test hole 9-738	252	4 3/4	Dr	5-23-62
162-75-7aaa	Test hole 8-738	94½	4 3/4	Dr	5-21-62
162-75-7bbb	Test hole 25-738	126	4 3/4	Dr	6-19-62
162-75-7cbb	Test hole 33-738	42	4 3/4	Dr	6-27-62
162-75-7ddd	Test hole 7-738	63	4 3/4	Dr	5-21-62
162-75-8cdd	Test hole 14-738	63	4 3/4	Dr	6- 7-62
162-75-17add	Geo. Laugsand	110	4	Dr	1958
162-75-17cc1	Harold Amsbaugh	28	4	Dr	-
162-75-17cc2	Harold Amsbaugh	100 +	4	Dr	-
162-75-18bb	Test hole 16-738	52½	4 3/4	Dr	6-11-62
162-75-18bcc	Test hole 23-738	52½	4 3/4	Dr	6-18-62
162-75-18daa	Test hole 3-738	63	4 3/4	Dr	5-15-62
162-75-18ddd	Richard Little	14	-	--	-
162-75-19acd	Arvid Ring	14	4	Dr	-
162-75-19adc	Arvid Ring	60	4	Dr	-
162-75-20bab	Test hole 24-738	84	4 3/4	Dr	6-19-62
162-75-20dcc	Joe Krzebetkowski	--	-	--	-
162-75-21aba	Test hole 21-738	231	4 3/4	Dr	6-14-62
162-75-21ab1	Lewis Wagner	30	8	Dr	-
162-75-21ab2	Lewis Wagner	65(?)	4	Dr	1910(?)
162-75-21cd	Henry Kofoid	134	3	Dr	-
162-75-22aad	Test hole 20-738	126	4 3/4	Dr	6-12-62
162-75-27bcb	Harold White	28	2	Dr	-
162-75-27dcc	Test hole 5-738	63	4 3/4	Dr	5-16-62
162-75-28cad1	Joe Johnson	153	4	Dr	-
162-75-28cad2	Joe Johnson	20	-	--	-

Depth of well: Measured depths in feet and tenths; reported depths in feet.

Use of water: D, domestic; U, unused; PS, public supply; S, stock; T, test hole; O.T., Oil test hole.

Remarks: C.A., chemical analysis.

Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
20	--	S	--	Soft, C. A.
24	--	D	Sand	Hard, C. A.
22	--	D,S	Sand	Hard.
--	--	T	--	See log.
--	--	T	--	See log.
--	--	T	--	See log.
--	--	T	--	See log.
--	--	T	--	See log, C. A.
3.55	6-19-62	T	Sand & Gravel	See log.
--	--	T	--	See log.
--	--	T	--	See log.
--	--	T	--	See log.
Flow	6-14-62	D,S	Gravel	Rusty,hard,flows 1gpm, C.A.
--	--	S	--	Hard, C. A.
--	--	D	--	Soft, C. A.
--	--	T	--	See log.
--	--	T	--	See log.
--	--	T	--	See log.
6	--	D,S	Gravel	Hard, C. A.
--	--	D	--	Soft, C. A.
--	--	S	--	Hard, C. A.
--	--	T	--	See log.
--	--	D,S	--	Soft, C. A.
Flow	6-14-62	T	Sand & Gravel	See log, plugged.
19'	--	U	--	--
Flow	6-14-62	D,S	Sand	Soft, flows 1 gpm, C. A.
Flow	--	D,S	Sand	Soft, C. A.
--	--	T	--	See log.
20 ≠	--	D,S	Gravel	Hard, C. A.
Flow	--	T	--	See log, plugged.
--	--	D	--	Soft.
--	--	S	--	Hard.

Location No.	Owner	Depth (feet)	Diameter (inches)	Type	Date completed
162-75-29aca	Fred Kofoid	160	4	Dr	-
162-75-30ddd	Test hole 4-738	94½	4 3/4	Dr	5-16-62
162-75-31ccc	Test hole 6-738	73½	4 3/4	Dr	5-16-62
162-75-32bc_1	Henry Brusletten	164	-	Dr	-
162-75-32bc_2	Henry Brusletten	64	-	Dr	-
162-75-33aa	Wilfred Fletcher	60	3	Dr	-
162-75-33cb	Grey	125	4	Dr	-
162-75-34bbb	Bennie Schneider	62	4	Dr	-
162-76					
162-76-1bcb	Test hole 31-738	42	4 3/4	Dr	6-26-62
162-76-1dab	Frank Paryzek	5	36	Du	-
162-76-2aba	Test hole 18-738	73½	4 3/4	Dr	6-12-62
162-76-9aaa	Test hole 19-738	42	4 3/4	Dr	6-12-62
162-76-11aba	Test hole 29-738	63	4 3/4	Dr	6-12-62
162-76-11da	Test hole 22-738	210	4 3/4	Dr	6-14-62
162-76-12bbb	Test hole 30-738	42	4 3/4	Dr	6-26-62
162-76-12ccc	Harold Vinje	107	4	Dr	-
162-76-13bcc	Harry Vikan	75	-	--	-
162-76-14bbb	Lion Oil Co. Wallace #1	3917	-	Dr	7-9-55
162-76-14bdb	Wallace Hall	135	4	Dr	-
162-76-23aa_1	Kenny Garder	158	4	Dr	-
162-76-23aa_2	Kenny Garder	60	16	Bo	-
162-76-24add	Test hole 2-738	191	4 3/4	Dr	5-15-62
162-76-25aad	Test hole 32-738	68	4 3/4	Dr	6-26-62
162-76-25ccc	Duane Garben	100	4	Dr	-
162-76-26bab	Test hole 1-738	42	4 3/4	Dr	5-15-62
162-76-26cc	Floyd McNey	40	14	Bo	-
162-76-35daa	W. G. Steward	18	-	Du	-
162-76-36bba	Dr. O. H. Curry	86	-	--	-
163-75					
163-75-17baa	Test hole 15-738	273	4 3/4	Dr	6- 8-62
163-75-23bbb	Lion Oil Co. G.A. Huss #1	6440	-	Dr	9- 8-52
163-75-28aad	Test hole 13-738	283½	4 3/4	Dr	6- 6-62
163-75-29abb	Test hole 11-738	126	4 3/4	Dr	6- 4-62
163-75-30bbc	Test hole 12-738	357	4 3/4	Dr	6- 5-62
163-75-31cb	Test hole 27-738	262½	4 3/4	Dr	6-20-62
163-76					
163-76-23add	Test hole 17-738	279½	4 3/4	Dr	6-11-62
163-76-36dad	Test hole 28-738	200	4 3/4	Dr	6-20-62

