DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
MINNESOTA DEPARTMENT OF CONSERVATION
DIVISION OF WATERS, SOILS, AND MINERALS
AND THE CITY OF ST. JAMES, MINNESOTA

HYDROLOGIC INVESTIGATIONS
ATLAS HA-334

INTRODUCTION

The purpose of this investigation was to evaluate the quality and quantity of the ground-water resources in the area of St. James, Minnesota. St. James is located in the center of Watonwan County in south-central Minnesota. The area is covered by a thick layer of glacial drift which is underlain by Cretaceous, Cambrian, and Precambrian rocks. St. James presently obtains its water supply from two aquifers. One is a Cretaceous sandstone 160 feet below the surface, in which two wells are completed. This aquifer yields abundant water but it is of poor quality and is expensive to treat. The second source, tapped by three municipal wells, is a surficial sand and gravel deposit less than 40 feet thick at the well field. This aquifer produces water of better quality, but its extent and capacity are not known. There are other wells in the area completed at depths ranging from 15 to 500 feet.

GLACIATION

The Des Moines lobe of the Wisconsin Glaciation covered most of south-central Minnesota, including all of Watonwan County. Associated with this glaciation is the St. James morainic system. The moraine enters Watonwan County near the northwest corner and extends southwestward toward St. James. In the vicinity of St. James, the moraine is formed by a few low mounds that rise about 25 feet above the general land surface.

Associated with the St. James moraine are glacial outwash deposits which form the surficial sand and gravel aquifer. The deposits consist of silt, sand, and gravel and are part of a system of outwash channel deposits that extends northwestward into South Dakota (fig. 1).

