Ground Water for Irrigation Near Lake Emily, Pope County, West-Central Minnesota

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GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1899-J

Prepared in cooperation with the
West-Central Minnesota Resource
Conservation and Development
Committee and the Minnesota
Department of Conservation,
Division of Waters, Soils, and
Minerals

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By WAYNE A. VAN VOAST

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UNITED STATES

GROUND WATER FOR IRRIGATION NEAR LAKE EMILY, POPE COUNTY, WEST-CENTRAL MINNESOTA

By WAYNE A. VAN VOAST

ABSTRACT

In the Lake Emily area, thickness of the glacial drift ranges from about 200 feet to more than 400 feet. Within the drift are sand and gravel aquifers, some of which can yield adequate water supplies for irrigation. Outwash, as much as 60 feet thick, lies at the surface. The outwash has saturated thicknesses of more than 40 feet and transmissivities of more than 50,000 gallons per day per foot locally in the northern and western parts of the area. In the places of large saturated thickness and high hydraulic conductivity, the aquifer should yield more than 600 gallons per minute to wells. Theoretical maximum yields to wells in most of the area are more than 100 gallons per minute.

Chemically, water in the buried and surficial aquifers is mainly of a calcium magnesium bicarbonate type and is suitable for irrigation. Calculated and estimated sodium adsorption ratios and salinity and boron concentrations are below the limits recommended by the U.S. Department of Agriculture.

INTRODUCTION

This investigation of the availability of ground water for irrigation near Lake Emily is one of several investigations conducted in sandy-soil areas in Minnesota where development of irrigation supplies from ground water in surficial aquifers might be feasible to supplement precipitation. Because of low water-holding capacity in these sandy soils and insufficient rainfall during the growing season, crop yields generally are poor. The purpose of the study is to investigate the adequacy of ground-water quantity and quality for irrigation. Results of this study should provide guidelines to local planners and irrigators in the proper development of the area's water resources. The study was made by the U.S. Geological Survey in cooperation with the West-Central Resource Conservation and Development Committee and the Division of Waters, Soils and Minerals, Minnesota Department of Conservation.

The report area is in west-central Minnesota (fig. 1), about 130 miles west of Minneapolis and St. Paul. The area occupies about 35 square miles in T.124 N., R.40 W. (Walden Township) and T.123 N., R.40 W. (Hoff Township) in the southwestern corner of Pope County. There are no towns in the report area. Nearby towns include Hancock, about 1 mile west of the area; Morris, about 10 miles northwest; and Benson, about 10 miles south.

The report area is in the central part of the Chippewa River watershed unit as outlined in the Minnesota Division of Waters Bulletin 10, "Hydrologic Atlas of Minnesota." The Chippewa River is the main watercourse draining the area in addition to several unnamed tributaries, most of which are ephemeral.

Farming is the principal occupation; corn, soybeans, and hay are the principal crops. The soils are sandy and are subject to droughtiness and wind erosion. Mean annual precipitation is about 24 inches, of which about 18 inches fall during the growing season (May through September). Average daily maximum temperatures during the growing season vary from about 56°F (13°C) in April to about 86°F (30°C) in July.

PREVIOUS INVESTIGATIONS

The earliest investigation which included the Lake Emily area was a cursory survey of the general geology of Minnesota (Upham, 1888). A report on the geology and water resources of northwestern Minnesota by Allison (1932) and a report on the glacial geology of Minnesota and adjacent states by Leverett (1932) gave brief mention of the project area. A cartographic presentation of the hydrology of the Chippewa River watershed by Cotter, Bidwell, Van Voast, and Novitzki (1968) included a general description of the geology and water resources of the western third of the report area.

METHODS OF INVESTIGATION

Fieldwork began in the summer of 1966. Selected domestic wells in the area were inventoried, and water samples were collected for chemical analysis. More than 50 power-auger test

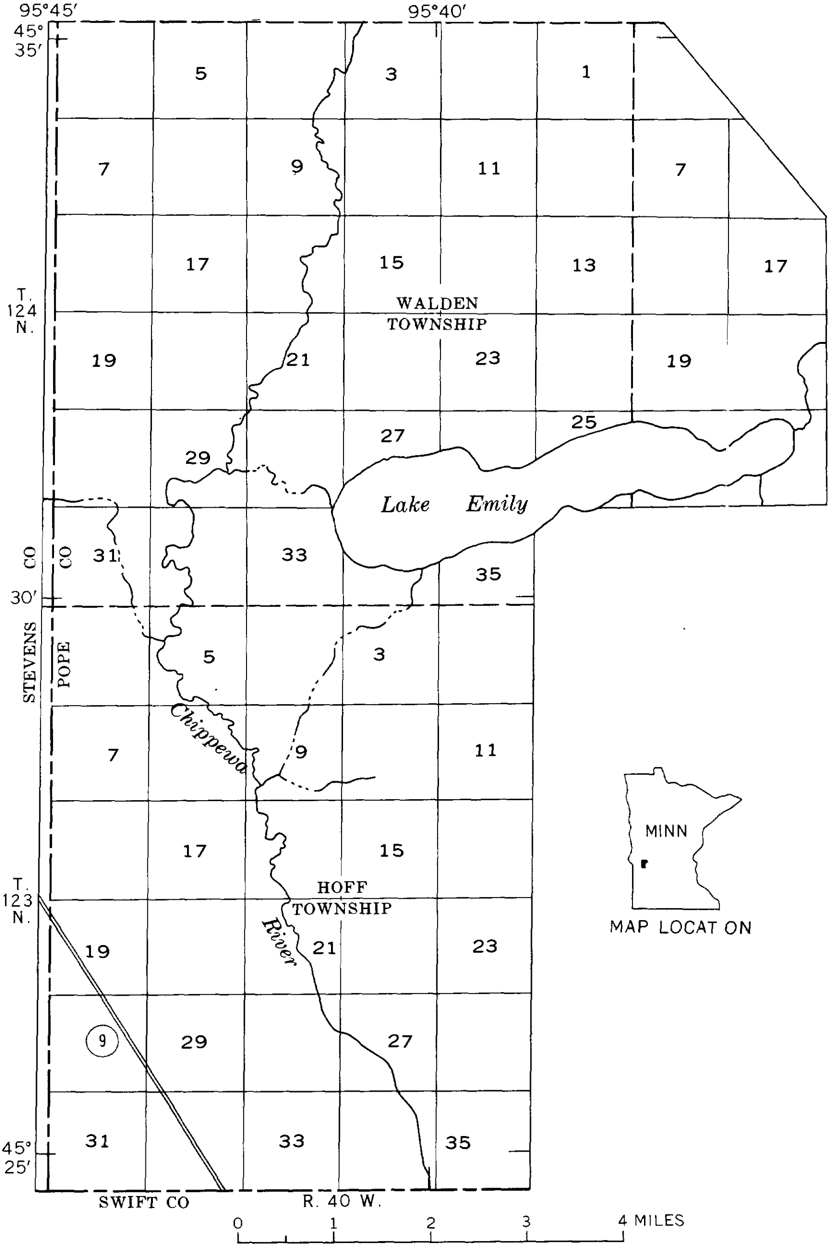


Figure 1.—Area of this report.

holes were drilled to determine the extent and geologic characteristics of the water-table aquifer. Altitudes were obtained from topographic maps or by altimeter.

Continuous records of water-level fluctuations were collected at two observation wells from December 1966 to December 1968. Precipitation during the growing season of 1967 was recorded at three points for comparison with water levels in observation wells. Base flow in all streams in the area was measured in September 1968.

TEST-HOLE 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 Lake Emily 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 base line; 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. The letters are assigned in a counter-clockwise direction, beginning in the northeast quarter. Within one 10-acre tract, consecutive numbers beginning with one are added as suffixes.

Figure 2 illustrates the method of numbering a test hole. Thus, the number 124.40.8ddbl identifies the first well or test hole located in the NW¼SE¼SE¼ sec.8, T.124 N., R.40 W.

ACKNOWLEDGMENTS

The author thanks the many residents and well drillers who provided information and assistance. A special debt is owed to residents who recorded precipitation data during the study.

GEOLOGY

BEDROCK

Crystalline rocks of Precambrian age form the basement complex. Where reached by wells in west-central Minnesota, the Precambrian rocks are granitic, and locally their upper surface is weathered to a soft kaolinitic clay. According to Cotter, Bidwell, Van Voast, and Novitzki (1968), basement rocks lie about 200 feet below land surface in the northern part of the area and more than 400 feet below land surface in the south.

