GEOLOGICAL SURVEY CIRCULAR 274

DEPARTMENT OF THE INTERIOR
March 3, 1849

WATER RESOURCES OF THE MINNEAPOLIS-ST. PAUL AREA MINNESOTA

Based on data collected in cooperation with the Minnesota Department of Conservation, Division of Waters and St. Paul District, Corps of Engineers, U. S. Army.

UNITED STATES DEPARTMENT OF THE INTERIOR
Douglas McKay, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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By C. H. Prior, Robert Schneider, and W. H. Durum

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Washington, D. C., 1953

Free on application to the Geological Survey, Washington 25, D. C.

PREFACE

This report is one of a series concerning water resources of certain selected industrial areas of national importance and is intended to provide information of value for national defense and for the orderly planning of municipal and industrial expansion. The series is prepared in the Water Resources Division of the U. S. Geological Survey under the guidance of the Water Utilization Section of the Technical Coordination Branch. This report was prepared under the direct supervision of Paul R. Speer, district engineer (Surface Water), succeeded by Leon R. Sawyer, Robert Schneider, district geologist (Ground Water), and Paul C. Benedict, regional engineer, Missouri River basin (Quality of Water).

Most of the data summarized in this report other than those relating to chemical quality have been collected over a period of many years by the U. S. Geological Survey in cooperation with the Minnesota Department of Conservation and the Corps of Engineers. The Geological Survey has no program at present for the collection of chemical and physical quality of water data for streams in the Minneapolis–St. Paul area.

Analytical data presented were obtained chiefly from published or unpublished records of the Minneapolis and St. Paul water departments and the Minneapolis–St. Paul Sanitary District.

Additional data were obtained from industries and local government officials. A few of those who have contributed time and effort in supplying data for the report are S. A. Frellsen, director, Division of Waters, Minnesota Department of Conservation; J. B. Moyle, Division of Game and Fish, Minnesota Department of Conservation; K. L. Mick, chief engineer and superintendent, Minneapolis–St. Paul Sanitary District; M. L. Robins, chief chemist and sanitary engineer, Minneapolis–St. Paul Sanitary District; H. G. Erickson, city engineer, Minneapolis; Frank P. Bruce, senior sanitary engineer, Minneapolis; E. W. Johnson, superintendent, Minneapolis Water Department; A. C. Janzig, superintendent of the Purification Plant, Minneapolis; L. N. Thompson, superintendent, St. Paul Water Department; R. A. Thuma, superintendent of Filtration, St. Paul Water Department; Carl A. Flack, registrar, St. Paul Water Department; W. C. Thompson, Northern States Power Co.

Plate 1.—View of Mississippi River valley at St. Paul showing areas flooded in April 1952.

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WATER RESOURCES OF THE MINNEAPOLIS-ST. PAUL AREA, MINNESOTA

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ABSTRACT

The water supply of the Minneapolis-St. Paul area is adequate to satisfy present requirements and requirements for many years to come if the area continues to develop at about the present rate.

The flow of the Mississippi River at the Twin Cities is more than sufficient to meet the demands of the water-supply systems of Minneapolis and St. Paul. The lowest momentary flow during the period 1931–51 was more than twice the present combined maximum demand of Minneapolis and St. Paul. The lake storage of the St. Paul system combined with possible regulations by the Mississippi River headwater reservoir system, in case of an emergency, provides a reserve supply ample to meet a greatly expanded demand. The lowest average daily flow of the Mississippi River at the intakes of the Minneapolis and St. Paul water supply was 389 mgd (602 cfs). The flow at the water supply intakes has been less than 452 mgd (700 cfs) for not more than 6 consecutive days.

Except for the Mississippi River, the streams in the Twin Cities area have not been extensively developed for water supply. The only known use of them for water supply is for the steam-electric generating plant on the Minnesota River at Savage. Thus, the St. Croix River, within 12 miles on the east, the Minnesota River entering the Twin Cities from the southwest, the Vermilion within 12 miles on the south, and the Crow River within 25 miles on the west offer untapped supplies for industrial and municipal uses.

Many water-bearing formations occur in the area. A blanket of glacial deposits, as much as 400 feet thick, covers the area. Small domestic ground-water supplies can be developed practically everywhere in the glacial deposits, and larger industrial supplies can be obtained by exploring and testing. Below the glacial materials is a thick series of rock formations including several prolific sandstone aquifers. The formations dip toward the center of the area forming an artesian basin.

The estimated average daily withdrawal of ground water from all aquifers in the area is about 90 mgd. Practically all the communities that are not supplied by the Minneapolis or St. Paul water-supply systems obtain their water from wells.

Where many large-capacity wells have been concentrated in relatively small areas, there has been a great lowering of artesian pressures. However, there are large areas, distant from the centers of concentrated pumping, which are favorable for the development of additional ground water. With an adequate program of exploration and testing to determine precisely the geologic and hydrologic characteristics of the water-bearing formations, it is likely that large additional supplies of ground water can be developed for municipal and industrial uses.

Both Minneapolis and St. Paul obtain their municipal water supplies from the Mississippi River above the Twin Cities and are thus assured of a large supply that is not subject to contamination by industrial wastes and sewage effluents. Treatment at municipal plants for both cities provides water for diversified industrial use and for domestic use that meets U. S. Public Health Service drinking water standards. The treated water is remarkably uniform in chemical composition throughout the year and is virtually free of all color, iron, manganese, and turbidity. Currently, (1952), the two supplies are softened to about 75 ppm (as $CaCO_3$), which is an average reduction of about 55 percent in hardness of river water. The dissolved-solids content of the treated water for St. Paul currently (1952) averages about 100 ppm; the dissolved-solids content of the Minneapolis water is slightly higher. As a matter of further interest to industrial consumers, temperatures of the untreated river water, which is only slightly altered at the Minneapolis treatment plant, averages less than 60 F for about 8 months of the year and is less than 40 F for 4 winter months.

The Mississippi River as it enters the Twin Cities is moderately mineralized, averaging 241 ppm dissolved solids and 179 ppm hardness during the period 1940–49. Average turbidity is very low and silica is moderately low, but the quantities of iron and color in solution are relatively high. Color increases markedly during the period March to July in response to an increase in streamflow. The average chemical composition of the water has remained virtually unchanged except for seasonal variations since 1907.

Data collected by the Minneapolis-St. Paul Sanitary District have shown improved sanitary conditions of the river at the Twin Cities lock and dam since the sewage plant went into operation in 1939.

The Minnesota River is more than twice as mineralized and hard as the Mississippi River, and it exerts a noticeable effect on the chemical and sanitary quality of the Mississippi River at St. Paul.

Other principal tributary streams to the Mississippi River, including Crow River, Vermilion River, and

Bassett Creek, were sampled during the 1952 flood season, at which time they were of the calcium-bicarbonate type, more dilute, and of lower hardness than the Minnesota River. Lake waters in the Twin Cities area generally are less mineralized than those of the streams.

Waters from the drift deposits and bedrock formations overlying the Hinckley sandstone are hard and calcareous and generally contain troublesome quantities of iron. Regular treatment is required of some public-supply wells for removal of iron encrustations. Water from these sources generally exceeds 300 ppm hardness, but in some places the St. Peter sandstone and St. Lawrence formation yield water of better quality. The Hinckley sandstone yields the best quality ground-water because of its comparatively lower hardness and uniform temperature (about 52 F). However, the average hardness of the treated municipal supplies of St. Paul and Minneapolis is considerably less than water from the Hinckley.

INTRODUCTION

Purpose

A satisfactory water supply is one of the factors that affect the economic growth of a region. Cities and towns have adequate amounts of pure water for domestic use. Industries must have suitable water in sufficient quantities for all purposes. In order to assure success and economy, the development of water resources should be based on adequate knowledge of the present and potential quantity and quality of the water, and the magnitude of its present and future use. As a Nation, it is unwise to run the risk of dissipating our resources, especially in times of national emergency, by building projects that are not founded on sound engineering and adequate water-resources information. In times of national emergency, immediate action is imperative. Building sites must be chosen, often without adequate advance information, and locations for huge plants for manufacturing armament must be decided upon without long delays for investigation of the potential water supply. During World War II, the deciding factor in selecting plant sites was often the amount of data available at a site under consideration. Lack of information resulted in installations at some places that later proved to have water supplies inadequate in quantity, or quality, or both, and the installation was, therefore, found to be impossible or too costly to operate.

Shifts in trends in water use with changes in manufacturing methods and changes in centers of population do, to a certain extent, preclude definite statements regarding future consumption. Changes in industrial processes often require changes in water quality, and large quantities of industrial wastes may cause pollution to such a degree that the water downstream becomes unfit for use. This was clearly demonstrated at the Gopher Ordnance Plant in the Vermilion River basin south of St. Paul where a proposed program for the disposal of waste would have rendered the stream totally unfit for any use, even for watering of domestic stock. Thus an adequate supply today may become inadequate in the near future, and any statement of availability must be made with reservations.

The purpose of this report is to summarize and interpret all available water-resources information for the Minneapolis-St. Paul area. The report will be useful for initial guidance in the location or expansion of water facilities for defense or nondefense industries and the municipalities upon which they are dependent. No attempt has been made to present a complete record of the hydrologic information for the area. The Twin Cities area, is quite large; therefore, additional investigations will be necessary to determine the availability of water supplies for large-scale specific uses.

Description of Area

The area considered in this report is approximately 2,086 square miles. It includes the counties of Ramsey, Hennepin, and Washington, and parts of the counties of Carver, Scott, Dakota, and Anoka (pl. 2). Rich farmlands comprise a substantial part of these counties and, near the Twin Cities, truck gardening is relatively important. Dairy farming is an important industry.

Since the establishment of Fort Snelling at the mouth of the Minnesota River in 1819, the area has been a natural trading and industrial center. At the head of navigation on the Mississippi River, within 150 miles of the head of navigation on the Great Lakes, and served by ten railroads, the Twin Cities area is well situated as a midwest distribution center and as a manufacturing center for commodities of nearly every description. Long famed as a flour-milling and food-producing center, the area has now also become a leading producer of many kinds of machinery.

The area is generally characterized by a gently undulating topography, which is typical of recently glaciated regions. In the north there is a flat sandy plain, and nearly flat alluvial terraces border the Mississippi and Minnesota Rivers. The flood plains of the Minnesota River and the Mississippi River below the mouth of the Minnesota are conspicuous broad flat areas.

The tops of many hills are between 1,000 and 1,100 feet above sea level. In the northern part of the area the plains are about 900 feet above mean sea level, and the rivers are 800 to 860 feet above mean sea level. The flood plains of the Minnesota River and the Mississippi River below the Minnesota are 700 to 760 feet above mean sea level.

Most of the lakes and swamps occupy depressions formed in the glacial deposits when the glacier receded. Some of the depressions in the glacial drift are in partly filled preglacial valleys in the bedrock.

Accessibility of the whole area is an outstanding feature. The gently rolling terrain presents no problems of approach by rail, highway, air, or water.

Climate

According to records collected by the U. S. Weather Bureau, the average annual precipitation at St. Paul for the period 1871 to 1951 is 27.22 inches (fig. 1). The minimum annual precipitation during the same period was 10.21 inches in 1910; the maximum was 40.44 inches in 1911. The average seasonal snowfall for the

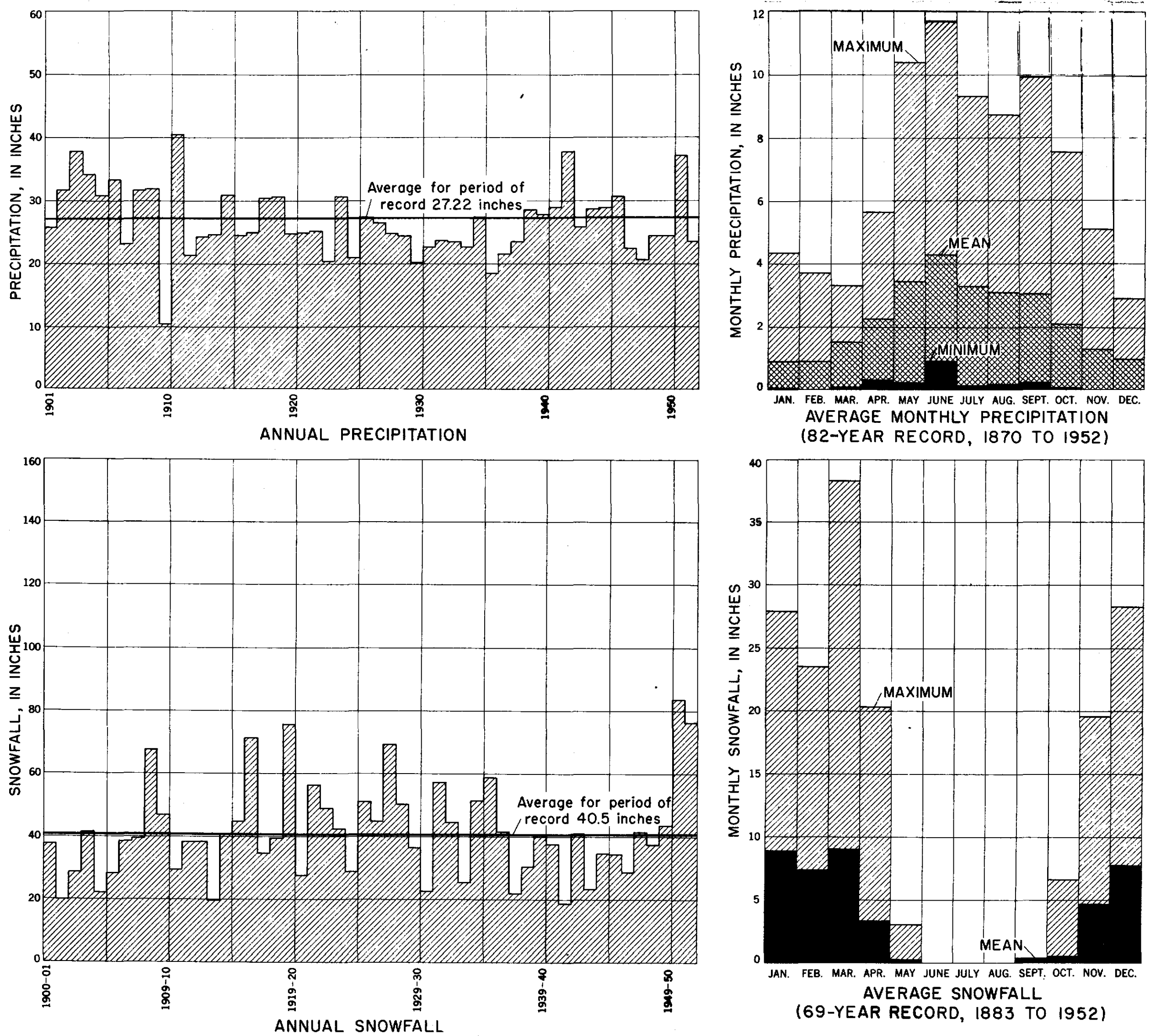

Figure 1.—Climatological data for St. Paul.

period 1871 to 1951 is 40.5 inches; the maximum was 83.3 inches during the 1950–51 season, and the minimum was 18.7 inches during the 1941–42 season (fig. 1).

