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Geological Survey

RECONNAISSANCE GEOLOGY AND HYDROLOGY ON THE NETT LAKE INDIAN RESERVATION, MINNESOTA

By

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Prepared in cooperation with the

Public Health Service of the

U.S. Department of Health, Education, and Welfare

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CONTENTS

ILLUSTRATIONS - Short List

ILLUSTRATIONS - Long List

TABLES

RECONNAISSANCE GEOLOGY AND HYDROLOGY

ON THE NETT LAKE INDIAN RESERVATION, MINNESOTA

Ralph F. Norvitch

ABSTRACT

The Nett Lake Indian Reservation is in northern Minnesota, about 210 miles north of Minneapolis and St. Paul. The village of Nett Lake (population about 400) is the only community on the reservation. This report is the result of an investigation made to provide a central water source for the village, at the request of the Public Health Service of the U.S. Department of Health, Education, and Welfare.

The climate of the area is continental, characterized by cool, subhumid summers and long, severe winters. The average annual precipitation is 24.2 inches.

Altitudes in the area range from about 1,190 feet above mean sea level in the Little Fork River channel on the west border of the reservation to about 1,550 feet on top of the Vermilion end moraine, just south of Nett Lake. During the latter part of the Pleistocene Epoch most of the area was inundated by the waters of glacial Lake Agassiz. The area is now drained by the Little Fork River which flows north into the Rainy River, thence into Lake of the Woods, and eventually into Hudson Bay.

The geologic units in the Nett Lake area consist of unconsolidated deposits of Recent and Pleistocene age and crystalline rocks of Precambrian age.

Most ground water in the Nett Lake area occurs in three different zones: 1) surficial sand and gravel deposits, 2) lake sand underlying compact lake clay, and 3) bedrock fractures. The lake sand underlying the compact clay is the best source of ground water for the village of Nett Lake. It occurs in a small channel immediately west of the village, and it ranges in depth from about 11 to 30 feet below land surface and in thickness from 0 to about 3 feet. The water level is near the surface. A test well yielded 30 gpm (gallons per minute). Two 15 gpm wells would not exceed the long-term yield of the aquifer and would be adequate for the needs of the village.

INTRODUCTION

Nett Lake Indian Reservation (see fig. 1) is in northern Minnesota,

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Figure 1.--Map of Minnesota showing location of area described by this report.

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about 210 miles due north of Minneapolis and St. Paul. The reservation forms a rectangle about 12 miles wide and 14 1/2 miles long. About 140 square miles is in Koochiching County and 35 square miles of the eastern part is in St. Louis County.

Nett Lake village has a population of about 400 and is the only community on the reservation.

The major economy on the reservation is logging and several logging camps are in the area. Seasonal work is provided by harvesting wild rice and two wild rice processing plants are on the east outskirts of the village.

Purpose and Scope

The geologic and hydrologic studies of the Nett Lake Indian Reservation were made for the Public Health Service of the U.S. Department of Health, Education, and Welfare to locate a central sanitary water source for the village of Nett Lake. The existing water supply consists of a number of low-capacity, community and privately owned wells which are in danger of becoming contaminated by influent sewage seepage. The lake is contaminated and is therefore unsatisfactory. The Public Health Service desired a source of water that was near the village, that would yield as much as 50 gpm from one or more wells, and that would be free from possible contamination. The reconnaissance of the geology of the remainder of the reservation was made to provide a geologic base for development of future water requirements of the reservation.

Previous Reports

No detailed geologic or hydrologic studies had been made previously on or near the Nett Lake Reservation although the area was included in part of several regional geologic studies. Mention of Precambrian rock outcrops at Nett Lake and supposed Cretaceous shale exposures (now recognized as Quaternary clay) along the Little Fork River is made by Grant (1899). Descriptions of surface formations and agricultural conditions for Koochiching and St. Louis Counties are described by Leverett and Sardeson (1917). An analysis of clay taken from outcrops along the Little Fork River within and near the reservation is included in U.S. Geological Survey Bulletin 678 by Grout (1919).

Method of Investigation

The geology of the Nett Lake Indian Reservation was mapped on high altitude aerial photographs and transferred to the base map by means of a vertical sketchmaster. During the fall of 1961, about one week was spent in the field checking the aerial mapping and about four weeks were spent augering test holes and installing and pumping test wells. Logs of auger holes are given in table 2. The geology west of the Little Fork River was not checked in the field. The power auger was loaned by the Department of Iron Range Resources and Rehabilitation. Development of the test wells was accomplished with an air compressor. A pumping test using a centrifugal pump was run on October 5, 1961.

Auger holes 13-17, listed in table 2, were drilled in 1959 by Survey personnel as a preliminary part of this investigation. The two partial chemical analyses of water listed in table 3 are from the records of the Minnesota Department of Health; and the one complete chemical analysis was made by the U.S. Geological Survey Quality of Water Branch laboratory at Lincoln, Nebraska.

This investigation was made under the general supervision of Richmond F. Brown, District Geologist, U.S. Geological Survey, St. Paul, Minnesota.

GEOGRAPHY

Climate

The climate in the Nett Lake area is continental and is characterized by cool, subhumid summers and long, severe winters. The average annual precipitation, including snowfall, is 24.2 inches; the average monthly precipitation ranges from 0.89 inch in January to 3.73 inches in July.

Topography and Drainage

The Nett Lake Indian Reservation is a glaciated region separated into two physiographic divisions by an eastward-trending hummocky ridge of the Vermilion end moraine. (See figure 2.)

The northern half consists of extensive, flat swampy lake plains, patches of lake-washed ground moraine, and linear bedrock ridges. The topography of the southern half is more complex. It is composed of swampy lake plains and higher areas of moderate relief formed by a complex of outwash plains and remanent beaches. The channel of the Little Fork River is incised across the southwestern part of the reservation to a depth of about 50 feet.

Altitudes in the Nett Lake area range from 1,190 feet in the channel of the Little Fork River on the west border of the reservation to about 1,550 feet on top of the Vermilion end moraine a short distance south of Nett Lake. Except for higher bedrock ridges in the northeast corner, the northern part of the reservation lies between altitudes of 1,250 and 1,400 feet. Altitudes along the Vermilion end moraine range from more than 1,500 feet through the eastern and middle segments to less than 1,400 feet along the western segment. In the southern part of the reservation the surface slopes generally upward from the Little Fork River toward the Vermilion end moraine. Nett Lake is a shallow remnant of former glacial Lake Agassiz that covers about 11 square miles. It is drained by Nett Lake River which joins the Little Fork River at a point about 7 miles east of the reservation.