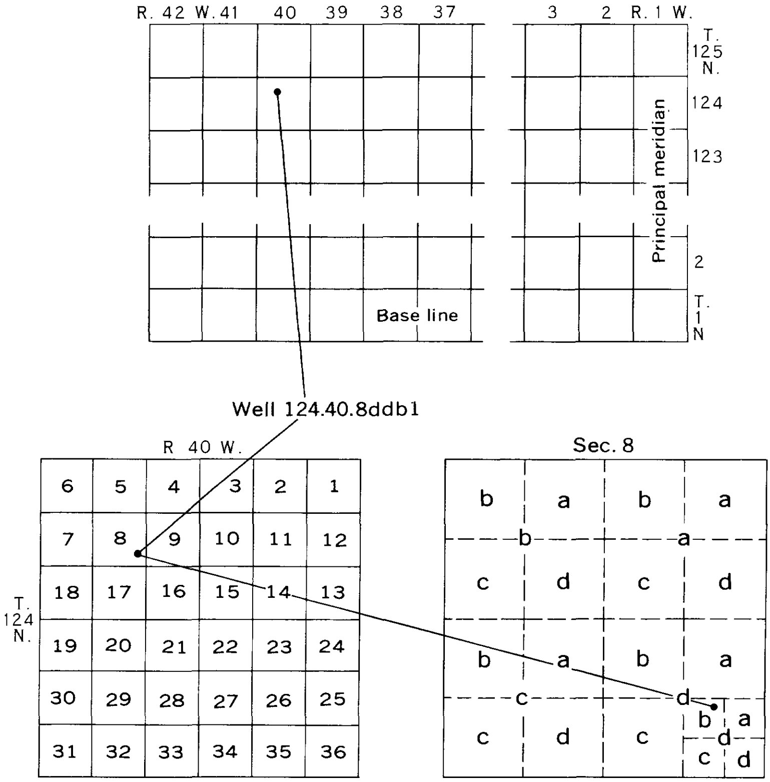


FIGURE 2.—Well and test-hole numbering system.

Sedimentary rocks of Cretaceous age commonly overlie the basement complex in west-central Minnesota, but according to Cotter, Bidwell, Van Voast, and Novitzki (1968), are not present in the report area.

GLACIAL DRIFT

Glacial drift representing the Wisconsin Glaciation forms the land surface in the project area (fig. 3). Pre-Wisconsin drift may be present in the subsurface. The glacial deposits are about 200 feet thick north of Lake Emily and are more than 400 feet thick in the southwestern part of the project area (fig. 3). The drift is of two main types: till, an unstratified, unsorted mixture of clay, silt, sand, and gravel deposited directly by glacial ice; and outwash, stratified beds of sand and gravel deposited by glacial meltwaters.

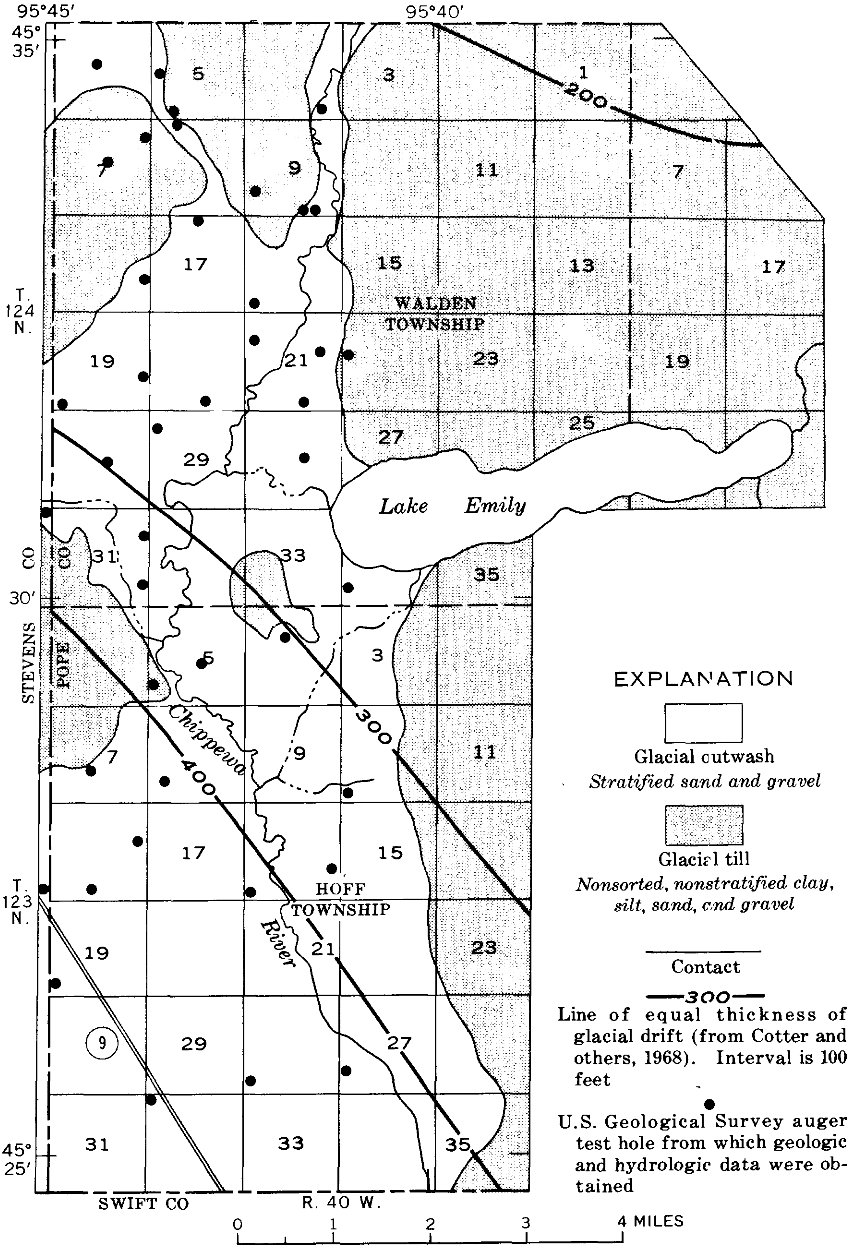


FIGURE 3.—Generalized surficial geology and thickness of glacial drift.

The drift in the project area was deposited by the Des Moines lobe of glacial ice (Leverett, 1932), which advanced southeastward across western Minnesota. Outwash was deposited by meltwaters from the ice sheet as it receded to the north and west. The meltwaters flowed southward into the Lake Emily area by way of two main channels, the eastern one of which is now occupied by the Chippewa River. The streams of meltwater flowed into a broad, shallow lake which covered most of the project area (R. Diedrick, written commun., 1967), and was centered southwest of Lake Emily. Most of the outwash near Lake Emily was deposited as a delta in this temporary glacial lake. Figure 4 shows the configuration of the till surface beneath the deltaic deposits. Along the southern and western boundaries of the project area, where the lowest depressions in the till surface occur, the outwash is as much as 60 feet thick; here it is composed of fine to coarse sand. In the northern part of the area, closer to the ancient meltwater channels, thickness of the outwash is mainly less than 40 feet, and grain sizes are mostly medium to very coarse. Narrow gravel bars are common within both channels.

GROUND-WATER HYDROLOGY

PRINCIPLES OF OCCURRENCE

Ground water occurs within the basement rocks and glacial deposits in the project area. The uppermost surface below which the geologic materials are saturated under hydrostatic pressure is termed the "water table." Water is stored within spaces between grains which make up geologic materials; the ratio of volume of pore space to total volume of material, expressed as a percentage, is known as porosity. All geologic materials are porous to some degree. The ability to transmit water is termed "hydraulic conductivity" and depends upon the size of the pore spaces and their degree of interconnection. Hydraulic conductivity, as used in this report, is defined as the flow of water in gallons per day through a cross-sectional area of geologic material 1 foot high and 1 foot wide under a hydraulic gradient of 1 foot per foot. In the project area, geologic materials of significant hydraulic conductivity include sand and gravel, and where saturated with water will be referred to herein as aquifers. Less permeable materials in the area are granitic rock, till, silt, and clay. Transmissivity is used to indicate the ability of an aquifer to transmit water and is equivalent to the hydraulic conductivity multiplied by the aquifer thickness in feet. Transmissivity is defined as the flow of water in gallons per day through a strip of aquifer 1 foot wide under a hydraulic gradient