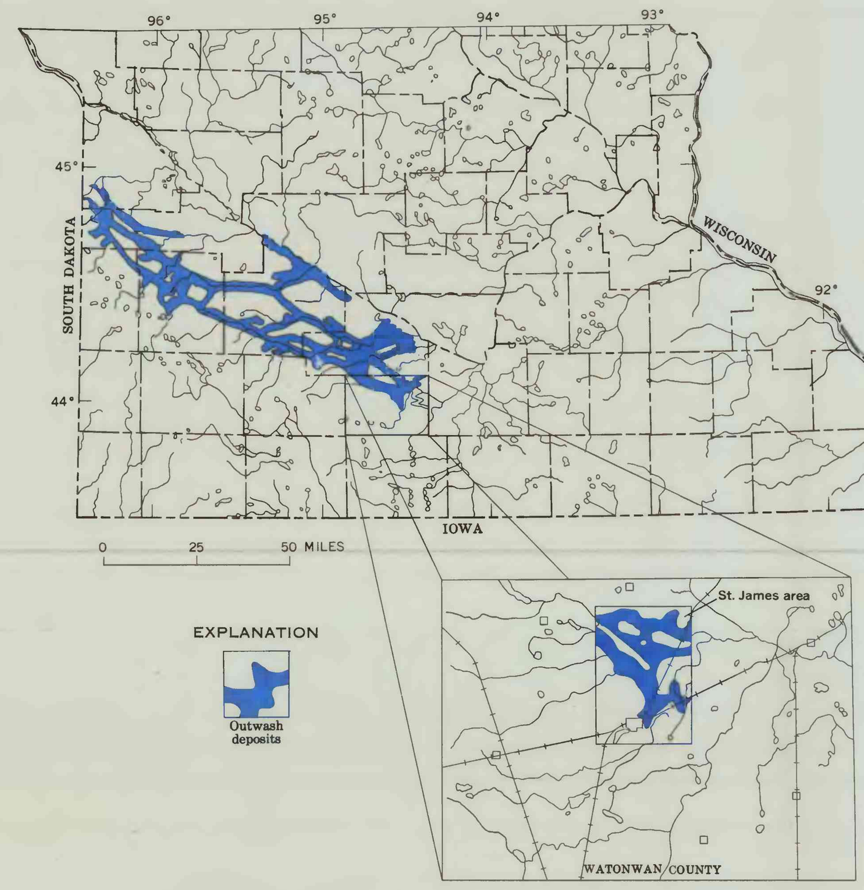

FIGURE 1.—*Location of area and extent of outwash deposits*

SURFICIAL SAND AND GRAVEL AQUIFER

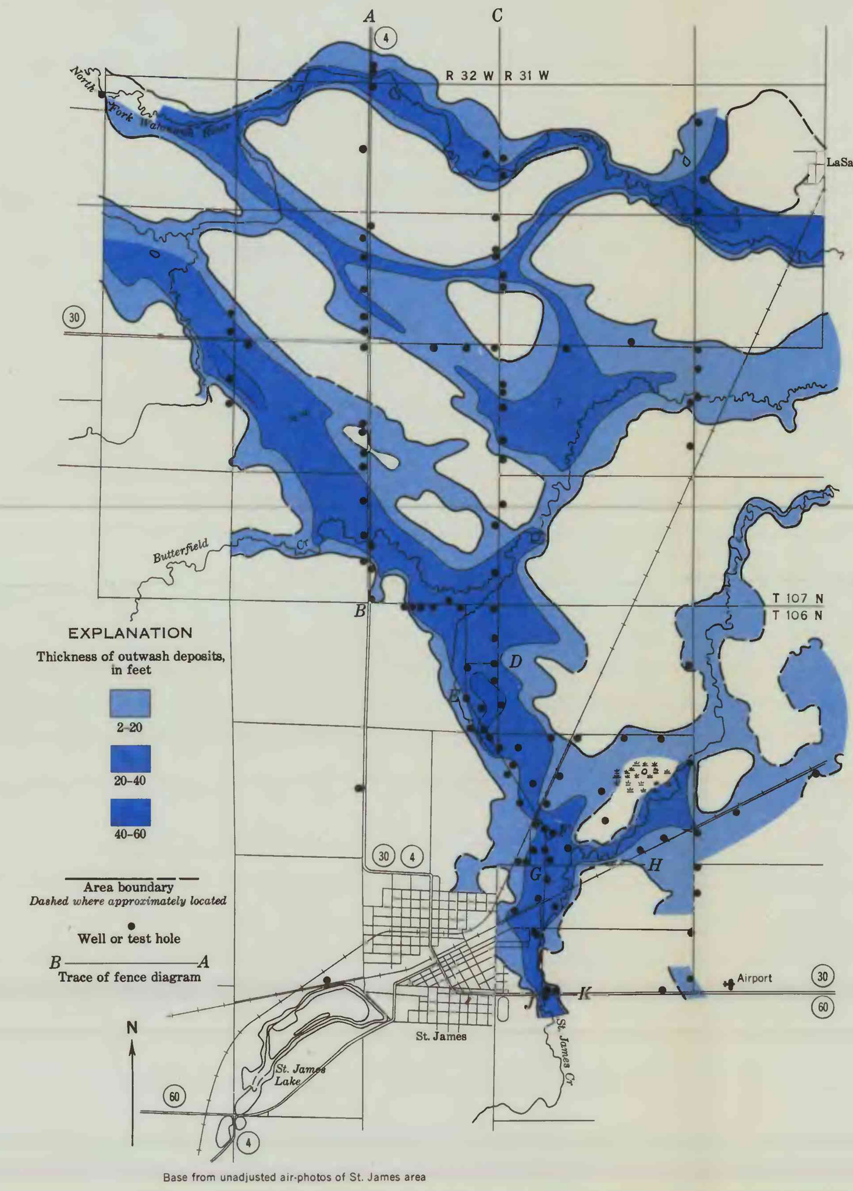

FIGURE 2.—*Thickness of outwash deposits*

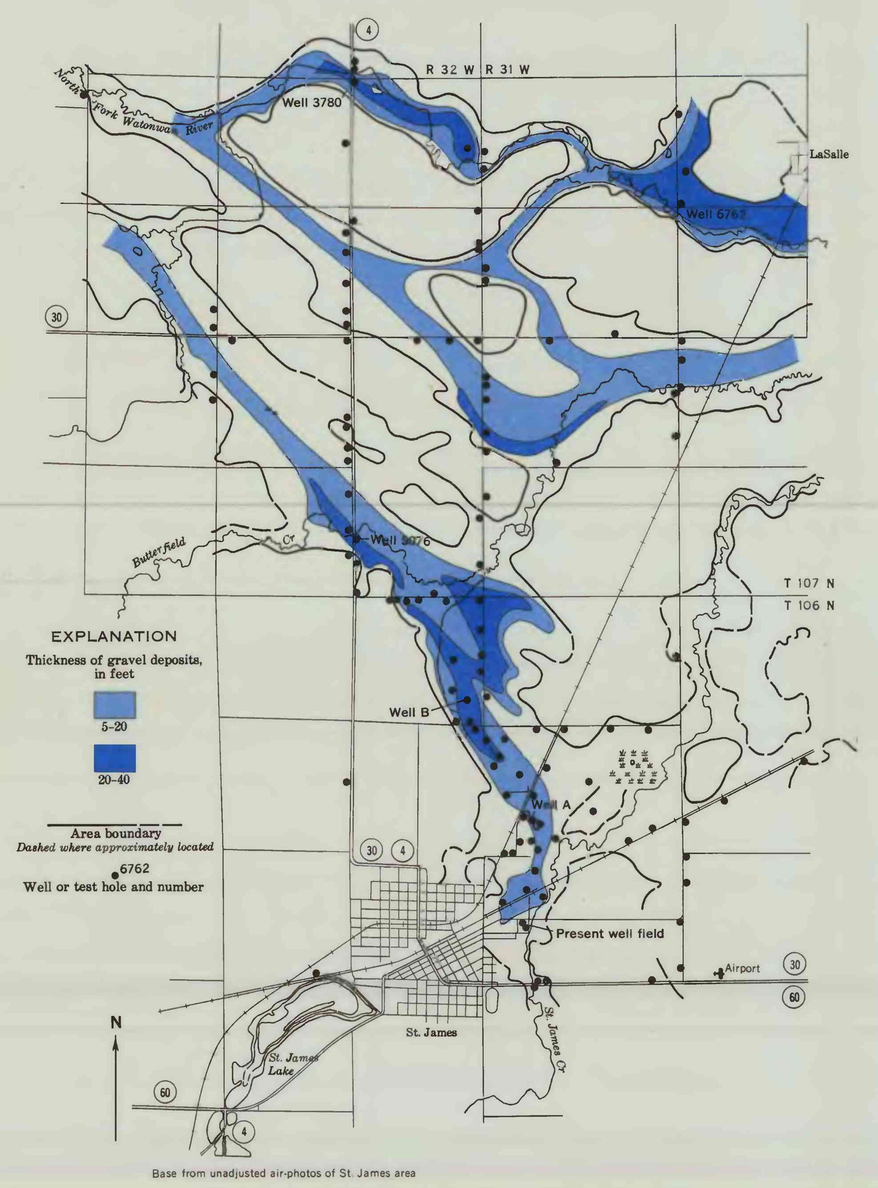

FIGURE 3.—*Thickness of gravel part of outwash deposits*

SCALE 1:62 500
1 ½ 0 1 2 3 4 MILES
1 .5 0 1 2 3 4 KILOMETERS
DATUM IS MEAN SEA LEVEL

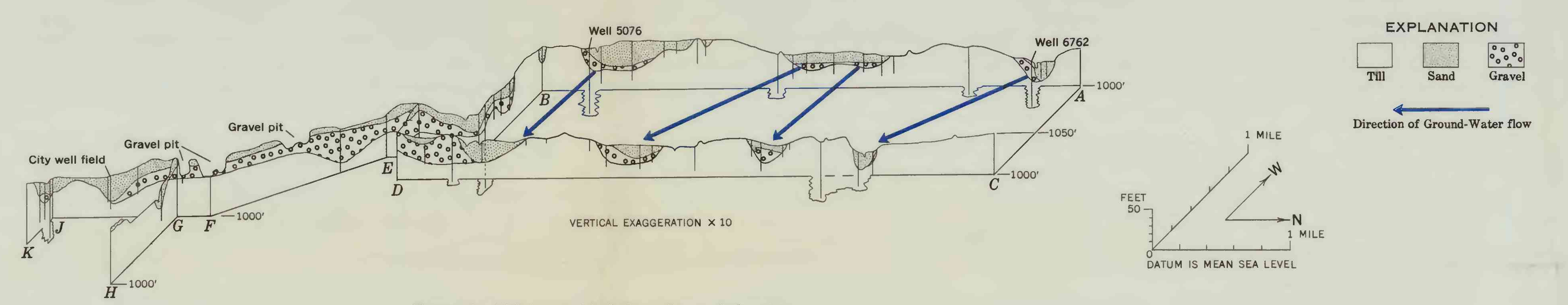

FIGURE 4.—*Lithology and hydrology of outwash deposits*

SURFICIAL SAND AND GRAVEL AQUIFER

LOCATION AND THICKNESS

The outwash deposits make up an aquifer of great lateral extent having a saturated thickness of as much as 30 feet. Figure 2 shows the total thickness and area of these deposits north of the city of St. James. Because this is a surficial deposit, the depth to till and the thickness of outwash deposits are synonymous if the thin soil layer is not considered. Figure 3 shows the extent and thickness of the part of the deposit that is predominantly gravel. Generally, the gravel is in the lower part of the deposit. The fence diagram (fig. 4) illustrates these relationships along selected sections. Auger test holes are the primary data control.

DESCRIPTION OF DEPOSITS

Conditions vary considerably during the melting and recession of a glacier. Seasonal and short-term variations in temperature result in changes in the rate of melting, with corresponding fluctuations in the amount of flow of outwash streams. The sediment load of the glacier itself varies. The ice margin recedes as the glacier melts. The streams flow in and on recently deposited unconsolidated material, causing rapid bank erosion and channel shifting. The great variation in deposition and materials produces a heterogenous system of deposits in glacial outwash channels. Figure 5 illustrates this condition. The diagonal cross section of the outwash stream, just west of Chicago and Northwestern Railroad tracks one-fourth mile north of the city, shows the gravel pit face at 5- to 10-foot depths. The truncated cross-bedding is the result of repeated deposition and subsequent partial erosion. There is a general tendency toward a graded bedding with coarser materials deeper in the deposit and also lower in each lens.
This may result from decrease in streamflow each season, recession of the glacier, and decrease in source of overall water supply. Commonly there are fine white sands, yellow when wet, in the uppermost 5 feet. A mixed deposit, predominantly of coarse gravel, overlies the bell-shaped sand lenses. Immediately above the gravel is a layer of dark hematitic silts and very fine sands. These abrupt textural changes indicate equally abrupt changes in depositional environment.