GEOLOGY

The geologic units in the Nett Lake area include unconsolidated deposits of Recent and Pleistocene age and crystalline rocks of Precambrian age. (See fig. 2.) Clay deposits believed to be of Cretaceous origin by

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Figure 2.--Surficial geology map of the Nett Lake Indian Reservation, Minnesota.

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early observers (Grant, 1899, p. 183) and later classed as postglacial or interglacial by Grout (1919, p. 183) are now considered to be interglacial deposits on the basis of auger-hole data collected during this investigation. Geologic units and areal geologic features are briefly described in table 1.

Quaternary Deposits

The Quaternary deposits in the Nett Lake area are of Late Wisconsin age. Prior to Late Wisconsin time the area was glaciated by earlier continental ice advances that eroded the bedrock surface and deposited glacial drift which was removed or reworked during Wisconsin Glaciation. Recent alluvial and colluvial deposits consist of clay, sand, and gravel derived almost entirely from the glacial drift. Paludal deposits of Recent age cover extensive areas of the flat lake plains and ground moraine.

The Rainy lobe drift was deposited during Late Cary time on an eroded surface of Precambrian rocks (Wright, 1956, p. 19). It consists of till and associated outwash sand. The till is composed predominantly of sand and gravel with many large boulders and is typically gray as its constituents are derived from dark, metamorphic and igneous rocks. It forms the bulk of the Vermilion end moraine and at altitudes of more than 1,400 feet the Rainy lobe till is well exposed. High outwash deposits consisting mostly of medium sand with some fine to coarse gravel lie along the southeastern margin of the Vermilion end moraine at an altitude of more than 1,400 feet. Three samples of typical material from the central part of the outwash are 50 to 72 percent medium sand. The relatively high percentage of medium sand suggests fluvial sorting. The sand, gravel, clay, and boulders in the small channel at the village of Nett Lake are believed to be Rainy lobe drift. (See fig. 3 and fig. 4.) It was not possible to accurately place a boundary between the various lithologic units in the channel from auger logs; however, hydrologic data collected during the pumping test indicated the sand unit extended across the channel. Pre-Lake Agassiz lake clay overlies the Rainy drift in the lower areas of the reservation; however, no exposures of the clay were found on the reservation. Augered samples of this old lake clay were dark, highly impervious, compact, with calcareous, white, silty laminae separating the dark laminae. At some test sites the clay was so well compacted it was difficult to distinguish by drill action between lake clay and till. The thickness of the old lake clay ranges from less than a foot to about 20 feet.

The St. Louis sublobe drift overlies the old lake clay in low areas and either the Rainy lobe drift or bedrock in the higher areas. The St. Louis till has a sandy, clay matrix and its larger particles are predominantly gravel size. It is typically calcareous and commonly a buff color. In contrast to the almost total absence of limestone or dolomite in the Rainy lobe drift, the St. Louis lobe drift contains much carbonate rock. The thickness of St. Louis till penetrated by auger test holes ranges from 0 to 18 feet and average about 7 feet. The thicker sections were found at lower altitudes.

Two kames were identified in the Nett Lake area. A high kame in the NW$\frac{1}{4}$, sec. 3, T. 64 N., R. 22 W., consists mostly of Rainy lobe materials but contains some surficial limestone possibly of St. Louis lobe origin up to an altitude of 1,450 feet. A lower kame, in SW$\frac{1}{4}$, sec. 34, T. 65 N., R. 21 W., contains a high percentage of limestone and shale pebbles deposited by the St. Louis drift.

The St. Louis lobe drift was covered subsequently by former glacial Lake Agassiz. Thin beds of lake clay, silt, and sand were deposited on this drift below an altitude of about 1,360 feet. Clay of glacial Lake Agassiz in the Nett Lake area is noncompacted to slightly compacted. The upper part of the clay is generally silty and brownish, whereas the lower part is dark gray or green. The thickness of the Lake Agassiz clay penetrated by the augered holes ranged from 5 to 39 feet. The maximum thickness was penetrated in auger hole 12 in a low swampy area about a mile from the nearest area of slightly higher land. The clay commonly is progressively more silty and sandy toward isolated patches of higher ground, as near the village of Nett Lake.

Beach deposits of glacial Lake Agassiz formed at the 1,360-foot stage lie adjacent to the Vermilion end moraine and are widespread in the west half of the reservation. (See fig. 2.) These beach deposits were derived mostly from the Rainy lobe drift by shoreline erosion. It is believed that erosion was more effective along the western and lower segment of the moraine as indicated by the greater extent and thickness of beach sand. Isolated boulders are scattered along the beach area near the moraine. They are believed to be residual relicts remaining after shore erosion removed the finer materials.

The beach deposits are predominantly fine to coarse sand and contain some gravel and boulders especially near the moraine. The thickness ranges from less than a foot to about 10 feet.

Recent paludal (swamp deposits) of silt, muskeg, and peat are widespread throughout the low area. Thickness of these deposits in augered test holes ranged from 0 to 7 feet; however, much thicker deposits probably exist in the low areas near the village of Nett Lake.

Recent alluvium and colluvium is largely confined to the valley of the Little Fork River. The Little Fork River is deepening its channel, removing more material from its channel than it is depositing. No test holes were drilled and the areal extent of alluvial and colluvial deposits was inferred from aerial photographs. The local lithology and thickness of these deposits was not determined. The lithology of these deposits probably is similar to the lithology of the drift in the vicinity. Some alluvial sand occurs along the Nett Lake River and smaller streams, however, these deposits were not mapped.

Precambrian Rocks

Granitic and metamorphic rocks of Precambrian age form the basal unit upon which the unconsolidated materials of Quaternary age were deposited. (See table 1.) Exposures of the Knife Lake Group occur within the village of Nett Lake and undoubtedly occur at other places in the Reservation. Rocks of this group include slate and metamorphosed graywacke, tuffs, and agglomerates. They are commonly dark and dense. The dark, dense graywacke near the village of Nett Lake is not significantly fractured. Vermilion granite is exposed in a large area in the northeast corner of the reservation and fine-grained Knife Lake rocks cut by narrow granitic dikes are exposed locally in the village of Nett Lake.