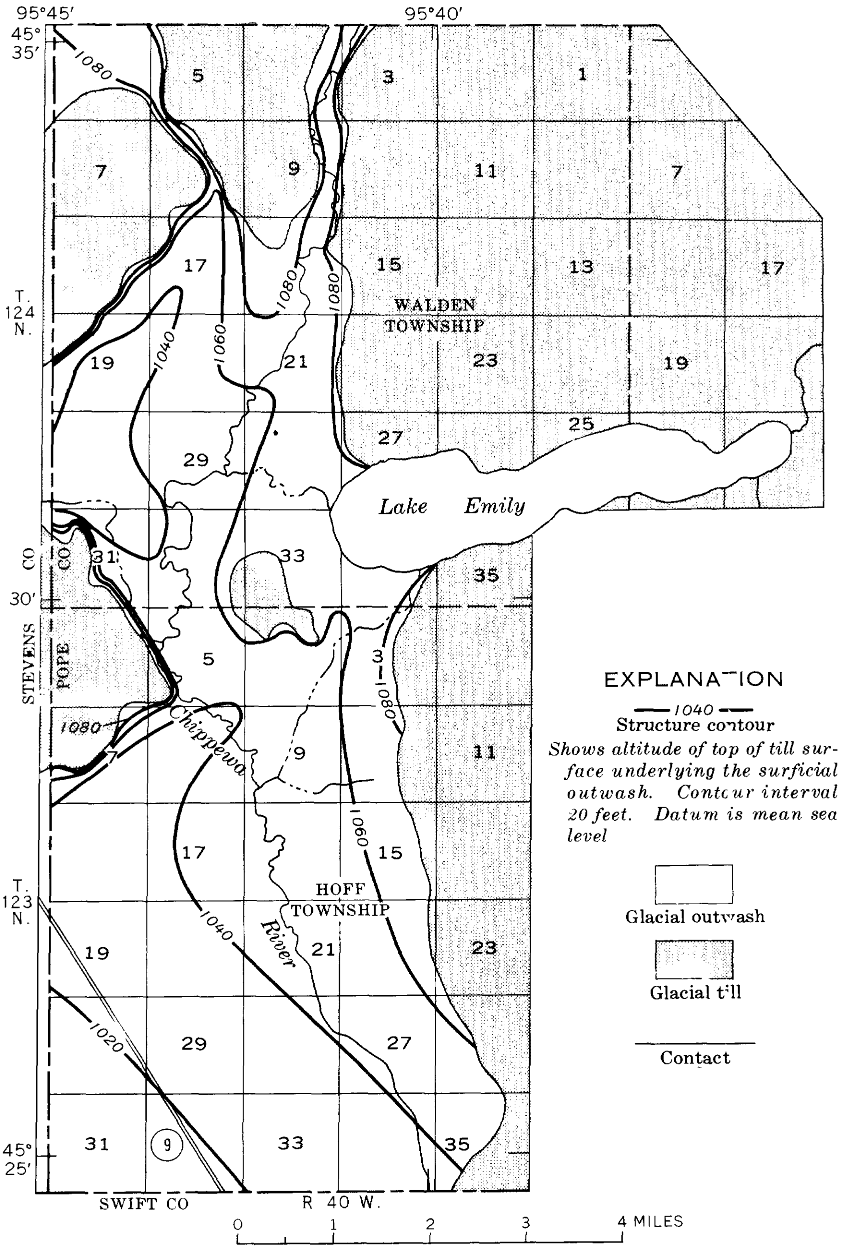


FIGURE 4.—Configuration of the till surface underlying the surficial outwash west of Lake Emily.

of 1 foot per foot. The volume of water that geologic materials can release from or take into storage per unit of aquifer surface per unit of change in head is known as the storage coefficient. Storage coefficient and transmissivity are the main characteristics which determine the worth of an aquifer as a source of water.

Aquifers described in this report are sand and gravel deposits which occur buried beneath less permeable deposits of clay, silt, and till, and sand and gravel deposits which occur at the land surface. Buried and surficial aquifers will be discussed separately, with major emphasis on the surficial aquifer.

BURIED AQUIFERS

Sand and gravel deposits, which occur at various depths in the glacial drift, are common in and near the Lake Emily area. The individual aquifers generally do not have wide areal extent and may be highly variable in thickness and hydraulic conductivity. Most wells which penetrate buried aquifers in the area are less than 150 feet deep and probably tap the uppermost sand and gravel deposits. Other aquifers probably occur at greater depths. That nonpumping (static) water levels in the deep wells are lower than the water level in the surficial sand and gravel deposits by as much as 50 feet indicates that the deeper aquifers may be recharged at least partly by water from the surficial aquifer. Little information on well performance is available. Most domestic and stock wells are pumped at less than 10 gpm (gallons per minute) but are probably capable of greater yields. Municipal wells in the town of Hancock, about 1 mile west of the project area, reportedly yield as much as 500 gpm and have specific capacities of as much as 50 gpm per foot of drawdown after 6 hours of pumping. Data presented by Cotter, Bidwell, Van Voast, and Novitzki (1968), indicates that the wells at Hancock yield greater volumes of water than most wells in the Chippewa River watershed. It is not known whether the aquifer at Hancock is also in the project area. Test drilling will be necessary to locate buried aquifers that can yield water in sufficient quantity for irrigation.

SURFICIAL AQUIFER

PHYSICAL AND HYDROLOGIC PROPERTIES

A surficial aquifer in glacial outwash covers most of the project area (fig. 3). The aquifer's upper limit is the water table, and its base is the top of the glacial till. It is bounded by poorly permeable till to the north and east and extends beyond the southern and western limits of the project area.

The water level is within 10 feet of the land surface in most of the project area (fig. 5); however, in the northern part of the area, the depth to water is locally somewhat greater but is generally less than 20 feet.

Saturated thickness of the outwash varies from less than 10 feet along the eastern edge of the aquifer to more than 50 feet in the western part of Walden Township (fig. 6). Saturated thicknesses are more than 40 feet in the meltwater channel in sec. 6, Walden Township and more than 30 feet in the southwest corner of Hoff Township.

An interpretation of the transmissivity of the aquifer, based on aquifer thickness and grain-size data, is shown in figure 7. Hydraulic conductivities of materials were estimated by correlating grain-size information and using the hydraulic conductivity values shown in table 1. Validity of these values for the Lake Emily area could not be verified because of the absence of aquifer performance data. The values were used in this study because they were found to be compatible with hydraulic conductivities determined from controlled pumping tests and from specific capacity information in similar materials in the Brooten-Belgrade area, about 25 miles east of Lake Emily (Van Voast, 1968).

The highest transmissivities occur along the western edge of the project area and in the narrow channels in northern Walden Township, (See fig. 7.) In these areas the aquifer is relatively thick and consists of relatively coarse materials. Transmissivity values are low in the southeastern part of Hoff Township because the aquifer is relatively thin and is composed mainly of fine to medium sand.

TABLE 1.—*Values of hydraulic conductivity used in the estimation of transmissivity of the surficial aquifer west of Lake Emily*

[Values are taken from a more detailed study of similar material near Brooten, Minnesota (Van Voast, 1968)]

Material (based on Wentworth size scale)	*Hydraulic conductivity (gpd per sq ft)*
Clay and silt	0– 100
Sand, very fine, silty	100– 300
Sand, fine to medium	300– 400
Sand, medium	400– 600
Sand, medium to coarse	600– 800
Sand, coarse	800– 900
Sand, very coarse	900–1,000
Sand and gravel	1,000–2,000

Storage coefficient or specific yield for the water-table aquifer is estimated to be about 0.2, a reasonable value for unconfined

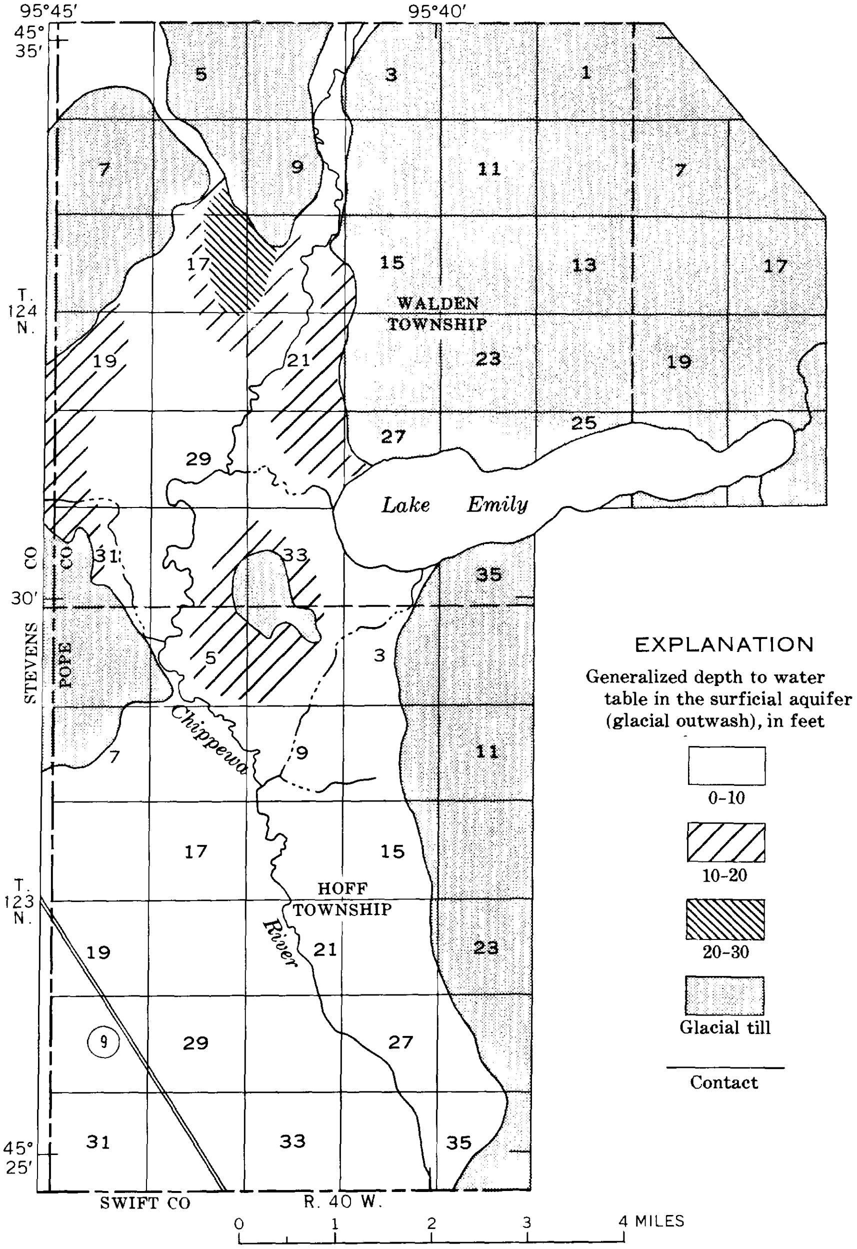


FIGURE 5.—Depth to water table in surficial aquifer.