Depth to water below land surface (feet)	Date of measurement	Use of water	Aquifer	Remarks
8	-	D,S	Sand	Soft.
-	-	T	-	See log.
-	-	T	-	See log.
-	-	D,S	-	Soft, pumps dry in 10 min.
-	-	S	-	Hard, pasture well.
-	-	D	-	Soft.
100 ±	-	D	Gravel	Soft.
Flow	-	D,S	Sand	Soft, C. A.
-	-	T	-	See log.
Flow	-	D,S	-	Hard, bottomed in magnesium deposit.
-	-	T	-	See log.
4.85	6-12-62	T	Sand	See log.
-	-	T	-	See log.
-	-	T	-	See log.
-	-	T	-	See log.
35	-	D,S	-	Moderately hard.
-	-	D	-	Haul water for drinking.
-	-	O.T.	-	See log.
45	-	D,S	Sand	Soft.
-	-	D	Blue Sand	Soft.
-	-	S	Sand	Hard.
-	-	T	-	See log.
-	-	T	-	See log, cored from 63-68'
82	-	D	Gravel	Soft, C. A.
-	-	T	-	See log.
-	-	S	-	Hard, C. A.
12	-	D	Sand	Hard, C. A.
12	-	D	-	Pumps 3 g.p.m. at 40', C. A.
-	-	T	-	See log.
-	-	O.T.	-	See log.
-	-	T	-	See log.
11.9	6-6-62	T	Sand & Gravel	See log, C. A.
-	-	T	-	See log.
-	-	T	-	See log.
-	-	T	-	See log.
-	-	T	-	See log.

TABLE 4.--Logs of test holes

162-75-5bab
Test hole 10-738
Elevation-2142 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Topsoil, black	1	0	- 1
	Clay, silty to gravelly, moderate yellowish brown, oxidized, calcareous, (till)	10	1	- 11
	Clay, silty to gravelly, moderate yellowish brown and dark yellowish brown, oxidized, calcareous, (till)	8	11	- 19
	Silt, dark yellowish brown to olive gray, cohesive, highly calcareous	11	19	- 30
	Clay, silty to sandy, dark yellowish brown to dark greenish gray, highly calcareous, (till)	15	30	- 45
	Clay, silty to gravelly, dark greenish gray, calcareous, (till)	13	45	- 58
	Clay, very silty, olive gray, cohesive, calcareous, (till)	69	58	- 127
	Sand, medium to very coarse, gravelly, subangular to subrounded	2	127	- 129
	Clay, very silty, olive gray, cohesive, calcareous, (till)	67	129	- 196
	Silt, sandy to pebbly, olive gray, (till)	38	196	- 234
	Gravel, fine to coarse, sandy, subrounded to rounded	13	234	- 247
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous, (till)	31	247	- 278
	Clay, silty to gravelly, dark yellowish orange and grayish orange to light olive, oxidized, calcareous, (till)	12	278	- 290
	Clay, as above, partially oxidized (till)	6	290	- 296
	Gravel, fine to medium sandy, angular to well rounded	6	296	- 302
	Clay, very gravelly, dark greenish gray, calcareous, (till)	38	302	- 340
Cannonball Formation (?)				
	Sand, very fine to medium, silty to clayey, medium bluish gray with light greenish gray and brownish black areas	6½	340	- 346½

Electric Log

TABLE 4.--Logs of test holes - Continued

162-75-6cbc
Test hole 35-738
Elevation-1960 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From		To
Souris River Ground Moraine					
	Topsoil, silty, dark, organic.........	1	0	-	1
	Silt, clayey, sandy to pebbly, moderate olive brown, oxidized, highly calcareous, (till)...........	21	1	-	22
	Clay, silty, olive gray, highly calcareous, (till)..................	31	22	-	53
	Sand, fine to coarse, with fine and medium gravel, subangular to subrounded......................	7	53	-	60
	Silt, clayey, light olive gray, cohesive, highly calcareous (till)..	14	60	-	74
	Gravel, fine to medium, with fine to coarse sand, subangular to subrounded	9	74	-	83
	Silt, clayey to gravelly, moderate olive brown, slightly oxidized, highly calcareous, (till)..........	9	83	-	92
	Silt, clayey, olive gray, highly compacted, highly calcareous (till).	12	92	-	104
Undifferentiated					
	Silt, dark greenish gray, smooth, well sorted, cohesive, noncalcareous	12	104	-	116
	Sand, fine, clayey, olive gray, subangular to subrounded, nonindurated, very slightly calcareous...........	10	116	-	126

162-75-6cd
Test hole 27-738
Elevation-1960 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From		To
Turtle Mountains Moraine					
	Topsoil, silty, dark, organic.........	1	0	-	1
	Clay, silty, moderate olive brown oxidized, highly calcareous (till)..	44	1	-	45
Cannonball Formation (?)					
	Sand, fine, grayish green, well sorted, slightly indurated, noncalcareous...	7½	45	-	52½

TABLE 4.--Logs of test holes -- Continued

162-75-6dda
Test hole 9-738
Elevation-2162 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From		To
Turtle Mountains Moraine					
	Topsoil, black...........................	1	0	-	1
	Clay, silty to gravelly, dark yellowish brown, oxidized, highly calcareous (till)	16	1	-	17
	Clay, silty to gravelly, dark greenish gray, calcareous, (till)...............	86	17	-	103
	Sand, very fine to medium, very silty, grayish olive, calcareous..............	39	103	-	142
	Silt, light olive gray, cohesive, calcareous............................	6	142	-	148
	Clay, silty, olive gray to dark greenish gray, cohesive to tough, calcareous (till)	8	148	-	156
	Gravel, fine to medium, sandy, subrounded..	7	156	-	163
	Gravel, fine to coarse, with coarse to very coarse sand, subrounded to rounded.	7	163	-	170
	Gravel, fine, sandy, subrounded..........	9	170	-	179
	Clay, silty to gravelly, dark greenish gray, very tough, highly calcareous (till)	21	179	-	200
	Gravel, fine, sandy, subrounded..........	3	200	-	203
	Clay, silty to gravelly, dark greenish gray, very tough, highly calcareous (till)	28	203	-	231
	Gravel, fine, sandy, angular to rounded...	11	231	-	242
Undifferentiated					
	Clay, very silty, olive gray, indurated, noncalcareous.........................	10	242	-	252