Economic Deposits

Four mineral deposits in the Nett Lake Reservation may have some economic value. They are: 1) clay, 2) sand and gravel, 3) peat, and 4) bedrock. The deposits were mapped as a part of this investigation but their extent and value were not determined.

Calcareous, plastic, compact, laminated, gray clay underlies the pebbly, calcareous, gray glacial St. Louis till in much of the Nett Lake area. The clay contains little grit, if any. Deposits of clay were penetrated in 13 of the holes augered for this investigation. (See fig. 3 and table 2.) Grout (1919, p. 182-186) mentions the Koochiching County clays, including those in the Nett Lake vicinity, to be of possible economic value. However, a sample analyzed by the Minnesota U.S. Bureau of Mines laboratory was excessively high in $CaCO_3$.

Sand and gravel is abundant in the Nett Lake area, as shown on figure 2. Sand and gravel in a pit in the NW$\frac{1}{4}$ of sec. 3, T. 64 N., R. 22 W. is being mined for road metal. Similar deposits may occur at other places within the high outwash deposit and in the Vermilion end moraine (fig. 2). Sand is abundant in the area mapped as "Lake and beach sand".

Peat deposits underlie some of the swamp areas shown on fig. 2. The peat is as much as 7 feet thick locally (auger hole 12, fig. 3 and table 2). This test hole was drilled near the north edge of a broad, low channel that trends northwest from the southeast tip of Nett Lake (fig. 3); the deposit may thicken toward the center of the channel.

Analyses of two peat samples from Koochiching County are included in a work on the mineral resources of Minnesota by Emmons and Grout (1943, p. 117).

GROUND WATER

Ground water is stored beneath the land surface in the zone of saturation. Within this zone all voids, or pore spaces, are filled with water. The upper surface of the zone of saturation is called the "water table". Ground water in the report area occurs under both water-table and artesian conditions.

Occurrence

A deposit that will yield water in sufficient quantity to be a source of supply is called an aquifer. The value of a rock or stratum as an aquifer is dependent upon two of its physical properties--porosity and permeability. Porosity is the property of a rock of containing openings and is expressed as the ratio of the total volume of the openings to the total volume of the rock, usually stated as a percentage. Permeability is the property of a rock to transmit water under pressure and is dependent upon the interconnection of passageways of supercapillary size. Permeability is generally stated as a coefficient and is expressed as the rate of flow of water, at the prevailing temperature, in gallons per day through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot.

Most ground water in the Nett Lake area occurs in three zones: 1) surficial sand and gravel deposits, 2) lake sand underlying compact lake clay, and 3) bedrock fractures. The water in the surficial deposits is under water-table conditions; in the buried lake sand it is under artesian conditions; and, in the bedrock fractures, it is generally under artesian conditions, except where the fractures are open to the atmosphere.

Source and Movement

The source of all ground water available to wells in this area is precipitation in the form of rain or snow. Part of the precipitation becomes surface runoff, part is evaporated, part is consumed or transpired by plant life, and the remainder seeps to the ground-water body.

Ground water moves down the hydraulic gradient from areas of recharge to areas of discharge. It discharges into surface-water bodies as springs, seeps, and the base flow of streams and by evapotranspiration where the aquifer lies near the surface.

Sufficient data were not collected to determine the exact direction of ground-water flow in this area. However, the water table is generally a subdued model of the surface topography. The direction of ground-water movement is assumed to be similar to that of the existing drainage and the ground-water divides are assumed to be roughly coincident with the surface-water divides.

Recharge and Discharge

Maximum recharge to the aquifers occurs during the spring thaw and after heavy summer rains. Recharge to the surficial sand and gravel is nearly instantaneous; in comparison, recharge to the lake sand underlying the gray clay is slow. The lake sand probably receives recharge from percolating water largely where it laps up in the subsurface against the end moraine and bedrock knobs and ridges. Probably very little water passes through the overlying compact lake clay. Recharge to fractured bedrock takes place in its outcrop areas and where it underlies the Vermilion end moraine.

Ground water is discharged from the area by effluent flow into surface streams and by underflow moving down gradient into adjacent areas. The greatest ground-water loss from the area is by evaporation through the soil zone and plant transpiration. An insignificant amount of water is discharged through wells.

Present Water Supply

The inhabitants of the village of Nett Lake obtain their water supply from public and private wells. These wells are either dug or drilled and they range in depth from 22 to about 500 feet (fig. 3). Reported capacities of the wells range from 1 1/2 to 6 gpm. One private owner reported his well ($SW\frac{1}{4}SW\frac{1}{4}SW\frac{1}{4}$ sec. 17, T. 65 N., R. 21 W.) was pumped at 28 gpm immediately after completion, but in 1961 it produced only 4 gpm.

Figure 3.--Locations of wells and test holes in the vicinity of the village of Nett Lake.

No central water system is installed. Most of the village inhabitants pump water by hand from public wells and carry it by bucket into their homes. A conservative estimate of the amount of water required for a village the size of Nett Lake (about 400 persons) is about 20,000 gpd (gallons per day) or about 14 gpm. The present village well water use is estimated to be between 1 and 2 gpd per person.

AVAILABILITY OF GROUND WATER

No abundant source of ground water is known within the boundaries of the Nett Lake Indian Reservation. The purpose of this report was to find a water source adequate for the village of Nett Lake; therefore, the exploration for water was conducted principally within and near the community. (See fig. 3.) The discussion of availability of water in the deposits outside of the vicinity of the village is based on a reconnaissance of the area and on interpretation of aerial photographs.

Surficial Sand and Gravel Deposits

The surficial sand and gravel deposits in the Nett Lake area include widespread lake and beach sands, high altitude deposits of outwash sand and gravel, and sand and gravel alluvium that occurs within the stream courses. The end moraine is largely sand, gravel, and boulders and is included under this heading. Ground water is available from any one of these deposits where they are thick enough and saturated.

The lake and beach sands generally range in thickness from 0 to about 10 feet, however, they may be thicker locally. The sand is fine and the permeability probably is low resulting in large water-level drawdown in pumped wells. Sufficient supplies for small-capacity users may be available in places where the combination of thick deposits and high water levels are found.