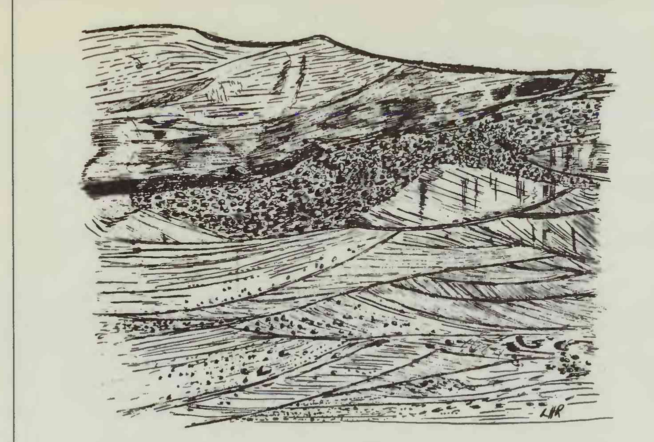

FIGURE 5.—*Exposure of outwash deposits in a gravel pit*

The complexity of the deposits as shown in figures 5 and 6 indicates the variation in permeability of the outwash deposits. Wells completed in one area may have significantly different yields than wells completed in a nearby area. At some locations, however, sorting of the deposits is good and indicates that a large supply of water may be obtained. Histograms (fig. 6) of the extremes of 242 sieve analyses of samples from four gravel pits within the study area further demonstrate variable sorting. They emphasize the difficulty that would be encountered in predicting material size and distribution at a given position and depth in the sand and gravel aquifer even if an accurate sieve analysis had been made in the immediate area.

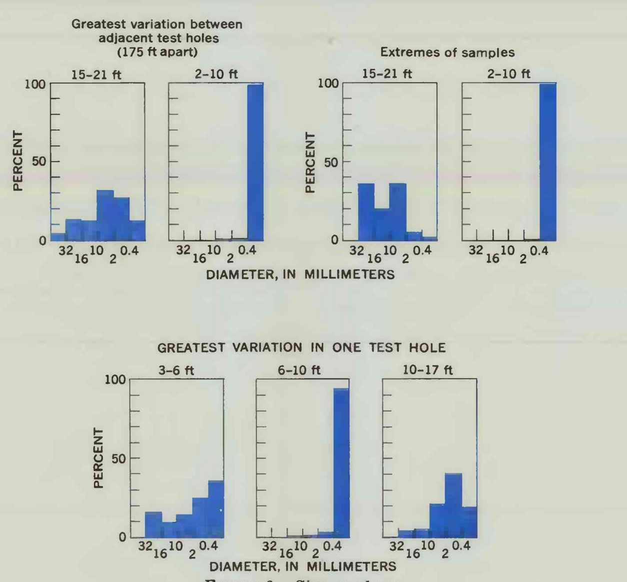

FIGURE 6.—*Sieve analyses*

HYDROLOGY

The position of the water table in the sand and gravel aquifer (fig. 4) indicates a general gradient of the ground-water discharge to the streams from the northwest to the southeast. St. James is downgradient from the greatest part of the outwash deposits. The flow of ground water, determined by the relative difference in hydraulic head, is in the direction of the arrows shown on figure 4. The material classification shown on figure 4 represents predominant materials only. The tills generally are nearly impermeable and produce little water except for the upper few feet, which may have been reworked by the outwash streams. The buried sand and gravel deposits, which are 30 to 70 feet below the land surface in some areas, will yield enough water for farm uses even in very dry years. The combined yield of the two St. James municipal wells, which tap the surficial sand and gravel aquifer, yield 300 gpm (gallons per minute).

The hydrographs (figs. 7 and 8) show the relative positions of the water table at several locations in the outwash deposits and the relationship between water-table fluctuation, river stage, and precipitation. Figure 7 shows that water levels in wells fluctuate in response to precipitation, thereby indicating recharge to the aquifer. The response is similar in magnitude to changes in the stage of the streams. Figure 8, which is a part of figure 7 drawn to an expanded scale, shows at least a 2-day response to the recharging precipitation.
The observation wells near the streams show that ground water is almost always discharged to the streams except at time of flooding. The period of record, 1964-66, for the hydrographs is one of generally higher-than-normal precipitation. Therefore, the altitude of the water table in the aquifer during time of drought is unknown. Local residents have reported that many wells in the aquifer continued to supply farms in the dry year of 1959. The stages of the major streams, North Fork Watonwan River and Butterfield Creek, are good indicators of the ground-water level. Ground-water inflow can be observed just west of the bridge at well 3780 as a fresh, clear stream of water tributary to the turbid North Fork Watonwan River.