The maximum temperature recorded at Minneapolis since 1871 is 108 F in 1936, and the minimum is 34 F below zero in the same year. During the winter there are on an average 31 days with temperatures below zero and during the summer an average of 15 days with temperatures above 90 F. The mean annual temperature is 42.1 F. The growing season, which is the average length of time between killing frosts, is 166 days. The latest killing frost on record was on May 20 and the earliest on September 13. Figure 2 shows the maximum, minimum, and average monthly air temperatures.

Evaporation is an important consideration in the use and conservation of water. It is measured by measuring the water lost from a standard evaporation pan. The annual evaporation at St. Paul ranged from 25.5 inches to 43.4 inches during the period 1891–1940 (fig. 3).

Table 1.–Population of political subdivisions

Name	Population	
	1950	1940
Minneapolis	521,717	492,370
St. Paul	311,349	287,736
St. Louis Park	22,644	7,737
Richfield	17,502	13,778
South St. Paul	15,909	11,844
Robbinsdale	11,289	6,018
Edina	9,744	5,855
Columbia Heights	8,175	6,035
West St. Paul	7,955	5,733
Stillwater	7,674	7,013
Hopkins	7,595	4,100
Anoka	7,396	6,426
Hastings	6,560	5,662
Crystal	5,713	2,373
Golden Valley	5,551	2,048
Hennepin County	676,579	568,899
Ramsey County	355,332	309,935

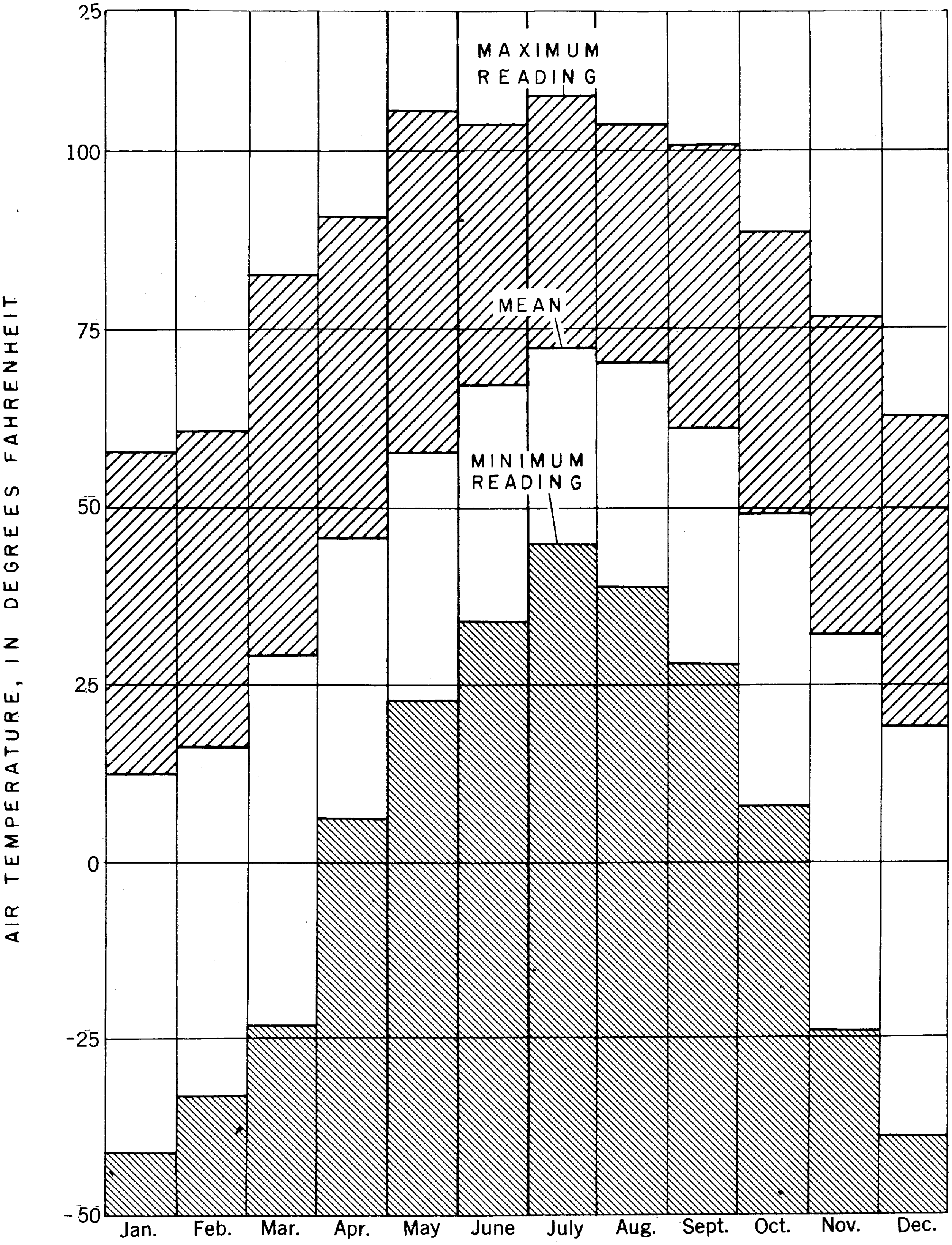

Figure 2.—Maximum, minimum, and average air temperature at St. Paul, 79-year record.

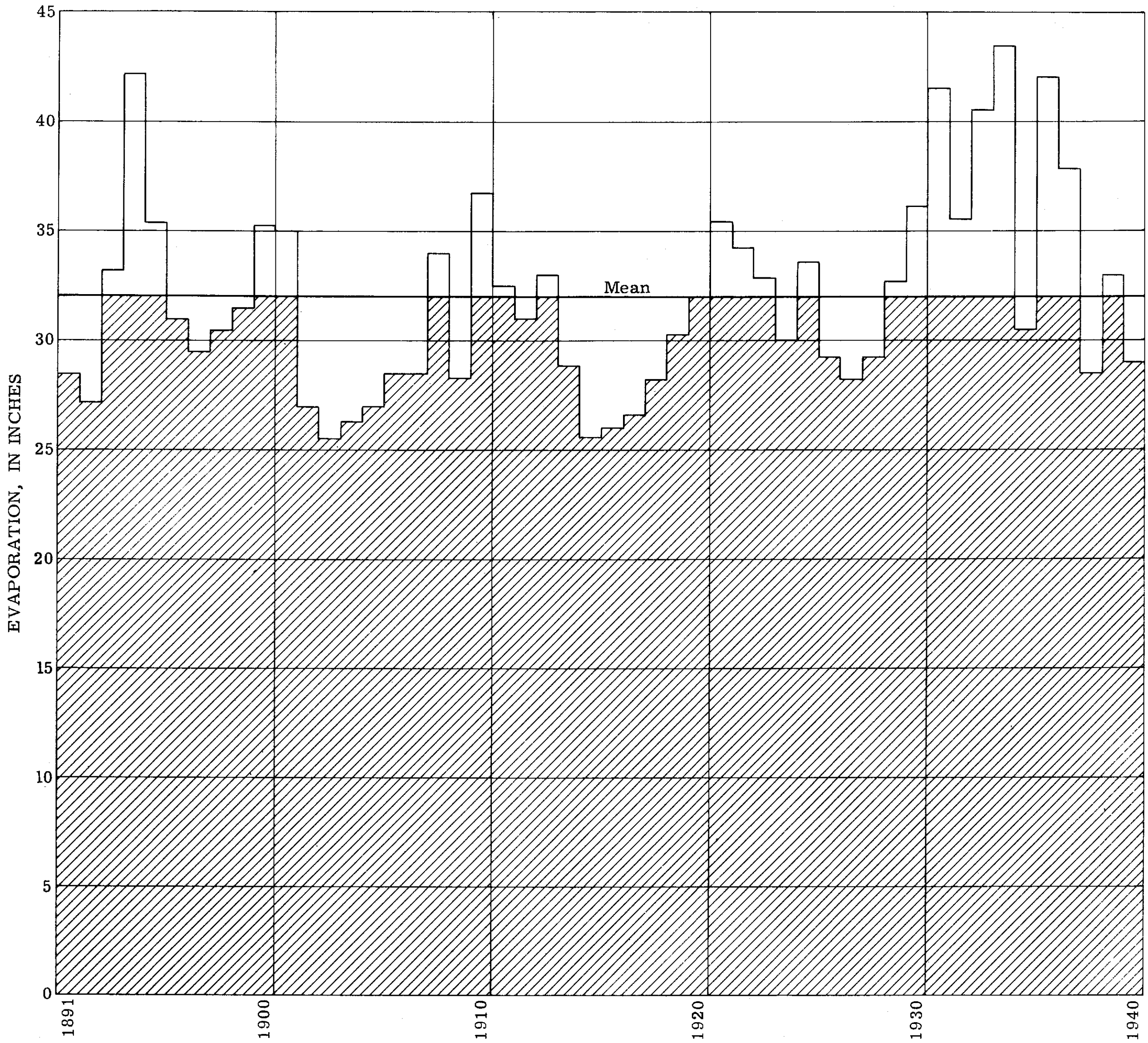

Figure 3.—Annual evaporation at St. Paul, 1891–1940.

Population

The total population of the area cannot be determined exactly because parts of several counties are involved, but a fairly reliable approximation is 1,156,600. The greatest concentration of population, 833,067 in 1950, was in the Twin Cities. The 1940 and 1950 population of most of the important political subdivisions in the area are shown in table 1.

The population growth from 1900 through 1950 for a few selected political subdivisions is shown in figure 4. As in most metropolitan districts, the greatest percentage increase has been in the suburban areas. The Minnesota Department of Business Research and Development has estimated that the total population of Ramsey and Hennepin Counties will be 1,200,000 by 1960.

The growth in industrial development is shown by the increase in production workers in Hennepin and Ramsey Counties from 43,588 in 1939 to 85,702 in 1947. The Department of Business Research and Development has estimated that there will be 110,000 production workers in the two counties by 1960.

Transportation

Minneapolis is the head of navigation on the Mississippi River. The average navigation season extends from late March to near the middle of November, with some variation at each end depending on ice conditions in the channel. According to the Corps of Engineers, approximately 465,066 tons of freight were received and 6,272 tons were shipped at Minneapolis during the

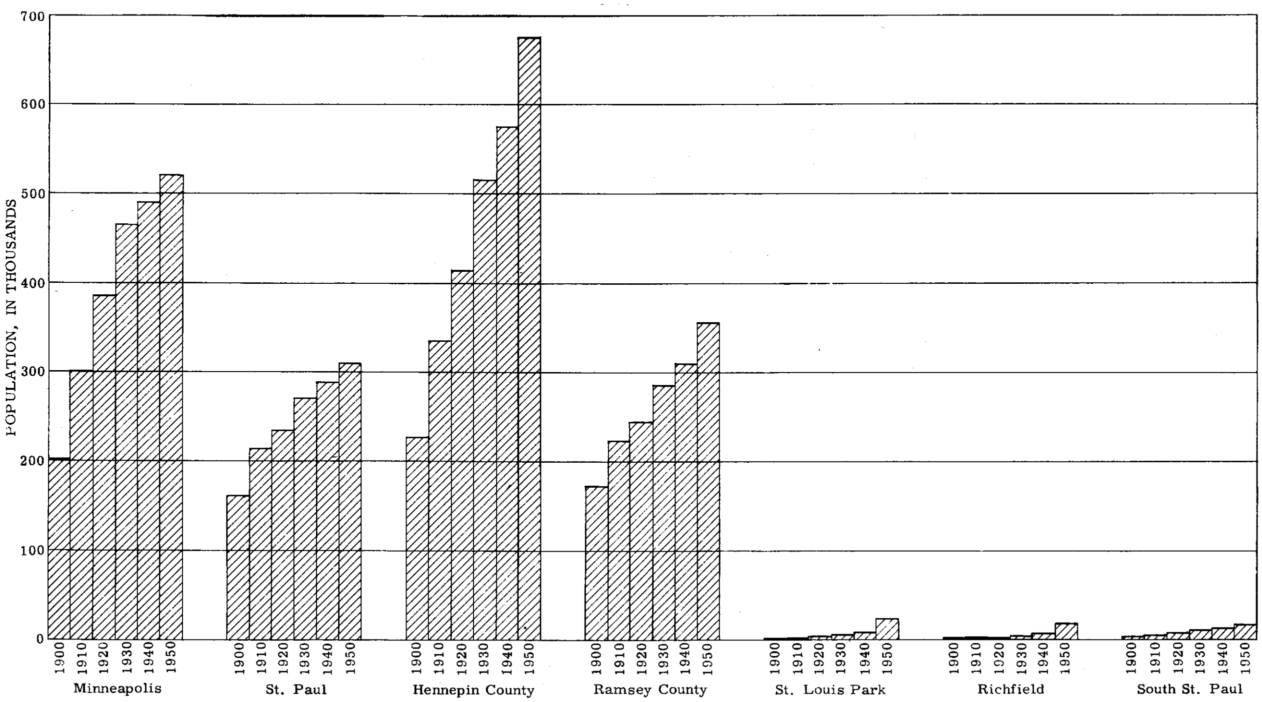

Figure 4.—Growth in population of selected subdivisions in the Minneapolis-St. Paul area.

1951 season. The tonnage received and shipped at St. Paul during the same season was approximately 1,202,108 and 77,051 tons, respectively. The chief commodity shipped to the Twin Cities area by water is coal; gasoline is second in importance, and fuel oil is third.

The Corps of Engineers maintains a channel 9 feet deep in the Twin Cities area by considerable dredging. The river between lock and dam 2, near Hastings, and Minneapolis requires almost continuous dredging during most of each summer. A project to extend the channel about 4.6 miles upstream and above St. Anthony Falls is under construction (1952). It will make about 4 miles of additional riverfront available to Minneapolis for port facilities. Two locks of 25 and 50 feet lifts will be required.

Rail service to the area is excellent. Minneapolis and St. Paul are at the intersection of ten railroads.

Many highways lead into the area. The U. S. Bureau of Motor Carriers estimates that there are at least 1,000 motor freight companies licensed to haul into the area and that probably there are more than 500 companies operating on an exempt basis.