The high outwash sand and gravel of Rainy lobe drift is about 50 feet above the surrounding lake plain and only its lowest parts are saturated. A well near the west-central part of sec. 1, T. 64 N., R. 22 W., on top of the high outwash deposit, reportedly penetrated about 60 feet of sand over bedrock. The entire sand section was reported to be dry. No springs were noted along the erosion channels in secs. 1 and 12, T. 64 N., R. 22 W. whose floors are about 50 feet lower than the top of the outwash deposit; this indicates the zone of saturation is below this level.

In some areas the outwash may be saturated in its lower part; if so, small supplies may be available.

The sand and gravel alluvium along the stream courses will yield water where it is saturated. Where the alluvium lies below stream level and is hydraulically connected to the stream, pumping may induce recharge from the stream and yield an appreciably greater quantity of water. However, no large alluvial deposits exist in the area.

Lake Sand Underlying Compact Lake Clay

The best available source of ground water for the village is the fine to medium, gray sand that underlies a small channel in the NE$\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W. west of the Nett Lake village proper. (See fig. 3.) The sand underlies compact lake clay. (See fig. 4.)

Figure 4.--Generalized cross section of small channel west of the village of Nett Lake.

The position and thickness of the sand in the channel is shown on figure 4.

A 3-hour pumping test of this aquifer was run in the SE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W. (fig. 3). Auger hole 20 was the pumping well, and drawdown and recovery measurements were taken in auger hole 19. The pumping well was completed in the sand between about 14-17 feet below land surface and its casing was equipped with a 30-inch 40-slot screen. The static water level in the pumped well was 5.53 feet below land surface. The observation well, 36.8 feet south of the pumping well, was completed in sand about 25-27 feet below land surface; the sand stratum apparently dips steeply to the south between the 2 holes. Well 20 was pumped at a maximum rate of 30 gpm with a centrifugal pump. Due to a loss of lift of the pump as the water level declined, the pumping rate during the test decreased from 30 to 17 gpm during the first 10 minutes of the test but was maintained between 16 and 18 gpm during the remainder of the test.

The coefficient of transmissibility (T) of the sand was calculated to be 6,000 gpd per foot and the storage coefficient (S) to be 0.00004. The coefficient of transmissibility is defined as the number of gallons of water that will pass in one day through a vertical strip of the aquifer 1 foot wide extending the saturated height of the aquifer under a unit hydraulic gradient. The coefficient of storage is defined as the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The calculated aquifer constants indicate that water levels at distances of 200 feet from a well discharging at a rate of 20 gpm will decline as much as 4.3 feet after 80 days of pumping. (See fig. 5.) The

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Figure 5.--Water-level drawdown-distance graphs for the aquifer in the small channel west of the village of Nett Lake. (Not adjusted for boundaries.)

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curves in figure 5 are not adjusted for hydraulic boundaries and are based on the assumption of no recharge to the aquifer; they give an approximation of aquifer performance in the general area of the pumping well and the observation well. As an example of the application of the curves: after steady pumping at a rate of 20 gpm for 100 days the water level 1 foot from the pumping well would drop about 8.4 feet below static level or about 13.9 feet below land surface. The amount of drawdown is directly proportional to the rate of discharge; therefore, for a 10 gpm rate the drawdown would be one-half the above figure. The drawdown 50 feet from the pumped well for the same period would be about 5.4 feet below static level at the 20 gpm rate. Any combination of wells pumping would produce total drawdowns equal to the sum of the effects of the individual drawdowns; that is, if the two above-mentioned wells (50 feet apart) were pumped simultaneously for 100 days at 20 gpm, the drawdown would be about 13.8 feet in each well.

The curves on figure 5 are helpful in determining safe pumping rates and correct well spacing in order to obtain the maximum amount of water available from the aquifer without drawing water levels below the well screens. Because hydraulic boundaries, such as probably exist in the area, the figures should be used only as a guide to well development.

Auger hole 18 (fig. 3) was pumped in an attempt to determine the hydraulic characteristics of a fine sand layer between about 32 and 34 feet below land surface. The sand at this site was oxidized to a buff-brown color and imparted the same color to the water contained in it. On developing with compressed air, as was done in all test wells, only 3 gpm were obtained and the water remained turbid.

Precambrian Rocks

A number of deep wells in the area are drilled into the crystalline rock at the village of Nett Lake. One well drilled 6 feet into the rock yields 4 1/2 gpm; other wells drilled deeper into the rock yield even less. The available data show that increased penetration into the bedrock does not increase the well yield.

Several bedrock outcrops are shown on figure 2. The bedrock contains few fractures on the surface. As even these few fractures probably decrease with depth, it is not feasible to drill far into the rock to obtain water.

QUALITY OF WATER

Chemical analyses of two samples of ground water taken from public wells in Nett Lake village and one sample taken during the pumping test near the village (see p. 36) are listed in table 3. The analyses expressed in parts per million (a unit weight of a constituent in a million unit weights of water) show the dissolved mineral constituents in the water. Color, and iron and manganese content are greater than the limits for potable water for use on interstate carriers recommended by U.S. Public Health Service (1962).

The test holes in the small channel just west of the village of Nett Lake are considered to be relatively safe from contamination. The area is about a quarter of a mile from the village and the sand is overlain by a compact, relatively impermeable, lake clay. This clay is about 20 feet thick in auger holes 3 and 4 and should serve as an effective barrier to surface contaminants.

CONCLUSIONS

The principal source of potable ground water for the village of Nett Lake is a thin deposit of fine to medium, gray, lake sand. The largest known saturated deposit of the sand lies in a small channel immediately west of the village where it ranges in depth from about 11 to 30 feet below land surface and in thickness from 0 to about 3 feet. The water in the sand is artesian and rises to within about 5 to 11 feet of the land surface in the area of the small channel. Because of the artesian conditions and the low storage coefficient (0.00004) the effects of pumping in this aquifer will spread quickly over a wide area. The drawdown prediction curves drawn show what the approximate effects of pumping will be at various distances from the pumped well for periods up to 100 days. The curves can be used as a guide to determine safe pumping rates and proper well spacing for the amount of water needed for the Indian village. In application of the curves it should be understood that they are drawn on the assumption of steady pumping with no recharge and boundary conditions are not accounted for. When pumping is stopped for a period equal to the pumping period, water levels will return to near static levels. After prolonged pumping the cone of influence of the well may intercept a recharge boundary or induce some vertical leakage. This will add to the long-term yield of the well or wells. Conversely, the interception of a discharge boundary such as the impermeable clay on the side of the channel will decrease the potential yield of the wells.