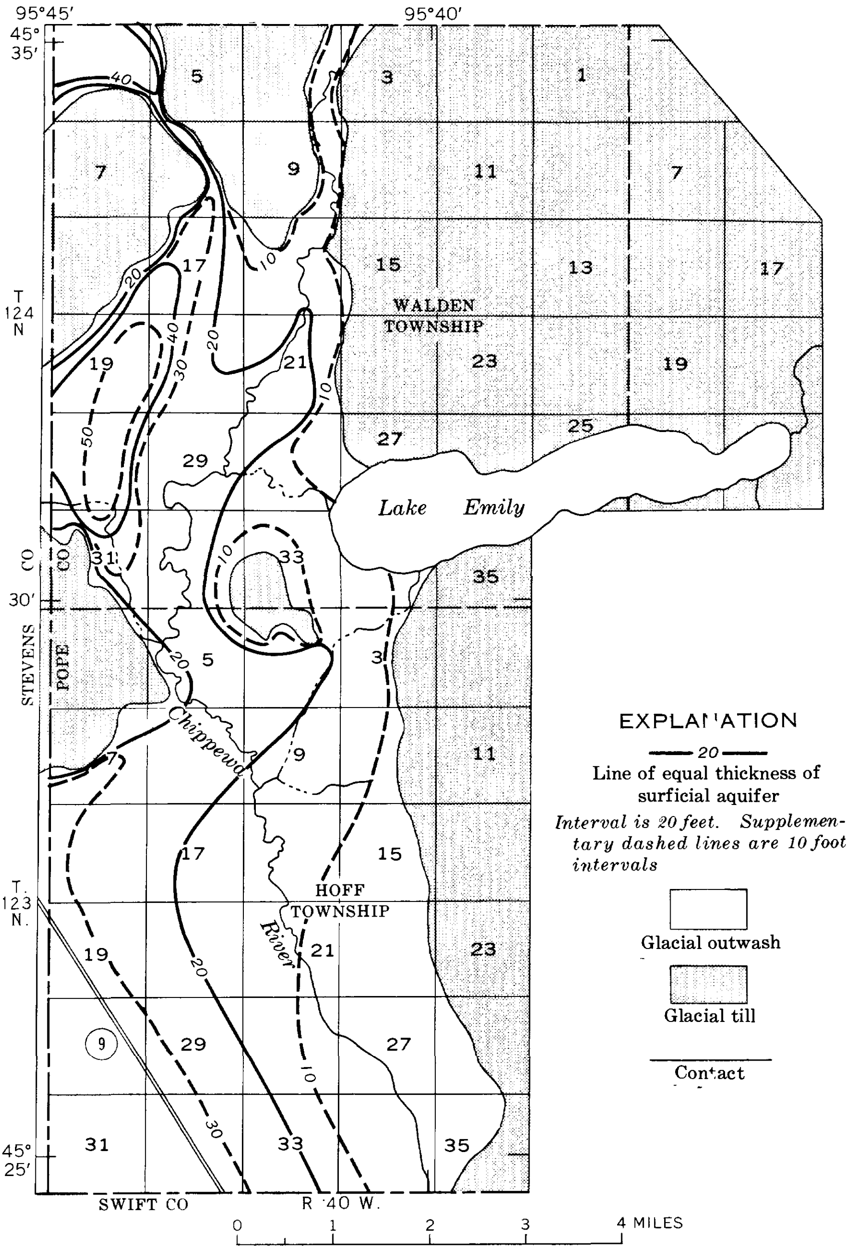


FIGURE 6.—Saturated thickness of the surficial aquifer.

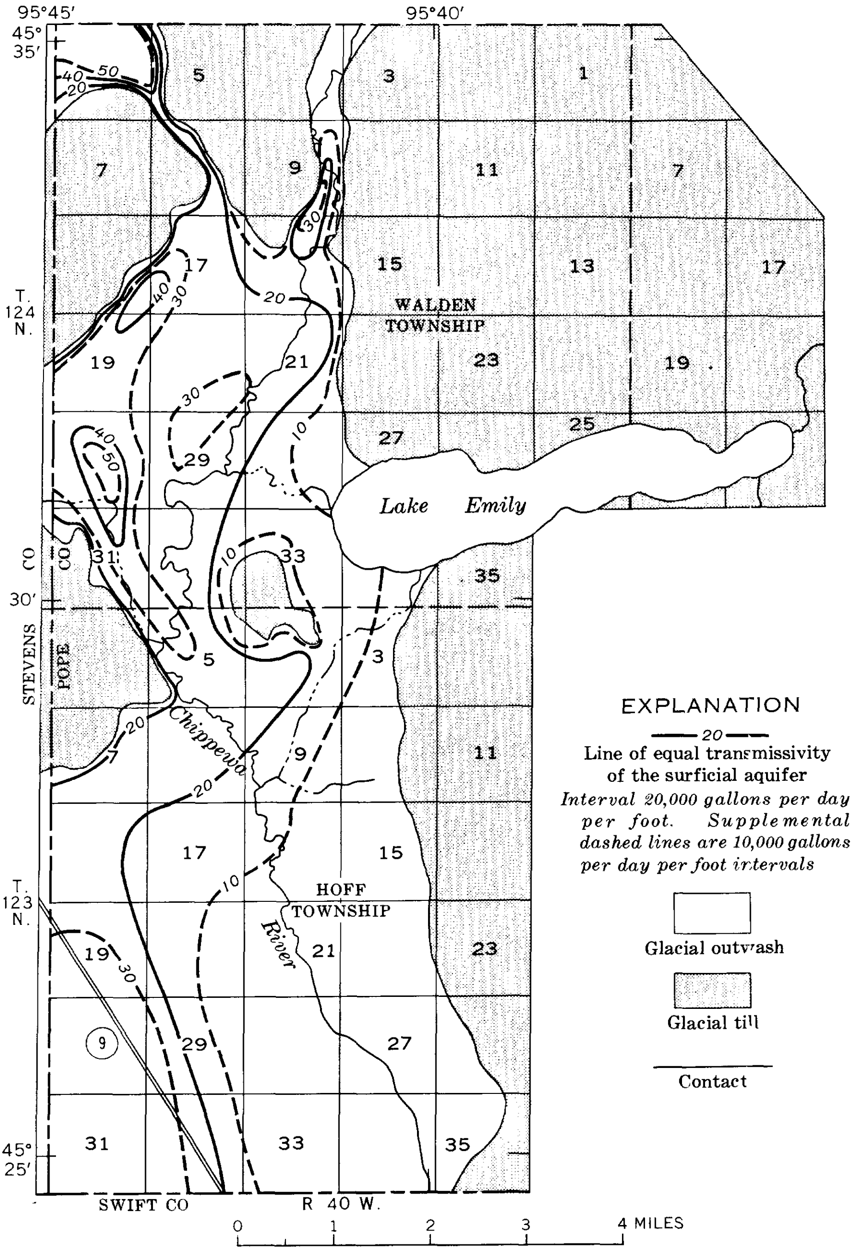


FIGURE 7.—Transmissivity of the surficial aquifer.

aquifers. On the basis of this value, it is estimated that about 115,000 acre-feet of water is contained in storage in the surficial aquifer within the project area.

WATER MOVEMENT

The general direction of ground-water movement is shown in figure 8. Ground water enters the aquifer as underflow near Lake Emily and through narrow channels of sand and gravel in the northern part of Walden Township. Ground water leaves the area as underflow along the southern boundary of Hoff township. Ground-water flow to the Chippewa River occurs along its entire reach in the project area (fig. 9), but the tributaries have relatively little base flow.

WATER BUDGET

Under natural conditions, the ground-water system is in a state of dynamic equilibrium, continually recharging in some places and discharging in others, but always tending toward a balance between input and output. Sources of recharge to the surficial aquifer include precipitation, overland flow from topographically higher adjacent areas, surface runoff, and ground-water underflow. Most recharge occurs during the spring because of snowmelt and heavy rainfall. Ground water leaves the area as underflow, seepage to streams (base flow), and as evaporation and transpiration. Underflow is continuous; base flow occurs during most of the year; and evapotranspiration occurs mainly during the growing season.

No long-term depletion of storage in the aquifer is assumed, and the ground-water system is considered to be in a state of equilibrium in which inflow is equal to outflow. A general water budget for 1968 (table 2) shows the relative magnitudes of recharge and discharge components for the surficial aquifer.

The estimated water budget indicates that spring recharge is much greater than recharge by underflow. The budget also indicates that ground-water discharge to the Chippewa River is much greater than ground-water losses as underflow and evapotranspiration. Most water pumped for irrigation will originate as spring recharge and will be intercepted before discharging to the Chippewa River.

