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GEOLOGY AND GROUND-WATER CONDITIONS IN THE CHISHOLM-DEWEY LAKE AREA, ST. LOUIS COUNTY, MINNESOTA

By

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Prepared in cooperation with the

Department of Iron Range Resources and Rehabilitation

and the Division of Waters, Minnesota Department of Conservation

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IN THE CHISHOLM-DEWEY LAKE AREA,

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ABSTRACT

The Chisholm-Dewey Lake area is in St. Louis County, northeastern Minnesota, and is about 175 miles north of Minneapolis and St. Paul. Included at the south edge of the 105 square mile project area is the city of Chisholm (1960 population, 7,144) which is situated at about the midpoint of the northeastward-trending Mesabi Range, the major iron ore producing district in the United States.

The area is in the Superior Upland physiographic province. A high ridge of Giants Range Granite forms the Laurentian Continental Divide and crosses the lower southeast quarter of the area. Several water and wind gaps dissect this granite ridge; the broadest is at Chisholm where a gap is about 1½ miles wide. North and south of the granite ridge the surface is characteristic of glaciated terrain. It contains numerous swamps and lakes and many knobs and ridges which consist largely of sand, gravel, and boulders. Altitudes within the area range from 1,796 feet above m.s.l. (mean sea level) atop of the divide in the southeast to 1,365 feet at the surface of Shannon Lake in the northwest.

The surficial deposits in the Chisholm-Dewey Lake area consist of glacial clay, silt, sand, gravel, and boulders of Quaternary (Pleistocene) age and organic (peat) deposits and alluvium of Recent age. The bedrock is of Precambrian age and consists of igneous and sedimentary rocks that have been slightly metamorphosed.

Some water is obtainable from every formation in the Chisholm-Dewey Lake area; however, the major aquifers occur in the oxidized zones of the Biwabik Iron-Formation and the sand and gravel (outwash) deposits in the glacial drift. Although the Biwabik Iron-Formation yields large quantities of water, the power costs required to lift the water more than 200 feet, as compared with lifts of 20 feet in glacial drift aquifers, and the constant threat of interruption by mining operations prevent selection of the iron-formation as a dependable source of water supply at Chisholm.

A Chisholm municipal well completed in a glacial outwash deposit that occurs in a bedrock channel on the north edge of the city has been pumped at 1,200 gpm (gallons per minute) for 8-10 hours with 14 feet of drawdown in the well. Another city well, presumably completed in outwash material that occurs between 55 and 74 feet below land surface, was pumped at 125 gpm with 52 feet of drawdown.

A pumping test made of a sand and gravel aquifer underlying an area in the northwest corner of Chisholm showed a coefficient of transmissibility (T) of 15,000 gpd (gallons per day) per foot and a coefficient of storage (S) of 0.0003.

Ground-water recharge, which is derived from local precipitation, occurs mainly after the spring thaw and during heavy, prolonged rainstorms in the summer and early fall. An average annual estimate of total precipitation during 1952-59 on 90.67 square miles of the Chisholm-Dewey Lake area included in the Sturgeon River drainage basin amount to 45 billion gallons. For the same period an estimated 34 billion gallons of water per year was lost through evapotranspiration; 11 billion gallons per year flowed in streams out of the area; and 0.2 billion gallons per year was withdrawn by pumping.

Thirteen comprehensive chemical analyses and reports from well owners show that iron and manganese are the most troublesome dissolved mineral constituents in ground water in the Chisholm-Dewey Lake area. The combined concentration of iron and manganese ranges from 0.04 to 14 ppm (parts per million). The combined concentrations are greater in ground water from aquifers adjacent to or underlying swamp areas than they are in ground water from bedrock and drift aquifers along the slopes of bedrock hills and ridges. Dissolved-solids contents of all water samples analyzed range from 108 to 360 ppm which is below the 500 ppm recommended limit of the U.S. Public Health Service (1961) for public water supplies.

INTRODUCTION

Location and Extent

The Chisholm-Dewey Lake area is in west-central St. Louis County in northeastern Minnesota about 175 miles north of Minneapolis and St. Paul. It includes all of the U.S. Geological Survey Dewey Lake and Dewey Lake SE quadrangles between lat 47°30' and 47°37'30" N. and long 92°45' and 93°00'W. Also included in the south-central part of the area is an appendage of about 3 1/2 square miles which includes most of the city of Chisholm. The project area totals about 105 square miles as shown on the index map of figure 1.

Figure 1.--(caption on next page) belongs near here.

Chisholm, the only city in the project area, is located at about the midpoint of the northeastward-trending Mesabi Range, the major iron ore producing district in the United States. Parts of George Washington Memorial Forest and Superior National Forest are included in the area.

Purpose and Scope

The investigation of ground-water conditions in the Chisholm-Dewey Lake area was made by the U.S. Geological Survey in cooperation with the Department of Iron Range Resources and Rehabilitation and the Division of Waters, Minnesota Department of Conservation. It is a direct result of water-supply shortages reported by the residents of the area who have experienced difficulty in obtaining suitable water supplies. As high-grade iron ore reserves approach depletion, lower grade wash ores and taconite will be mined in increasing quantities, thus enlarging the industrial demand for water. In addition to the large water requirements for beneficiating low-grade ores, an expanding population increases the ground-water demand.

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

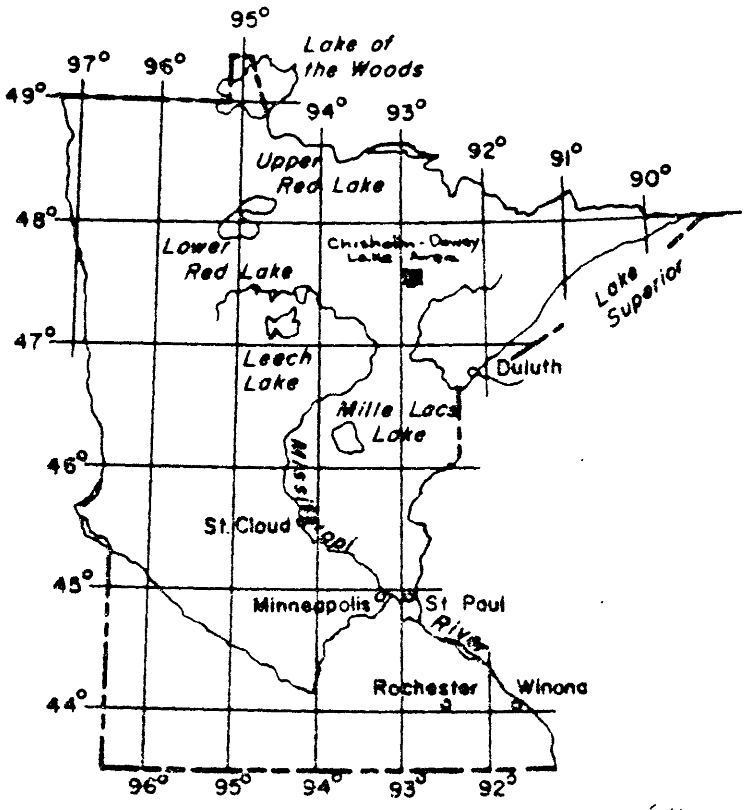

Figure 1.— Map of Minnesota showing location of the area described by this report

The Geological Survey is making similar investigations with the cooperating agencies in other areas of the Mesabi Iron Range where problems in present or future water supplies are expected.

The report describes the geology of the project area briefly, the occurrence of ground water, the hydrology of one of the water-bearing deposits, and the chemical characteristics of the ground-water supplies. Included in the report are a surficial geology map, a piezometric surface map, and several geologic cross sections.

The primary object of this report is to evaluate the glacial deposits as major water-bearing formations in this area. It does not describe in detail the geology of the iron-bearing rocks.

Methods of Investigation

This investigation was started in the spring of 1954. Selected wells were canvassed for information on depth of well, depth to water, water-bearing material, quality of water, and adequacy of supply. A reconnaissance geologic map of the area was made with the aid of aerial photographs. Thirteen water samples were analyzed by the U.S. Geological Survey.