The surficial sand and gravel aquifer is easily drilled and contains water of good quality. Pumping tests on wells 3780 and 5756 indicate coefficients of transmissibility (T) of 3,000 and 10,000 gpd/ft (gallons per day per foot) respectively. The storage coefficient (S) is estimated to be in the range of 0.1 to 0.2 (see "Definitions").

The surficial sand and gravel deposits constitute a good aquifer; however, because of the heterogeneous nature of the deposits and thickness of the aquifer from one location to another, local test drilling and sampling are necessary to estimate water yields and determine the best well design.

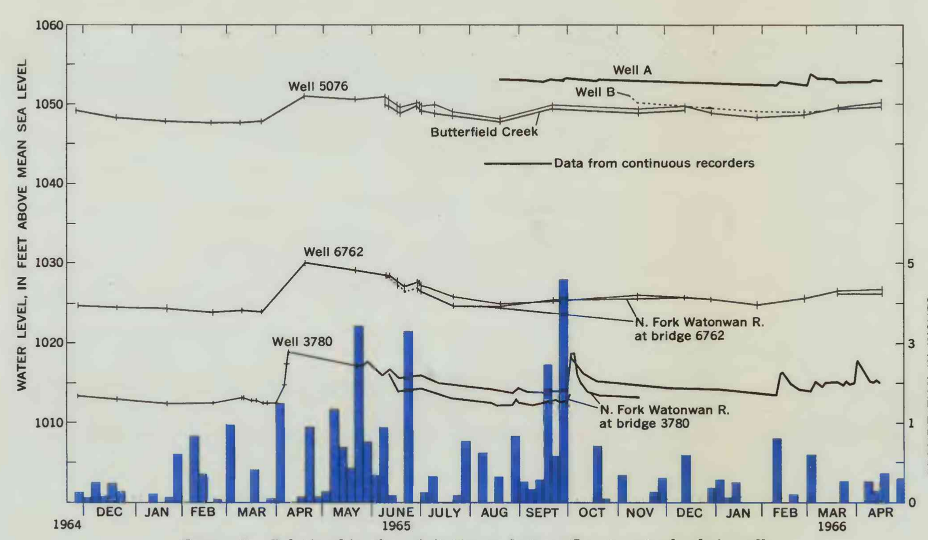

FIGURE 7.—*Relationship of precipitation and streamflow to water levels in wells*

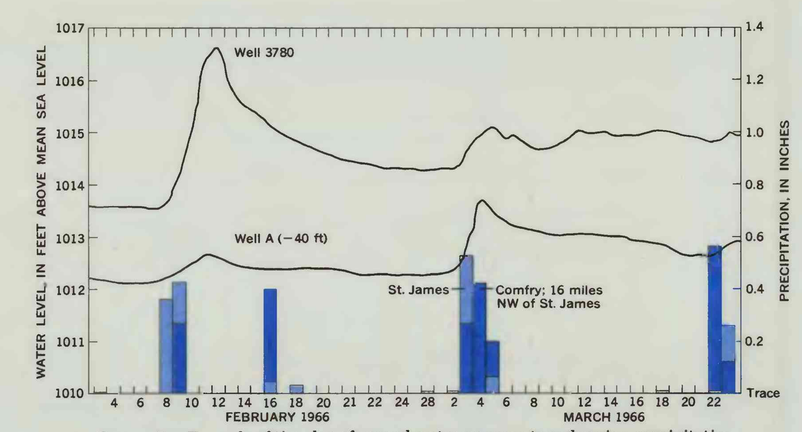

FIGURE 8.—*Example of time lag of ground-water response to recharging precipitation*