162-75-7aaa
Test hole 8-738
Elevation-2061 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From		To
Turtle Mountains Moraine					
	Topsoil, black...........................	2	0	-	2
	Clay, silty to gravelly, dark yellowish orange, oxidized, calcareous, (till)....	24	2	-	26
	Clay, silty to gravelly, dark yellowish brown, oxidized, calcareous (till)......	7	26	-	33
	Clay, silty to gravelly, dark greenish gray, calcareous (till)................	21	33	-	54
	Clay, as above, with layers of fine to coarse sandy gravel....................	4	54	-	58

TABLE 4.--Logs of test holes - Continued

162-75-7aaa - continued
Test hole 8-738
Elevation-2061 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine - continued				
	Silt, dark yellowish brown, partially oxidized, calcareous....................	5	58	- 63
	Silt, sandy, olive gray, with layers of very fine to very coarse subrounded sand and fine to coarse subangular gravel................................	11	63	- 74
	Gravel, fine to medium, clayey to sandy, subrounded..............................	8	74	- 82
	Gravel, fine to medium, sandy, angular to rounded................................	9	82	- 91
Undifferentiated				
	Clay (?), very indurated, no samples......	3½	91	- 94½

162-75-7bbb
Test hole 26-738
Elevation-1890 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Kame Terrace, Alluvial, or Outwash Deposits				
	Topsoil, silty, black, organic............	3	0	- 3
	Silt, sandy, olive gray, noncohesive......	1	3	- 4
	Gravel, fine to coarse, sandy, yellowish brown, subangular to rounded.........	4	4	- 8
Souris River Ground Moraine				
	Clay, silty, yellowish brown, oxidized, slightly calcareous (till)..............	2	8	- 10
	Clay, silty to pebbly, moderate olive brown, oxidized, slightly calcareous (till)................................	5	10	- 15
	Sand, fine to coarse, with fine gravel, well rounded...........................	3	15	- 18
	Clay, silty, grayish olive, cohesive and plastic, slightly calcareous (till).....	14	18	- 32
	Silt, clayey, dark greenish gray, smooth..	16	32	- 48
	Gravel, fine to coarse, subangular to subrounded, clean......................	4	48	- 52
	Sand, fine to coarse, silty and clayey, angular to subrounded..................	10	52	- 62

TABLE 4.--Logs of test holes -- Continued

162-75-7bbb - continued
Test hole 26-738
Elevation-1890 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Undifferentiated				
	Sandstone, fine, grayish olive, subangular to rounded, high indurated, calcareous cement..................	12	62	- 74
	Clay, moderate olive brown, smooth, soapy.............................	19	74	- 93
	Sand, fine, grayish olive, rounded, well sorted, slightly indurated..........	11	93	- 104
	Shale, silty, dark brown, oily, high organic content, slightly indurated...	22	104	- 126

162-75-7cbb
Test hole 34-738
Elevation-1820 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Kame Terrace, Alluvial, or Outwash Deposits				
	Sand, medium to coarse, with fine to coarse gravel, pebbles, cobbles and boulders...........................	5	0	- 5
Cannonball Formation(?)				
	Sand, fine, silty, moderate olive brown, subangular to subround, oxidized, noncalcareous......................	5	5	- 10
	Sand, fine, silty, dark greenish gray, noncalcareous......................	14	10	- 24
	Silt, dark greenish gray, compacted....	7	24	- 31
	Sand, fine, silty, dark greenish gray, progressively more indurated with depth.............................	11	31	- 42

TABLE 4.--Logs of test holes - Continued

162-75-7ddd
Test hole 7-738
Elevation-1854 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Kame Terrace, Alluvial, or Outwash Deposits				
	Topsoil, black	2	0	2
	Gravel, fine to coarse, sandy, subrounded.	5	2	7
Souris River Ground Moraine				
	Clay, silty to gravelly, dark yellowish orange, cohesive, oxidized, calcareous (till)	6	7	13
	Clay, silty to gravelly, dark greenish gray, cohesive (till)	25	13	38
	Gravel, fine to medium, sandy, subrounded to rounded	2	38	40
	Clay, silty to gravelly, dark greenish gray, cohesive (till)	1	40	41
Cannonball Formation (?)				
	Sand, very fine to medium, very silty, angular to subrounded	9	41	50
	Silt, clayey to sandy, olive gray, noncalcareous	13	50	63

Electric Log

162-75-8cdd
Test hole 15-738
Elevation-1930 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Turtle Mountains Moraine (?)				
	Clay, silty, moderate olive brown, oxidized, calcareous (till)	9	0	9
	Sand, medium to very coarse, with fine to medium gravel, subrounded to rounded, loosely consolidated	11	9	20
	Sand, fine to medium, with some gravel, subrounded to rounded	7	20	27
	Clay, silty, olive black, fairly cohesive (till)	24	27	51
Undifferentiated				
	Shale, silty, olive black, smooth, sticky, noncalcareous	12	51	63

TABLE 4.--Logs of test holes -- Continued

162-75-18bb
Test hole 17-738
Elevation-1780 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Lake Souris Deposits				
	Topsoil, sandy, black	1	0	1
	Sand, medium, dark yellowish brown, subangular to rounded, well sorted	5	1	6
Kame Terrace, Alluvial, or Outwash Deposits				
	Gravel, very coarse, no samples	3	6	9
	Sand, fine to medium with some silt and fine gravel, light olive gray, well rounded	8	9	17
	Sand, fine to coarse, silty to gravelly	5	17	22
Undifferentiated				
	Sand, fine, dark greenish gray, well rounded, well sorted, noncalcareous	21	22	43
	Shale, olive black, thinly laminated, platy, noncalcareous	9½	43	52½