Several transcontinental airways either cross or terminate in the area, and some flights to the Orient originate at the Twin Cities airport. There are 2 major and 4 secondary ports under the jurisdiction of the Metropolitan Airports Commission of Minneapolis-St. Paul and several other independent airports in the immediate vicinity. During 1951, there were 6,262,402 pounds of mail, 5,129,507 pounds of express, and 10,158,438 pounds of freight handled at the Twin Cities airport via scheduled flights. In addition, there were 377,666 passenger arrivals and 372,491 passenger departures.

Natural Resources

Except for the potential water supply, the area is not generally considered as being outstanding for its natural resources, although there are several that are worthy of note.

The St. Peter sandstone, which crops out along the Mississippi River, underlies a large portion of the cities of Minneapolis and St. Paul; it is one of the purest quartz sand formations in the world. Another good source of quartz sand is the Jordan sandstone, which crops out along the Minnesota, St. Croix, and Mississippi valleys. In purity this formation approaches that of the St. Peter. Both sandstones are of high silica content which makes them particularly adaptable for sandblasting. The St. Peter is used by the Ford Motor Co. in the manufacture of glass at their St. Paul plant.

Limestone is quarried from the Platteville, which is exposed along the bluffs of the Mississippi River. An excellent building material, this stone is used extensively for construction and is also crushed for aggregate in bituminous pavements. The St. Lawrence formation, also found along the Mississippi bluffs, is being used more and more extensively in the manufacture of rock wool. Material from the Oneota and Shakopee dolomites is also of some economic importance.

Sand and gravel are found in abundance in the Minneapolis-St. Paul area. Many concrete products industries have been established because of the abundant supply and wide distribution of sand and gravel in the area.

Clay is rather widely distributed, and is used for the manufacture of brick. Face bricks manufactured in the area have a nationwide distribution.

SOURCE OF WATER

Precipitation in its various forms is the source of all fresh water, both surface and underground. During rainstorms, water falling in excess of that which the ground is able to absorb, flows over the ground into the streams. The water that percolates into the ground replenishes the shallow zone of soil water that supports vegetation; the water not held in this zone continues to move by gravity to the zone of saturation, the upper surface of which is the water table. The water in the zone of saturation slowly moves through the ground in directions determined by the topography, geologic structure, and location of areas of discharge. Ground-water discharge may occur naturally as from springs and seeps to become part of the flow of streams and by evaporation and transpiration where the water table lies near the land surface. The water obtained from wells is supplied by ground water.

SURFACE WATER

The Mississippi River has sufficient flow to meet the needs of the Twin Cities and is by far the largest source of water in the area. The lowest flow recorded at the

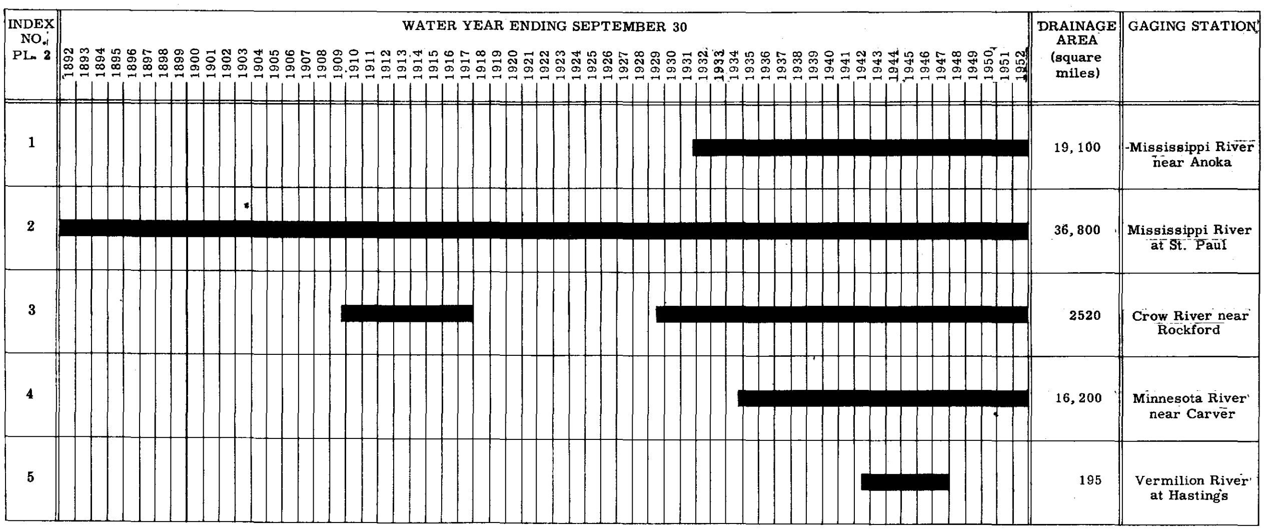

Figure 5.—Duration of records at gaging stations in the Minneapolis–St. Paul area.

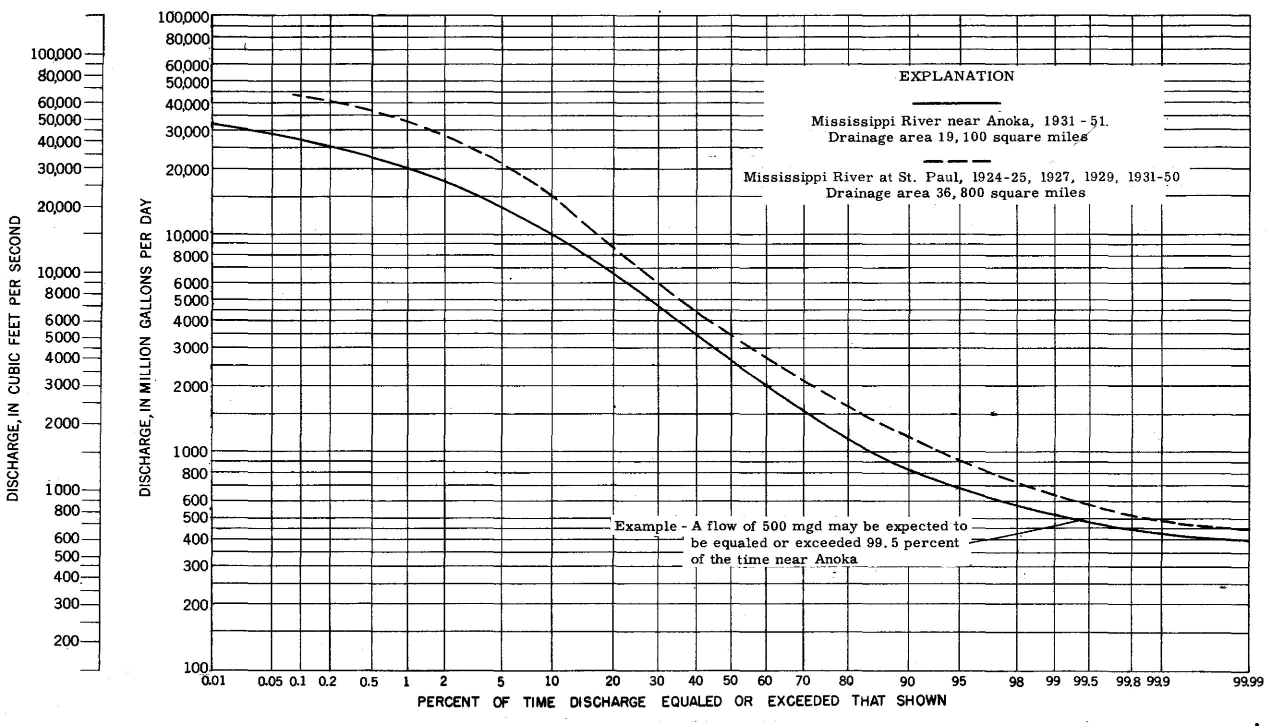

Figure 6.—Duration curve of daily flows, Mississippi River.

gaging station upstream from the Minneapolis and St. Paul water-supply intakes was 379 mgd. The maximum capacity of the combined Minneapolis and St. Paul water systems is about 225 mgd; therefore, had the maximum demand been met, there would still have been more than one-third of the flow not being used. At the time of minimum flow however, the city of St. Paul did not utilize the river flow as the stage was below its intakes, and the lake storage of the system was adequate to supply the city during the period of low flow. The Mississippi River headwater reservoirs were contributing about 65 mgd during the period of low flow.

The length of the Mississippi River is 2,364 miles of which 510 miles, or nearly 22 percent, is above Minneapolis–St. Paul. The drainage area above Minneapolis is 19,400 square miles.

The Mississippi River has an average slope of about 3 feet per mile between Minneapolis and Crow Wing River. Between the Crow Wing River and Lake Bemidji, the area drained is largely lakes and swamps, and the slope of the river is only a little more than 0.6 foot per mile. Between Lake Bemidji and Lake Itasca, the slope increases slightly and averages about 1.3 feet per mile.

There are several powerplants above St. Paul on the Mississippi River and its tributaries, but the capacities of the pools at the plants are small; so regulation from this source is negligible. An important factor in the regulation of the flow is storage in the Mississippi River headwater reservoir system, comprised of six large lakes with a total usable storage under normal operating conditions of 1,640,610 acre-feet. This system is operated primarily for improving navigation conditions below Minneapolis, although there are at times secondary benefits to waterpower, water supplies, flood control, and recreational activities.

Many gaging stations have been operated on the Mississippi River basin above St. Paul. Figure 5 shows the records available at gaging stations in the area considered in this report. The gaging stations are shown on plate 2.

Mississippi River above the Minnesota River

A gaging station has been operated near Anoka, about $5\frac{1}{2}$ miles upstream from the city limits of Minneapolis, since 1931. The zero of the gage is 805.02 feet above mean sea level, adjustment of 1912.

Drainage area.—19,100 square miles.

Average discharge.—20 years (1931–51), 4,112 mgd (6,362 cfs).

Low flow.—The minimum instantaneous flow near Anoka since 1931 is 379 mgd (586 cfs) on Sept. 13, 1934; the minimum daily flow is 389 mgd (602 cfs) on Oct. 10, 1934. About 65 mgd (100 cfs) was being contributed to both the minimum instantaneous and minimum daily flows by the headwater reservoirs. The low-flow characteristics are illustrated by figures 6, 7, and 8. The duration curve of daily flows (fig. 6) shows the percent

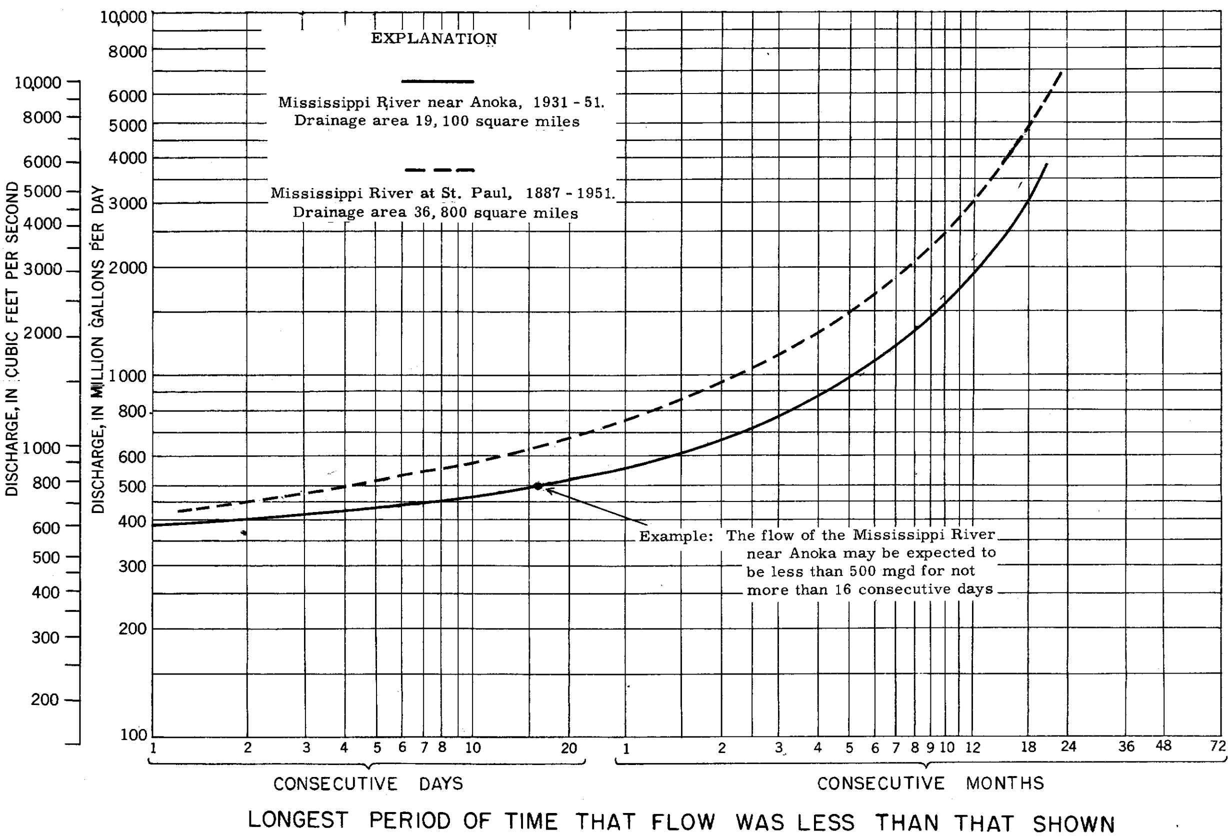

Figure 7.—Maximum period of deficient discharge, Mississippi River.