During the period 1957-59, 27 test holes were drilled in the project area, under a contract drilling program, as part of the overall ground-water investigation on the Mesabi Iron Range. Survey geologists collected drill samples, and ran electric logs on most of the test holes. In the summer of 1959 a pumping test was made, under Survey contract, during which water-level drawdown and recovery measurements were recorded. The local hydraulic characteristics of the aquifer underlying the test site were determined using data obtained from this pumping test. Using computed hydraulic constants water-level drawdown prediction curves were drawn up for various distances from a hypothetical well pumping at a constant rate from the aquifer under study.

In October, 1960, 11 test holes were drilled to supplement the existing data; a power auger belonging to the Department of Iron Range Resources and Rehabilitation was used to drill the holes. Additional data were obtained from mining company test-hole records and private driller records.

Acknowledgments

Many property owners allowed the measurement of and provided information concerning their wells. Mr. Harold S. Hanson, Chisholm City Water Superintendent, gave data on city wells and assisted in test pumping in Chisholm. The Oliver Iron Mining Division, United States Steel Corporation, released test-hole information of bedrock depths in the Mesabi Iron Range. The McCarthy Well Company of St. Paul, Minnesota, generously allowed Survey geologists to collect formation samples and record drilling logs on a number of test holes near Chisholm.

This investigation was under the supervision of the District Geologist, U. S. Geological Survey, St. Paul, Minnesota.

Previous Reports

The geology north of the Laurentian Divide (fig. 2) in the area of this report has received little study in previous investigations. A brief description of the topography and general physical features of the area by township is included in the Geological and Natural History of Minnesota (Winchell, 1899). Leverett (1929, 1932) describes the general glacial geology of the region in U. S. Geological Survey professional papers, but Wright (1955) revised Leverett's delineation of the St. Louis sublobe and the Superior lobe in northeastern Minnesota. In the same work Wright proposes that the Valders Drift, described by Thwaites (1943), is in the Minnesota Pleistocene sequence in this part of the state.

The bedrock geology of the iron-bearing rocks of the Mesabi Range south of the Laurentian Divide is described in detail by numerous authors. The first comprehensive study of the Mesabi Range area is by Van Hise and Leith (1911). White (1954) describes the stratigraphy and structure of the Precambrian rocks and briefly discusses the Cretaceous formations and the Pleistocene deposits in a comprehensive study of the Mesabi Range.

Data on the Chisholm water supply are included in a report about the general geology and ground-water occurrence in northeastern Minnesota (Thiel, 1947).

As a part of this project all basic data collected during the investigation were compiled by Thompson and Cotter (1961).

Well-Numbering System

The system of numbering test holes and wells is based on the U.S. Bureau of Land Management's system of subdivision of the public lands. The Chisholm-Dewey Lake area is in the fifth principal meridian and base-line system. The first segment of a well or test-hole number indicates the township north of the baseline, the second the range west of the principal meridian, and the third the section in which the test hole is situated. The lowercase letters a, b, c, and d, following the section number, locate the well within the section. The first letter denotes the 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract as shown in the diagram below. The letters are assigned in a counterclockwise direction, beginning in the northeast quarter. Within one 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

The following sketch of a township and section indicates the method of numbering a test hole. Thus the number 58.20.24ccbl identifies the first well or test hole located in the NW$\frac{1}{4}$SW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 24, T. 58 N., R. 20 W.

GEOGRAPHY

Culture

The 1960 population of the Chisholm-Dewey Lake area was about 8,000; Chisholm has a population of 7,144. The area is served by Minnesota State Highway 73, U. S. Highway 169, and several county and township roads. Ore shipments from the mines in the vicinity of Chisholm are transported to Lake Superior ports via the Duluth, Missabe and Iron Range, and the Great Northern Railroads. North Central Airlines provides scheduled passenger service at the Hibbing Municipal Airport, about 6 miles south of Chisholm.

The economy of Chisholm depends almost entirely on the iron ore industry. Tourism is of some importance; dairying is common in the outlying areas north of Chisholm but usually is performed on a part-time basis by people who are associated with mining. The sale of pulp wood constitutes a small part of the total economy.

Climate

The climate in the Chisholm-Dewey Lake area is characterized by cool, subhumid summers and long, severe winters. Abrupt changes in temperature and precipitation are common. Mean monthly temperatures (U. S. Weather Bureau,Mahoning Mine Station) range from 8.1°F in January to 67.9°F in July. The average annual temperature is 39.3°F. The average growing season is 90-100 days. The mean annual precipitation, including snowfall, is 24.21 inches. The mean ranges from 0.63 inch in February to 3.68 inches in July. Most of the precipitation during the summer period comes in the form of thunderstorms of which there are an average of 27 per year. Snowfall averages near 70 inches per year.

Topography and Drainage

The Chisholm-Dewey Lake area is in the Superior Upland physiographic province of the Laurentian Upland division as described by Fenneman (1938, p. 537-558). Present relief in the area ranges from an altitude of 1,796 feet atop the divide in the SE$\frac{1}{4}$ sec. 5, T. 58 N., R. 19 W., to 1,365 feet at the surface of Shannon Lake in the W$\frac{1}{2}$ sec. 2, T. 59 N., R. 21 W. (See fig. 2.) The most significant topographic feature is the ridge of Giants Range Granite whose prominence forms the Laurentian Continental Divide. The divide is in the lower part of the southeast quarter of the report area and trends southwest. The flanks of the granite ridge dip gently on the south and steeply on the north. A number of water and wind gaps dissect the ridge; the broadest is at Chisholm where the gap is about 1$\frac{1}{2}$ miles wide. West of Chisholm the ridge is progressively less pronounced and gradually merges into the general upland surface.

The streams north of the divide, in this area, are tributary to the Sturgeon River whose waters eventually drain into Hudson Bay. The streams south of the divide are tributary to the St. Louis River which drains into Lake Superior. A little more than one square mile in the extreme southwest corner of the area is included in the Prairie River drainage basin which is tributary to the Mississippi River.

On either side of the divide the surface is characteristic of glaciated terrain. It contains numerous swamps and lakes and many knobs and ridges which consist largely of sand, gravel, and boulders. In some places the topography is controlled by bedrock features which crop out at the surface or underlie a thin mantle of glacial drift.

GEOLOGIC HISTORY

The geologic history of northeastern Minnesota is closely related to that of the general Lake Superior region and, at least in part, to that of the Precambrain Canadian Shield. Therefore, because lengthy gaps exist in the local record, a summary of the geologic history of the Chisholm-Dewey Lake area necessarily includes geologic detail from adjoining regions.

In the general region of the Mesabi Iron Range, which includes the Chisholm-Dewey Lake area, metamorphosed basic lava flows and clastic sediments (Ely Greenstone) suggest a volcanic and aquatic environment during early Precambrain time. Relatively stable conditions prevailed during the deposition of the Soudon Iron-Formation. Subsequent instability produced folding of the rock sequence accompanied by intrusion of dikes and plutons (Saganaga Granite) (Goldich and others, 1961, p. 67). Deposition of sediments (Knife Lake Group) continued as subsidence occurred in some areas and contemporaneous erosion and uplift occurred in other areas.

Near the end of early Precambrain time a major period of deformation, accompanied by intrusion of granitic magma from the Giants Range and Vermilion batholiths produced the Algoman Range of mountains. The long period of erosion that followed reduced the Algoman mountains to a peneplain.

The Animikie sediments were deposited in a sea that spread out over a broad relatively level erosion surface during middle Precambrian time. The general fine-grained to granular nature of the Animikie Group indicates that an oscillating Animikie sea (White, 1954, p. 41-49) stood over the present site of the Mesabi Iron Range. Presumably this sea extended at least several miles northward to a land mass that consisted of Keewatin Greenstone, Algoman Granite, and other rock. The Biwabik Iron-Formation, and Pokegama Quartzite are the formations of the Animikie Group that were deposited in this environment.

This brief discussion of Precambrian history for the Chisholm-Dewey Lake area is based on the stratigraphic succession in Minnesota described by Goldich and others (1961).