162-75-18bcc
Test hole 24-738
Elevation-1730 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Lake Souris Deposits				
	Topsoil, sandy, black, organic	1	0	1
	Silt, clayey to sandy with some fine gravel, light olive gray	3	1	4
	Gravel, fine to coarse, yellowish orange, subangular to rounded	5	4	9
	Clay, silty with some fine sand, dark yellowish brown, oxidized, calcareous	9	9	18
	Clay, silty, olive gray, calcareous	4	18	22
	Silt, clayey, olive gray, calcareous	4	22	26
Undifferentiated				
	Sand, fine, dark greenish gray, well sorted, noncalcareous	12	26	38
	Shale, silty, dark greenish gray, smooth, moderately indurated	4	38	42
	Carbonaceous material, brownish black, oily	6	42	48
	Shale, black, smooth, tar-like, very sticky.	4½	48	52½

TABLE 4.--Logs of test holes -- Continued

162-75-18daa
Test hole 3-738
Elevation-1785 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Kame Terrace, Alluvial, or Outwash Deposits				
	Gravel, fine, sandy, subrounded..............	7	0	7
	Clay, silty, dark yellowish orange, slightly cohesive, highly calcareous................	4	7	11
	Gravel, granular, sandy, subrounded..........	6	11	17
Souris River Ground Moraine				
	Clay, silty to gravelly, dark greenish gray, cohesive (till)...........................	33	17	50
Undifferentiated				
	Sandstone, very fine to fine, clayey to silty, olive black, indurated, noncalcareous......	8	50	58
	Lignite, black, fissile......................	1	58	59
	Sandstone, very fine, clayey to silty, greenish gray, indurated, noncalcareous....	2	59	61
	Sandstone, very fine to fine, clayey to silty, olive black, indurated, noncalcareous......	2	61	63

Electric Log

162-75-20bab
Test hole 25-738
Elevation-1770 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Topsoil, sandy, dark, organic................	1	0	1
	Silt, sandy with some clay, moderate olive brown, oxidized, slightly calcareous (till)..................................	5	1	6
	Silt, clayey with some sand, moderate olive brown, oxidized, very slightly calcareous (till)..................................	4	6	10
	Silt, clayey to sandy, light olive gray, fairly cohesive,slightly oxidized, moderately calcareous, (till)..............	15	10	25
	Clay, silty, olive gray, very cohesive and plastic, moderately calcareous, (till).....	27	25	52
	Silt, clayey, olive gray,cohesive (till).....	15	52	67
Undifferentiated				
	Shale, olive black, indurated, noncalcareous.	12	67	79
	Shale, olive gray, smooth, moderately indurated, noncalcareous.......................	5	79	84

TABLE 4.--Logs of test holes -- Continued

162-75-21aba
Test hole 22-738
Elevation-1845 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Topsoil, sandy, dark	1	0 -	1
	Silt, clayey with some fine sand, light olive brown, oxidized, highly calcareous (till)	5	1 -	6
	Silt, clayey to sandy, moderate olive brown, slightly cohesive, oxidized, highly calcareous (till)	13	6 -	19
	Silt, clayey to sandy, brownish olive gray, slightly cohesive, slightly oxidized, calcareous (till)	3	19 -	22
	Silt, clayey with some fine sand, olive gray, very cohesive, calcareous (till)	41	22 -	63
	Silt, clayey, olive gray, very cohesive, calcareous (till)	19	63 -	82
	Gravel, fine to coarse, with some sand, subangular to subrounded	8	82 -	90
	Clay, silty to gravelly, olive gray, very cohesive, plastic, calcareous (till)	44	90 -	134
Undifferentiated				
	Sand, very fine, silty, dark greenish gray, subangular to subrounded, slightly indurated	2	134 -	136
	Shale, silty with very fine sand, brownish olive gray, slightly calcareous	15	136 -	151
	Lignite, black, fissile	2	151 -	153
	Shale, brownish gray to olive gray, moderately to well indurated, noncalcareous	17	153 -	170
	Siltstone, clayey, olive black, fissile, poorly indurated, noncalcareous	7	170 -	177
	Sandstone, dark greenish gray, subangular to subrounded, moderately indurated	11	177 -	188
	Shale, silty with fine sand, brownish olive black, organic, laminated with thin layers of above sandstone	5	188 -	193
	Sandstone, very fine, dark greenish gray, subangular to subrounded, moderately well indurated	2	193 -	195
	Sandstone, clayey and silty, light gray, smooth, soapy, noncalcareous	5	195 -	200
	Lignite, fissile	2	200 -	202
	Siltstone, clayey, greenish gray, noncalcareous	19	202 -	221
	Shale, silty and sandy, brownish olive gray	10	221 -	231

Flowing Well

162-75-22aad
Test hole 21-738
Elevation-1940 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Turtle Mountains Moraine				
	Clay, silty to gravelly, light to moderately olive brown, cohesive, oxidized, highly calcareous (till).....	11	0	- 11
	Clay, as above with some subrounded to rounded gravel (till)................	18	11	- 29
	Clay, very silty, greenish black, highly calcareous (till)....................	12	29	- 41
	Sand, fine to coarse with some fine gravel, subangular to rounded.........	9	41	- 50
	Clay, very silty, greenish black,cohesive sticky, highly calcareous.............	18	50	- 68
Undifferentiated				
	Silt, clayey, greenish black, smooth, fairly cohesive, slightly calcareous...	28	68	- 96
	Silt, as above, lighter greenish black, brittle, tight........................	8	96	- 104
	Silt, as above, blue tint...............	12	104	- 116
	Silt, as above, brown tint..............	10	116	- 126

162-75-27dcc
Test hole 5-738
Elevation-1670 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Alluvium				
	Topsoil, black..........................	1	0	- 1
	Silt, clayey to sandy, dark yellowish orange, cohesive, oxidized, highly calcareous............................	6	1	- 7
Souris River Ground Moraine				
	Clay, silty to gravelly, dark yellowish orange to pale yellowish orange to dark yellowish brown, non-to slightly cohesive, oxidized, highly calcareous (till)..................................	3	7	- 10
	Clay, silty to gravelly, dark greenish gray, cohesive (till)..................	20	10	- 30
	Sand, fine to medium, angular to well rounded, well sorted...................	2	30	- 32
	Clay, silty to gravelly, dark greenish gray, cohesive.......................	23½	32	- 55½
Cannonball Formation (?)				
	Sand, very fine to fine, greenish gray, noncalcareous.........................	7½	55½	- 63