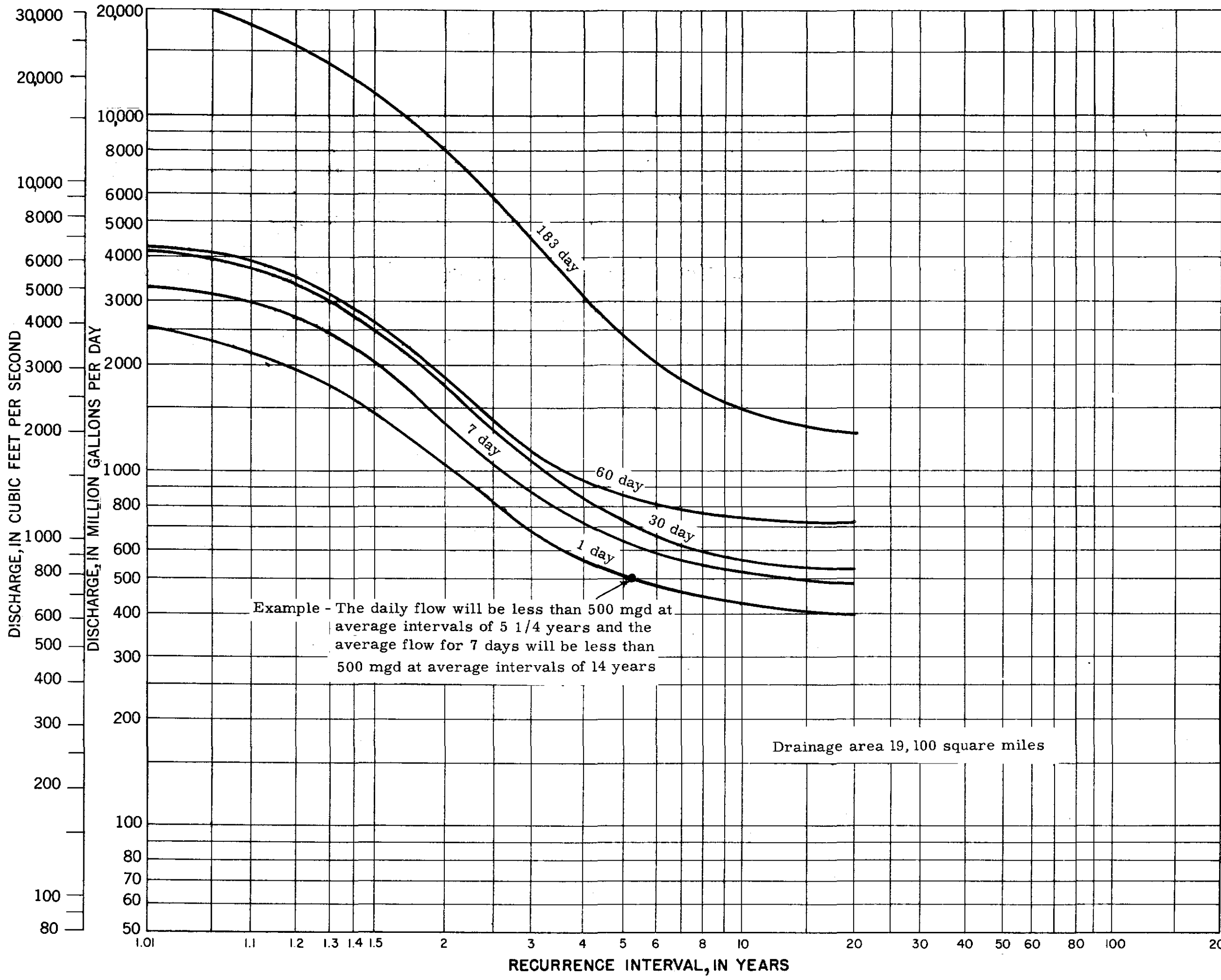

Figure 8.—Drought-frequency graph, Mississippi River near Anoka, 1931–51.

of time that the daily flow equaled or exceeded a given flow. The maximum period of deficient discharge curve (fig. 7) shows the greatest number of consecutive days that the flow may be expected to remain less than a given flow. The drought-frequency graph (fig. 8) shows the expected frequency of occurrence of average minimum flows for 1-, 7-, 30-, 60-, and 183-day periods. All low flows are affected by release of water from headwater reservoirs.

In addition to giving graphically the general flow characteristics of the streams, these curves are valuable for use in solving problems of plant location and operation. For example, assume that it is desirable to locate a manufacturing plant on the Mississippi River at Minneapolis. Construction of a storage dam is not contemplated. A flow of 500 mgd is required to operate the plant. It is necessary to know the average number of days each year when there will be a shortage of water. Using the flow-duration curve (fig. 6), it is seen that a flow equal to or greater than 500 mgd will prevail 99.5 percent of the time. On the average there would be sufficient water 99.5 percent of the year and a shortage for only 2 days per year.

It may be possible to operate the plant for short periods on less than 500 mgd. However, it is necessary to know the maximum number of consecutive days, even in unusual years, when the flow will be less than 500 mgd. The flow of the Mississippi River at Minneapolis may be expected to be less than 500 mgd for not more than 16 consecutive days (fig. 7).

It may also be desirable to know how frequently the flow will be less than 500 mgd. The drought-frequency curve (fig. 8) shows that the daily flow will be less than 500 mgd at average intervals of $5\frac{1}{4}$ years and that the average flow for 7 consecutive days will be less than 500 mgd at average intervals of 14 years.

Floods.—The greatest flood since 1931 occurred on Apr. 14, 1952, when the discharge was 75,900 cfs and the gage height was 17.51 feet. The area flooded during April 1952 is shown on plates 1 and 2. Floods of this magnitude can be expected at average intervals of about 50 years. Crest elevations of this flood at several places are shown on the profile (fig. 9). Data on the 7 highest floods since 1931 are given in table 2.

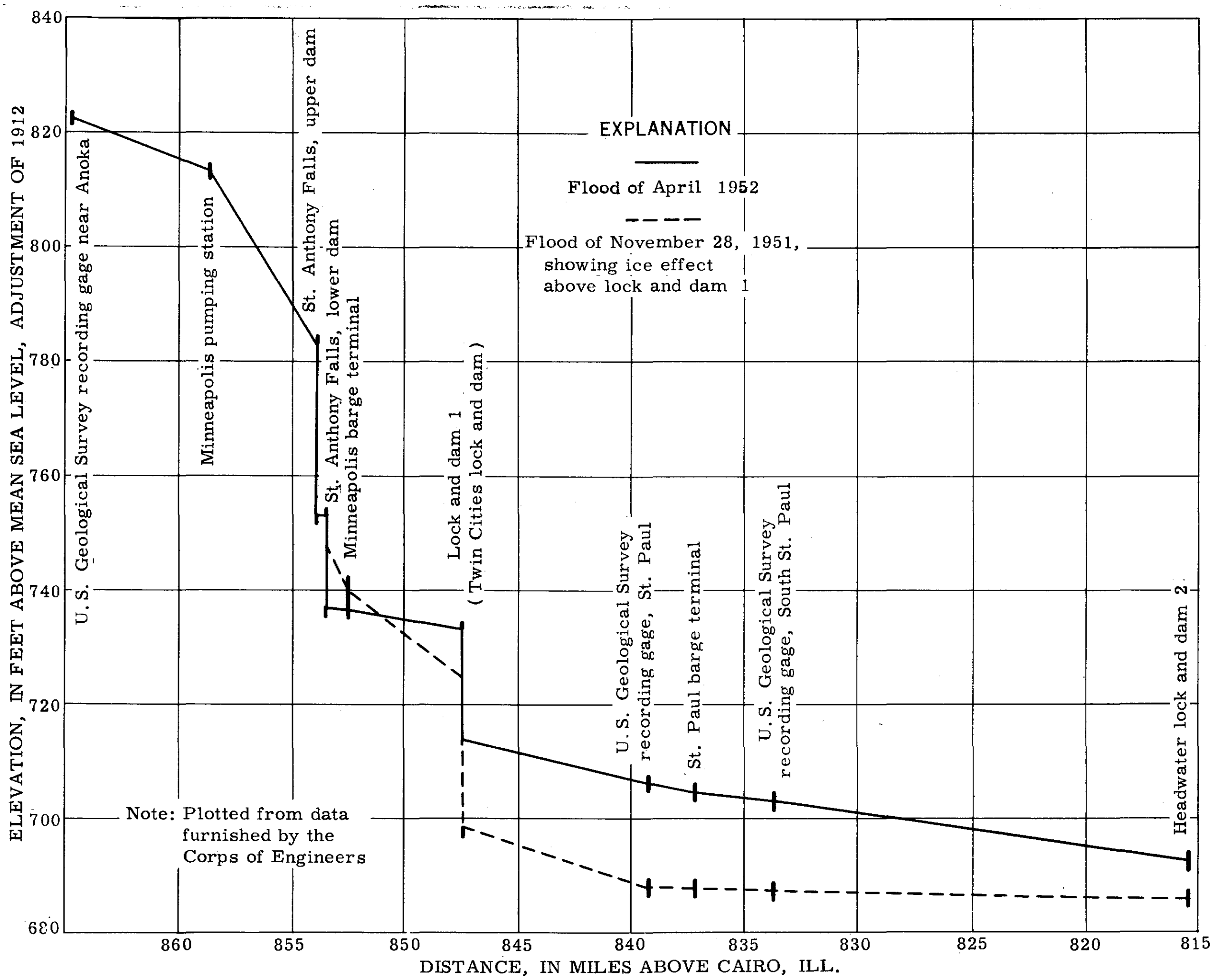

Figure 9.—Flood profile of Mississippi River from gage near Anoka to headwaters of lock and dam 2.

Table 2.–Selected major floods on Mississippi River near Anoka, 1931-52

Date	Discharge (cfs)	Gage height (feet)	Elevation in feet above mean sea level (adjustment of 1912)
Apr. 14, 1952	75,900	17.51	822.53
May 11, 1950	50,700	13.82	818.84
Apr. 6, 1943	47,000	14.11	819.13
Mar. 21, 1945	44,300	13.46	818.48
Apr. 15, 1951	41,800	12.07	817.09
Mar. 26, 1939	40,800	13.15	818.17
June 18, 1944	39,000	12.34	817.36

Table 3.—Chemical and physical characteristics of untreated Mississippi River water at Fridley, 1940-49

[Analyses by city of St. Paul; analytical results in parts per million except as indicated]

	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	Average 1940—49
Temperature (° F)	52	53	52	53	51	50	52	52	54	53	52
Silica (SiO_2) [1]	9.29	10.31	9.63	10.70	8.30	8.02	8.92	11.73	6.83	6.76	9.0
Aluminum (Al)	.44	.91	1.05	1.04	.87	.62	.47	.70	.60	.51	.72
Iron (Fe)	.36	.39	.31	.168	.35	.23	.17	.54	.25	.18	.30
Manganese (Mn)	.16	.08	.07	.06	.09	.060	.09	.10	.10	.14	.10
Calcium (Ca)	46.98	44.40	46.0	44.7	41.7	41.42	43.80	43.04	42.61	40.62	43.53
Magnesium (Mg)	17.37	17.28	18.6	15.6	15.03	14.55	14.38	15.06	14.95	14.21	15.70
Sodium and potassium as Na	7.19	5.54	2.7	2.9	4.15	1.48	1.16	1.76	1.91	1.62	3.04
Sulfate (SO_4) [2]	18.78	19.32	20.4	13.8	16.8	13.1	12.7	14.0	17.0	12.8	15.87
Chloride (Cl)	2.86	2.44	3.7	4.00	2.96	3.42	2.29	3.31	2.62	2.29	2.99
Fluoride (F)	-	-	-	-	-	-	.24	.16	.14	.13	-
Nitrate (NO_3) [3]	.22	.26	.62	.51	.80	.35	.57	.44	.22	.22	.42
Residue	235	247	252	259	246	221	239	237	234	240	241
Hardness as $CaCO_3$	192	192	199	182	173	169	172	175	173	163	179
Alkalinity as $CaCO_3$	169	158	177	162	158	154	158	159	155	150	160
pH	8.1	7.9	8.0	8.0	8.1	8.3	8.1	8.2	8.3	8.3	8.1
Color	46	92	73.8	90	62.0	52.0	59	48.9	41.0	60.0	62.5
Turbidity	6.0	3.8	7.3	17.0	15.0	9.8	8	7.9	8.0	8.3	9.1
Dissolved oxygen	9.5	8.4	9.9	8.6	9.5	10.3	9.8	10.4	9.7	10.3	9.6

1 Calculated from Si.
2 Calculated from S.
3 Calculated from N.

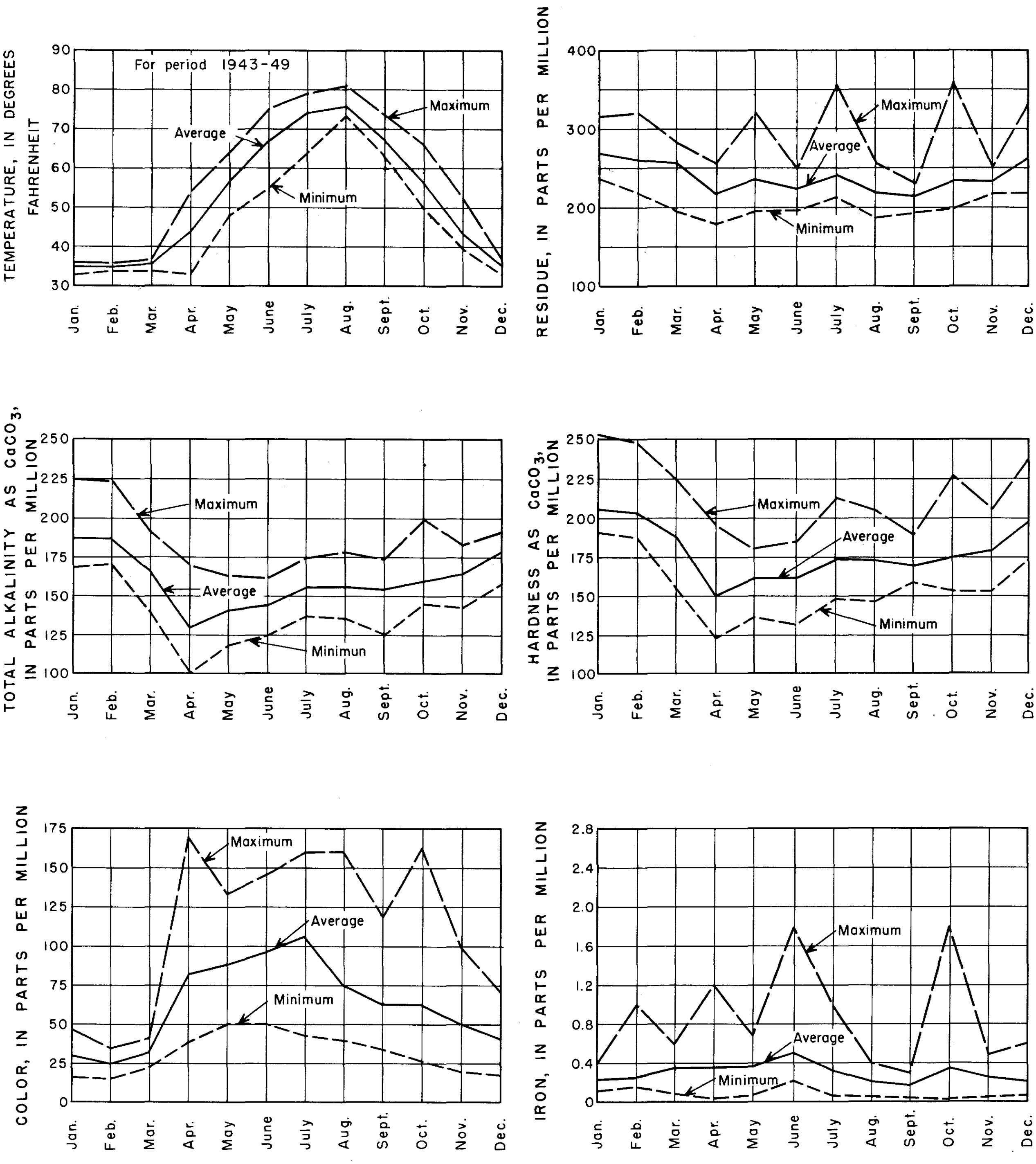

Figure 10.—Maximum, minimum, and average monthly values of several physical and chemical characteristics of untreated Mississippi River waters above Minneapolis, 1940–49. (Analyses furnished by the city of St. Paul.)