Because of the low transmissibility (6,000 gpd per ft.) of the sand, more than one well will be needed to provide the required amount of water. The sand probably underlies the entire length of the small channel and additional test drilling to the north may penetrate deeper and thicker sections. The small grain size of the sand should be considered in any specifications for well construction and development.

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Table 2.--Logs of auger holes

Auger hole 1
$SW\frac{1}{4}NE\frac{1}{4}NE\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Soil, black	$\frac{1}{2}$	$\frac{1}{2}$
Sand, fine, medium	1	$1\frac{1}{2}$
Till, clayey, pebbly, gray	$9\frac{1}{2}$	11
Clay; sand; gravel; cobbles	13	24
Boulders or bedrock (?)		24

Auger hole 2
$SW\frac{1}{4}NE\frac{1}{4}NE\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Soil, sandy, pebbly, black-brown	2	2
Till, clayey, pebbly, gray grading to brownish-gray	10	12
Clay, dark-gray	10	22
Clay; sand; gravel; cobbles	8	30
Bedrock (?)		30

Auger hole 3
$SE\frac{1}{4}NW\frac{1}{4}NE\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Fill	1	1
Soil, sandy, black-brown	2	3
Till, clayey, pebbly, gray	8	11
Clay, gray	19	30
Clay; sand; gravel; cobbles	$3\frac{1}{2}$	$33\frac{1}{2}$
Bedrock (?)		$33\frac{1}{2}$

Table 2.--Logs of auger holes (Continued)

Auger hole 4
$SE\frac{1}{4}NW\frac{1}{4}NE\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Fill	$\frac{1}{2}$	$\frac{1}{2}$
Soil, sandy, black-brown.	1	$1\frac{1}{2}$
Till, clayey, pebbly, gray grading to tan-gray. .	$8\frac{1}{2}$	10
Clay, gray	$19\frac{1}{2}$	$29\frac{1}{2}$
Clay; sand; gravel; cobbles	$\frac{1}{2}$	30
Sand; clay	9	39
Sand; gravel; clay; cobbles	5	44
Bedrock		44

Auger hole 5
$NW\frac{1}{4}NW\frac{1}{4}SE\frac{1}{4}$ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Soil, sandy, brown.	2	2
Till, clayey, pebbly, brown	6	8
Bedrock or boulder (?).		8

Auger hole 6
$NW\frac{1}{4}NW\frac{1}{4}SE\frac{1}{4}$ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Clay, silty, tan.	6	6
Till, clayey, pebbly, tan	3	9
Sand, fine, tan	2	11
Bedrock or boulder (?).		11

Table 2.--Logs of auger holes (Continued)

Auger hole 7
$SW\frac{1}{4}SW\frac{1}{4}NE\frac{1}{4}$ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Sand, fine, brown	3	3
Till, clayey, pebbly, tan-brown	6	9
Boulders	$6\frac{1}{2}$	$15\frac{1}{2}$
Boulders or bedrock (?)		$15\frac{1}{2}$

Auger hole 8
$SW\frac{1}{4}SW\frac{1}{4}NE\frac{1}{4}$ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Sand, silty, tan	2	2
Till, clayey, slightly pebbly, tan, calcareous	4	6
Clay, light gray and dark gray, thinly bedded	$5\frac{1}{2}$	$11\frac{1}{2}$
Boulders	2	$13\frac{1}{2}$
Boulders or bedrock (?)		$13\frac{1}{2}$

Auger hole 9
$SE\frac{1}{4}SE\frac{1}{4}NW\frac{1}{4}$ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Sand, medium; some gravel	5	5
Clay, brown, gray-green, gray, noncompacted to slightly compacted	5	10
Clay (reworked till?), pebbly, mottled brown and gray, compact	4	14
Clay, gray, interbedded compacted and noncompacted layers	9	23
Till, clayey, pebbly, brown	6	29
Clay, gray, very compact	8	37
Bedrock (?)		37

Table 2.--Logs of auger holes (Continued)

Auger hole 10
NE¼SE¼NW¼ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Soil, sandy, brown	2	2
Till, clayey, pebbly, tan, calcareous	18	20
Clay, gray, very compact.	10	30
Boulders; gravel; clay.	4	34
Bedrock (?)		34

Auger hole 11
NE¼SE¼SE¼ sec. 13, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Soil	1	1
Sand, fine, tan	1	2
Clay, gray, some white.	4	6
Clay, gray, noncalcareous; sand; gravel	3½	9½
Bedrock or boulders (?)		9½

Auger hole 12
SW¼NE¼SE¼ sec. 17, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Fill.	3	3
Peat, brown	7	10
Clay, gray, noncompacted; becomes more compact at 16 feet; bottomed in clay	39	49

Table 2.--Logs of auger holes (Continued)

Auger hole 13
SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 13, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Silt, clayey, gray	12	12
Till, silty, gray; contains few pebbles	7	19
Boulder or bedrock (?)		19

Auger hole 14
SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 13, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Silt, clayey, gray	1	1
Till, clayey, gray	5$\frac{1}{2}$	6$\frac{1}{2}$
Boulder or bedrock (?)		6$\frac{1}{2}$

Auger hole 15
SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 13, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Till, clayey, pebbly, gray	8	8
Clay, silty, gray, plastic	15$\frac{1}{2}$	23$\frac{1}{2}$
Boulders	$\frac{1}{2}$	24
Silt, clayey; boulders	4	28

Auger hole 16
SW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 18, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Silt, clayey, gray	8	8
Till, clayey, gray	2	10
Clay, gray	7	17
Boulders or bedrock (?)		17

Table 2.--Logs of auger holes (Continued)

Auger hole 17
SE¼NW¼NW¼ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Clay, silty, gray; contains few pebbles.	26	26
Clay or till, bouldery	3	29
Clay	5	34
Bedrock or boulders (?).		34

Auger hole 18
NW¼NE¼NW¼ sec. 19, T. 65 N., R. 21 W.