THEORETICAL MAXIMUM YIELDS

To quantify hydraulic properties of the surficial aquifer, potential well discharges were determined (fig. 10). The values

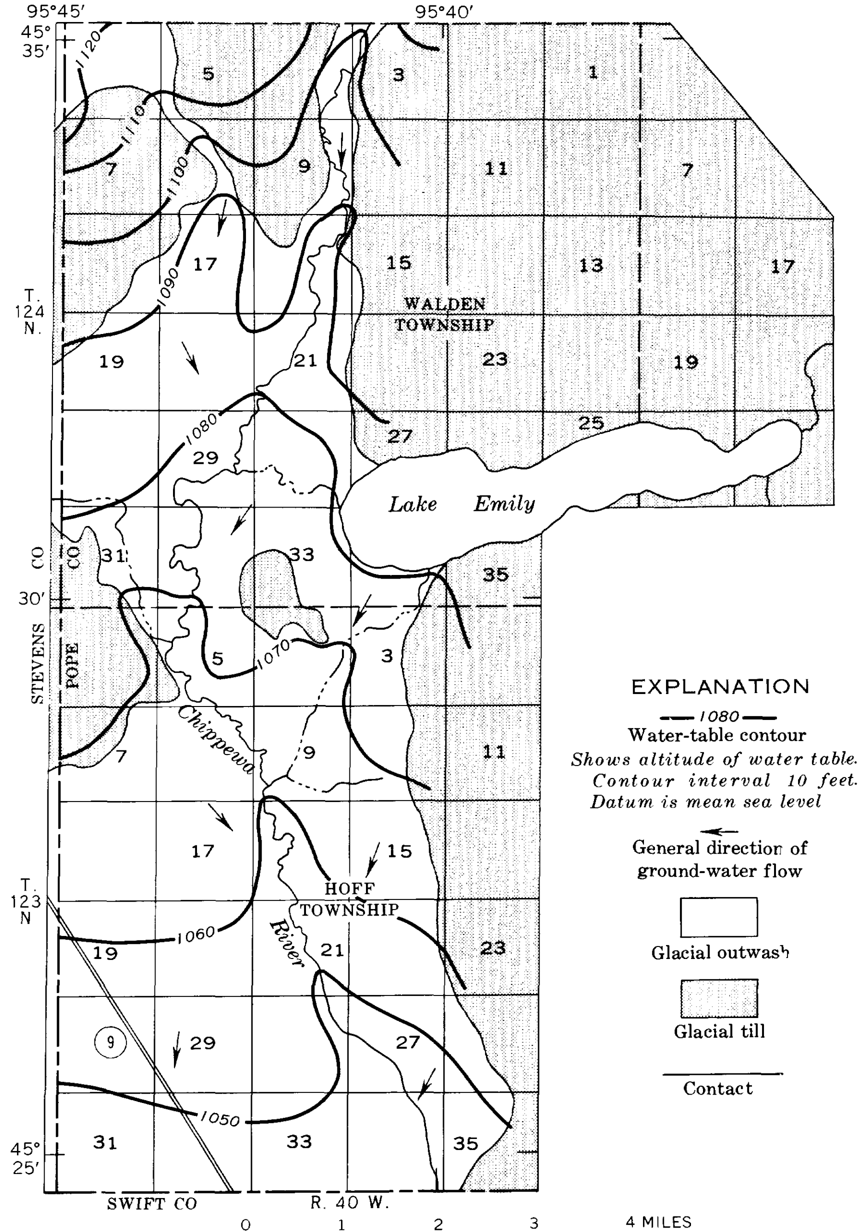


FIGURE 8.—Configuration of water table and direction of ground-water flow in the surficial aquifer.

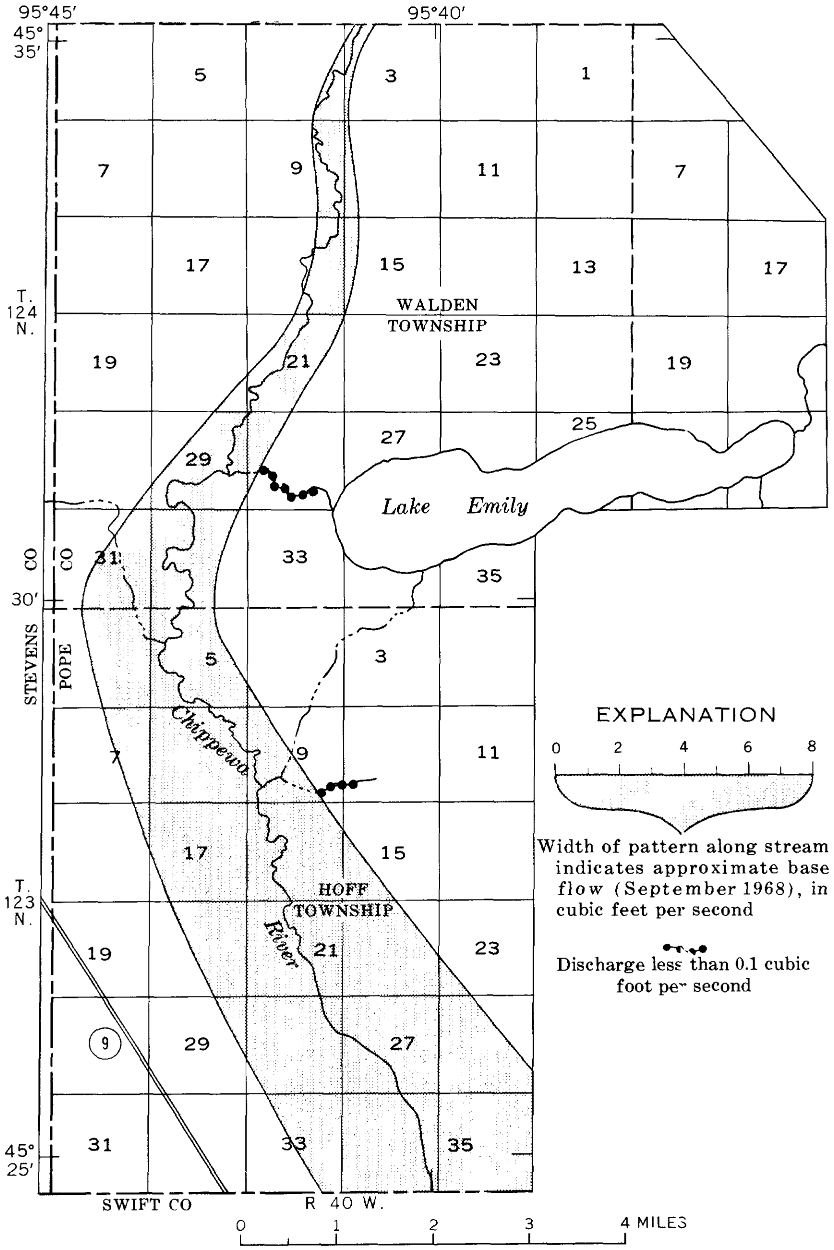


FIGURE 9.—Approximate base flow (September 1968) in the Chippewa River and tributaries.

TABLE 2.—*Approximate hydrologic budget for 1968 for the surficial aquifer west of Lake Emily*

Budget components for the surficial aquifer	*Volume of water (acre-feet per year)*
Spring recharge, estimated from observation-well hydrographs	4,900
Underflow, calculated by Darcy's law	400
Total inflow	5,300
Baseflow, measured in the Chippewa River	4,800
Underflow, calculated by the Darcy equation	300
Evapotranspiration, estimated to balance annual budget	200
Total outflow	5,300

were calculated using the nonequilibrium equation of Theis (1935), and they represent the theoretical possible yields, disregarding well interference, for 30 days of continuous pumping with drawdowns limited to about two-thirds of the aquifer thickness. When drawdown equals two-thirds of the aquifer thickness, about 90 percent of maximum yield is being obtained and the well is being pumped at maximum efficiency (Edward E. Johnson, Inc., 1966, p. 107, 108). In calculation of values for figure 10, interference between wells was assumed to be negligible, and drawdowns at the wells were corrected for decreasing transmissivity caused by dewatering of the aquifer (Jacob, 1944). It must be noted that 30 days of continuous pumping is a stringent condition when applied to present irrigation practices in western Minnesota, and probably would be necessary only in abnormally dry years. Further, local exceptions to the yield values shown will be common because of local variations in transmissivity. The map is intended only to show relative differences in water-yielding capacity for general areas.

The areas of highest maximum yields correspond generally with areas of highest hydraulic conductivity and greatest saturated thicknesses. Yields of more than 600 gpm (gallons per minute), under the time and drawdown conditions described above, should be available to individual wells in the outwash channel in northwestern Walden Township and near the project area boundary directly west of Lake Emily. Yields of more than 300 gpm, but probably less than 600 gpm, should be available to wells in southwestern Hoff Township. In most of the outwash in Walden Township, yields of between 100 and 300 gpm should be obtainable. In a large part of Hoff Township, directly south of