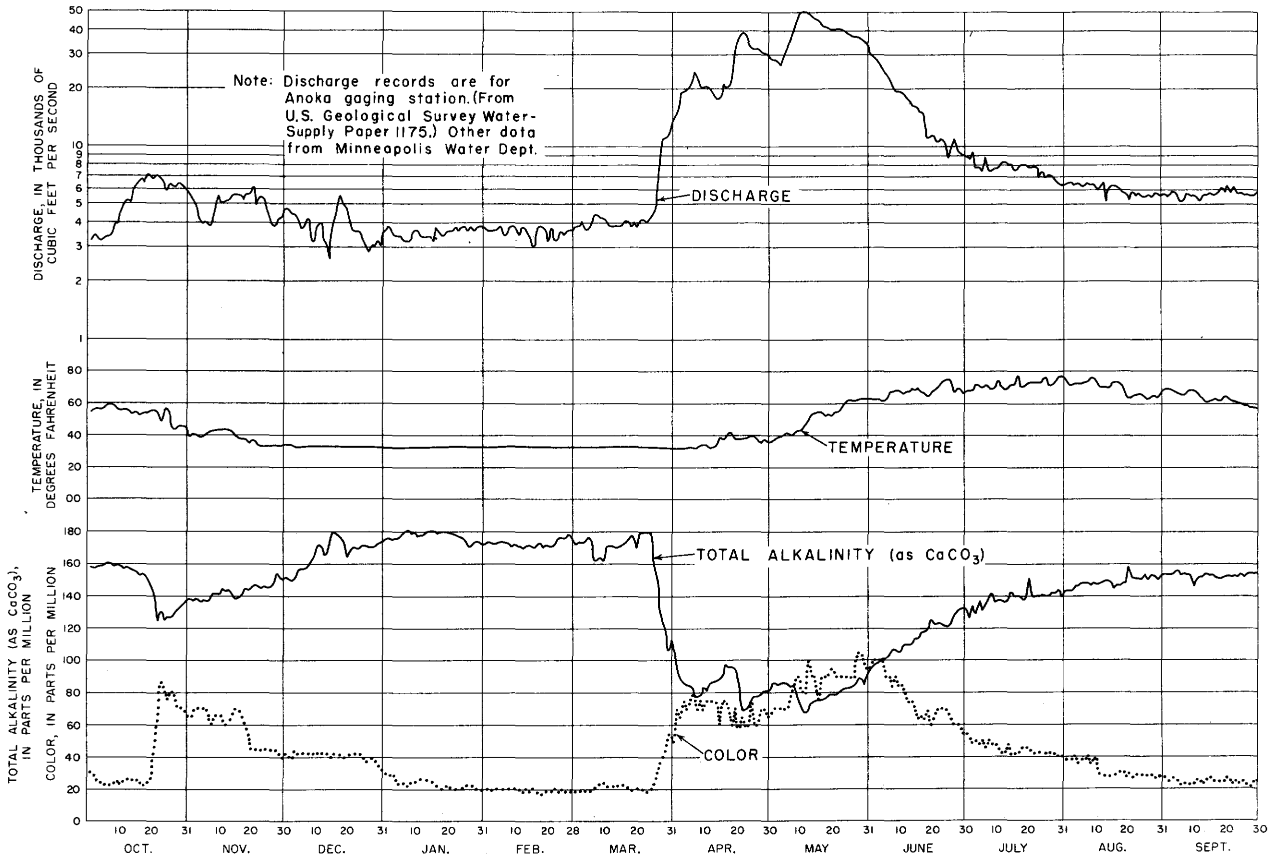

Figure 11.—Relation between streamflow and selected chemical and physical characteristics of Mississippi River waters at Minneapolis, Fridley intake, 1949–50.

Under ordinary conditions of winter flow the reach of river above Twin Cities lock and dam (lock and dam No. 1) is not appreciably affected by backwater from ice. However, under certain conditions, frazil ice can lodge in the channel in and above the upper end of pool 1 and cause considerable damage. In the vicinity of the Minneapolis barge terminal, damage was caused by this condition in November and December of 1951. Crest elevations at several places during this flood are shown in figure 9.

Chemical quality.—Systematic collection of data on the quality of Mississippi River water began as early as 1913, when the city of Minneapolis began filtering the public water supply. Then as now (1952), Minneapolis obtained water from the Mississippi River at Fridley, a few miles north of the Minneapolis city limits. The city of St. Paul also began a sampling program in 1925, when a new pumping plant was erected at Fridley, just north of the Minneapolis pumping plant, and Mississippi River water was delivered into the Vadnais Lake chain for the first time.

Daily records of chemical and physical constituents of the untreated and treated water at these plants are maintained. Annual averages of the more important chemical constituents in the untreated river water at the St. Paul intake for the 10-year period 1940–49 are present in table 3. The 10-year average for dissolved solids (residue), 241 ppm, and for hardness, 179 ppm, reveals that the Mississippi River, as it enters the industrialized areas of the Twin Cities, is a moderately mineralized and relatively hard calcium bicarbonate type water. The average turbidity is very low, silica is moderately low, but the quantities of iron and color are relatively high and present distinct problems in treatment for public supply and industrial use. Although the content of dissolved solids and turbidity remains rather uniform from day to day and from year to year, color varies widely and fluctuations in alkalinity, hardness, and iron are noticeably rapid. Fluctuations in monthly averages of several chemical and physical characteristics of untreated water are shown in figure 10. The data in figure 10 are particularly useful because they show the marked increase in color during the period March to July and the concurrent decrease in alkalinity, hardness, and dissolved solids (residue).

The hydrologic conditions that cause these rapid changes in color, alkalinity, hardness, and iron are more easily observed by comparison of the constituents with streamflow. (See fig. 11.) Color and alkalinity responded to the increase in streamflow that occurred in the latter part of October. After this initial increase, color decreased slowly, and alkalinity increased and remained relatively uniform from January through March. At the end of March, the spring breakup was accompanied by a rapid increase in color and an equally rapid decrease in alkalinity. Maximum concentrations of color and minimum alkalinity occurred in May. As the river receded in June, alkalinity again increased and color decreased gradually through September.

Table 4.—Summary of chemical and bacteriologic conditions in the Mississippi River between Camden and Fort Snelling Bridge (above mouth of Minnesota River), 1950

[Analyses by Minneapolis-St. Paul Sanitary District]

Location	January	February	March	April	May	June	July	August	September	October	November	December
Temperature (degrees Fahrenheit)												
Camden, Fridley Plant	32	32	32	34	48	70	73	70	66	50	39	32
Washington Ave., Minneapolis	32	32	32	36	48	70	73	72	66	48	39	32
Twin Cities, lock and dam	32	32	32	36	48	70	73	73	68	50	39	32
Fort Snelling Bridge	32	32	34	36	48	70	73	73	68	50	39	32
Turbidity (parts per million)												
Camden, Fridley Plant	6	5	15	30	40	25	10	9	6	7	7	5
Washington Ave., Minneapolis	4	7	20	40	45	25	25	15	8	9	8	6
Twin Cities, lock and dam	6	6	25	40	45	30	25	25	10	10	10	6
Fort Snelling Bridge	4	6	20	40	45	30	25	20	10	10	10	6
pH												
Camden, Fridley Plant	7.3	7.5	7.4	7.6	7.7	7.9	8.1	8.2	8.3	8.2	8.2	7.7
Washington Ave., Minneapolis	7.3	7.6	7.5	7.7	7.7	7.9	8.1	8.2	8.3	8.2	8.3	7.7
Twin Cities, lock and dam	7.3	7.6	7.5	7.8	7.8	8.0	8.1	8.2	8.3	8.3	8.2	7.7
Fort Snelling Bridge	7.3	7.6	7.5	7.8	7.8	8.0	8.3	8.2	8.3	8.3	8.2	7.8
Dissolved Oxygen (parts per million)												
Camden, Fridley Plant	6.90	6.80	7.95	12.30	10.95	7.70	8.00	8.10	8.50	10.70	12.15	9.75
Washington Ave., Minneapolis	8.50	8.45	10.05	14.15	11.90	8.65	8.00	8.15	9.15	11.10	12.80	13.45
Twin Cities, lock and dam	8.60	8.50	9.90	12.60	11.60	8.05	7.80	7.50	8.60	10.75	12.50	13.55
Fort Snelling Bridge	9.10	9.00	10.40	13.85	11.85	8.55	7.95	7.60	8.55	10.75	12.55	13.35
Biochemical Oxygen Demand (5-day) (parts per million)												
Camden, Fridley Plant	1.35	1.35	2.15	3.55	2.65	2.35	2.00	1.20	1.25	1.40	1.40	1.55
Washington Ave., Minneapolis	.90	1.30	2.70	3.75	2.55	1.85	1.90	1.50	1.25	1.40	1.50	1.10
Twin Cities, lock and dam	1.10	1.25	3.45	4.30	2.90	2.25	2.50	1.75	1.55	1.35	1.50	1.10
Fort Snelling Bridge	.80	1.00	3.30	4.10	2.55	1.85	2.75	1.65	1.55	1.25	1.35	.85
Bacteria per cubic centimeter at 37° C, 24 hour agar												
Camden, Fridley Plant	450	390	1,900	2,900	1,100	2,600	610	1,200	1,800	2,500	800	490
Washington Ave., Minneapolis	360	310	2,400	3,700	840	1,800	840	1,500	1,300	1,800	590	1,300
Twin Cities, lock and dam	320	450	6,800	9,300	18,000	2,100	420	3,100	2,400	1,400	640	390
Fort Snelling Bridge	480	380	6,300	6,300	6,200	2,700	590	2,300	2,200	1,900	700	370

One explanation that can be given for the iron-color-alkalinity phenomenon in the Mississippi River is that drainage from muskeg swamps in the headwaters probably carries appreciable iron humate dissolved from the organic humus that constitutes the forest soils. However, some local lakes are high in color also, which is probably related to the high iron content of the glacial drift in combination with organic material. The apparent color is a significant problem in the treatment of the water for municipal and industrial uses in the area. However, the problem has been successfully overcome. The quantity of constituents in the water has not been appreciably altered by the growth in municipal and industrial uses of water upstream from Minneapolis (fig. 12).

Dale (1907) reports a mean dissolved solids concentration of 200 ppm for the Mississippi River at Minneapolis for the period September 1906 to September 1907. However, he does not report the quantity of color; therefore, a more suitable comparison can be made with sums of the individually determined constituents for the 1906–07 and the 1940–49 records. Excluding color, the sum of the dissolved solids for the period 1906–07 was 193 ppm; the sum for the period 1940–49 was 189 ppm. Figure 12 shows that the percentage composition of the water (excluding color) was very similar.

Sanitary quality.—The city of Anoka discharges sewage to the Mississippi River above the Twin Cities area, but no sewage is discharged to the river in the area above the sewage disposal plant at Pig's Eye Lake except that which is received from the Minnesota River at Fort Snelling and the overflow from combined sanitary and storm sewers at the Twin Cities during and after periods of precipitation.

A summary of the chemical and bacteriologic conditions in the Mississippi River between Camden (North Minneapolis) and Fort Snelling Bridge (above the mouth of the Minnesota River) during 1950 is given in table 4. The results, which were determined by the Minneapolis–St. Paul Sanitary District, are based on a few monthly samples. Dissolved oxygen levels are observed to be well above 4.0 ppm, which has been established by the State Conservation Department as the minimum value for the preservation of fish life in the Mississippi River in this area.

Temperature.—During the period 1943–49, daily river water temperatures generally ranged from near-freezing to a maximum of 83 F. The maximum, minimum, and average monthly temperatures of the water of the Mississippi River above Minneapolis are shown in figure 10. Daily fluctuations in temperature for the water year October 1949 to September 1950 are shown in figure 11. Temperatures decreased gradually during October and November and remained at near-freezing from the latter part of November through the middle of April, then increased gradually in response to rise in air temperature and in river stage.

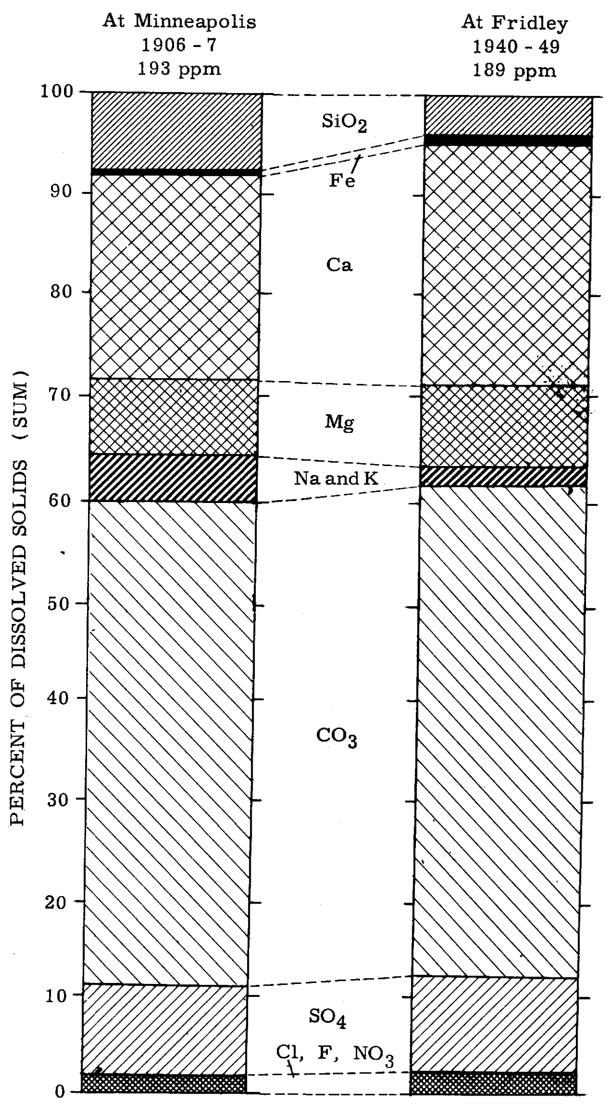

Figure 12.—Average composition of dissolved solids in Mississippi River water, 1906–07 and 1940–49. (1940–49 analyses by city of St. Paul.)