	Thickness (feet)	Depth (feet)
Soil	½	½
Till, clayey, pebbly, tan to gray, calcareous. . . .	8½	9
Till, gray; gray clay.	3	12
Clay, dark gray, plastic, calcareous	19	31
Rocks and clay	2	33
Sand, fine, oxidized	1	34
Boulders (and clay?)	2½	36½
Boulders or bedrock.		36½

Table 2.--Logs of auger holes (Continued)

Auger hole 19*
SE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Soil, brown, peaty	$\frac{1}{2}$	$\frac{1}{2}$
Till, clayey, pebbly, brown to gray, calcareous.	$6\frac{1}{2}$	7
Clay, gray, slightly calcareous.	17	24
Rocks and clay	1	25
Sand, very fine to medium, gray.	2	27
Rocks and clay	$7\frac{1}{2}$	$34\frac{1}{2}$
Boulders or bedrock.		$34\frac{1}{2}$

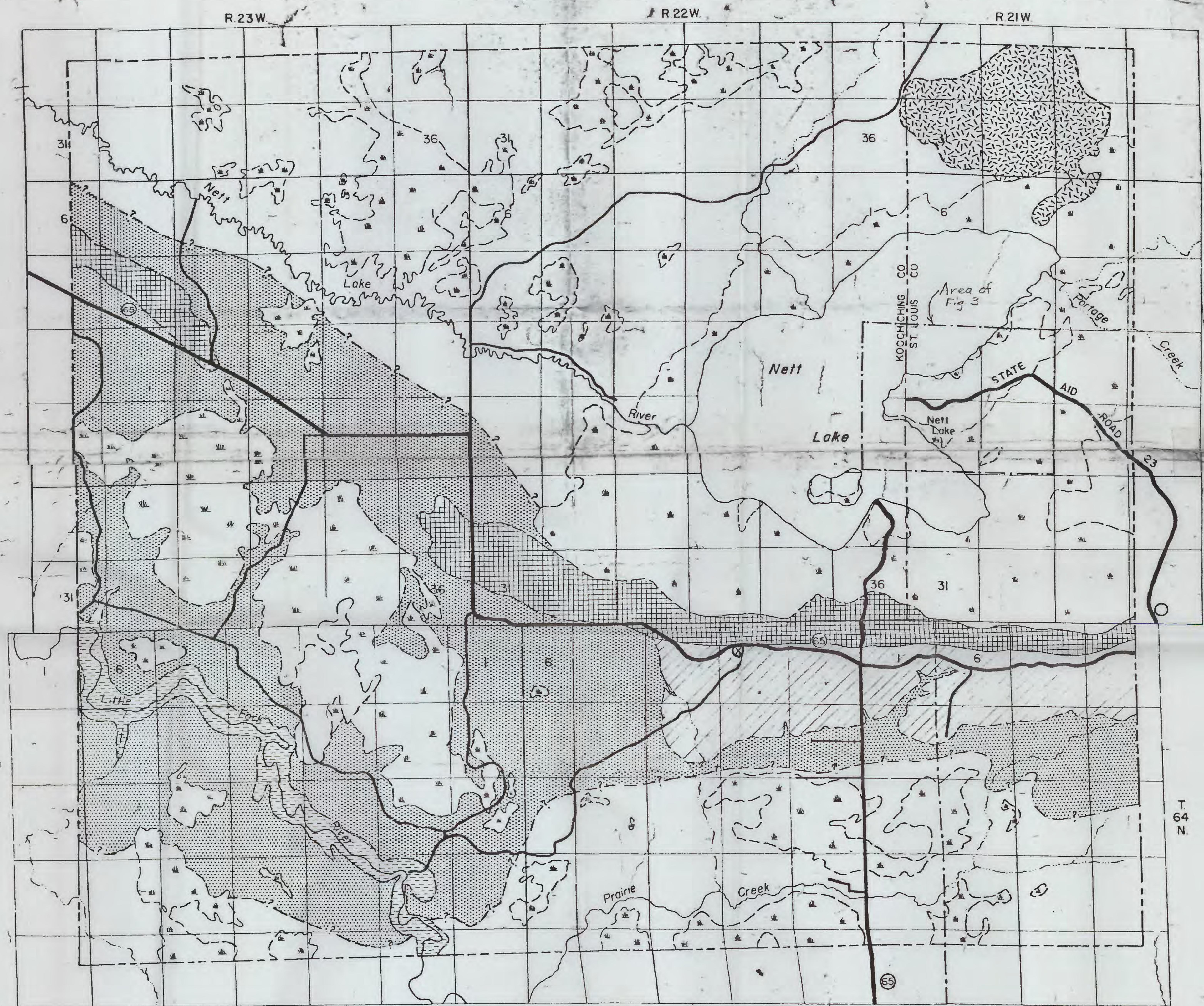
*Hole used as observation well during testing of auger hole 20.

Auger hole 20*
SE$\frac{1}{4}$NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 24, T. 65 N., R. 22 W.

	Thickness (feet)	Depth (feet)
Soil, brown, peaty	1	1
Till, clayey, gray, few pebbles, calcareous. . .	9	10
Clay, gray, plastic.	3	13
Rocks and clay	1	14
Sand, very fine to medium.	3	17
Rocks and clay	2	19
Boulders or bedrock.		19

*Hole used as pumped well for test.

63-104



Base from General Highway Map series of Minnesota. Geology transferred from unadjusted aerial photographs.

Geology by Ralph F. Norvitch, 1961.

EXPLANATION

Quaternary

Recent

Alluvium and colluvium
Mostly deposits derived from the cut banks of the entrenched Little Fork River

Paludal (swamp) deposits
Consists chiefly of black silty soil and peat ranging in thickness from 0 to more than 7 feet; may include some areas of sand and lake-washed till. Only the more pronounced deposits are delineated

Pleistocene

Lake and beach sand
Chiefly lake sands deposited in the littoral zone of glacial Lake Agassiz; contains some gravel, in places, and areas of swamp and lake-washed calcareous clay till. Large boulders on the surface are believed to be residual from washed-out parts of the end moraine

Ground-moraine deposits of St. Louis sublobe origin
Mostly lake-washed clay till; calcareous, gray, contains limestone pebbles; includes some sand and swamp areas

End-moraine deposits (Vermilion) of Rainy lobe origin
Most prominent directly south of Nett Lake; grades progressively downward to the east and west; partially obliterated by glacial lake washing in west-central part of map; far western part composed largely of sand and some gravel. Huge fragments in segment south of Nett Lake believed to be of local origin

High outwash sand and gravel
Mostly medium sand with a fine to coarse gravel veneer to the east and some coarse ice-contact gravel to the west. The sand in the central part is more than 50 feet thick. The origin of the deposit is unknown, but it is believed to be largely composed of Rainy lobe material

Precambrian

Precambrian granite
Largely light-colored granite; ridges trend southwest; inter ridge area is till, sand, gravel, and swamp

Bedrock outcrop
Contains rocks of the Knife Lake Group. Mostly dark, dense, metamorphosed rocks cut by granitic dikes

Kame

Gravel pit

Geologic contact

All contacts approximate and inferred from aerial photographs.