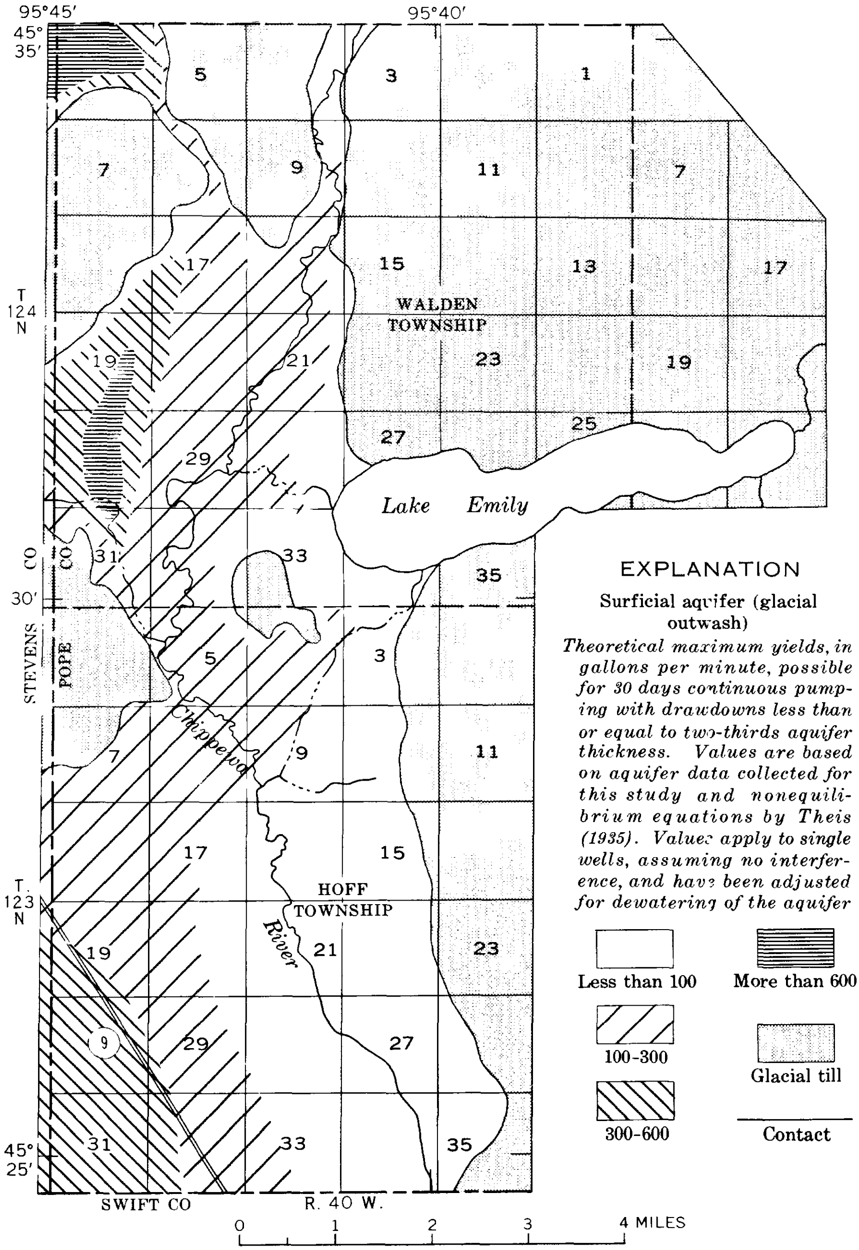


FIGURE 10.—Theoretical maximum possible yields for individual wells finished in the surficial aquifer.

Lake Emily, yields to individual wells will probably be limited to less than 100 gpm because of small aquifer thickness and low hydraulic conductivity.

It is likely that in most areas where maximum yields of less than 300 gpm are indicated in figure 10, prospective irrigators will have to rely upon multiple well systems or pits dug in the surficial aquifer, or must try to get additional water from deeper aquifers buried in or beneath the glacial drift.

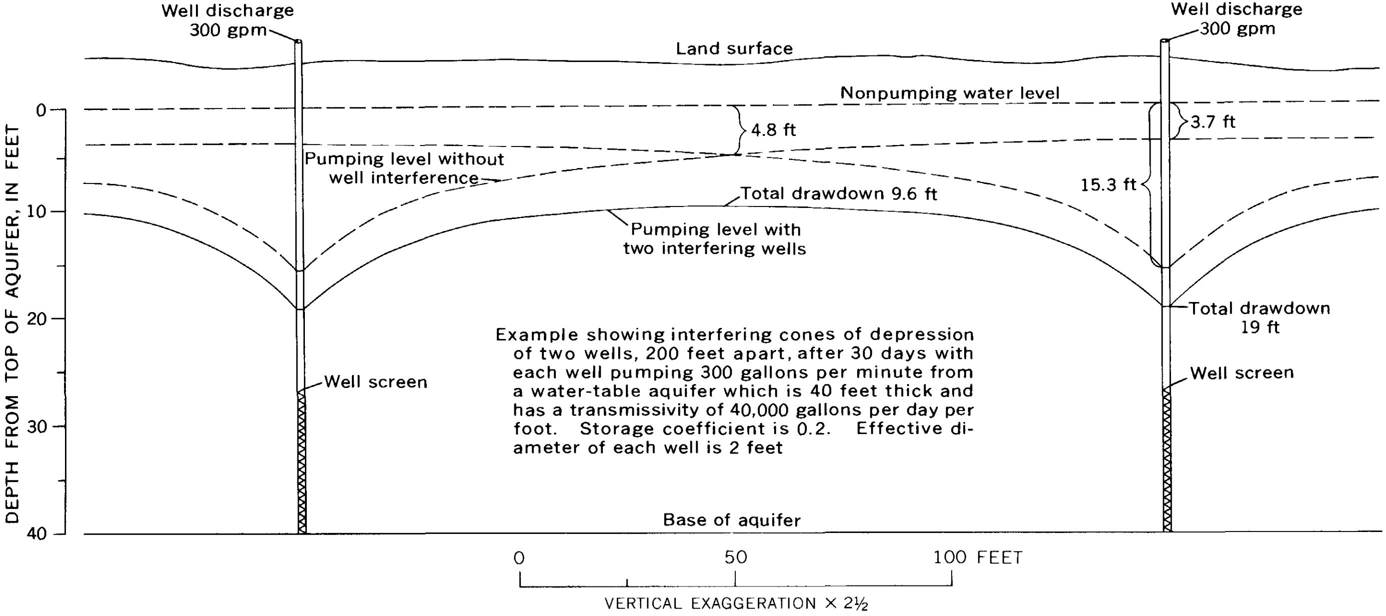
WELL INTERFERENCE

In an area where high well yield and high pumping efficiency are needed, a common problem can be the interference of the cones of depression of wells. Some well interference will be necessary for optimum development; however, a decrease in yield or in pumping efficiency can occur should interference cause drawdown at a well to exceed two-thirds of the aquifer thickness. Drawdown at any particular point in an area of influence of one or more wells will be the sum of drawdowns caused by the individual wells (fig. 11). Figures 12 and 13 can be used to estimate approximate drawdowns in the water-table aquifer between 1 and 800 feet from a pumping well. Because drawdown decreases the aquifer's saturated thickness, theoretical drawdowns (fig. 12) calculated by the nonequilibrium formula (Theis, 1935) must be adjusted for the decreased transmissivity. Adjustment of drawdown for dewatering of the aquifer can be made with an equation derived by Jacob (1944), presented graphically in figure 13. To best explain use of figures 12 and 13 for estimating or predicting well interference, a hypothetical problem corresponding to figure 11 is presented and solved below.

Example: Two wells, 200 feet apart, are each pumping 300 gpm from a water-table aquifer which is 40 feet thick and has a transmissivity of 40,000 gpd per ft. Storage coefficient is 0.2. Each well fully penetrates the aquifer and is 100 percent efficient.

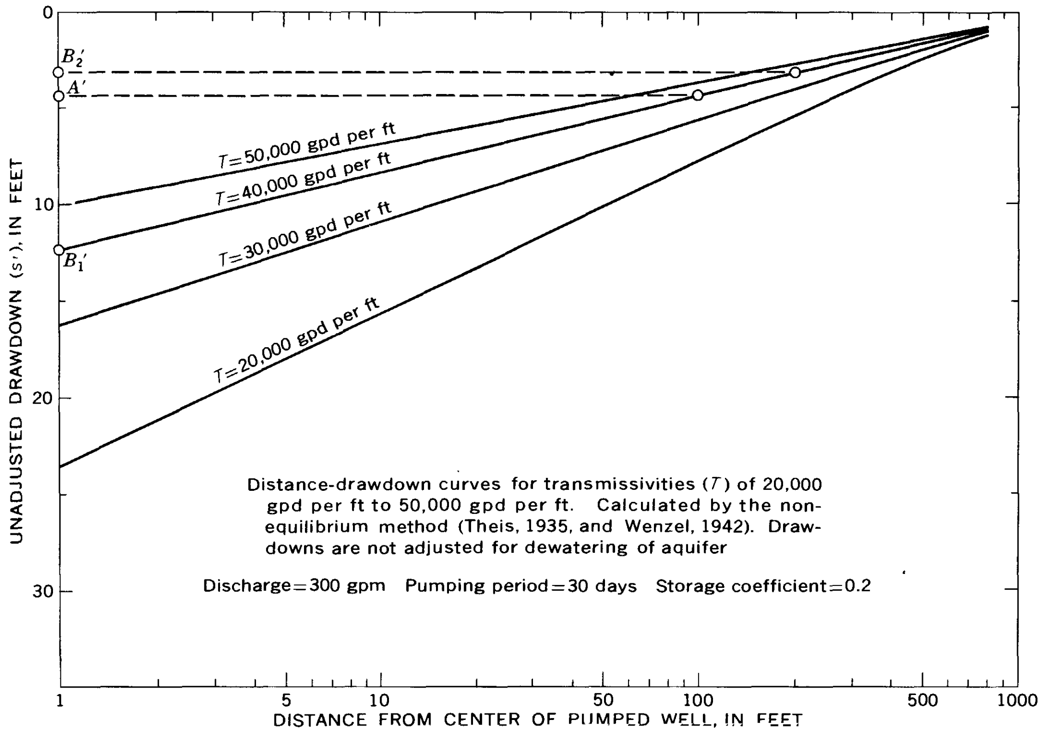
Find the drawdown midway between the two wells after 30 days of continuous pumping.