Downstream in the industrialized sections of Minneapolis, temperatures of powerplant effluents are reported to be high enough during the winter season to provide some opening of channels. However, the effect is very localized.

Minnesota River

The Minnesota River enters the Mississippi River at Fort Snelling, between the business districts of Minneapolis and St. Paul. Its source is Big Stone Lake on the

Table 5.–Selected major floods, Minnesota River near Carver, 1935-52

Date	Gage height (feet)	Discharge (cfs)
Apr. 11, 1951	28.00	64,100
Apr. 16, 1952	28.31	60,600
Apr. 5, 1949	23.59	32,400
June 21, 1943	22.64	25,900
May 25, 1944	22.82	25,100

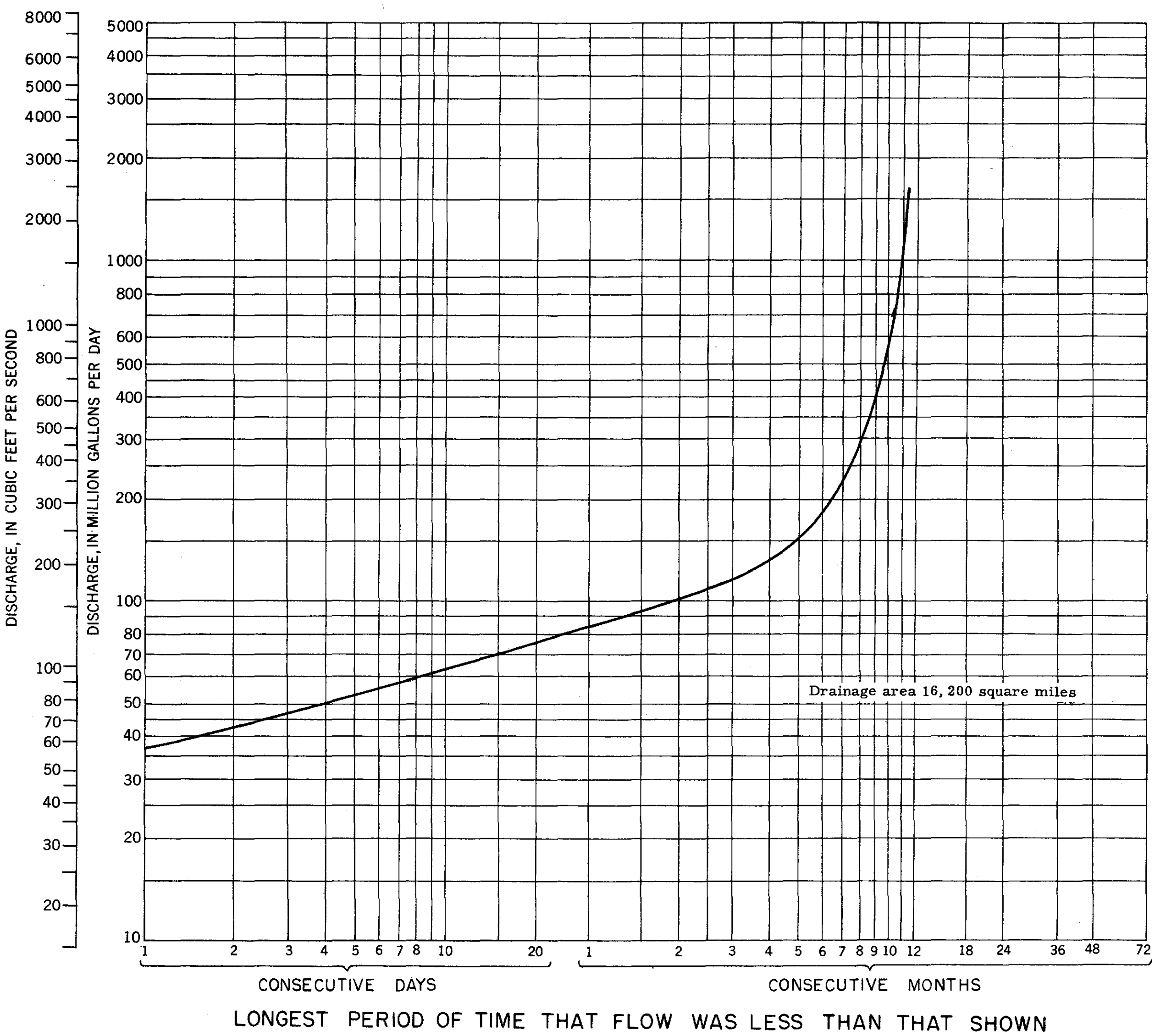

Figure 13.—Maximum period of deficient discharge, Minnesota River near Carver, 1934–51.

boundary between Minnesota and South Dakota. The Minnesota River drains 16,920 square miles of gently undulating prairie land, most of which is devoted to agriculture. The average precipitation in the Minnesota River basin is much less than that in the upper Mississippi River basin and therefore the runoff per square mile from the Minnesota River basin is only about 55 percent of that from the Mississippi River basin above the Minnesota River. The length of the Minnesota River is 332 miles of which the lowest 25 miles have been improved for navigation. This part of the channel is used to some extent by pleasure craft. At the present time (1952), the lowest 14 miles are used for commercial shipments. Grain is the chief commodity shipped, and coal is received at a steam-electric power generation plant at Savage. During World War II, oceangoing tankers were built at Savage and transported down the river.

The fall in the river from Big Stone Lake to the mouth averages slightly over 0.5 foot per mile with the largest fall in the vicinity of Granite Falls, where 2 power dams develop a total head of 39 feet. Some of the headwater tributaries have relatively steep slopes; but, except for 1 plant on the Blue Earth River, there are no power developments of importance. The plants are without facilities for appreciable storage, thus storage for power purposes is not of importance in the basin.

A major consideration, however, is storage for flood control. There are two major flood-control reservoirs, Big Stone Lake and Lac qui Parle. Usable storage figures are not available. The reservoirs are usually drawn down during the winter so as to accommodate a part of the high discharges during the spring. Insofar as is possible, the lakes are kept full during the summer for recreational uses. The effect of the reservoir operation is not very noticeable on the lower reaches of the river; but it is probable that, should an acute emergency arise during a period of deficient flow requiring an increase in discharge, a small amount of help could be obtained by releases from the flood-control reservoirs.

Records of stage and discharge have been collected at several sites in the Minnesota River basin. Records have been obtained on the Minnesota River near Carver, 37 miles upstream from the mouth, since September 1934. The zero of the gage is 690.00 feet above mean sea level, datum of 1929.

Drainage area.—16,200 square miles.

Average discharge.—17 years (1934-51), 1890 mgd (2,924 cfs).

Low flow.—The minimum daily flow near Carver since 1934 is 55 mgd, (85 cfs), Jan. 21, 22, 1940. The minimum gage height during the same period is 2.66 feet, Nov. 22, 1935. Figure 13 shows the maximum number of consecutive days that the discharge may be expected to be less than any selected value.

Floods.—The highest stage since 1934, 28.31 feet, occurred on Apr. 16, 1952; the discharge was 60,600

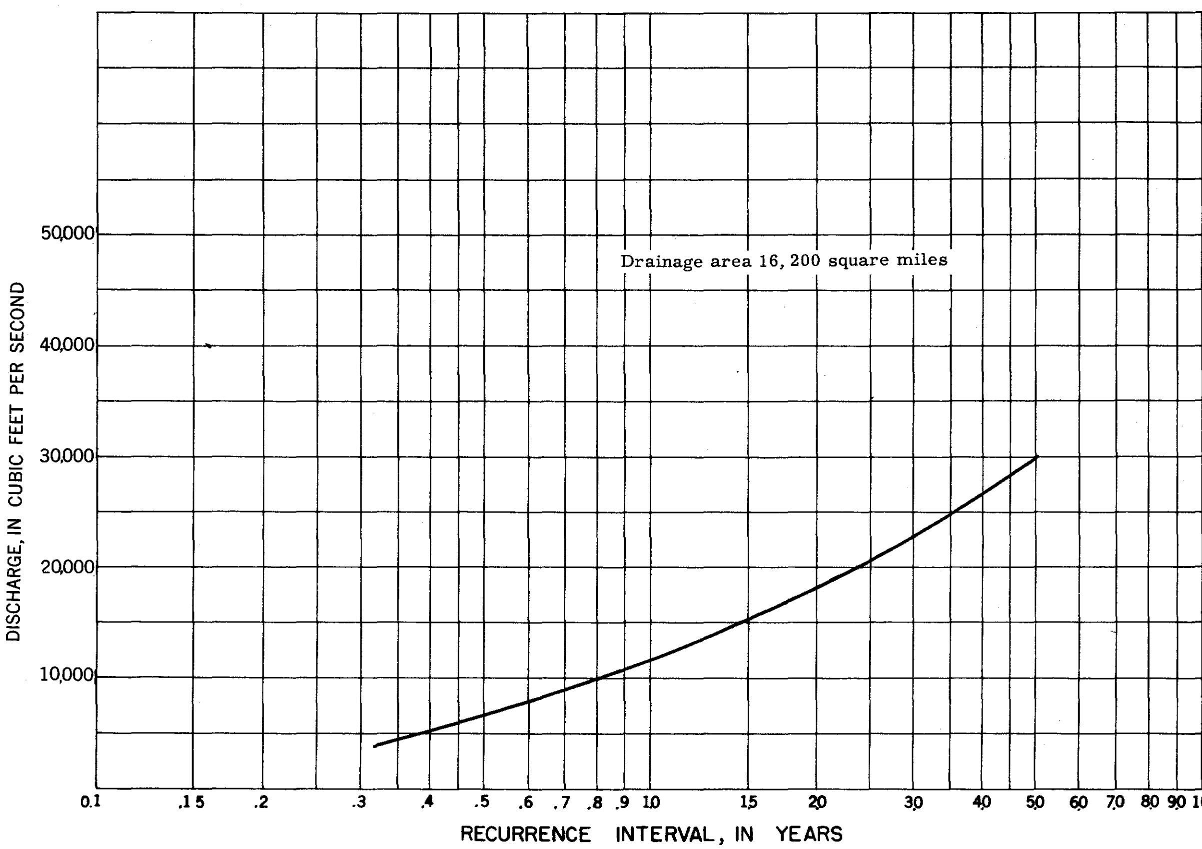

Figure 14.—Flood frequencies, Minnesota River near Carver, 1934–52.

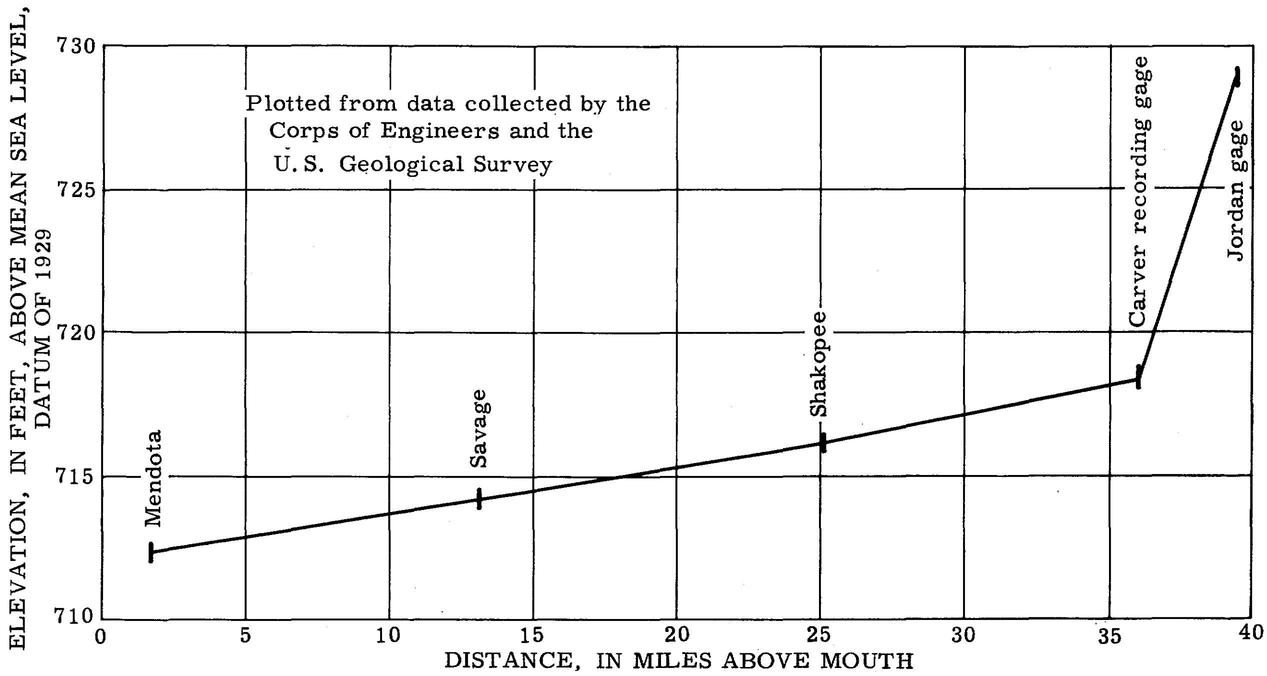

Figure 15.—Flood profile of Minnesota River, Jordan gage to Mendota, April 16, 1952.

cfs. At the peak of the flood the stage-discharge relation was affected by backwater from the Mississippi River. Data on the 5 greatest floods since 1934 are given in table 5. The expected frequency of floods between 4,000 and 30,000 cfs are given in figure 14. This curve is not well enough defined to warrant extension above 30,000 cfs. Crest elevation of the April 1952 flood at several places along the river between Jordan and Mendota are shown in figure 15.

Chemical quality.—The only available continuous record of chemical quality of Minnesota River water was obtained by the U. S. Geological Survey during the period September 1906 to October 1907 (table 6). The Northern States Power Co. analyzed a sample of Minnesota River water taken at Mankato in 1946.