Figure 2.--Surficial geology of the Nett Lake Indian Reservation, Minnesota.

Figure 2.- Surficial geology map of the Nett Lake Indian Reservation, Minnesota

63-104

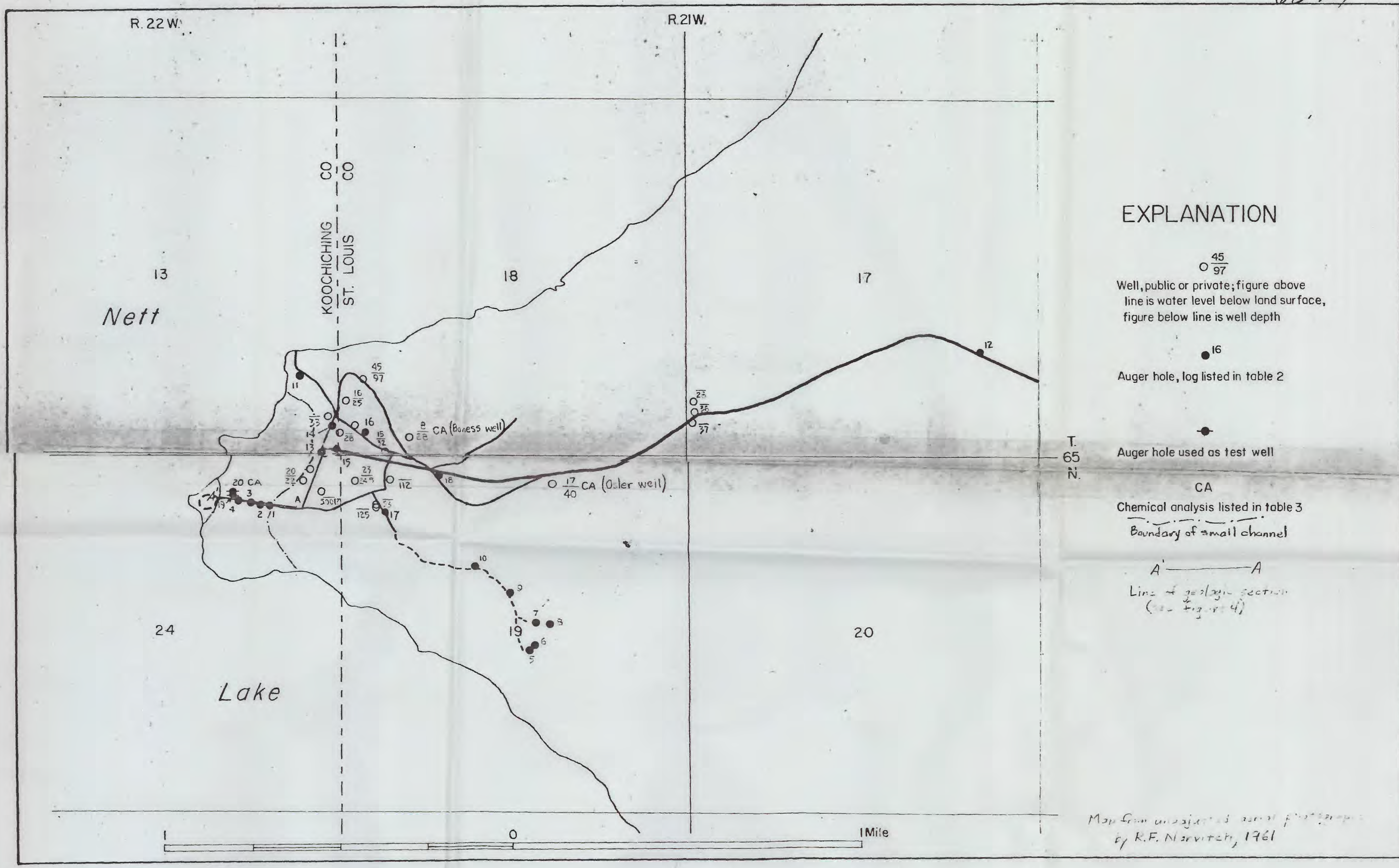


Figure 3. — Locations of wells and test holes in the vicinity of the Village of Nett Lake, Minnesota