Electric Log
Flowing Well

162-75-30ddd
Test hole 4-738
Elevation-1635 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty to gravelly, dark yellowish orange to dark yellowish brown, cohesive, oxidized, calcareous (till)............	22	0	- 22
	Clay, silty to gravelly, moderate yellowish brown to dark greenish gray, partially oxidized, calcareous (till)............	11	22	- 33
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)............	29	33	- 62
	Clay, as above with lenses of fine sandy subrounded gravel......................	5	62	- 67
	Boulder................................	2	67	- 69
	Clay, silty to gravelly, dark greenish gray, tough, calcareous (till).........	11	69	- 80
Undifferentiated				
	Siltstone, clayey to sandy, greenish gray, indurated, noncalcareous...............	5	80	- 85
	Shale, very silty to silty to slightly silty, dark greenish gray to greenish gray to yellowish gray, indurated to poorly indurated............................	5	85	- 90
	Sandstone, very fine to fine, clayey, greenish gray to brownish black, very poorly indurated......................	4½	90	- 94½

Electric Log

162-75-31ccc
Test hole 6-738
Elevation-1586 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Alluvium				
	Topsoil, black..........................	1	0	- 1
	Silt, clayey to sandy, yellowish gray, non-to slightly cohesive, oxidized, very highly calcareous.....................	5	1	- 6
	Silt, dark yellowish orange to moderate yellowish brown, slightly cohesive to cohesive, calcareous..................	6	6	- 12

162-75-31ccc - continued
Test hole 6-738
Elevation-1586 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty to gravelly, moderate yellowish brown, cohesive, oxidized, highly calcareous (till)............................	5	12 -	17
	Clay, silty to gravelly, moderate yellowish brown to olive gray, cohesive, partially oxidized, calcareous (till).............	5	17 -	22
	Gravel, fine to medium, angular to rounded.	2	22 -	24
	Clay, silty to gravelly, olive gray, cohesive, calcareous (till)......................	8	24 -	32
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till).............	6	32 -	38
	Sand, fine to coarse, angular to rounded...	1	38 -	39
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)........	13	39 -	52
	Clay, as above, abundant fine gravel.......	12	52 -	64
Cannonball Formation (?)				
	Sandstone, very fine, greenish gray, indurated, noncalcareous................	9½	64 -	73½

Electric Log

162-76-1bcb
Test hole 32-738
Elevation-1850 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Kame Terrace, Alluvial, or Outwash Deposits				
	Topsoil, sandy, black.....................	1	0 -	1
	Silt, clayey with much fine sand, dark yellowish brown, loose and non cohesive...	4	1 -	5
Souris River Ground Moraine				
	Clay, silty to pebbly, moderate olive brown, cohesive, oxidized, highly calcareous (till).................................	16	5 -	21
	Clay, silty, olive gray, cohesive, compacted, calcareous (till)......................	9	21 -	30
Cannonball Formation (?)				
	Sand, fine, greenish gray, nonindurated....	12	30 -	42

162-76-2aba
Test hole 19-738
Elevation-1860 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Kame Terrace, Alluvial, or Outwash Deposits				
	Topsoil, sandy, dark	1	0	- 1
	Gravel, fine to coarse, sandy to bouldery, rusty, subangular to rounded, coarser with depth	18	1	- 19
Souris River Ground Moraine				
	Clay, silty to sandy, moderate olive brown, oxidized, calcareous (till)	2	19	- 21
	Clay, silty to sandy, olive gray, cohesive (till)	21	21	- 42
	Silt, some fine sand, olive gray,uniform, calcareous	11	42	- 53
Undifferentiated				
	Silt, sandy, to shaley, brownish, non-calcareous	10½	53	- 63½

162-76-9aaa
Test hole 20-738
Elevation-1660 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Alluvium				
	Topsoil, sandy, dark, organic	1	0	- 1
	Silt, clayey to sandy, white, marly,soapy, highly calcareous	2	1	- 3
	Silt, as above, light gray	3	3	- 6
	Silt, sandy, light olive gray, leached, oxidized, calcareous	5	6	- 11
	Sand, fine to coarse, some silt and gravel, oxidized	7	11	- 18
Souris River Ground Moraine				
	Clay, silty, olive black, cohesive, calcareous (till)	2	18	- 20
	Sand, fine to medium, gray, coarser with depth	5	20	- 25
Cannonball Formation (?)				
	Sand, fine, dark greenish gray, rounded, well sorted, uniform	17	25	- 42

TABLE 4.--Logs of test holes -- Continued

162-76-11aba
Test hole 30-738
Elevation-1790 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Souris River Ground Moraine				
	Topsoil, sandy, dark, organic...............	1	0	1
	Silt, clayey with much fine sand, moderate olive brown, moderately cohesive, oxidized, moderately calcareous (till)....	15	1	16
	Silt, clayey with a little fine sand, olive gray, cohesive, plastic, moderately calcareous (till)........................	2	16	18
	Sand, fine, with much silt, olive gray, subrounded, moderately calcareous............	10	18	28
	Silt, olive gray, well sorted, smooth, loose and noncohesive, slightly to moderately calcareous..............................	5	28	33
	Silt, clayey, olive gray, cohesive, plastic, moderately calcareous....................	11	33	44
Cannonball Formation (?)				
	Sand, fine, dark greenish gray, subrounded, well sorted.............................	19	44	63

162-76-11da
Test hole 23-738
Elevation-1772 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	Depth (feet) To
Kame Terrace, Alluvial, or Outwash Deposits				
	Sand, very fine to fine, clayey and silty, moderate olive brown, oxidized, highly calcareous..............................	11	0	11
	Sand, fine to coarse, with fine to medium gravel, subangular to rounded, oxidized...	4	11	15
	Sand, very fine, with silty clay, light olive gray, slightly to moderately oxidized, calcareous.....................	11	15	26
	Gravel, fine to coarse with sand, silt, and clay, olive gray, subangular to subrounded.	13	26	39
	Clay, silty with minor amounts of sand and gravel, olive gray, slightly calcareous...	12	39	51
	Sand, fine to coarse, gray.................	3	51	54