The changes that occurred in the chemical and sanitary quality of its waters between 1906–07 and 1946 are

Table 6.—Chemical quality of water from Minnesota River

[Results in parts per million except pH]

	1906-07 [1]			June 17, 1946[2]
	Maximum	Minimum	Mean	
Discharge (cfs)	-	-	-	4,610
Silica (SiO_2)	32	11	23	17
Iron (Fe)	.60	.01	.09	[3]6.3
Calcium (Ca)	150	43	82	77
Magnesium (Mg)	58	19	35	36
Sodium (Na)	39	11	23	3.0
Potassium (K)	-	-	-	-
Bicarbonate (HCO_3)	489	154	296	217
Carbonate (CO_3)	-	-	-	0
Sulfate (SO_4)	215	66	144	116
Chloride (Cl)	11	1.4	4.7	15
Nitrate (NO_3)	7.8	.4	2.0	-
Dissolved solids (residue on evaporation)	722	250	480	383
Hardness as $CaCO_3$	613	185	348	342
Alkalinity ($CaCO_3$)	-	-	-	178
pH	-	-	-	8.3
Turbidity	330	5.0	97	-

1 Analyses of Minnesota River water at Shakopee by U. S. Geological Survey.
2 Analyses of Minnesota River water at Mankato by Northern States Power Co.
3 Iron and aluminum.

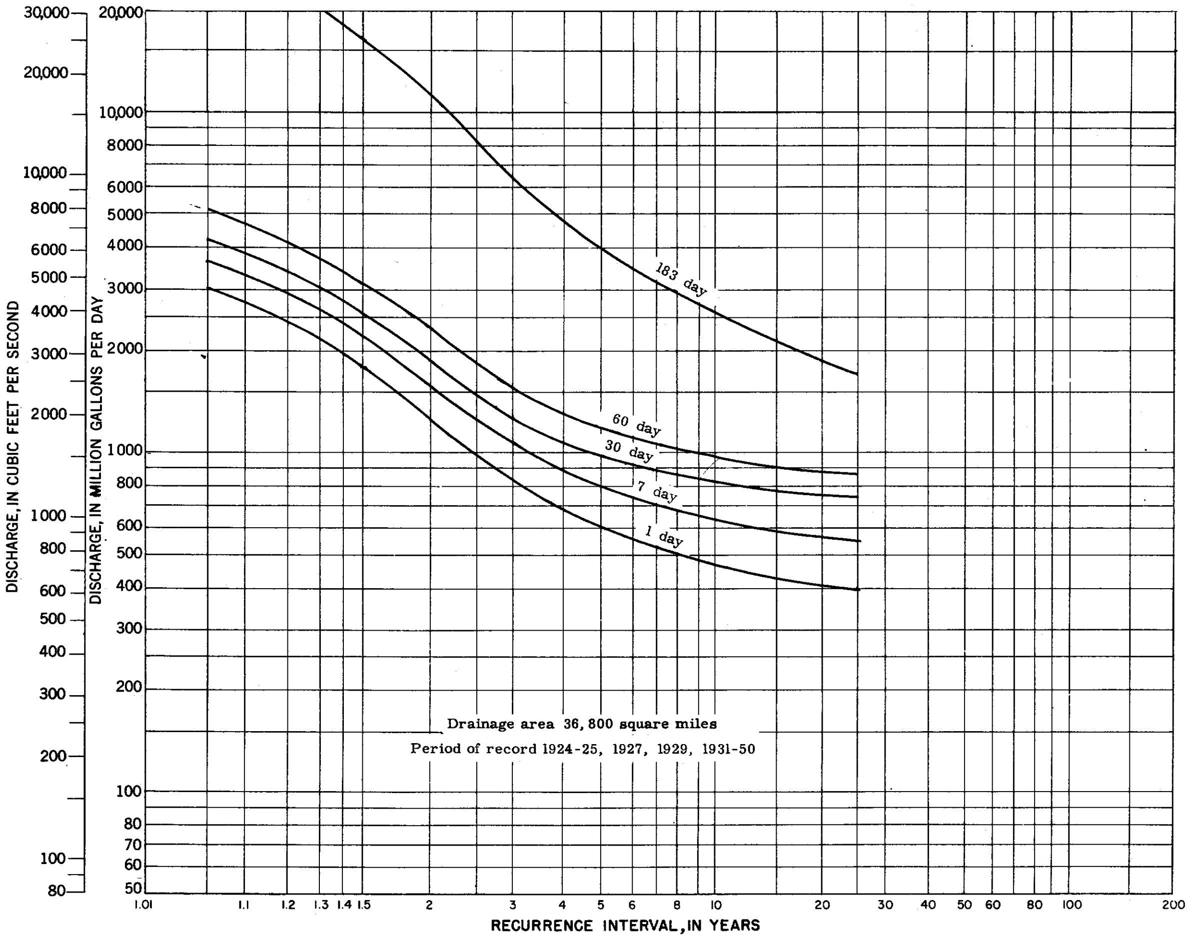

Figure 16.—Drought-frequency graph, Mississippi River at St. Paul.

Table 7.—Summary of physical, chemical, biochemical, and bacteriologic conditions in the Minnesota River 1.6 miles above mouth, 1950

[Analyses by St. Paul-Minneapolis Sanitary District]

Month	Number of samples	Temperature (°F)	Turbidity (ppm)	pH	Dissolved oxygen	B.O.D.[1] (5-day)	Bacteria per cc at 37°C (24-hour agar)
					Parts per million		
January	1	32	9	7.3	7.60	1.35	460
February	2	32	10	7.4	2.75	1.60	580
March	5	32	150	7.5	6.40	4.45	10,000
April	3	39	220	7.8	10.65	4.40	9,800
May	4	54	80	7.9	9.35	3.15	1,600
June	2	73	110	7.9	5.00	3.20	1,400
July	1	75	85	8.3	5.45	3.85	1,400
August	3	73	55	8.0	5.20	3.35	16,000
September	2	68	20	8.1	6.35	3.75	4,200
October	2	54	35	7.9	3.20	2.50	7,600
November	4	41	15	7.9	7.30	4.10	5,300
December	2	32	9	7.5	4.15	4.60	3,900
Average	3	50	65	7.8	7.8	3.35	5,200

1 Biochemical oxygen demand.

Table 8.–Selected major floods on Mississippi River at St. Paul since 1892

Date	Discharge (cfs)	Gage height (feet)	Recurrence interval (years)
Apr. 16, 1952	125,000	22.02	62.0
Apr. 16, 1951	92,800	18.79	31.0
Apr. 6, 1897	80,800	18.0	20.7
Apr. 6, 9, 1916	73,500	16.6	15.5
June 29, 1908	73,000	16.8	12.4
Apr. 8, 1917	68,600	16.0	10.3
July 11, 1905	59,800	14.8	8.86
May 5-7, 1893	58,800	14.7	7.75
Apr. 7, 1943	58,300	14.46	6.89
June 21, 1944	57,000	14.26	6.20
Apr. 22, 1919	54,500	13.8	5.64

Note.–Datum of gage is 684.16 feet above mean sea level, adjustment of 1912.

the effects of sewage effluent from municipalities upstream and from the towns of Jordan, Chaska, Shakopee, and others within the area.

Table 6 and figure 12 show that for the same period the water of the Minnesota River was more than twice as mineralized and hard as that of the Mississippi River above the Minnesota River and was higher in the percentage composition of sulfate and carbonate. These higher concentrations are attributed to the more common occurrence of gypsum and limestone rocks in the Minnesota River basin.

On the average, silica is more prominent in the Minnesota River waters than in the Mississippi River waters, and it has proved troublesome in high pressure steam boilers and in turbines. One industrial plant successfully reduces the quantity of silica by lime-softening.

Sanitary quality.—The St. Paul–Minneapolis Sanitary District collected and analyzed samples of Minnesota River water one or more times a month during 1950. (See table 7.) During 1950, the Minnesota River waters were noticeably lower in dissolved oxygen than those of

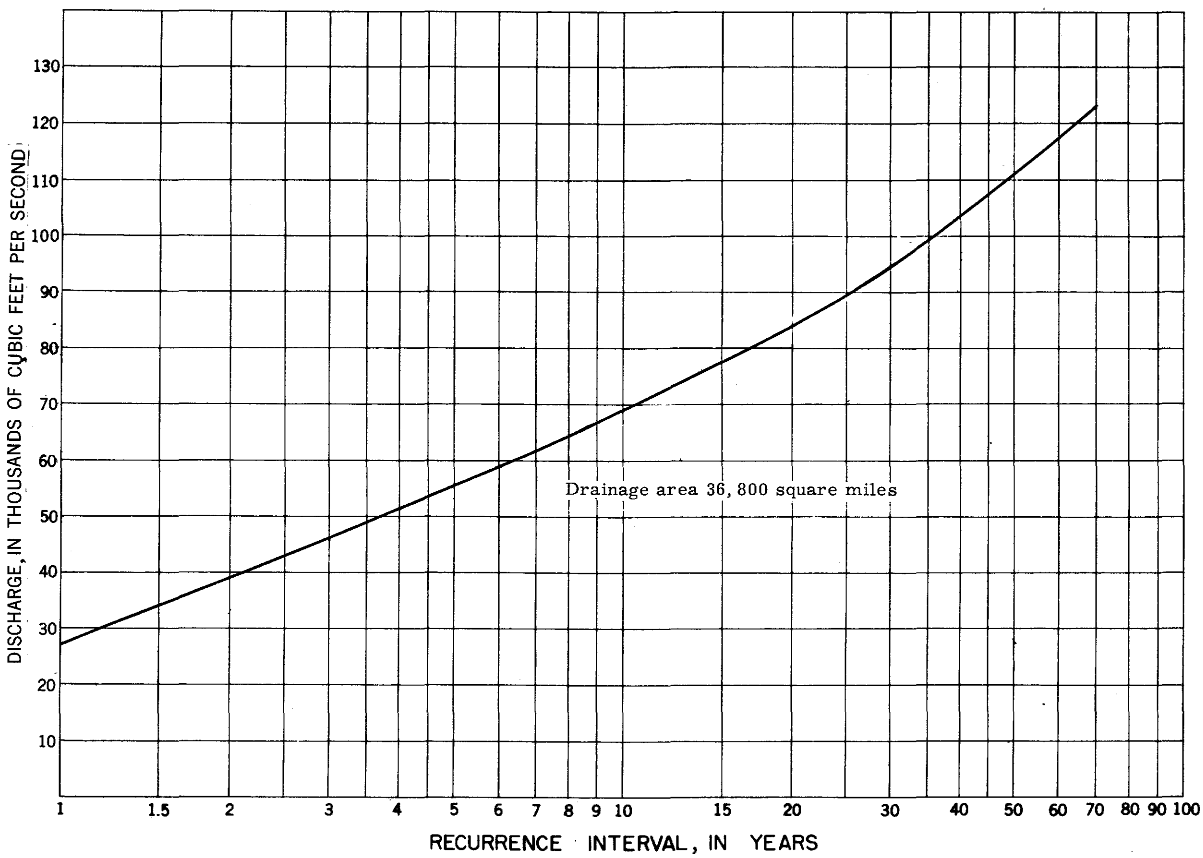

Figure 17.—Flood frequencies, Mississippi River at St. Paul, 1892–1952.

the Mississippi River above the Minnesota River and higher in biochemical oxygen demand (B. O. D.) and bacteria count.

Mississippi River below the Minnesota River

Records of stage and flow have been collected at St. Paul, 6 miles downstream from the Minnesota River, since 1887. The zero of the gage is 684.16 feet above mean sea level, adjustment of 1912.

Drainage area.—36,800 square miles.

Average discharge.—59 years (1892–1951), 6,163 mgd (9,535 cfs); (includes flow diverted past the gage through the Minneapolis and St. Paul sewers).

Low flow.—The minimum daily discharge at the St. Paul gaging station since 1887 was 408 mgd (632 cfs) on Aug. 26, 1934. The minimum gage height was not determined. The low-flow characteristics are illustrated by figures 6, 7, and 16. The duration curve of daily flows (fig. 6) shows the percent of time that the daily flow equaled or exceed a given flow. The maximum period of deficient flow curve (fig. 7) shows the greatest number of consecutive days that the flow may be expected to be less than a given value, and the drought-frequency graph (fig. 16) shows the expected frequency of occurrence of average minimum flows for 1-, 7-, 30-, 60-, and 183-day periods. (See example in fig. 8.) All low flows are affected by release of water from headwater reservoirs.

Floods.—The greatest flood since 1887 was that of Apr. 16, 1952, when the discharge was 125,000 cfs and the gage height was 22.02 feet. The second highest discharge was 92,800 cfs on Apr. 16, 1951, at a stage of 18.79 feet. The greatest discharge known before 1892 was 107,000 cfs on Apr. 29, 1881. Floods before 1892 are not comparable to those subsequent to 1892 owing to storage in the headwater reservoir system. Data on 11 selected major floods on the Mississippi River at St. Paul since 1892 are given in table 8. Flood frequencies on the Mississippi River at St. Paul are given in figure 17. Crest elevations of the 1951 and 1952 floods at several places are shown in figure 9.

Chemical quality.—Available data are insufficient to define adequately the effect of the Minnesota River on the quality of the Mississippi River water. However, hardness and the concentrations of calcium, bicarbonate, sulfate and chloride in water from the Mississippi River below the mouth of the Minnesota River slightly exceed those of water from the Mississippi River at Fridley. (See tables 3 and 9.)

Sanitary quality.—A summary of the chemical and bacteriologic conditions in the Mississippi River between the Minnesota River and the Hastings highway bridge during 1950 is shown in table 10. The variations in turbidity, dissolved oxygen, biochemical oxygen demand, and the high bacteria count are attributed chiefly to the influence of the Minnesota River and effluent from the sewage treatment plant and the South St. Paul packing plants. However, about 98 percent of the coliform content is dissipated before the river reaches the Hastings bridge.

Table 9.—Chemical quality of water from Mississippi River at St. Paul

[Results in parts per million except pH]

	1936-42[1]	July 21, 1943[2]
Discharge (cfs)	-	10,700
Silica (SiO_2)	9.1	18
Iron (Fe) & Aluminum (Al)	4.2	trace
Calcium (Ca)	63	52
Magnesium (Mg)	15	19
Sodium (Na)	18	4.8
Bicarbonate (HCO_3)	244	220
Sulfate (SO_4)	38	25
Chloride (Cl)	9.2	8.2
Dissolved solids (residue on evaporation)	285	240
Hardness as $CaCO_3$	213	208
Alkalinity as $CaCO_3$	201	181
pH	7.7	7.9

1 Analyses by Northern States Power Co., average of 6 samples.
2 Analysis by U.S. Geological Survey.

Since the completion of the sewage disposal plant in 1939, the river has recovered rapidly from its previous offensive condition. The oxygen content has increased as much as 20 or 30 times at some places, and the number of bacteria has been reduced to a very small fraction of its previous quantity. For example, sanitary conditions of the river at the Twin Cities lock and dam have improved steadily since 1939 (Minneapolis–St. Paul Sanitary District, 1950). The dissolved oxygen content has increased 165 percent since 1939, biochemical oxygen demand has decreased 46 percent, and coliform bacteria per milliliter have decreased 96 percent. However, bacterial contamination of the river is sufficiently heavy, even above the sewage treatment plant, to make it unsafe for swimming much of the time, owing to overflow from the combined domestic and storm sewers of both Minneapolis and St. Paul.