The geologic history of this area during the Paleozoic Era and the early part of the Mesozoic is conjectural. Probably the northeastern region of Minnesota was relatively stable and stood above sea level until the beginning of Late Cretaceous time. However, data from drill holes and open-pit mines show that during the late Cretaceous Epoch a marine invasion moved eastward across the Mesabi Range as far as Keewatin (Bergquist, 1944, p. 3) and that continental deposition extended eastward as far as Virginia. The initial areal distribution of the Upper Cretaceous Series in northeastern Minnesota is either partly destroyed by pre-Pleistocene erosion or obscured by extensive glacial-drift cover. Near the end of the Cretaceous Period the retreat of the sea exposed the land surface to stream erosion and regional dissection.

During the Pleistocene ice age, which began about a million years ago, four major ice sheets advanced into Minnesota. The slowly moving ice scraped huge quantities of rock and soil from the land surface and redeposited the debris as glacial drift. This drift covers much of northeastern Minnesota, fills preglacial valleys, and comprises the belts of ridges that mark the former margins of glaciers.

The glaciation most prominent in Minnesota is the last, or Wisconsin Glaciation, which began almost 100,000 years ago. In a subsequent section of this report, a discussion of the Pleistocene, under the section on Geology, lists the stades that occurred during the Wisconsin and details the glacial effects in the project area.

A study of the glacial deposits indicates that glaciers moved into or across the project area during the Cary and Valders Stades. During Cary time the Rainy lobe moved southwestward into the area, crossed the Giants Range, and extended into central Minnesota. After the ice of the Rainy lobe had melted, the area was invaded again by the St. Louis sublobe and the Superior lobe of the Valders Stade. The St. Louis sublobe moved into the area from the northwest as an offshoot of the Des Moines lobe. It terminated just beyond the eastern boundary of the project area north of the Laurentian Divide, but south of the divide it extended about 30 miles farther east in the St. Louis basin. The Superior lobe then advanced out of the Lake Superior basin and ascended the south flank of the Giants Range overriding the ice of the St. Louis sublobe in the area between Keewatin and Aurora. Although the Superior lobe ice crossed the Laurentian Divide in a narrow gap north of Buhl and extended about a mile beyond the crest, it failed to enter the gap at Chisholm which is at an altitide more than 100 feet lower. The contemporaneous St. Louis sublobe ice apparently occupied and blocked the gap at Chisholm but not the gap north of Buhl, as suggested by the distribution of its drift.

The last episode in geologic history began about 10,000 or 11,000 years ago when the ice retreated and exposed the glaciated regions to subaerial erosion. In the Chisholm-Dewey Lake area during this relatively short interval of geologic time, the local streams eroded to their present level and deposited only minor amounts of alluvium along their channels; and many of the lakes slowly filled with decomposed vegetation to form the numerous swamps and peat bogs scattered throughout the area. The present glaciated topography is in a youthful stage; stream networks are not yet extensive and drainage is generally poor. Streams are slowly eroding their channels down to base level and removing the cover of glacial drift which overlies the bedrock in much of this area.

GEOLOGY

The surficial deposits in the Chisholm-Dewey Lake area consist of glacial deposits of clay, silt, sand, gravel, and boulders of Quaternary (Pleistocene) age and organic (peat) and alluvial deposits of Recent age. The Pleistocene deposits were laid down on an irregular, eroded bedrock surface. The thickest accumulation of glacial drift occurs in bedrock depressions. The Recent alluvial deposits are restricted to stream courses and lake basins. The organic deposits have encroached in lake basins and other depressions left after the retreat of the last glacier, completely filling some basins but leaving remnants of lakes in others. The bedrock which generally underlies the surficial deposits is of Precambrian age. It consists of rocks of igneous and sedimentary origin that have been slightly metamorphosed.

Table 1 lists the principal geologic units in the Chisholm-Dewey

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Table 1.--(captioned on the next page) belongs near here.

Lake area and briefly describes their physical and water-bearing characteristics. Figure 2 shows the surface geology of the area together with some related subsurface information. Figure 3 shows three generalized geologic sections of the area on which the relationship between

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Figures 2 and 3.--(captioned on the next page) belong near here.

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the bedrock and the overlying glacial deposits is shown. Control points for the subsurface geology were obtained from well schedule data and bedrock outcrops; the surface profiles were constructed from the U.S. Geological Survey topographic quadrangle base map of the area.

Table 1.--The Principal geologic units in the Chisholm-Dewey Lake area and their water-bearing characteristics.

Figure 2. Map of the Chisholm-Dewey Lake area showing surficial geology, areas where bedrock is near the surface, and lines of geologic sections.

Figure 3.--Generalized geologic sections in the Chisholm-Dewey Lake area, Minnesota.

Precambrian Rocks

The bedrock in the project area consists of igneous, metamorphic, and sedimentary rocks of Precambrian age. The rocks are divided into the Keewatin Series of the earlier Precambrian age, the Giants Range Granite of middle Precambrian age, and the Animikie Group of later Precambrian age.

Keewatin Series

The oldest rocks known in the area are the metamorphosed basic lava flows of the Keewatin Series. The lava flows, named the Ely Greenstone (Van Hise and Clements, 1901), underlie younger rocks in the southern part of the area and crop out only where the younger rocks are stripped away by erosion. They do not yield water to wells in the area.

Giants Range Granite

Granite intrudes greenstone of the Keewatin Series and crops out as knobs and ridges. It is best exposed along the Laurentian Divide near the southern limit of the area. This rock, the Giants Range Granite, is the chief bedrock type within the project area. It is mapped and described in detail by Allison (1925).

Animikie Group

The Pokegama Quartzite and the Biwabik Iron-Formation of the Animikie Group truncate the Giants Range Granite and older rocks in the southern part of the project area. Although these strata are obscured by the overlying glacial drift, detailed studies of rock exposures in open-pit mines correlated with drill-hole data indicate that they are conformable, dip to the south at a low angle, and strike east-northeast along the southern flank of the Giants Range (Grout and others, 1951; White, 1954).

The Biwabik Iron-Formation is an important aquifer in the area, whereas the Pokegama Quartzite is relatively insignificant. Accordingly, the following discussion regarding the relationship of hydrology to rock alteration is limited to the Biwabik Iron-Formation.

Biwabik Iron-Formation.-- The Biwabik Iron-Formation is not only a commercially important source of iron ore, but it is also an abundant source of water for municipal and industrial uses in the Mesabi Range area. The water-bearing characteristics of the formation are not uniform but range widely as they are directly associated with the degree of fracturing and alteration within the rock. The porosity and permeability of the unaltered iron formation, which is called taconite (White, 1954), are related to fractures and fissures. The porosity and permeability of the iron-enriched zones, however, are related to the enlargement of voids produced by the leaching of silica.

The Quarternary deposits within the project area consist of glacial drift of Pleistocene age and swamp and alluvial deposits of Recent age. The glacial drift overlies the bedrock in most of the area, resting on an erroded crystalline rock surface.

The surficial geologic map (fig. 2) shows the figuration of the buried crystalline rock near Chisholm, subsurface data from test-hole records and wells indicate the drift fills a southeast-trending buried erosion channel cut in granite bedrock. This channel breeches the Laurentian Divide in the vicinity of Longyear Lake immediately east of Chisholm. Although the thickness of drift in the channel varies somewhat, it attains a known depth below the present surface of about 140 feet. The channel increases in width and decreases in depth northwest and northeast of Chisholm where it apparently separates into two branch channels.

The drift is probably very thin in secs. 20, 29, 30, and 31, T. 59 N., R. 20 W. Locally, granite crops out at the surface and the characteristics of the topography indicate that this is an area underlain by a broad, low relief bedrock high. (See fig. 2.)

Quaternary

Swamp deposits and some alluvial deposits overlie the glacial drift. These have accumulated since the retreat of the last ice sheet. They are not differentiated on the surficial geologic map.

Pleistocene

The Wisconsin stades are classified through the naming of ice lobes and sublobes. Three ice lobes traversed the project area; they are: 1) the Rainy lobe of the Cary stade, 2) the St. Louis sublobe of the Valders stade, and 3) the Superior lobe of the Valders stade.