CRETACEOUS SANDSTONE AQUIFER

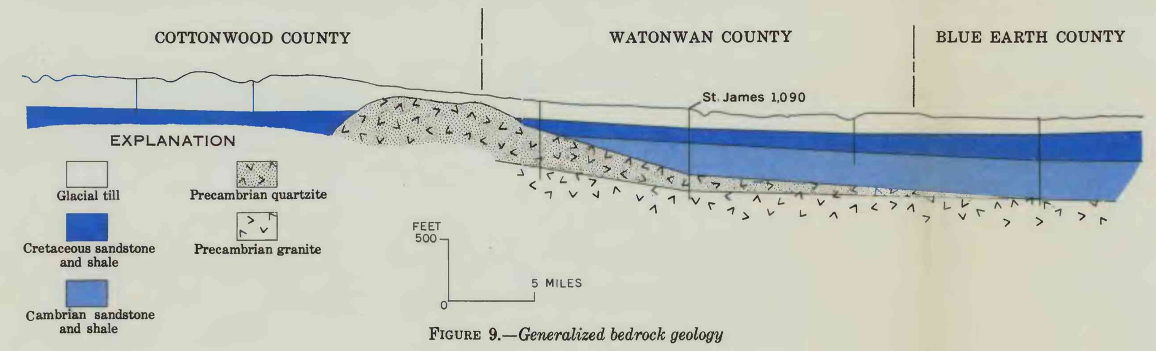

FIGURE 9.—*Generalized bedrock geology*

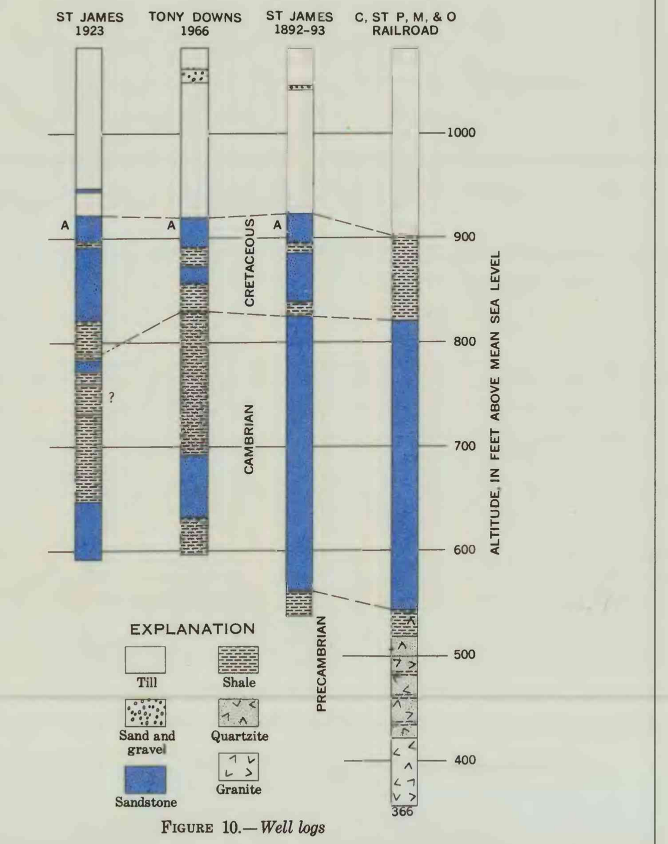

FIGURE 10.—*Well logs*

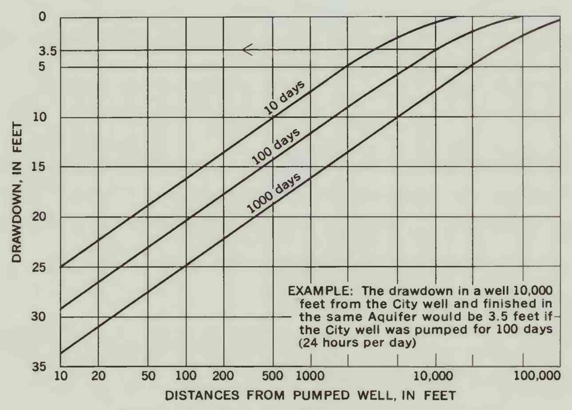

FIGURE 11.—*Time drawdown curves; pumping rate 1,000 gallons per minute*

BEDROCK AQUIFER

The generalized bedrock geology underlying Watonwan and adjacent counties is shown in figure 9. All bedrock units except the Precambrian granite, yield water to commercial and municipal wells in the St. James area. Abundant supplies are available to a depth of 480 feet.

Logs of four wells (fig. 10) located in St. James show in more detail the rock formations underlying the glacial drift. The Cretaceous sandstone "A" is the formation in which two of the wells are completed and are presently (1968) being utilized by the city. This aquifer is under artesian pressure and the water rises to within 10 feet of the land surface, which is at an altitude of about 1,070 feet above mean sea level. A 19-hour pumping test was run using city well 1 as the pumped well and city well 2 as the observation well. The hydrologic characteristics of the aquifer are: $T^1 = 60{,}000$ gpd/ft and $S^2 = 0.00034$.

Time drawdown curves for the Cretaceous sandstone aquifer (fig. 11) indicate the magnitude of drawdown that will occur as a result of pumping. The curves were drawn on the basis of data from the pumping test. Using this graph, one can predict the drawdown that will occur in a well nearby a pumping well in the same aquifer if the pumped well is steadily and continuously producing 1,000 gpm for 10-, 100- and 1,000-day periods. The curves can be interpolated. It is emphasized that the drawdown scale is arithmetic and the distance scale is logarithmic. In preparing the time-drawdown curves, leaky artesian conditions and great lateral extent of a homogeneous aquifer were assumed.