63-104

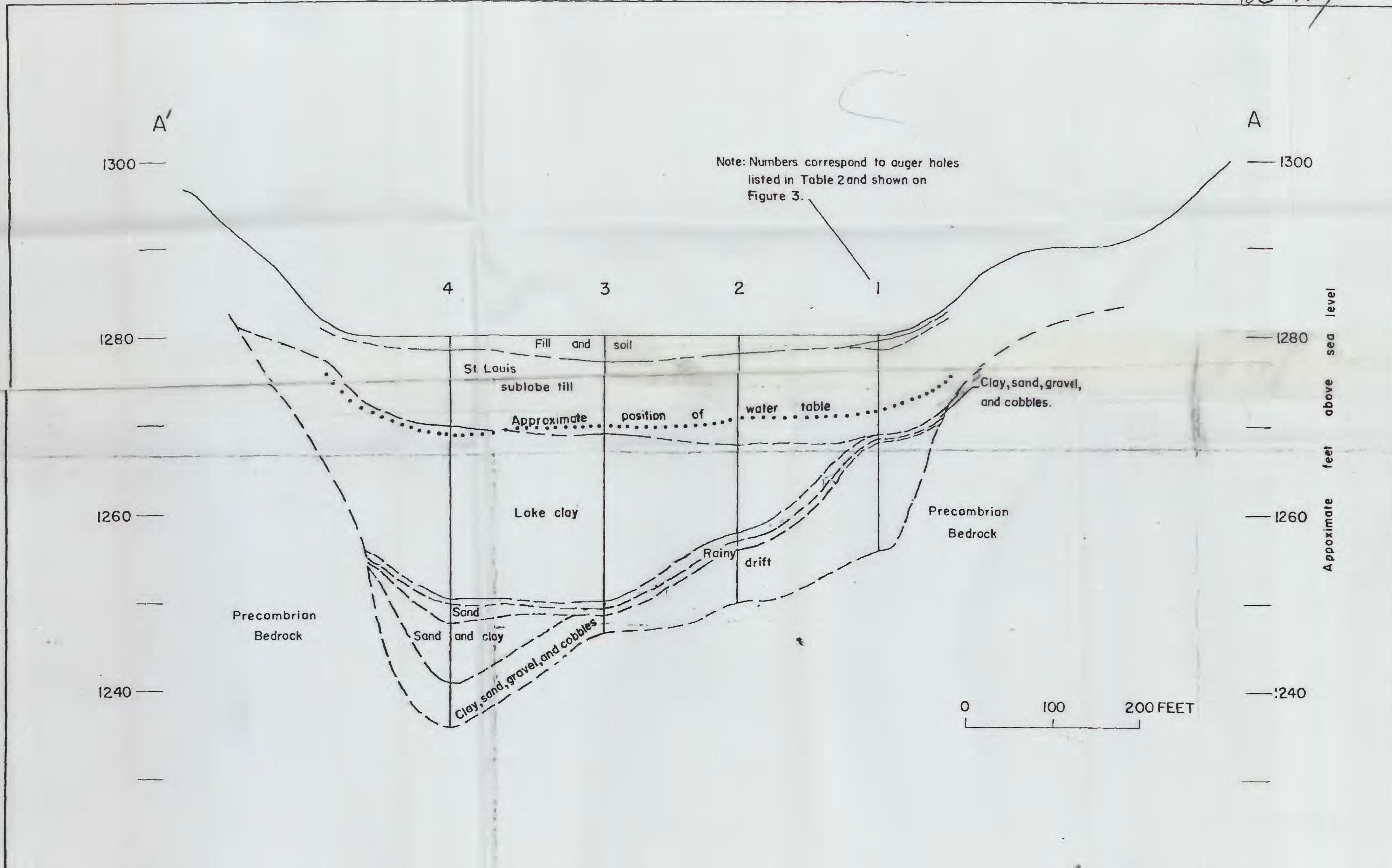


Figure 4.– Generalized cross section of small channel just west of Village of Nett Lake, Minnesota.

Table 1.--Description and water-bearing properties of the principal geologic units in the Nett Lake Indian Reservation, Minnesota

63-104

System	Series or group	Geologic unit	Approximate thickness (feet)	Description	Water-bearing properties
Quaternary	Recent	Alluvium and colluvium	?	Clay, sand, gravel, and boulders in stream channels and slump slopes along Little Fork River.	Locally sand and gravel alluvium will yield adequate supplies to low-capacity wells; no extensive deposits are known in this area. Colluvium is not considered water bearing.
		Paludal (swamp) deposits	0-7±	Black silty soil and brown peat.	Not a source of potable water.
	Pleistocene	Lake and beach sand	0-10±	Fine to coarse sand, some gravel included.	Where saturated the deposits may yield small supplies to wells; however, the deposits are generally thin and the water table is so shallow that the ground water freezes in winter.
		St. Louis sublobe drift	0-18±	Mostly gray, calcareous, pebbly, lake-washed till (buff where oxidized); outwash consists of sand to gravel and contains many limestone pebbles.	Till is not considered water bearing. Outwash is a good aquifer where it is saturated and sufficiently thick, but no saturated, thick, extensive outwash deposits are known in this area.
		Lake clay (not exposed in area)	0-20±	Compact gray, plastic, calcareous, laminated clay; contains white calcareous coatings between lamina.	Lake clay is practically impervious.
		Sand unit (not exposed in area)	0-3±	Mostly very fine to medium, gray sand; interbedded with angular gravel and clay.	Water from sand has been pumped as much as 30 gpm. Sand is so fine that it constitutes a problem in well development.
		Rainy lobe drift	0-100±	End moraine is sand to huge boulders, without noticeable clay. Outwash adjacent to end moraine contains fine sand to coarse gravel and is as much as 50 feet above the surrounding lake plain.	Sand and gravel of end moraine, where penetrable and saturated, should constitute a fair source of water. Outwash is a good aquifer where it is coarse and saturated; however, it is generally perched above the surrounding lake plain and probably only a small part is saturated.
Precambrian		Vermilion Granite	?	Granitic intrusion, generally light-colored.	Unknown.
	Knife Lake		?	Slate, graywacke, tuff, lava, and conglomerate.	Yields small supplies from fractures; fractures are few.

Table 3.--Chemical analyses of water from the Nett Lake Indian village

Locations of wells shown on figure 3

(Results are expressed in parts per million)

63-104

	Boness well	Osler well	Auger hole no. 20	Recommended U.S. Public Health Service Standards (1962) for Interstate Carriers
Analyst	M.D.H.a/	M.D.H.a/	U.S.G.S.b/	
Date of collection	7-14-60	7-14-60	10-5-61	
Silica (SiO_2)	----	----	25	----
Iron (Fe)	4.0	2.3	5.3	0.3
Manganese (Mn)	.1	.09	.00	.05
Calcium (Ca)	----	----	97	----
Magnesium (Mg)	----	----	6.8	----
Sodium (Na)	----	----	6.2	----
Potassium (K)	----	----	4.9	----
Bicarbonate (HCO_3)	----	----	293	----
Sulfate (SO_4)	70	16	35	250
Chloride (Cl)	26	3.7	5.7	250
Fluoride (F)	.14	.15	.1	0.8-1.7c/
Nitrate (NO_3)	----	----	.5	45d/
Nitrate Nitrogen (N)	less than 1	less than 1	----	----
Dissolved solids Total	----	----	----	500
Residue at 180°C	----	----	325	----
Hardness as $CaCO_3$	470	410	270	----
Alkalinity as $CaCO_3$	370	340	----	----
Specific conductance (micromhos at 25°C)	----	----	518	----
pH	----	----	7.1	----
Color	----	----	20	15

a/ Minnesota Department of Health

b/ U.S. Geological Survey

c/ Average concentration based on annual average of maximum daily air temperatures.

d/ In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.