Glacial drift is differentiated into two principal types of deposits based in general on the nature of deposition. The two types are 1) till, or nonstratified drift, and 2) outwash, or stratified drift. Till is generally a compact, unsorted sediment whose particles range in size from clay to boulders. It is deposited on the land by lodgment of debris as the glacier moves over the surface and by accretion of the glacier's load, in place, as the ice melts. Outwash deposits are generally poorly to well-sorted sand and gravel but may contain sizes from clay to boulders. They were deposited by glacial melt water flowing within and from the ice mass. Outwash deposits accumulate under complex and changing environments; therefore, their compositions vary considerably through short distances. For example, horizontal silt and sand beds that were deposited in glacial lakes are commonly interbedded with crossbedded sand and gravel beds that were deposited by heavily loaded melt-water streams.

Glacial drift deposits in the Chisholm-Dewey Lake area, which are differentiated on the basis of their form and environment of deposition, consist of: ground moraines, valley fill deposits, kames, kame terraces, and eskers. Ground moraine is commonly gently rolling terrain composed largely of till and is deposited when glacial movement is more or less uniform or when mass wasting from the ice occurs. In the project area, however, ground moraine was plastered over a bedrock surface and is not gently rolling but reflects the more rugged terrain of the underlying surface. Valley fill deposits consist of valley-bottom fill and stream-terrace fill composed largely of sand and gravel. They were deposited in melt-water sluiceways by overloaded streams emanating from the fronts of the glaciers. A kame is a hill or knob of outwash deposited by melt water and formed in contact with ice walls on one or more sides. Because of the mode of deposition grain sizes within a kame range from silt to large boulders. The material is generally poorly sorted adjacent to the ice walls where collapse has occurred and well sorted away from the ice walls where deltaic-like deposition occurs. Kames are common in the Chisholm-Dewey Lake area. A kame terrace is similar to a kame except that it is composed of outwash deposited between a valley wall and an ice tongue that occupied the valley at the time of outwash deposition. Structurally a kame terrace is similar to a stream-terrace-fill deposit except that bedding on the side originally held up by the ice wall was distorted after the ice wall collapsed. Also, most kame terraces are composed of a wider range of particle sizes than stream-terrace-fill deposits. Eskers are sinuous ridges of outwash that are believed to have been formed in ice-walled passageways of subglacial and englacial streams. They have steep sloping sides and contain particles ranging in size from silt to boulders. Eskers are common in the project area.

The foregoing features are not always easily definable in the field. Many of these features were formed under local environments that merged and the deposits graded into one another. For complete descriptions of glacial processes, see works by Flint (1957) and Thwaites (1946).

Drift of the Rainy lobe.-- The drift of the Rainy lobe, named after the Rainy River area of northeastern Minnesota (Elftman, 1898), is the oldest glacial deposit recognized in the project area. It consists predominantly of rock particles derived from the granitic and metamorphic rocks of northeastern Minnesota. The glacial lobe that deposited the drift moved southwestward into this area. Glacial drift in Cook County, similar to the drift in the project area, was described by Sharp (1953) and assigned to an age of "about middle Wisconsin (Wisconsin III or Cary)." In a more recent interpretation of the glacial geology of eastern Minnesota, drift from the Rainy lobe was traced southwestward into east-central Minnesota where the lobe apparently separated into two sublobes, the Brainerd and the Pierz. According to Wright (1956, p. 10), who bases his interpretation largely on drumlin (elongate hill) patterns, stratigraphic relations with other drift sheets, and moraines, the Rainy drift is of Cary age.

Till of the Rainy crops out in a small segment of the project area near Chisholm. North of Chisholm the drift is exposed in road cuts and gravel pits where it is composed largely of sand, gravel, and boulders. Known thicknesses of the drift range from 0 to 30 feet. Although a mantle of younger till nearly obscures the drift of the Rainy, its surface dominates the topography in large areas around the bedrock hills and ridges. Kames and kame terraces of drift of the Rainy lobe are the major landforms that flank these bedrock highs.

The diverse conditions that prevailed during the deposition of Rainy lobe outwash are suggested by the internal structure and range in sorting in adjacent interbedded lenses of sand and gravel. For example, the complex internal structure of a kame is exposed in a gravel pit in the SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 24, T. 59 N., R. 21 W. Here beds of sand and gravel are interbedded and crossbedded, and although the grain sizes range from silt to pebble gravel, sand predominates in the individual beds. In contrast, a gravel pit in a Rainy lobe kame in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 23, T. 59 N., R. 20 W., shows about 6 feet of boulder gravel overlying about 12 feet of pebble gravel. Silt-size grains are included in each bed but most particles are larger than very coarse sand.

Drift of the St. Louis sublobe.-- The youngest glacial drift in the project area is dominantly gray calcareous clayey till that weathers to a buff color. It was deposited by the St. Louis sublobe of the Des Moines lobe, which moved into Minnesota from the Keewatin district of northern Manitoba (Leverett, 1932; Wright, 1955).

The till veneers much of the older drift and bedrock in the project area. Although it is generally less than 10 but more than 5 feet thick, in one road cut it is 20 feet thick and in several gravel pits it is absent.

Soil profiles on the till are immature and rarely extend to depths greater than one foot. The till is slightly calcareous and contains some limestone pebbles, but most of the particles larger than pebbles are fragments of the Giants Range Granite. Clay- and silt-size carbonate particles are leached to depths ranging from two feet in compact clayey till to eight feet in relatively loose textured silty till.

Leverett's (1932, pl. 2) border for the easternmost extent of the St. Louis sublobe drift is drawn about N. 30° E. from about the SW$\frac{1}{4}$ sec. 17, T. 58 N., R. 20 W., to the center of the south side of sec. 1, T. 59 N., R. 20 W., from whence it trends northwest, out of the project area.

The outwash deposits associated with the drift of the St. Louis sublobe are generally restricted to channels cut into the underlying drift of the Rainy. In a few places channels are cut into the underlying bedrock. Eskers of probable St. Louis sublobe deposition are common in the area.

One outwash deposit, probably of St. Louis sublobe deposition, is exposed in a gravel pit in the SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 9, T. 58 N., R. 20 W. This deposit underlies 2 to 6 feet of clayey till and consists of a medium- to coarse-grained, well-sorted, stratified sand. The most prominent outwash body of the drift is north of and in the notch that breaches the ridge of Giants Range Granite at Chisholm. Well and test-hole records indicate that the outwash lies in a channel cut into the underlying drift of the Rainy (Oakes, 1963). The narrowest part of this channel, which is at the north end of Longyear Lake, is about a quarter of a mile wide. On either side of the marshy area that marks the channel, drift of the Rainy lobe, veneered with clayey till of drift of the St. Louis, rises abruptly above the lowland surface.

The eskers trend north and northeast and are believed to have formed during the waning stages of the St. Louis sublobe ice. They have sharp crests, and bedding of included sand lenses is undisturbed. An excellent example of an esker is near the Balkan Township Garage, along State Highway 73 about one mile north of Chisholm. The highway cuts the esker transversely and exposes material that ranges in size from fine sand to boulders. Near the base, well-sorted sand and fine gravel lenses are interbedded in layers from 1 to 3 feet thick. Nearer the surface the material is poorly sorted and boulders measuring as much as 3 feet in diameter are common within the sand and gravel. The surface layer consists of sand, gravel, and small patches of till, and it is thickly strewn with boulders as much as 7 feet in diameter. The crest of the esker is about 30 feet above the surrounding low areas and the sides repose at angles of about 30 degrees.

Drift of the Superior lobe (Valders age).-- Valders Drift of the Superior lobe mantles a small part of the project area in the southeast corner (fig. 2). The ice lobe approached this area from the south after it was diverted from its southwestward advance through the Superior basin by contemporaneously existing St. Louis sublobe ice. The history and regional extent of the Valders Drift in Minnesota have been defined by Wright (1955).

The Valders Drift in the project area is composed of clayey till, red brown in color. Slate pebbles from south of the Giants Range are the major rock fragments incorporated in the till. The drift is locally calcareous. Outwash deposits from the Superior lobe are insignificant in the project area.

Recent

Alluvium and Swamp Deposits

Alluvium occupies a relatively small part of the area. It consists largely of reworked glacial drift along stream courses and present day beaches around lake shores. Fragments in the alluvium range in size from clay to boulder, and the deposits are generally thin.

Swamp deposits, consisting of organic accumulations of muskeg and peat, make up a large part of the surface in the project area. Many closed depressions, which were formerly occupied by lakes, are now completely filled with swamp deposits. The lakes that remain are partly filled by an encroaching sedge mat and peat.