1. The curve for 40,000 gpd per ft (fig. 12) shows that the unadjusted drawdown 100 feet from one well would be about 4.4 feet (*A′*). The 40-foot curve (fig. 13) shows that the adjusted drawdown would be about 4.8 feet (*A*).
2. The drawdown midway between the interfering wells would be the sum of the drawdowns 100 feet from each well, or about 9.6 ft.



Example showing interfering cones of depression of two wells, 200 feet apart, after 30 days with each well pumping 300 gallons per minute from a water-table aquifer which is 40 feet thick and has a transmissivity of 40,000 gallons per day per foot. Storage coefficient is 0.2. Effective diameter of each well is 2 feet

FIGURE 11.—Interfering cones of depression caused by hypothetical wells pumping from a water-table aquifer.



Distance-drawdown curves for transmissivities (*T*) of 20,000 gpd per ft to 50,000 gpd per ft. Calculated by the nonequilibrium method (Theis, 1935, and Wenzel, 1942). Drawdowns are not adjusted for dewatering of aquifer

Discharge=300 gpm Pumping period=30 days Storage coefficient=0.2

FIGURE 12.—Theoretical distance-drawdown curves for wells pumping 300 gallons per minute at the end of 30 days of continuous pumping.

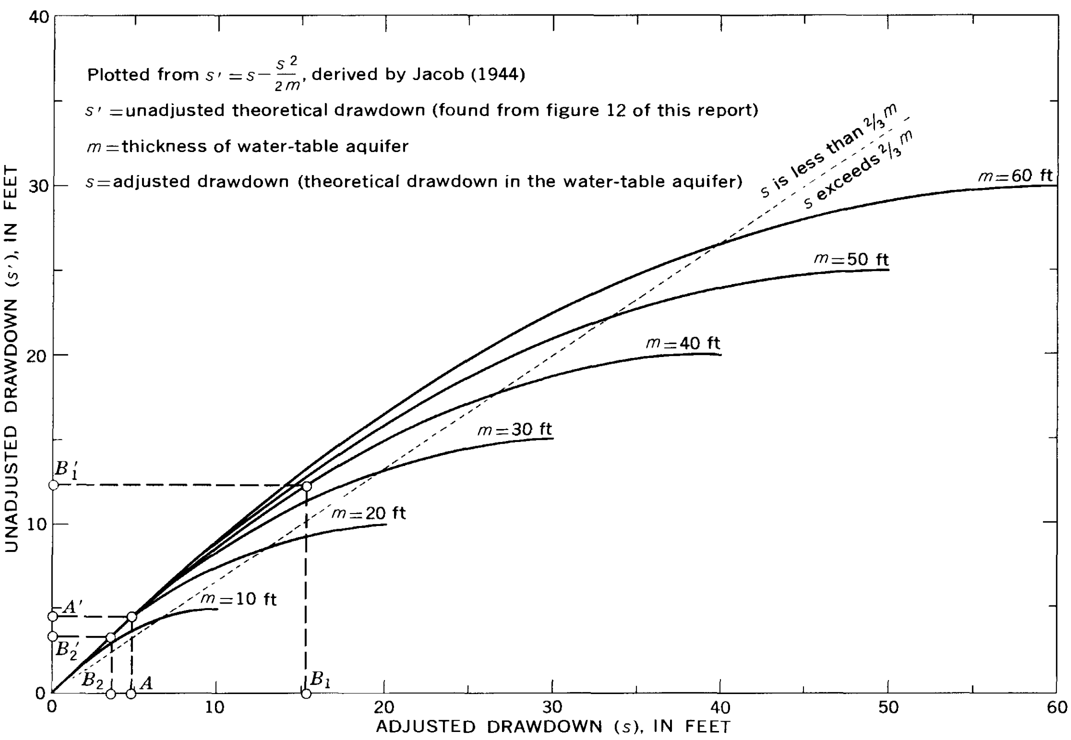


FIGURE 13.—Theoretical curves for adjustment of drawdown data from figure 12 to compensate for dewatering of the water-table aquifer.

Find the drawdown 1 foot from the center of each well after 30 days.

1. The curve for 40,000 gpd per ft (fig. 12) shows that the unadjusted drawdown at one well would be about 12.4 feet (B'_1). The 40-foot curve (fig. 13) shows that the adjusted drawdown would be about 15.3 feet (B_1).
2. The curve for 40,000 gpd per ft (fig. 12) shows that the unadjusted drawdown 200 feet from the other well would be about 3.2 feet (B'_2). The 40-foot curve (fig. 13) shows that the adjusted drawdown would be about 3.7 feet (B_2).
3. The drawdown at either well when influenced by the other would be the sum of the drawdowns found in steps 1 and 2, or about 19 feet.

Although the curves in figure 11 and the example problem are for a well discharge of 300 gpm, they are also applicable to different discharges. Drawdown varies directly with discharge; for example, if 600 gpm is the anticipated or obtained yield, drawdowns could be found by doubling those indicated by figure 12 before adjustment for dewatering.

WATER QUALITY

Ground water in the surficial aquifer near Lake Emily is of the calcium magnesium bicarbonate type (table 3). Water in the buried aquifers is chemically similar to that in the surficial aquifer but commonly contains higher concentrations of sulfate. Because water-table aquifers receive much of their recharge directly from the land surface, they are highly susceptible to pollution. However, sulfate, chloride, and nitrate concentrations in water from the surficial aquifer are relatively low and do not indicate any present pollution problems. A major concern resulting from irrigation in the area will be the possibility of pollution in the surficial aquifer through the increased use of fertilizers. Chemical analyses of samples obtained periodically would provide the necessary data to warn of any incipient pollution problem.

SUITABILITY OF WATER FOR IRRIGATION

The chemical suitability of water for irrigation depends upon the concentrations of dissolved mineral constituents in the water. In western Minnesota, chemical factors in ground water which can be harmful to plant growth include sodium concentration, salinity, and boron concentration. The chemical factors are most critical in arid regions where dissolved constituents are

TABLE 3.—*Chemical analyses of water in and near the Lake Emily area*

Well No. or surface-water location	Depth of well (ft)	Date of collection of sample	Constituents in milligrams per liter (mg/l) Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)
122.39.8.dcd	[1]47	8–25–65	----	----	15	3.9	510	0	32	1.6	0.2
124.38.6.cbb	[1]143	8–30–65	----	----	5.2	3.6	450	0	55	.5	.2
124.41.13.add	[1]183	8–30–65	----	----	14	4.0	427	0	240	1.2	.2
122.41.33.cdd	[1]113	8–25–65	210	74	141	8.8	415	0	735	2.5	.2
124.39.17.bdc	[1]208	8–30–65	82	109	25	5.4	418	6	325	2.0	.2
123.40.10.bbb	[2]16	9– 5–67	87	47	----	----	341	----	72	2.5	----
123.40.20.daa	[2]10	9– 5–67	84	32	----	----	318	----	50	9.0	----
124.40.29.aca	[2]15	9– 5–67	90	45	----	----	378	----	69	2.5	----
West End, Lake Emily	[3]0	9– 5–67	50	60		----	358	----	68	11	----

Well No. or surface-water location	Depth of well (ft)	Date of collection of sample	Constituents in milligrams per liter (mg/l) Nitrate (NO_3)	Boron	Dissolved solids	Hardness as $CaCO_3$ (mg/l) Calcium, magnesium	Noncarbonate	Sodium-adsorption-ratio	Specific conductance (micromhos at 25°C)	pH
122.39.8.dcd	[1]47	8–25–65	4.4	----	470	390	0	0.2	720	7.5
124.38.6.cbb	[1]143	8–30–65	4.4	----	490	420	50	.0	780	7.5
124.41.13.add	[1]183	8–30–65	4.4		470	800	450	.1	750	7.7
122.41.33.cdd	[1]113	8–25–65	5.4	0.72	1520	828	488	2.1	1810	7.9
124.39.17.bdc	[1]208	8–30–65	20	.18	831	653	300	.4	1170	8.3
123.40.10.bbb	[2]16	9– 5–67	22	----	----	382	102	----	680	----
123.40.20.daa	[2]10	9– 5–67	8.0	----	----	320	60	----	580	----
124.40.29.aca	[2]15	9– 5–67	2.0	----	----	380	70	----	680	----
West End, Lake Emily	[3]0	9– 5–67	1.0	----	----	332	44	----	630	----

[1] Wells finished in buried aquifers.

[2] Wells finished in the surficial aquifer.

[3] Surface water.

allowed to accumulate in the root zone because of inadequate leaching. In western Minnesota the amount and distribution of rainfall and snowmelt are such that leaching of the root zone probably occurs annually, particularly in areas of highly permeable soil such as near Lake Emily.

Dangers from excessive concentrations of sodium in irrigation water include possible breakdown of soil structure and possible nutritional disturbance in crops. A parameter used to evaluate sodium hazard for irrigation water is the sodium adsorption ratio (*SAR*) recommended by the Salinity Laboratory of the U.S. Department of Agriculture (1954). The *SAR* is defined by the equation:

$$SAR = \frac{Na^{+}}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$$

where the concentrations of the constituents are expressed in milliequivalents per liter. Rating of *SAR* values of water for irrigation depends upon factors which include type of crop, soil texture, soil chemistry, and dissolved solids content of the irrigation water. A generalized rating based upon these and other factors (Bernstein, 1967) indicates that waters having *SAR* values less than about 8 should not cause breakdown of soil structure and that waters having *SAR* values less than about 4 should not cause nutritional disturbance to crops.