162-76-11da - continued
Test hole 23-738
Elevation-1772 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, very silty with some sand and gravel, olive gray, cohesive and compacted, slightly calcareous (till)...............	7	54	- 61
	Gravel, fine to coarse with some sand, angular to subrounded...................	9	61	- 70
	Clay, silty to gravelly, olive gray, extremely compacted and cohesive, slightly calcareous (till)..................................	24	70	- 94
	Gravel, fine to coarse, gray...............	11	94	- 105
	Sand, fine to coarse with some gravel, subangular to rounded......................	11	105	- 116
	Gravel, fine to coarse with much sand frequently changes from gravel to sand...	39	116	- 155
	Clay, very silty with fine sand, dark greenish gray, highly calcareous (till)..	29	115	- 184
	Sand, fine, clayey to silty, brownish olive gray.....................................	6	184	- 190
	Clay, silty, dark greenish gray, slightly cohesive, calcareous (till).............	10	190	- 200
Cannonball Formation (?)				
	Sand, fine, dark greenish gray, well sorted, noncalcareous..........................	10	200	- 210

162-76-12bbb
Test hole 31-738
Elevation-1805 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty, moderate olive brown, cohesive, plastic, oxidized, moderately to highly calcareous (till).......................	12	0	- 12
	Clay, very silty, dark yellowish brown slightly oxidized, moderately to highly calcareous (till).......................	4	12	- 16
	Clay, silty, olive gray, very cohesive and tenaceous, plastic (till)................	12	16	- 28
Undifferentiated				
	Sandstone, fine, dark greenish gray, well sorted, nonindurated....................	5	28	- 33
	Shale, brownish black, fissile, oily moderately indurated; interbedded with smooth, greenish white, slightly calcareous soapstone and carbonaceous material......	9	33	- 42

162-76-14bbb
Lion Oil Co.-Wallce #1
Elevation-1668 feet
(Partial Log)

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine (?)				
	Sand, medium coarse grained, clear white quartz, angular-rounded; buff dolomite, angular. Angular fragments of white, clear, pink feldspar. Angular fragments of greenstone and rounded gray chert fragments	30	0 -	30
Undifferentiated				
	Silt, light gray, micaceous, sandy, with brown-gray silt	30	30 -	60
	Sand, very fine grained to trace medium, quartzose, light gray, glauconitic (reworked?) with gray-brown silt and sand	60	60 -	120
	Sand, light gray, quarzose, fine grained, micaceous, "salt and pepper", slightly calcareous	30	120 -	150
	Silt and sand, as above, with brown-gray shale at 210-270	120	150 -	270

Total depth - 3917
No free oil

162-76-24add
Test hole 2-738
Elevation-1682 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty to gravelly, dark yellowish orange to dark yellowish brown, slightly cohesive to cohesive, oxidized (till)	10	0 -	10
	Clay, silty to gravelly, olive gray, cohesive (till)	37	10 -	47
Undifferentiated				
	Sand, very fine to medium, greenish gray, fairly well indurated, noncalcareous	15	47 -	62
	Shale, silty, dusky yellowish brown, lignite laminae, fairly well indurated, noncalcareous	12	62 -	74
	Shale, silty, greenish gray, indurated, noncalcareous	5	74 -	79
	Shale, silty, light olive gray to olive gray, indurated, noncalcareous	4	79 -	83

TABLE 4.--Logs of test holes - Continued

162-76-24add - Continued
Test hole 2-738
Elevation-1682 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Undifferentiated - continued				
	Sandstone, fine to very fine, silty, dusky yellowish brown, lignite seams, indurated, noncalcareous..............	7	83	- 90
	Sandstone, fine to very fine, silty, medium bluish gray, poorly indurated, noncalcareous........................	5	90	- 95
	Sandstone, fine, clayey to silty, medium bluish gray, indurated, non-calcareous............................	10	95	- 105
	Limestone, silty to very fine sand, light olive gray and dark greenish gray, very well indurated,highly calcareous..	2	105	- 107
	Sandstone, silty to clayey, greenish gray, poorly indurated, noncalcareous.......	12	107	- 119
	Siltstone,clayey with very fine sand, light olive gray, indurated,noncalcar-eous................................	11	119	- 130
	Siltstone, clayey to sandy, greenish gray, indurated, noncalcareous.........	7	130	- 137
	Siltstone,clayey to sandy, light olive gray, indurated,noncalcareous..........	9	137	- 146
	Sandstone, fine to very fine, silty, greenish gray, poorly indurated, non-calcareous............................	11	146	- 157
	Shale, very silty, light olive gray to greenish gray,indurated,noncalcareous..	14	157	- 171
	Sandstone, very fine to fine, clayey to silty, dark greenish gray,poorly in-durated,noncalcareous.................	8	171	- 179
	Shale, silty, greenish gray, indurated, noncalcareous........................	10	179	- 189
	Sandstone, very fine to fine, dark greenish gray, very well indurated, calcareous cement......................	2	189	- 191

Electric Log

162-76-25aad
Test hole 33-738
Elevation-1646 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty with fine sand, leached, highly calcareous (till).............	5	0	- 5
	Clay, silty to pebbley, moderate olive brown, cohesive, fairly plastic,oxidized, highly calcareous (till)..............	11	5	- 16
	Clay, silty to sandy, olive gray, cohesive, highly calcareous....................	3	16	- 19
	Silt, clayey, olive gray, cohesive, tenaceous and pliable.................	11	19	- 30
	Sand, fine to medium, light brown, subangular to subrounded, fairly well sorted..............................	2	30	- 32
	Silt, clayey, olive gray, cohesive, occasional gravel and boulders.......	18	32	- 50
Cannonball Formation (?)				
	Sand, fine, dark greenish gray, well sorted, friable, nonindurated, noncalcareous...........................	13	50	- 63
	Sand, as above, (core).................	5	63	- 68

162-76-26bab
Test hole 1-738
Elevation-1592 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Alluvium				
	Topsoil, black.........................	1	0	- 1
	Clay, silty, light, marly..............	3	1	- 4
	Gravel, fine, with medium to very coarse sand, subangular to subrounded........	2	4	- 6
	Gravel, fine to medium, with medium to very coarse sand, subangular to subrounded.............................	2	6	- 8
	Clay, silty to sandy, olive gray,cohesive highly calcareous....................	2	8	- 10
	Sand, medium to very coarse, granular, subangular to rounded................	9	10	- 19
Undifferentiated				
	Clay, silty, dark greenish gray,slightly cohesive, calcareous.................	8	19	- 27
	Clay, very sandy, dark greenish gray, slightly cohesive, noncalcareous; with clay, silty to sandy, olive gray,slightly cohesive, calcareous;and clay,silty, dusky yellowish brown, cohesive, organic streaks, highly calcareous...........	15	27	- 42