GROUND WATER

Occurrence

Ground water is subsurface water which occurs in the zone of saturation. The zone of saturation is that part of the subsurface in which all voids and pore spaces in the earth materials are filled with water under atmospheric or greater pressure. The water table is the surface of the zone of saturation. Subsurface water suspended by molecular attraction and cohesive forces above the water table is called vadose water. Vadose water occurs in the zone of aeration. Water in the zone of aeration is not available to wells but it is available for plant growth and evaporation.

Ground water in the project area fills the interstices in unconsolidated and semiconsolidated earth materials and the fractures in the crystalline bedrock. It occurs under both water-table and artesian conditions. Under water-table conditions the water is unconfined, that is, it is in contact with the atmosphere through the zone of aeration. Under artesian conditions the water is confined by an impervious layer of strata which causes the water to rise above the base of the confining bed when encountered in a well.

A rock or stratum that will yield a usable quantity of water to wells 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 largely 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.

Movement

Ground water generally moves down the hydraulic gradient from areas of recharge to points or areas of discharge. The hydraulic gradient depends on the permeability and cross-sectional area of the earth materials and the quantity of water in transit. Inasmuch as the foregoing factors are not constant, the hydraulic gradient and, consequently, the rate and direction of ground-water flow, vary considerably with time and place.

Figure 4 shows the piezometric (pressure) surface of ground water

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Figure 4 (caption on next page) belongs near here.

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in the Chisholm-Dewey Lake area during the summer of 1954. Points of equal hear (hydrostatic pressure) are connected by contour lines on the map. The water levels in the various wells used in drawing the contour lines were assumed to be at or very near the water table. Therefore, on this particular map, the piezometric surface and the water table coincide. The ground water generally moves from areas of high head to areas of low head, at right angles to the contour lines.

The piezometric contours on figure 4 compared with the bedrock data on figure 2 show that the direction of ground-water movement in the project area is largely controlled by the configuration of the bedrock surface. The piezometric surface slopes gently northeast of Chisholm to the 1,460= foot contour in the northeast quarter of the area, from which it begins a steeper ascent; to the west of this gently sloping shelf, the surface slopes more steeply to the 1,410-foot contour from which it begins to flatten out considerably. The declivity of the contours, in addition to being affected by the factors mentioned at the beginning of this section, may also be affected by the slope of the underlying bedrock surface. Therefore, the gradual slope of the piezometric surface northeast of Chisholm may be due largely to a dipping bedrock surface, a higher coefficient of permeability of the water-bearing materials underlying that area, or a combination of the two.

Figure 4.-- Map of the Chisholm-Dewey Lake area, Minnesota showing contours on the piezometric surface in summer 1954.

The Laurentian Divide, the major drainage divide in the area, is also a ground-water divide. This is shown by the reversal of ground-water flow direction in the notch at Chisholm.

Recharge

All ground water in the Chisholm-Dewey Lake area is derived from precipitation which falls on the land surface as rain, sleet, hail, and snow. Ground-water recharge is the component of precipitation that percolates to the zone of saturation. The percentage of precipitation that becomes recharge is dependent on factors related to climate and geology.

The seasonal distribution of precipitation is an important factor controlling the amount of annual recharge. Maximum recharge occurs during the spring thaw and after heavy summer rains. Evapotranspiration rates are low during the spring and more precipitation may reach the ground-water body than during summer or early fall when evapotranspiration rates are high. In addition, rainfall coincident with rapidly rising temperatures in the spring will increase the possibility of recharge from melting snow. Conversely, warm dry winds during the spring will reduce recharge by sublimation of snow and evaporation of snowmelt.

The frequency, intensity, and duration of rainfall influence the total increment of recharge and the rate of recharge. Frequent precipitation will tend to maintain the soil moisture at field capacity and thereby permit a comparatively constant flow of water to the zone of saturation. If rainfall is too light to exceed the interception capacity of vegetation or to satisfy the soil moisture deficiency, no recharge will occur. On the other hand, if precipitation is sufficiently intense to exceed the infiltration rate of the soil, water flows overland directly to streams flowing out of the area or it accumulates in depressions where part of it evaporates. In general, in comparing the effects of two or more rainfalls, other factors being equal, recharge will increase proportionately with the duration of precipitation.

Recharge is virtually at a standstill during the winter months owing to the impervious nature of the frost layer and the fact that precipitation is locked in the form of snow and ice. Some recharge may occur on a few days when daily temperatures rise above freezing and a small amount of frostmelt reaches the ground-water body.

Discharge

Ground water discharges from the project area through both natural and artificial means. Through natural means the ground water discharges as springs, seeps, and stream underflow into surface-water lakes and streams. Subsurface discharge from the area occurs as down gradient ground-water flow, through the earth materials, into the adjacent areas as shown on figure 4. Evapotranspiration (evaporation and plant utilization of ground water) accounts for the largest part of the discharge from the area. The following rough estimate of a water budget for that part of the area included within the Sturgeon River drainage basin is included here to give an idea as to the annual volume of water moving through this area. Computations are based on average precipitation for 1952-59 from Weather Bureau records at the Hibbing Power Substation (about 5 miles southwest of Chisholm) and on stream-flow measurements of the Sturgeon River for 1952-59 recorded at the gaging station (about 3 1/2 miles north of the project area) maintained by the Surface Water Branch of the U.S. Geological Survey in cooperation with the Minnesota Department of Conservation, Division of Waters, and the Department of Iron Range Resources and Rehabilitation. The Sturgeon River drains an area of 187 square miles above the gaging station near Chisholm of which 90.67 square miles is included within the Chisholm-Dewey Lake area. The results of the computations are as follows:

Average annual precipitation - - - - - - - - - - - - - 45 billion gallons

Increment of Sturgeon River flow

attributed to surface-water runoff - - - - - - - 7 billion gallons

Increment of Sturgeon River flow

attributed to ground-water discharge - - - - - - 4 billion gallons

Total average annual Sturgeon

River flow - 11 billion gallons

Average annual evapotranspiration - - - - - - - - - - 34 billion gallons

Only 0.2 billion gallons of water is discharged from the area annually through artificial means. Essentially all of the artificial discharge occurs as pumpage from individual domestic wells or from the municipal wells at Chisholm. Most of the water pumped from domestic wells is returned to the ground by way of septic tanks and cesspools. The rest of the domestic pumpage is transpired or evaporated. The water pumped from the Chisholm municipal wells is discharged to the drainage of the St. Louis River by way of the sewage treatment plant.

In the foregoing computations, the annual evapotranspiration would roughly equal the total precipitation minus the total Sturgeon River flow. Additions to or reductions in storage in the ground-water reservoir have not been accounted for; it is believed that ground-water storage, for this period, was more or less stable.

The computations indicate that there is no lack of water in this area. Withdrawal of ground water through wells is a means of intercepting discharge flowing from the area. Pumping also lowers local water levels, thereby cutting down on plant growth which in turn reduces evapotranspiration rates. Therefore, the introduction of additional pumping wells may increase the amount of water available for municipal and industrial consumption.

HYDROLOGY

Pumping Tests

The hydraulic characteristics of an aquifer are approximated by field pumping tests. An aquifer in the vicinity of Chisholm was tested in September, 1959. This aquifer, which is composed of glacial sand and gravel, occurs between depths of 11 and 43 feet in well 58.20.16cbc3 and 14 and 19 feet in well 58.20.17dda4.

Well 58.20.17dda5, which is located on the west side of Chisholm near the Calvary Cemetery, was tested at a rate of 80 gpm (gallons per minute) for 24 hours. The drawdown in the aquifer was measured in wells 58.20.16cbc3, 58.20.17dda6, and 58.20.17dda4. The drawdown data collected at well 58.20.17dda4 were not in accord with the data collected at the other observation wells.

Arithmetic graphs of the water-level drawdown and recovery measurements in the two usable observation wells are shown on figure 5. Computations

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Figure 5. (caption on next page) belongs near here.

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show that the average T of the aquifer in the vicinity of the test is about 15,000 gpd per foot and the average S is about 0.0003.

Figure 5.-- Water levels in observation wells during the pumping of well 58.20.17dda5 near the Calvary Cemetery at Chisholm.