QUALITY OF WATER

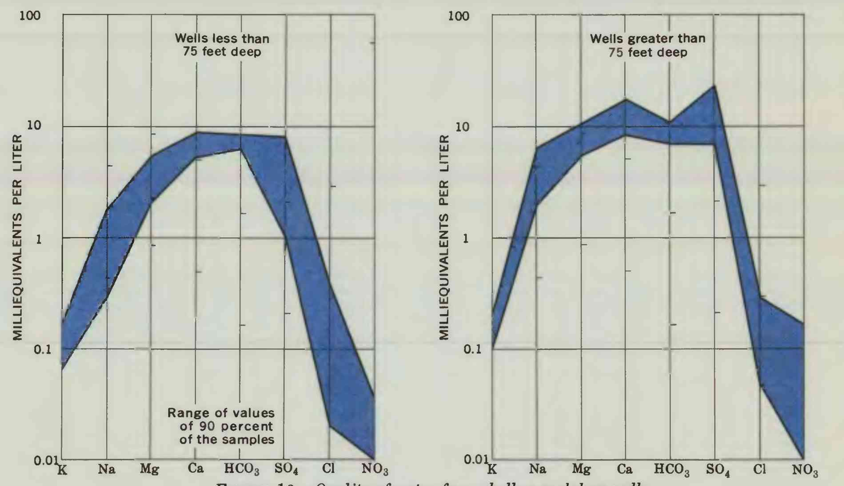

FIGURE 12.—*Quality of water from shallow and deep wells*

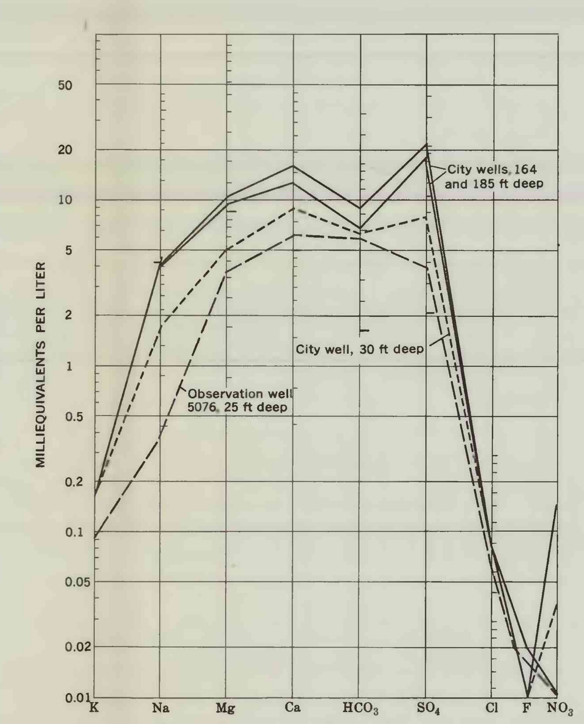

FIGURE 13.—*Quality of water from city wells*

AQUIFER	SOURCE	DEPTH (ft)	DATE	HARDNESS AS $CaCO_3$	IRON (Fe)	MANGANESE (Mn)	BORON (B)	PHOSPHATE (PO_4)	TOTAL DISSOLVED SOLIDS	SPECIFIC CONDUCTANCE IN micromhos/cm
				IN MILLIGRAMS PER LITER						
Cambrian sandstone	New food plant well	485	1966	1270	3.7	0.28		0.03	2060	2320
Cretaceous sandstone	St. James city well	169	1964	1080			0.46	0.03	1680	1950
Cretaceous sandstone	St. James city well	185	1965	1310	5.4	0.33			1950	2250
Cretaceous sandstone	St. James city well	185	1966	1290	5.7	0.26	0.32	0.02	1970	2220
Cretaceous sandstone	Trailer court well	193	1965	795	3.7	0.30			1100	1430
Cretaceous sandstone	Stock well north of city	160	1965	866	18	0.42			1250	1590
Cretaceous sandstone	New home east of city	190	1966	622	13	0.27		0.05	885	1180
Surficial outwash sand & gravel	St. James city well	30	1964	674			0.15	0.06	980	1290
Surficial outwash sand & gravel	Observation well B	22	1966	504	2.2	0.50	0.05	0.02	644	910
Surficial outwash sand & gravel	Observation well 3780	57	1966	380	1.7	0.35	0.05	0.01	485	728