162-76-25aad
Test hole 33-738
Elevation-1646 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Clay, silty with fine sand, leached, highly calcareous (till)	5	0	- 5
	Clay, silty to pebbley, moderate olive brown, cohesive, fairly plastic, oxidized, highly calcareous (till)	11	5	- 16
	Clay, silty to sandy, olive gray, cohesive, highly calcareous	3	16	- 19
	Silt, clayey, olive gray, cohesive, tenaceous and pliable	11	19	- 30
	Sand, fine to medium, light brown, subangular to subrounded, fairly well sorted	2	30	- 32
	Silt, clayey, olive gray, cohesive, occasional gravel and boulders	18	32	- 50
Cannonball Formation (?)				
	Sand, fine, dark greenish gray, well sorted, friable, nonindurated, noncalcareous	13	50	- 63
	Sand, as above, (core)	5	63	- 68

162-76-26bab
Test hole 1-738
Elevation-1592 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Alluvium				
	Topsoil, black	1	0	- 1
	Clay, silty, light, marly	3	1	- 4
	Gravel, fine, with medium to very coarse sand, subangular to subrounded	2	4	- 6
	Gravel, fine to medium, with medium to very coarse sand, subangular to subrounded	2	6	- 8
	Clay, silty to sandy, olive gray, cohesive highly calcareous	2	8	- 10
	Sand, medium to very coarse, granular, subangular to rounded	9	10	- 19
Undifferentiated				
	Clay, silty, dark greenish gray, slightly cohesive, calcareous	8	19	- 27
	Clay, very sandy, dark greenish gray, slightly cohesive, noncalcareous; with clay, silty to sandy, olive gray, slightly cohesive, calcareous; and clay, silty, dusky yellowish brown, cohesive, organic streaks, highly calcareous	15	27	- 42

TABLE 4.--Logs of test holes - Continued

163-75-17baa
Test hole 16-738
Elevation-2260 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Clay, silty to sandy, moderate olive brown, fairly cohesive, oxidized, calcareous (till)................................	22	0	- 22
	Clay, silty, olive black, very cohesive, moderately calcareous (till)...........	11	22	- 33
	Sand, fine to coarse, silty to gravelly, subrounded to rounded..................	2	33	- 35
	Clay, very silty,olive black, very cohesive	2	35	- 37
	Sand, fine to coarse, some gravel,yellowish to reddish brown, generally well rounded................................	3	37	- 40
	Clay, silty, olive black, very cohesive and compacted (till)..................	42	40	- 82
	Silt, olive black, smooth, uniform.......	3	82	- 85
	Clay, silty, olive black, very compacted.	31	85	-116
	Gravel, fine to coarse, angular to subrounded..............................	1	116	-117
	Clay, silty to gravelly, dark greenish gray, very tough, calcareous (till)....	25	117	-142
	Clay, silty with abundant fine to medium angular to rounded sandy gravel, dark greenish gray, tough, calcareous (till)	16	142	-158
	Silt, clayey, olive gray, very cohesive, calcareous............................	6	158	-164
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)......	5	164	-169
	Silt, clayey, olive gray, very cohesive, calcareous............................	11	169	-180
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)......	50	180	-230
	Clay, as above, abundant gravel and boulders.............................	43	230	-273

Electric Log

TABLE 4.--Logs of test holes - Continued

163-75-23bbb
Lion Oil Co.-G.A. Huss #1
Elevation-2190 feet
(Partial Log)

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
	(MISSING)	25	0	- 25
Turtle Mountains Moraine				
	Sand and gravel, subangular to subround; small amounts of gray shale, much shale beginning at 50'...............	175	25	-200
Tongue River Formation (?)				
	Shale, dark greenish gray, calcareous, slightly silty;some sand and gravel as above................................	50	200	-250
	Shale, very light brown, olive gray, calcareous, partly silty; some sand and gravel as above, much sand and gravel beginning at 300'....................	75	250	-325
	Shale, dark gray, soft, becoming more consolidated, silty starting at 375'.....	150	325	-475
	Shale, dark greenish gray, silty,slightly bentonitic...........................	25	475	-500
	Coal and lignite, brittle, black;increasing amounts of medium gray shale; much sandy,light gray bentonite at 530-540'.	40	500	-540
	Shale, grayed red purple, soft; slightly silty, much sandy, moderate yellow green bentonitic shale, some coal, increasing amounts of sand............	30	540	-570
	Sand, fine to medium; some shale as above and light gray soft shale, much coal and lignite (580'-600')..........	30	570	-600
	MISSING SAMPLES	68	600	-668
	Shale, light gray to light olive gray, lumpy, slightly silty and calcareous; traces of coal.......................	52	668	-720
	Shale, very light brown to very light gray, bentonitic, slightly silty, fossiliferous.......................	40	720	-760

Total depth-6435 feet
No free oil or water

TABLE 4.--Logs of test holes - Continued

163-75-28aad
Test hole 13-738
Elevation-2140 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Topsoil, black	1	0	- 1
	Clay, silty to sandy, dusky yellow, fairly cohesive, oxidized (till)	18	1	- 19
	Clay, silty to sandy, olive black, very cohesive (till)	10	19	- 29
	Gravel, coarse, generally rounded	8	29	- 37
	Clay, silty to sandy, olive black, sticky, tight (till)	111	37	-148
	Clay, silty to gravelly, olive black, very cohesive (till)	15	148	-163
	Silt, olive gray, smooth, laminated, highly calcareous	14	163	-177
	Silt, moderate olive brown, smooth slightly calcareous	10	177	-187
	Gravel, fine to coarse, some sand, subangular to subrounded, oxidized	9	187	-196
	Clay, silty, moderate olive brown, oxidized, (till)	4	196	-200
	Clay, silty to gravelly, olive black, very cohesive (till)	67	200	-267
	Silt, moderate olive brown, smooth, slightly calcareous	3	267	-270
Undifferentiated				
	Shale, silty, olive black, smooth, moderately indurated, laminated	13½	270	-283½

Electric Log

163-75-29abb
Test hole 11-738
Elevation-2150 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Clay, silty, moderate yellowish brown, cohesive, oxidized, calcareous (till)	10	0	- 10
	Clay, silty to sandy, moderate olive brown, oxidized, calcareous (till)	11	10	- 21
	Clay, silty, moderate olive brown, cohesive oxidized, calcareous (till)	7	21	- 28
	Clay, slightly silty, olive gray, cohesive, calcareous (till)	19	28	- 47