Using the above aquifer constants, theoretical prediction curves were drawn of water-level drawdowns at distances from 1 to 1,200 feet from the pumping well, discharging at a rate of 80 gpm; these curves are shown on figure 6. The theoretical curves are not adjusted for boundaries.

Figure 6.--(caption on next page) belongs near here.

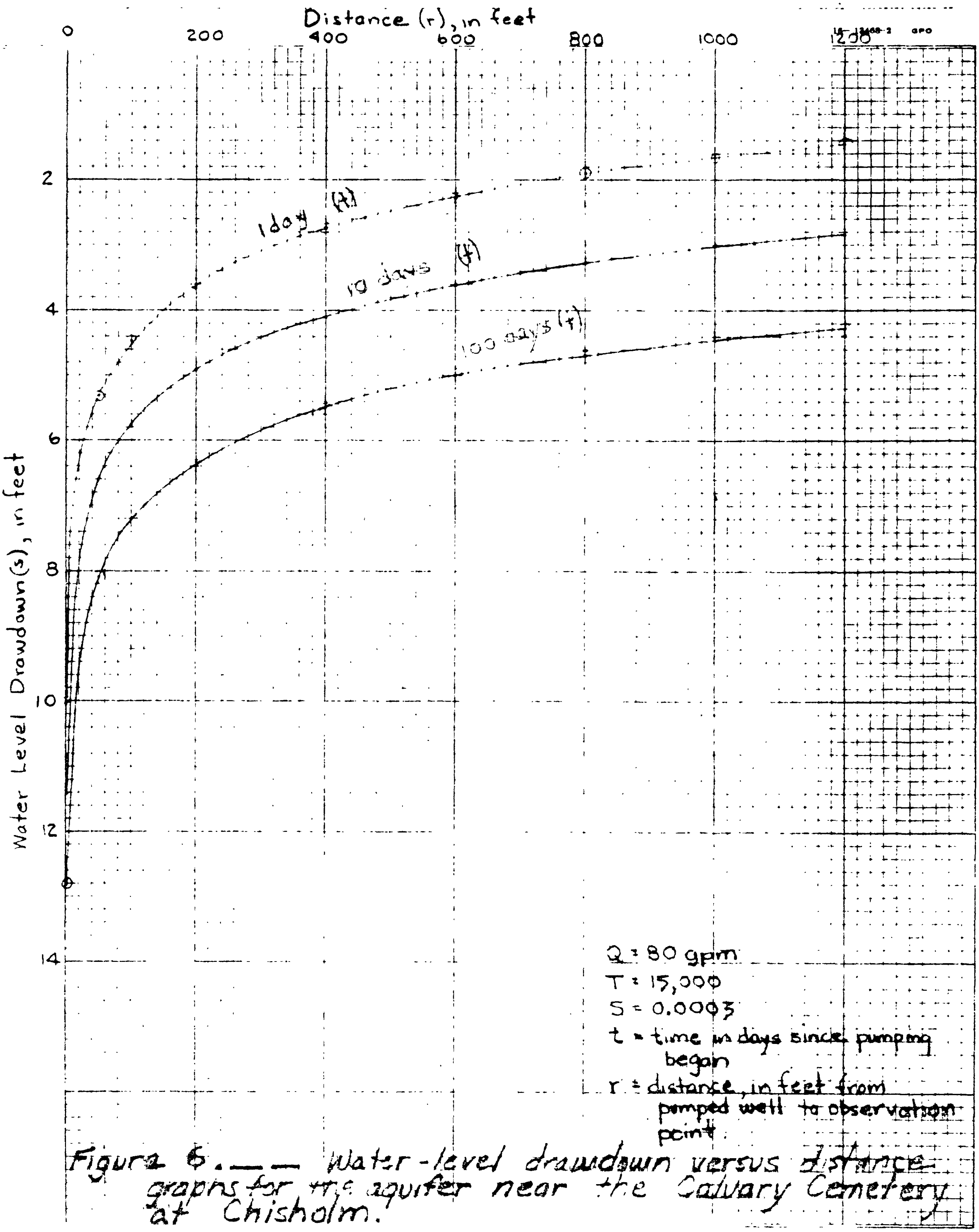
The curves on figure 6 give an approximation of aquifer performance in the general area of the pumping well and the observation wells.

The drawdown in the aquifer theoretically is directly proportional to the pumping rate. For example, doubling the pumping rate from 80 to 160 gpm doubles the drawdown; that is, after 1 day of pumping at 160 gpm the drawdown 1 foot from the well would be increased from 10 feet to 20 feet, 200 feet from the well from 3.6 to 7.2 feet, etc.

The curves are useful in determining the number, spacing, and pumping rates of wells in a well system design based on optimum drawdown in each well. By making the necessary adjustments for annual increments of recharge and for the effects of boundaries, a system of wells could be designed to yield the maximum amount of water without drawing water levels down below the tops of the well screens.

An analysis of the pumping test indicates that significant boundaries were reached by the cone of depression. The effects of recharge boundaries were detected in the data from well 58.20.17dda6 after 12 minutes and from well 58.20.16cbc3 after 45 minutes of pumping. Significant discharge boundaries were reached by the cone of depression at 250 minutes and 200 minutes in the two wells, respectively. Recharge boundaries tend to lessen the water-level decline in an aquifer, and discharge boundaries tend to increase it.

Figure 6. -- Water-level drawdown versus distance graphs for the aquifer near the Calvary Cemetery at Chisholm.



(DO NOT USE THIS SPACE EXCEPT FOR BINDING PURPOSES)

Figure 6.—— Water-level drawdown versus distance graphs for the aquifer near the Calvary Cemetery at Chisholm.

The recharge boundary may be due to the well's cone of depression intercepting a zone of more permeable material or to the inception of vertical leakage from the overlying material. The discharge boundary may be due to the well's cone of depression intercepting a zone of less permeable or nonpermeable material. Bedrock and till contacts constitute hydrologic discharge boundaries.

A sand and gravel aquifer in the north half of sec. 16, T. 58 N., R. 20 W. was pump tested using two-inch-diameter well points. The lense of sand and gravel is penetrated by test well 58.20.15babl between 11 and 39 feet below the land surface and represents a coarse phase of an outwash deposit. The coefficient of transmissibility indicated by the test is about 50,000 gpd per foot. Additional testing would be required to determine more accurately the T and S values and to detect boundaries of the aquifer.

Water-Level Fluctuations

Water-level fluctuations in wells are produced by various natural and artificial causes. Only those fluctuations that are attributed to changes in ground-water storage in the Chisholm-Dewey Lake area are significant in the evaluation of recharge and discharge.

The storage changes in an aquifer at Chisholm are reflected in the seasonal water-level fluctuations as recorded by a continuous water-level gage installed on an unused municipal well (fig 7).

Figure 7 -- (caption on next page) belongs near here.

Figure 7.--Graphs showing fluctuation of the water level in well 58.20.16dc1, discharges of the Sturgeon River near Chisholm, and precipitation at the Hibbing Power Substation for the period 1952-59.

Maximum recharge, reflected as peak water levels on the hydrograph, occurs in the spring when snow, frostmelt, and spring rains contribute to ground-water storage. At the onset of the growing season, the vegetation begins to flourish and the water level declines. Increased city pumpage from this aquifer adds to the decline which continues through the summer, fall, and winter months unless summer or fall precipitation produces sufficient recharge to delay or reverse the trend temporarily as happened in 1955 and 1959.

In 1958 the water level rose only slightly during the spring thaw as a result of deficient snowfall during the preceding winter. The water level continued to rise, however, in response to heavy precipitation from May through September and reached a maximum in November as above-average temperatures delayed the formation of the frost layer and thereby permitted recharge at a time when evapotranspiration rates were low.

The normal winter trend of the water level is downward as recharge is effectively reduced to zero during freeze up and discharge to streams continues.

The peak discharge on the Sturgeon River usually occurs during the spring thaw, but lesser peaks are common during summer storms. The magnitude of the spring peak discharge depends principally on moisture stored in the accumulated snow, the thickness and character of the frost layer, and the incidence of spring rain. Summer precipitation produces runoff only after the demands of interception by foliage, depression storage, soil field capacity, and infiltration rates have been exceeded.