TABLE 1.—*Selected ground-water analyses*

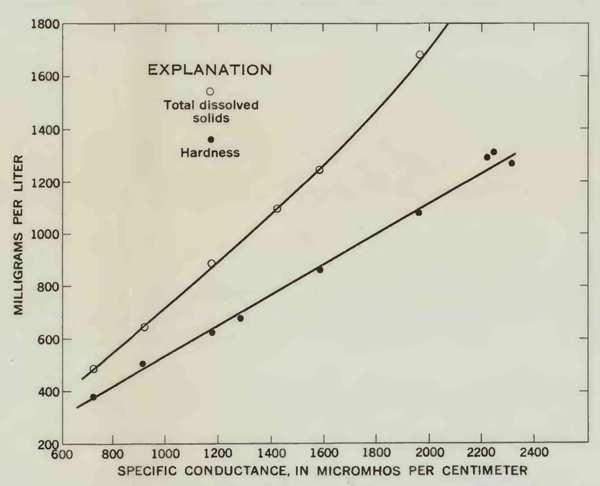

FIGURE 14.—*Relationship of specific conductance to quality of water*

QUALITY OF WATER

The quality of water commonly is as important as the quantity because treatment of poor-quality water to meet acceptable standards can be very costly. The city of St. James, with a population of 5,000 using about 500,000 gallons of water a day, requires more than 260 tons of lime per year for treatment of water. The major solutes in natural ground water are calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) cations; and bicarbonate (HCO_3), chloride (Cl), and nitrate (NO_3) anions. Each industry has its particular requirements as to the concentrations of these constituents as well as requirements with respect to temperature, color, turbidity, and other properties of water.

The graphs in figure 12 show that water from shallow wells contains about one-half as much dissolved minerals (all less than 10 milliequivalents per liter[3]) as water from deeper sources. The poorest quality (highest mineral content) water from the shallow wells is nearly equal to the best-quality water from deeper wells. Data are from 24 analyses of ground-water samples in the study area. The tic marks on some vertical divisions represent the milligrams per liter by weight scale as indicated. The bold tics falling between the 1 and 10 meq/l values are the 100 mg/l tics and so on. The highest tic on the Cl scale is 10 meq/l. This method enables concentrations to be read in either units.

Water from three city wells and one observation well are compared in figure 13. Water from the shallow city well is more mineralized than that from the observation well; yet they tap the same aquifer and are only 3 miles apart. This quality difference may be the result of the extensive use of the city well.

The specific conductance may be used to estimate the quality of ground water below values of 2,200 micromhos (fig. 14). The scatter of data above 2,200 micromhos is due to the very high sulfate content in the water.

Selected chemical analyses of ground water from both the surficial sand and gravel aquifer and the Cretaceous sandstone aquifer are shown in table 1.

CONCLUSIONS

The surficial outwash sand and gravel deposits in the area constitute a good aquifer. The aquifer has a saturated thickness of as much as 30 feet, high transmissibility, and extends over a large area from St. James, Minn., northwest to South Dakota. A standby well in the Cretaceous sandstone aquifer, which has abundant but lower quality water, would provide an assured water supply in case of temporary decline in yield from the surficial sand and gravel aquifer. For users who must meet high-quality standards, the use of better quality water from the surficial sand and gravel deposits would result in considerable reduction in water-treatment costs.

An abundant supply of moderately to highly mineralized water is available from the Cretaceous sandstone aquifer at depths generally less than 200 feet. Wells yielding 1,000 gpm can be developed in the aquifer. Pumping one well at a rate of 1,000 gpm for 100 days will result in a drawdown of 12 feet on the water level in another well at a distance of 1,000 feet. An abundant supply of slightly more mineralized water is also available from the underlying Cambrian rocks to a depth of 480 feet.

DEFINITIONS

[1] T—the coefficient of transmissibility is the rate of flow of water (at the prevailing temperature) in gallons per day through a vertical strip of the aquifer 1 foot wide, extending the full saturated thickness of the aquifer under a hydraulic gradient of 100 percent.

[2] S—the storage coefficient is the volume of water the aquifer releases from or takes into storage per unit surface area per unit change in the component of head normal to that surface. Under leaky artesian conditions assumed here, the water released is derived from storage by compaction of the aquifer and its associated beds, by water expansion and by vertical leakage through the confining beds.

[3] Milliequivalents per liter bear a direct relationship to the number, rather than the weight of ions in solution with a factor included to allow for the combining capabilities or equivalent reactive amounts.

SELECTED REFERENCES

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geol. Survey Water-Supply Paper 1536-E. p. 72-74

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.

Hall, C. W., Meinzer, O. E., and Fuller, M. L., 1911, Geology and underground waters of southern Minnesota: U.S. Geol. Survey Water-Supply Paper 256, p. 368-379

Leverett, Frank, 1932, Quaternary geology of Minnesota and parts of adjacent States: U.S. Geol. Survey Prof. Paper 161, p. 94-99

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GROUND-WATER RESOURCES OF THE ST. JAMES AREA, SOUTH-CENTRAL MINNESOTA

By
L. H. Ropes

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