163-75-29abb - continued
Test hole 11-738
Elevation-2150 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From - To
Turtle Mountains Moraine - continued			
	Sand, medium to very coarse, rounded.......	1	47 - 48
	Clay, silty to sandy, dark greenish gray, cohesive, calcareous (till)..............	22	48 - 70
	Clay, very silty, dark greenish gray to olive gray, cohesive, calcareous (till)..	9	70 - 79
	Gravel, fine to medium, sandy, rounded.....	5	79 - 84
	Sand, medium to very coarse, very gravelly, angular to rounded, occasional clay layers................................	33	84 -117
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)..............	9	117 -126

Electric Log

163-75-30bbc
Test hole 12-738
Elevation-2250 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From - To
Turtle Mountains Moraine			
	Silt, clayey, yellowish gray, noncohesive, oxidized, calcareous....................	1	0 - 1
	Gravel, fine, very sandy, rounded, with layers of yellowish gray clayey silt.....	32	1 - 33
	Silt, clayey, yellowish gray, noncohesive to cohesive, very calcareous.............	6	33 - 39
	Silt, clayey, dark greenish gray, cohesive, calcareous..............................	10	39 - 49
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)........	41	49 - 90
	Gravel, fine to coarse, sandy to very large pebbles, angular to rounded.............	34	90 -124
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)........	29	124 -153
	Clay, silty to gravelly, dusky yellow, cohesive, oxidized, very calcareous(till)	3	153 -156
	Gravel, fine, sandy, angular to rounded....	11	156 -167
	Clay, silty to gravelly, dusky yellow, cohesive, oxidized, very calcareous(till)	40	167 -207

163-75-30bbc - continued
Test hole 12-738
Elevation-2250 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine - continued				
	Clay, silty to gravelly, dark greenish gray, cohesive, calcareous (till)........	50	207	-257
	Clay, as above, abundant gravel............	24	257	-281
	Clay, silty to sandy, dark greenish gray, cohesive, slightly calcareous (till).....	55	281	-336
	Gravel, fine to medium, angular to rounded..................................	2	336	-338
Undifferentiated				
	Sandstone, very fine to fine, silty with clay matrix, light greenish gray to greenish gray, nonindurated, noncalcareous....................................	19	338	-357

Electric Log

163-75-31cb
Test hole 28-738
Elevation-2130 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Topsoil, clayey, dark, organic.............	1	0 -	1
	Clay, silty to sandy,marly matrix, light olive gray, leached, highly calcareous (till)..................................	3	1 -	4
	Clay, silty to sandy, moderate olive brown, oxidized, extremely calcareous (till)....	12	4 -	16
	Clay, silty to sandy, olive gray, cohesive and compacted, extremely calcareous(till)	74	16 -	90
	Gravel, fine and medium, sandy, angular to subrounded, clean....................	2	90 -	92
	Clay, silty, olive gray, cohesive, plastic, very calcareous (till)..................	20	92	-112
	Silt, clayey, olive gray, smooth,cohesive, plastic, highly calcareous (till).......	5	112	-117
	Gravel, fine to medium, subangular to subrounded, well sorted, clean..............	4	117	-121
	Clay, silty to sandy, light olive brown, cohesive, oxidized, highly calcareous (till)................................	10	121	-131

TABLE 4.--Logs of test holes - Continued

163-75-31cb - continued
Test hole 28-738
Elevation-2130 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine - continued				
	Clay, silty, moderate olive brown, fairly cohesive and compacted, oxidized, highly calcareous (till)	31	131	-162
	Clay, very silty, olive gray, very compacted and tight, highly calcareous (till)	64	162	-226
	Clay, silty to slightly gravelly, dusky yellowish brown, cohesive, compacted, tight, oxidized, extremely calcareous (till)	20	226	-246
Undifferentiated				
	Shale, silty, olive gray, platy, noncalcareous	5	246	-251
	Shale, silty, olive black, noncalcareous.	11½	251	-262½

163-76-23add
Test hole 18-738
Elevation-2240 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine				
	Topsoil, sandy, dark	1	0	- 1
	Gravel, fine to coarse, with medium to coarse sand, subrounded, coarser with depth	19	1	- 20
	Clay, silty, olive gray, cohesive, tight, calcareous (till)	33	20	- 53
	Gravel, fine to coarse, angular to subrounded	7	53	- 60
	Clay, silty, olive black, very cohesive (till)	46	60	-106
	Gravel, fine to coarse, sandy, subangular to to subrounded	8	106	-114
	Clay, silty, olive black, very cohesive and tight, boulders common (till)	16	114	-130
	Gravel, fine to coarse, silty and sandy, subangular to rounded	12	130	-142
	Clay, very silty, olive black, very cohesive	7	142	-149
	Clay, silty to sandy, olive gray, cohesive, calcareous (till)	36	149	-185

163-76-23add - continued
Test hole 18-738
Elevation-2240 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Turtle Mountains Moraine - continued				
	Clay, very silty, olive black, very cohesive, highly calcareous (till)......	89	185 -	274
	Clay, silty, dark yellowish brown, weathered, oxidized, calcareous (till)..	5	274 -	279
	Limestone boulder.......................	½	279 -	279½

163-76-36dad
Test hole 29-738
Elevation-2145 feet

Formation	Lithology	Thickness (feet)	Depth (feet) From	To
Souris River Ground Moraine				
	Topsoil, sandy, dark, organic.............	1	0 -	1
	Clay, silty and sandy, light olive gray, slightly cohesive, highly calcareous (till).................................	10	1 -	11
	Clay, silty to sandy, moderate olive brown, oxidized, highly calcareous, (till).....	22	11 -	33
	Clay, silty, olive gray, very cohesive and tight, highly calcareous (till).........	42	33 -	75
	Silt, clayey, olive gray, cohesive,plastic, sticky, smooth, very calcareous.........	7	75 -	82
	Clay, silty, dusky yellow, cohesive,tight, oxidized (till)........................	11	82 -	93
	Clay, silty to gravelly, olive gray, cohesive, highly calcareous (till)......	84	93 -	177
	Gravel, fine to medium,angular to sub-round.................................	4	177 -	181
Undifferentiated				
	Silt, olive black, slightly cohesive,non-calcareous..........................	19	181 -	200

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