The hydrographs of the observation well at Chisholm and the discharge of the Sturgeon River demonstrate that precipitation produces corresponding changes in surface water and ground water. The factors that control the magnitude of surface runoff to streams and recharge to ground water are variable during periods of equal increments of precipitation and accordingly produce effects that are generally in the same direction but not proportional nor in phase. For example, the peak discharge in the Sturgeon River shows a quick response to direct runoff from the spring thaw, whereas the maximum ground-water level occurs about a month later as a result of gradual increases in storage produced by recharge.

Effects of Pumping

The following discussion is based largely on a paper by C. V. Theis (1938) in which he discusses the significance of the cone of depression in ground-water bodies.

Before the introduction of wells, an aquifer is in a near state of equilibrium; that is, natural recharge is approximately equal to natural discharge. When additional discharge is imposed upon the aquifer by pumping, the balance is disturbed and either natural recharge must increase, natural discharge must decrease, or water storage must decline. Upon pumping a well, a cone of depression, whose apex is at the well, is formed in the vicinity of the well. Actually, it is not a true cone, but for purposes of explanation it may be considered as such. The lateral extent of the cone is dependent upon the transmissibility and storage coefficient of the aquifer and the length of time of pumping. The vertical extent of the cone is dependent upon the transmissibility and rate of pumping.

In water-table aquifers, the initial growth of the cone is in the order of hundreds to possibly thousands of feet per day. As the area influenced by the cone is increased, the radial growth of the cone diminishes to a few feet or tens of feet per day.

In the artesian aquifer where the storage coefficient is much smaller than in the water-table aquifer, the initial spread of the cone is in the order of thousands to tens of thousands of feet per day. As the cone deepens the hydraulic gradient of the moving water in the aquifer is increased and, in effect, water enveloped by the cone is funneled into the pumping well.

To satisfy the ever-increasing water demands of the spreading cone without mining water below critical levels in the aquifer, areas of rejected recharge or natural discharge must fall under the influence of the cone. Areas of rejected recharge occur where the water table is at or near the surface. This condition may cause heavy vegetation and loss of water to evapotranspiration, or it may cause the formation of springs or surface-water bodies because the water is unable to percolate into the ground-water body. Where areas of natural discharge fall under the influence of the cone, water which ordinarily would flow out of the area is diverted into the pumping well. By the same token, effluent surface-water streams which receive part of their flow from ground-water discharge may become influent streams which contribute water to the ground- water body where they fall under the influence of the cone.

Recharge and discharge appear to be in equilibrium in the Chisholm aquifer. The hydrograph of well 58.20.16dbc1 suggests that recharge occurs until the natural discharge and the water pumped from storage have been replaced. The nonpumping water level rises to within a few feet of the land surface during the spring thaw each year as indicated on the graph (fig. 7) in May 1954. The 1954 maximum was recorded when well 4 was temporarily out of service and represents a stage that approaches natural conditions without artificial discharge. During the succeeding years, the nonpumping levels, which are not shown on the graph because only monthly lows are plotted, also attained levels within a few feet of the land surface.

The marsh surrounding well 4 is submerged during the spring thaw and apparently furnishes recharge to the aquifer. Accordingly, the potential yield of the aquifer seems to be substantially greater than the current withdrawal. A uniform lowering of the water level throughout the aquifer would not only reduce natural discharge, but also would increase recharge of water that is rejected during the spring.

New wells in the Chisholm aquifer should have adequate separation from well 4 and from each other to maintain submergence of the well screens at all times. The proper well spacing and pumping rates that fulfill this requirement also will produce a relatively uniform widespread depression in the piezometric surface, a configuration that approaches the optimum for inducing additional increments of recharge.

AVAILABILITY OF GROUND WATER

Some water is obtainable from every formation in the Chisholm-Dewey Lake area; however, the major aquifers occur in the oxidized zones of the Biwabik Iron-Formation and the sand and gravel deposits in the glacial drift. Because the Biwabik Iron-Formation is present in such a small part of the area (fig. 2), the glacial deposits are considered the most important source of available ground water.

Ground Water in the Precambrian Bedrock

Ely Greenstone

No inventoried wells obtain water from the Ely Greenstone. The unaltered greenstone is a massive, compact rock and is impermeable except for sporadic zones of fracture near its surface. Where these zones are below the water table, small yields, sufficient for domestic needs, may be obtained.

Giants Range Granite

Like the Ely Greenstone, unaltered Giants Range Granite is a massive, compact, impermeable rock. Small quantities of ground water can be developed from its zones of fracture. Well logs and outcrops indicate that the zones of fracture are shallow and are limited in areal extent. The effect of shallow fracturing is demonstrated by comparing the yields of 17 wells in the area that penetrate granite. Nine wells out of twelve that penetrate granite to depths of less than 18 feet yield adequate domestic ground-water supplies. Five wells that penetrate granite to depths ranging from 26 to 268 feet are considered to be inadequate for domestic needs. In this area, the yield of wells drilled in granite commonly is not increased by drilling to depths greater than 20 feet.

Pokegama Quartzite

Information is not available on ground-water yields from the Pokegama Quartzite. The occurrence of water in the quartzite probably is similar to that in the Ely Greenstone and Giants Range Granite.

Biwabik Iron-Formation

A continual discharge of large quantities of water from mines indicates that, in places, the Biwabik Iron-Formation is very permeable. In such places, high rates of pumping are necessary to lower the water level sufficiently to permit mining operations. About half a mile southeast of Chisholm the Bruce mine shaft, which has been converted to a water well, is the only well in the area known to penetrate the Biwabik Iron-Formation. Mining operations have necessitated the pumping of as much as 2,000 gpm from this shaft for the purposes of dewatering the formation.

Use of the Biwabik Iron-Formation as a source of water supply has serious disadvantages. Commonly the pumping lift is more than 200 feet, which causes high power costs, and mining operations not only endanger the water quality but also the source of supply. Therefore, a known aquifer in the glacial drift is a more dependable source of supply and generally affords lower operating costs as well as better protection for the capital investment in the system.

Ground Water in the Quaternary Deposits

Pleistocene Deposits

Ground water in the glacial drift is abundant in some parts of the area and meager in others, depending upon the character and thickness of the outwash deposits and their relationship to the bedrock surface. The thickest deposits of outwash, which lie in bedrock channels and valleys, generally are completely saturated, and the water table is within a few feet of the land surface. On the crests or along the flanks of the bedrock ridges and knobs, outwash deposits are thin or absent, and the water table commonly occurs in the underlying crystalline bedrock.

Areas where bedrock ridges are at or near the surface are shown on figure 2. Thin deposits of glacial drift, which contain little or no ground water, also lie within the areas delineated.

The largest quantity of ground water available in the Chisholm-Dewey Lake area, excluding that from the iron formation, is in the outwash deposits. These deposits occur in bedrock valleys and channels and as kames that flank the bedrock highs. The city of Chisholm well 4 (58.20.-16dbbl) is completed in an outwash deposit that underlies the swamp area on the north edge of the city. A similar outwash deposit was explored by drilling auger test holes along the gravel road that crosses the swamp in the north half of sec. 16, T. 58 N., R. 20 W. about 0.6 miles north of Chisholm city well 4 (fig. 8). The overall similarity in the lithology

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Figure 8 (caption on next page) belongs near here.

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and stratigraphic position of the two deposits suggests that they may be connected beneath the swamp. The specific yield of the Chisholm well (85 gallons per minute per foot of drawdown) and a brief pumping test on well points in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 58 N., R. 20 W. (page 46) indicate that large quantities of water are available from the sand and gravel lenses in the outwash.

Figure 8.-- Geologic section through swamp north of Chisholm.

Recent Deposits

Recent alluvial deposits, consisting of silt, sand, and gravel along stream courses and in and around lake basins, are permeable and will support wells where the deposits are sufficiently thick and lie below the water table. Generally, however, they are too thin and limited in areal extent to be considered important ground-water sources.

Swamp deposits of muskeg and peat are not considered a source of ground water because they will not readily yield water to wells and the color, taste, and odor of most swamp waters make them unfit for human consumption.