SAR values for water in the buried aquifers (table 3) are mostly less than 1. One analysis for well 122.41.33cdd indicated an *SAR* value of 2.1. *SAR* values for water in the surficial aquifer could not be calculated because sodium concentrations were not analyzed. Approximations of sodium content, based upon a balancing of the relative concentrations of other common cations and anions, are less than 1 milliequivalent per liter and indicate that *SAR* values would be less than about 0.5. According to Bernstein's criteria, waters in the Lake Emily area are suitable for irrigation, with little danger of the development of harmful amounts of exchangeable sodium in the soil or toxic accumulations of sodium in plants.

Salinity or dissolved-solids concentrations can be critical to the growth of certain plants. Of the crops likely to be irrigated in the project area, green beans have the least tolerance to salinity. Crops which have a moderate tolerance for salinity and which could be grown in the Lake Emily area include peas, sweet corn, potatoes, and alfalfa.

The common test for salinity hazard in irrigation water is the measurement of specific conductivity of the water. Waters having specific conductivities less than about 2,250 micromhos per centimeter are probably satisfactory for irrigation where annual leaching of the root zone occurs (Wilcox, 1955, p. 15, 16). Values of specific conductivity for water in buried aquifers (table 3) are less than 2,000 micromhos per centimeter. Specific conductivity values for water in the surficial aquifer and for base flow in the Chippewa River (fig. 14) are less than 750 micromhos per centimeter. The salinity or dissolved-solids concentrations in all waters in the area, as indicated by specific conductivities, are suitably low for irrigation.

Relatively low concentrations of boron in irrigation waters can be toxic to certain crops. According to a classification of the tolerance of plants for boron by Wilcox (1955), crops grown in the project area may be sensitive to concentrations greater than about 1 mg/l (milligram per liter). Values of boron content are not available for most chemical analyses of water in the Lake

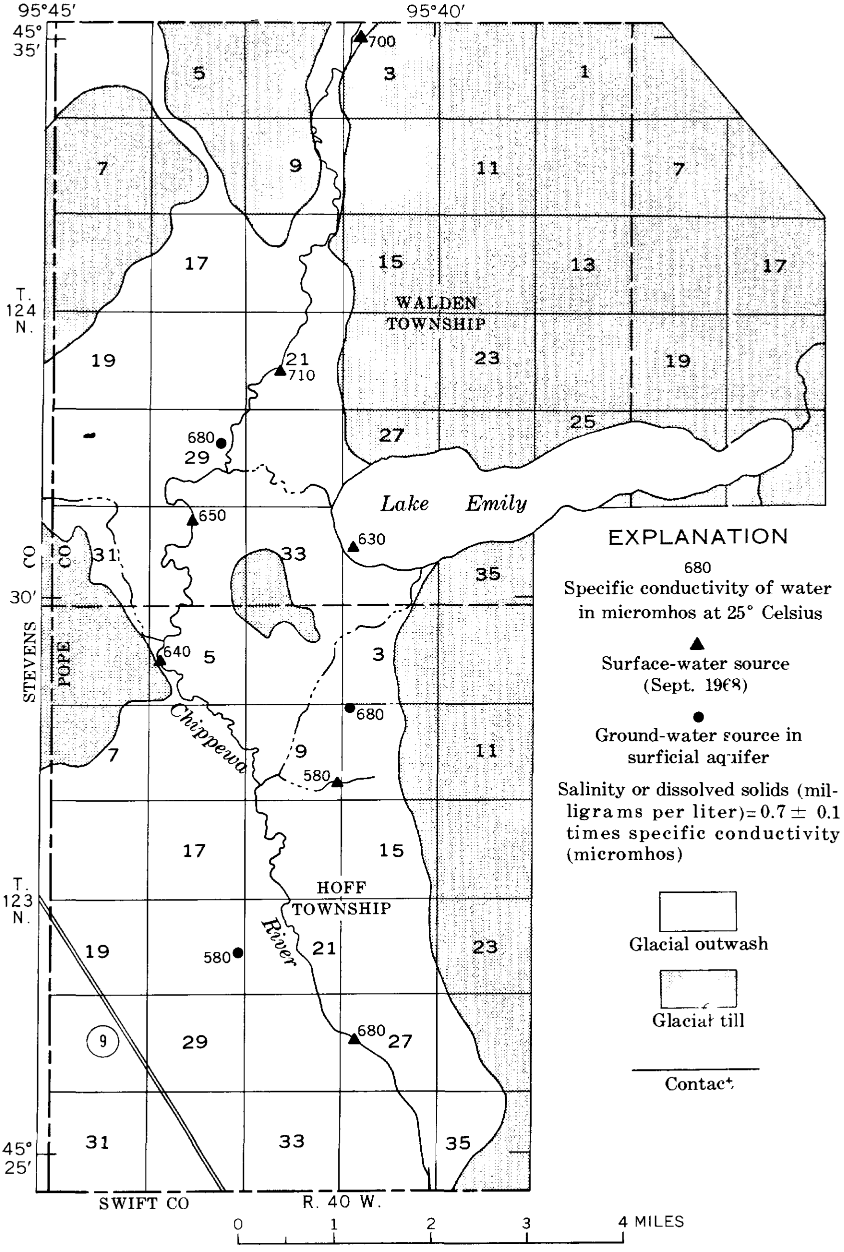


FIGURE 14.—Specific conductivity for ground water in the surficial aquifer and for base flow.

Emily area. Boron concentrations in ground water throughout western Minnesota commonly are highest in the deepest aquifers, particularly those in the Cretaceous sedimentary rocks. In waters from glacial drift aquifers less than about 100 feet below land surface, boron concentrations are rarely more than 0.5 mg/l. It is likely that most ground water in the Lake Emily area, particularly that in the surficial aquifer, does not contain dangerous boron concentrations, even for sensitive crops.

CONCLUSIONS

Glacial drift in the report area is more than 200 feet thick and probably contains significant aquifers buried at various depths. Extensive test drilling may be necessary to locate buried aquifers capable of yielding sufficient quantities of water for irrigation.

Outwash, deposited by meltwaters from the Des Moines lobe of glacial ice, covers the report area and is as much as 60 feet thick. The outwash contains a water-table aquifer having a saturated thickness of generally more than 20 feet and locally more than 40 feet. Thickness and hydraulic conductivity of the aquifer are greatest in the northern and western parts of the report area. The surficial aquifer holds an estimated 115,000 acre-feet of water in storage. Estimated maximum yields for wells, based upon 30-day pumping periods with drawdowns limited to less than two-thirds of the aquifer thickness, are more than 600 gpm in the northern and western parts of the report area. In the southeastern part of the area, potential yields from the surficial aquifer are less than 100 gpm, and prospective irrigators will have to rely upon groups of wells, infiltration pits, or wells in buried aquifers to obtain adequate water supplies.

Water in the buried and surficial aquifers is mainly of the calcium magnesium bicarbonate type and probably is chemically suitable for irrigation. Sodium-adsorption-ratios, calculated for water in buried aquifers and estimated for water in the surficial aquifer, are below recommended limits. Salinity hazards for all water in the area are below recommended limits. Boron concentrations are estimated to be below critical levels, even for sensitive crops.

REFERENCES

Allison, I. S., 1932, The geology and water resources of northwestern Minnesota: Minnesota Geol. Survey Bull. 22, 245 p.

Bernstein, Leon, 1967, Quantitative assessment of irrigation water quality, *in* Water quality criteria: Am. Soc. Testing Materials STP-416, p. 51–65.

Cotter, R. D., Bidwell, L. E., Van Voast, W. A., and Novitzki, R. P., 1968, Water resources of the Chippewa River watershed, west-central Minnesota: U.S. Geol. Survey Hydrol. Inv. Atlas HA–286.

Edward E. Johnson, Inc., 1966, Ground water and wells: St. Paul, 440, p.

Jacob, C. E., 1944, Notes on determining permeability by pumping tests under water-table conditions: U.S. Geol. Survey open-file report.

Leverett, Frank, 1932, Quaternary geology of Minnesota and parts of adjacent states: U.S. Geol. Survey Prof. Paper 161, 149 p.

Minnesota Division of Waters, 1959, Hydrologic atlas of Minnesota: Minnesota Div. Waters Bull. 10, 182 p.

Theis, C. V, 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Trans. Am. Geophys. Union, 16th Ann. Mtg., pt. 2, p. 519–524.

U.S. Salinity Laboratory Staff, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Dept. Agriculture Handbook 60, 160 p.

Upham, Warren, 1888, The geology of Douglas and Pope Counties, *in* Winchell, N. H., Geology of Minnesota: Geol. and Nat. History Survey Minnesota Final Rept., v. 2, p. 471–498.

Van Voast, W. A., 1968, Ground water for irrigation in the Brooten-Belgrade area, west-central Minnesota: U.S. Geol. Survey open-file report.

Wenzel, L. K., 1942, Methods for determining permeability of water bearing materials, with special reference to discharging-well methods: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wilcox, L. V., 1955, Classification and use of irrigation waters: U.S. Dept. Agriculture Circ. 969, 19 p.

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