Ground-Water Usage

Wells in the Chisholm-Dewey Lake area supply ground water for municipal, domestic, and stock use. The greatest quantity of water pumped is from two wells owned by the city of Chisholm. Water for domestic and stock use from private wells is only a small part of the total ground=water withdrawal from wells. Wells and test holes scheduled in the Chisholm-Dewey Lake area are shown on figure 9. Data concerning these wells

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Figure 9.--(caption on next page) belongs near here.

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and test holes is published in an open-file report by Thompson and Cotter (1961) and is available at the U.S. Geological Survey Ground Water Branch office, St. Paul 1, Minnesota, and at the St. Paul and Chisholm Public Libraries.

Of the two producing wells owned by the city of Chisholm, one is pumped at a rate of as much as 450 gpm and the other is pumped at a rate of about 150 gpm. Average daily water consumption for the city ranges from 400,000 to 600,000 gallons. The city also maintains two pumps on the Bruce mine shaft (see p. 58) as a standby water source.

Figure 9.-- Map of the Chisholm-Dewey Lake area showing the location of wells and test holes.

EXPLANATION

U.S.G.S. test hole

City of Chisholm test hole

Private well

Municipal well

Figure 9.--Map of the Chisholm-Dewey Lake area showing the location of wells and test holes.

QUALITY OF GROUND WATER

Chemical analyses of 13 samples of ground water taken from wells in the Chisholm-Dewey Lake area are listed in table 2. The samples were analyzed by the U.S. Geological Survey. The analyses expressed in ppm (a unit weight of a constituent in a million unit weights of water) show the dissolved constituents in the water.

Dissolved solids indicate the relative degree of mineralization of water. According to the U.S. Public Health Service standards (1961), the dissolved-solids content of drinking water should not exceed 500 ppm. All the water samples analyzed contained less than 500 ppm of dissolved solids; the highest dissolved-solids content was 360 ppm and the lowest was 108 ppm.

Degree of hardness is a physical-chemical property of water that varies with the amount of dissolved alkaline earths. It is recognized usually by the quantity of soap required to produce a lather of suds. Almost all hardness is caused by calcium and magnesium cations. The hardness, expressed as the equivalents of carbonate and bicarbonate, is called carbonate hardness. A water that has a total hardness in excess of the chemical equivalent of carbonate and bicarbonate, is said to have noncarbonate hardness. Most of the ground water in the Chisholm-Dewey Lake area is of the carbonate hardness type. The following table summarizes the criteria used in this report in evaluating the total hardness ($CaCO_3$) of water:

0 - 60 ppm	Soft
61 - 120 ppm	Moderately hard
121 - 200 ppm	Hard
Over 200 ppm	Very hard

The classification of water in the broad categories shown in the table above serve only as a general comparison guide. For industrial use, such a classification is usually unsatisfactory, as individual industries demand water of significantly different chemical characteristics. Furthermore, domestic or public requirements depend partly on the user's personal preference, and experience with the application of detergents and conditioning agents.

Soft water, as defined in the table, is suitable for public or domestic use and for some but not all industrial uses without treatment for hardness. Moderately hard water usually requires softening for all industrial uses but may be satisfactory for public or domestic uses. Hard and very hard waters, unless softened, generally are unsuitable for all uses except stock watering and irrigation.

By the preceding hardness classification, only one of the water samples analyzed was soft, six were moderately hard, five were hard, and one was very hard. Hardness in this area cannot be correlated with the geologic sources of the water because hard and moderately hard water is in both bedrock and glacial drift.

The most troublesome constituents of ground water in the Chisholm-Dewey Lake area are iron and manganese. According to the U.S. Public Health Service (1961), these elements in concentrations greater than 0.3 ppm stain porcelain fixtures and fabrics. Iron leaves a reddish-brown stain and manganese leaves a black stain. Five of the 13 water samples contained less than 0.3 ppm of iron and manganese combined. The rest contained enough iron and manganese to impart a taste to the water. In general, the greatest quantities of iron and manganese are found in water from aquifers that are adjacent to, or in low swampy areas. Ground water from aquifers along the slopes of bedrock hills and ridges and in bedrock is generally low in iron and manganese.

Although the chloride concentrations in all of the water samples analyzed were well below the limit of 250 ppm recommended by the U.S. Public Health Service (1961), three of the samples contained chloride concentrations much greater than the average for the area. The same three samples also contained nitrate in concentrations that are abnormally high. High concentrations of chloride and nitrate often indicate unsanitary conditions near well sites or contamination from septic tank wastes.

Fluoride in drinking water has received much publicity in recent years. Studies of the effects of fluoride on the teeth of growing children indicate that fluoride concentrations less than 1.5 ppm inhibit dental cavities, whereas concentrations greater than 1.5 ppm cause mottling of the teeth (Dean and others, 1941). Only one sample in the Chisholm-Dewey Lake area contained fluoride in excess of 1.5 ppm; the others contain less than 0.5 ppm fluoride.

SUMMARY AND CONCLUSIONS

The principal source of ground water in the Chisholm-Dewey Lake area is the outwash in the glacial drift of Pleistocene age. Yields of ground water of as much as 2,000 gpm also are available from the enriched zones of the Biwabik Iron-Formation; however the iron-formation is present only in the extreme southern part of the report area and mining operations seriously interfere with the installation of permanent wells in this formation.

The surface drift (St. Louis sublobe) in the area consists largely of till that ranges in thickness from 0 to 20 feet. Outwash deposits included in this drift occur in channels cut into the underlying drift and bedrock and as esker and kame deposits at the surface. In some places, outwash deposits underlie alluvial and swamp deposits of Recent age and some thin till deposits. Water has been pumped at a rate of as much as 1,200 gpm from outwash of the St. Louis sublobe in the subsurface channel cut through the Giants Range Granite ridge at Chisholm. Data on this aquifer at Chisholm indicate that a sustained yield of about one-half million gallons per day is possible from a single well. A probable extension of this aquifer occurs in the NW$\frac{1}{4}$NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 15, T. 57 N., R. 20 W.

The drift of the Rainy lobe underlies the drift of the St. Louis sub-lobe and the Recent age swamp and alluvial deposits in much of the project area. Both the sorted and unsorted parts of this drift are comprised of sand and gravel; therefore, differentiation of the two from drilling samples is difficult. The sorted drift is generally more permeable and will support, where saturated, higher pumping rates with less water-level draw-down than the unsorted drift. The unsorted drift, however, will yield sufficient ground water to domestic and stock wells and low capacity industrial and municipal wells.

Because bedrock valleys contain the greatest thicknesses of glacial drift, they are the best places to explore for aquifers that will support maximum long-term yields.

Small supplies of ground water suitable for domestic and stock use are obtained from fractures in the granite bedrock in some parts of the area. Only in the absence of drift aquifers should wells be drilled into the crystalline bedrock for water, and then drilling should not go below 20 feet in the rock.

Abrupt changes in depth, thickness, and permeability of the outwash and permeable drift occur within short distances; therefore, the installation of large capacity wells should be preceded by sufficient test drilling and pumping tests.

Recharge to aquifers in the Chisholm-Dewey Lake area is derived from local precipitation and occurs mainly after the spring thaw and after intense and prolonged precipitation during the summer and early fall. Average annual rainfall, computed for the period 1952-59, amounted to 45 billion gallons of water falling on that part of the Chisholm-Dewey Lake area included in the Sturgeon River drainage basin or on about 91 square miles of the total 105 square miles in the project area. Average figures show that 34 billion gallons per year is lost through evapotranspiration; and 11 billion gallons per year flows in streams from the area. The above figures indicate that there is no shortage of water in the overall area; additional wells placed in the proper places could divert part of the lost runoff for use within the area.

Iron and manganese are the most troublesome dissolved minerals in ground water in the Chisholm-Dewey Lake area. Data from 13 chemical analyses and reports from well owners indicate that the concentration of these constituents are highest in ground water from aquifers beneath or near swamps and lowest in ground water from aquifers near the slopes of buried bedrock hills and ridges. Hardness of the ground water in the area ranges from soft to very hard. (See hardness classification, p.59). The soft and moderately hard waters do not ordinarily require softening for domestic use, but the hard and very hard waters generally require softening for almost all uses. Nitrate and chloride contents of three samples indicate pollution.

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