The Minneapolis–St. Paul Sanitary District operates 52 miles of intercepting sewers and the sewage-treatment plant at Pig's Eye Lake. The main intercepting sewer leading to the treatment plant is about 9 miles long and has a capacity at its lower end of 610 mgd. A total of 45,194 million gallons of sewage was treated by the plant in 1951 from an estimated population of 890,000.

The Minneapolis–St. Paul sewage treatment plant is one of the largest of its type in the world. The plant consists of screen and grit chambers, flocculating and settling tanks, and sludge disposal equipment. The sludge disposal equipment consists of concentration tanks, vacuum filters, and incinerators. The treatment ordinarily provided by the plant consists of screening, grit removal, and sedimentation. With this degree of treatment, about 75 percent of the suspended solids present in the sewage can be removed. This compares with an expected removal, at the time of design, of 56 percent. When the river flow is unusually low, about 10 percent of the time, flocculation and chemical treatment will be provided. This treatment

Table 10.–Summary of chemical and bacteriologic conditions in Mississippi River between

[Analyses by Minneapolis–St.

Location	January	February	March	April	May	June
						Temperature (in
Robert Street	32	34	34	37	50	72
Immediately above treatment plant	-	-	-	-	-	72
Above South St. Paul	32	32	34	37	54	72
Hastings highway bridge	32	32	32	36	54	70
						Turbidity (parts
Robert Street	7	7	55	80	55	35
Immediately above treatment plant	-	-	-	-	-	35
Above South St. Paul	15	15	120	120	40	40
Hastings highway bridge	10	8	60	120	60	35
						pH
Robert Street	7.3	7.6	7.5	7.8	7.9	8.0
Immediately above treatment plant	-	-	-	-	-	8.0
Above South St. Paul	7.6	7.5	7.5	7.7	7.8	7.8
Hastings highway bridge	7.5	7.4	7.5	7.7	7.8	7.8
						Dissolved Oxygen
Robert Street	8.20	8.05	9.15	13.20	11.70	8.10
Immediately above treatment plant	-	-	-	-	-	7.95
Above South St. Paul	9.80	7.90	9.40	12.45	10.55	7.20
Hastings highway bridge	6.25	4.60	7.00	12.00	9.70	7.25
						Biochemical Oxygen Demand
Robert Street	1.10	1.15	5.05	5.25	3.70	2.45
Immediately above treatment plant	-	-	-	-	-	2.60
Above South St. Paul	9.30	9.25	9.85	5.35	3.20	7.25
Hastings highway bridge	4.75	3.15	5.35	5.10	3.35	3.20
						Bacteria per cubic centimeter
Robert Street	610	480	6,600	9,900	7,800	2,300
Immediately above treatment plant	-	-	-	-	-	1,800
Above South St. Paul	68,000	140,000	78,000	7,700	4,500	260,000
Hastings highway bridge	23,000	12,000	23,000	15,000	12,000	82,000

Robert Street and Hastings highway bridge (below confluence with Minnesota River), 1950

Paul Sanitary District]

July	August	September	October	November	December	Average
degrees Fahrenheit)						
75	73	68	52	41	32	50
75	72	66	55	-	-	-
73	72	66	55	41	-	52
73	72	64	55	39	32	50
per million)						
30	20	15	15	10	6	30
30	25	20	15	-	-	-
35	30	25	25	15	-	45
35	30	15	15	15	10	35
8.3	8.2	8.3	8.2	8.2	7.7	7.9
8.1	8.2	8.1	8.2	-	-	-
8.0	8.0	7.9	8.0	8.0	-	7.8
8.2	8.2	8.0	8.4	8.1	7.7	7.9
(parts per million)						
7.75	7.30	8.60	10.20	11.80	12.35	9.70
7.50	8.15	8.20	9.75	-	-	-
5.90	4.90	5.85	7.50	11.05	-	8.40
7.95	8.00	8.95	10.50	10.90	8.15	8.45
(5-day) (parts per million)						
2.45	2.15	2.15	1.65	2.25	1.85	2.60
2.40	1.75	1.75	1.80	-	-	-
7.95	11.5	9.5	13.6	10.2	-	8.80
4.10	4.60	4.20	3.95	4.85	5.45	4.35
at 37° C, 24-hour agar						
1,000	11,000	6,600	2,400	5,100	2,500	4,600
5,600	8,700	6,000	2,600	-	-	-
280,000	1,100,000	830,000	870,000	270,000	-	360,000
9,900	6,100	7,200	22,000	36,000	15,000	22,000

will remove about 90 percent of the suspended solids. An average of more than 100 tons of organic sewage solids per day are converted to an inert ash that is pumped to a dump for disposal. At certain conditions of river flow, a portion of the untreated sewage is diverted directly to the river below St. Paul.

St. Croix River

The St. Croix River is the first important tributary of the Mississippi River east of the Twin Cities. Its nearest approach to the city limits of St. Paul is about $11\frac{1}{2}$ miles near Bayport.

The St. Croix River drains an area of 7,650 square miles and is about 164 miles long. It rises only 20 miles from Lake Superior, flows toward the southwest and south, and empties into the Mississippi River at Prescott, Wis. From source to mouth, the stream descends 338 feet. All except 20 feet of the fall is in the upper 116 miles.

The lower part of the basin is devoted mostly to farming. In general the terrain is gently rolling glacial drift through which streams have cut rather deep channels. A large part of the upper basin is timberland; 3 percent of the total drainage area consists of lakes.

The largest power development in the basin is at St. Croix Falls where a head of 60 feet is utilized by an installed capacity of 34,500 horsepower. There are several other hydroplants in the basin.

All the power plants in the basin are without facilities for storage. Some storage was maintained at Nevers Dam, upstream from St. Croix Falls, until the control structure was damaged in the spring of 1950. It is questionable whether or not the control structure will be repaired.

The St. Croix River is navigable commercially to Stillwater, 23.4 miles above the mouth. Between Stillwater and Taylors Falls, a distance of 28.4 miles, the channel is considered navigable and at the present time (1952), a depth of about 3 feet is maintained for use of light pleasure craft.

Second in importance to the utilization of the electric power from the St. Croix basin, is the enjoyment by residents of benefits from the vacation and recreational facilities along Lake St. Croix. The lake extends from the mouth of the river to just above Stillwater, Minn. It has an average width of about 3,000 feet and a maximum width of about 7,000 feet. The area is ideally situated for summer homes and cottages because it is close to the Twin Cities, especially St. Paul. During recent years, more and more people employed in the Minneapolis–St. Paul area have moved to permanent homes on the banks of Lake St. Croix.

Records of stage and discharge have been collected at several sites in the St. Croix River basin. The site nearest to the Minneapolis–St. Paul area is at St. Croix Falls, 1,800 feet downstream from the Northern States Power Co. dam where records have been collected since 1902. The zero of the gage is 690.1 feet above mean sea level, unadjusted.

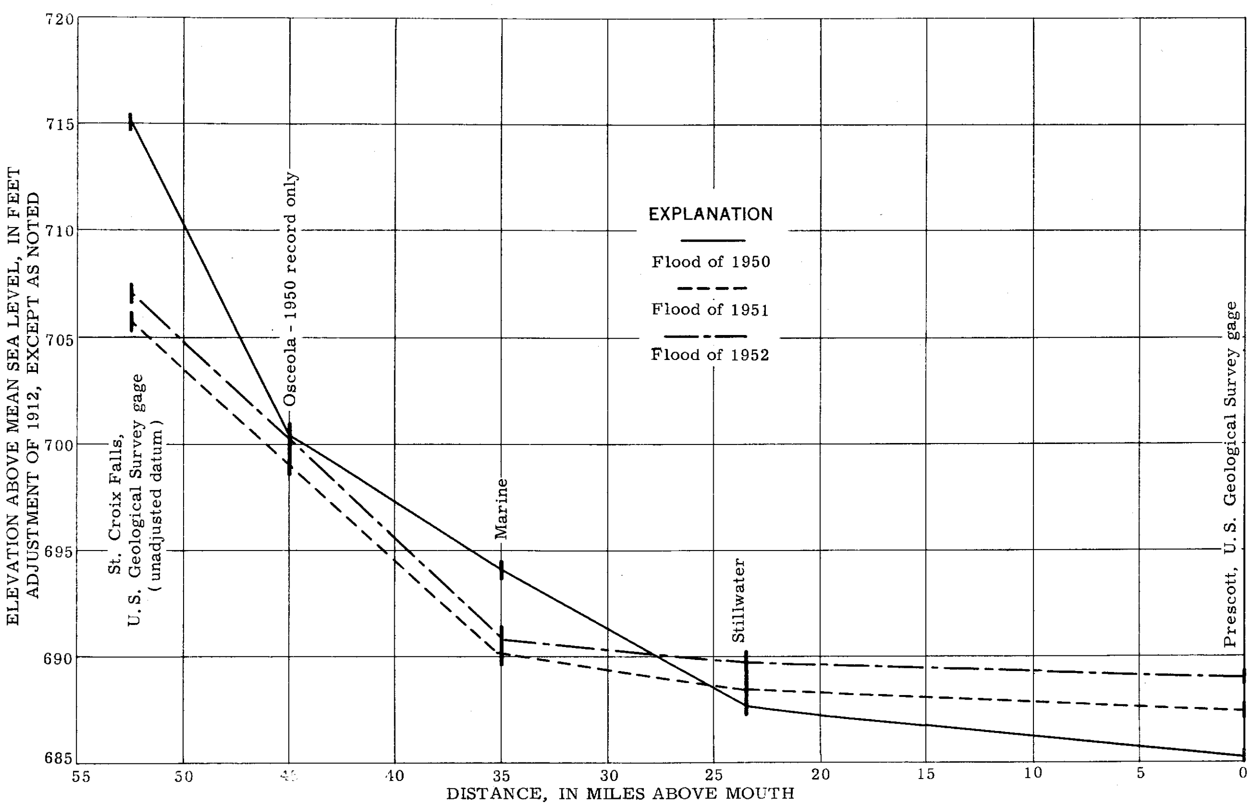

Figure 18.—Profiles of 1950, 1951, and 1952 floods, St. Croix River from St. Croix Falls to Prescott.

Drainage area.—5,930 square miles.

Average discharge.—46 years (1902–5, 1908–51), 2,473 mgd (3,826 cfs).

Low flow.—The minimum daily discharge at St. Croix Falls since 1902 is 48 mgd (75 cfs), July 17, 1910. Curves showing the low-flow characteristics were not prepared for this stream because of the regulation from powerplants.

Floods.—The maximum discharge at St. Croix Falls since 1902 is 54,900 cfs on May 8, 1950, at a stage of 25.19 feet. A flood-frequency curve has not been prepared because of regulation by powerplants. The stage of Lake St. Croix is affected by the stage of the Mississippi River at the outlet of the lake as well as by the discharge of the St. Croix River. In fact, the maximum stages recorded along the lake were due to backwater from the Mississippi River. Flood profiles on the St. Croix River between St. Croix Falls and Prescott for the floods of 1950, 1951, and 1952 are shown in figure 18.

Chemical quality.—The St. Paul–Minneapolis Sanitary District maintains a record of the quality of the St. Croix River waters in connection with pollution investigations of the Mississippi River.

In 1950, the St. Croix River water was similar to that of the Mississippi River at Hastings in temperature, dissolved oxygen, and pH; but it was less turbid and had a much lower biochemical oxygen demand, indicating better sanitary conditions (table 11).

Crow River

The Crow River basin lies directly west of Minneapolis and drains an area of 2,838 square miles. The Crow River is formed by the confluence of the North Fork and the South Fork, just above the village of Rockford. The North and South Forks flow eastward to their confluence and then northeastward to the Mississippi River at Dayton.

Both Forks have their sources in lakes, and flow through gently undulating farmlands. The distance from the head of the North Fork to the Mississippi River is about 150 miles and the fall is about 440 feet. Between 2 and 3 percent of the drainage area is composed of lakes; there are 70 in the North Fork basin and 120 in the South Fork basin. Creameries are the main industrial developments. At the present time (1952), there are no waterpower installations of more than 100 horsepower in the basin.

Water from this basin has not been utilized in the Twin Cities area except as it contributes to the flow of the Mississippi River. Consideration was given at one time to the diversion of a part of the high flows of the South Fork to Lake Minnetonka to offset depletion during drought years. Had such a project been undertaken and had enough water been diverted, the city of Minneapolis might have received some benefit in restoration of levels in two lakes in the Minnehaha Creek basin provided the water could be utilized when it was available.

Records of gage height and discharge have been collected at several sites in the Crow River basin. Continuous records of gage height and discharge have been obtained at the village of Rockford, about 23 miles upstream from the mouth, from June 1909 to September 1917 and since April 1929. The zero of the gage is 893.65 feet above mean sea level, adjustment of 1912.

Drainage area.—2,520 square miles.

Average discharge.—26 years (1909–17, 1930–31, 1934–51), 322 mgd (513 cfs).

Low flow.—The minimum discharge (1909–17, 1929–51) was 1.2 mgd (1.8 cfs) on Nov. 15, 1936. The minimum gage height during the period August 1934 to September 1951 was 1.05 feet on Nov. 15, 1936. The maximum number of consecutive days that the discharge

Table 11.–Summary of physical, chemical, biochemical, and bacteriologic quality of St. Croix River water at Prescott, 1950

[Analyses by St. Paul-Minneapolis Sanitary District]

Month	Number of samples	Temperature (°F)	Turbidity (ppm)	pH	Dissolved oxygen (Parts per million)	B.O.D.[1] (5-day) (Parts per million)	Bacteria per cc at 37°C (24-hour agar)
January	3	32	5	7.6	11.85	1.00	270
February	5	32	4	7.5	10.15	.75	52
March	4	32	30	7.4	8.60	1.70	1,500
April	3	36	35	7.3	9.70	1.90	1,200
May	5	41	10	7.4	9.90	1.70	280
June	4	68	9	7.7	7.05	1.70	260
July	4	73	9	8.3	8.90	2.60	70
August	5	73	7	8.1	7.10	1.90	430
September	3	66	8	7.8	6.75	1.25	2,400
October	4	57	7	8.2	7.70	.95	140
November	5	45	6	8.1	10.10	.85	140
December	3	32	4	8.0	12.20	1.15	53
Average	4	50	10	7.8	9.15	1.45	570

1 Biochemical oxygen demand.

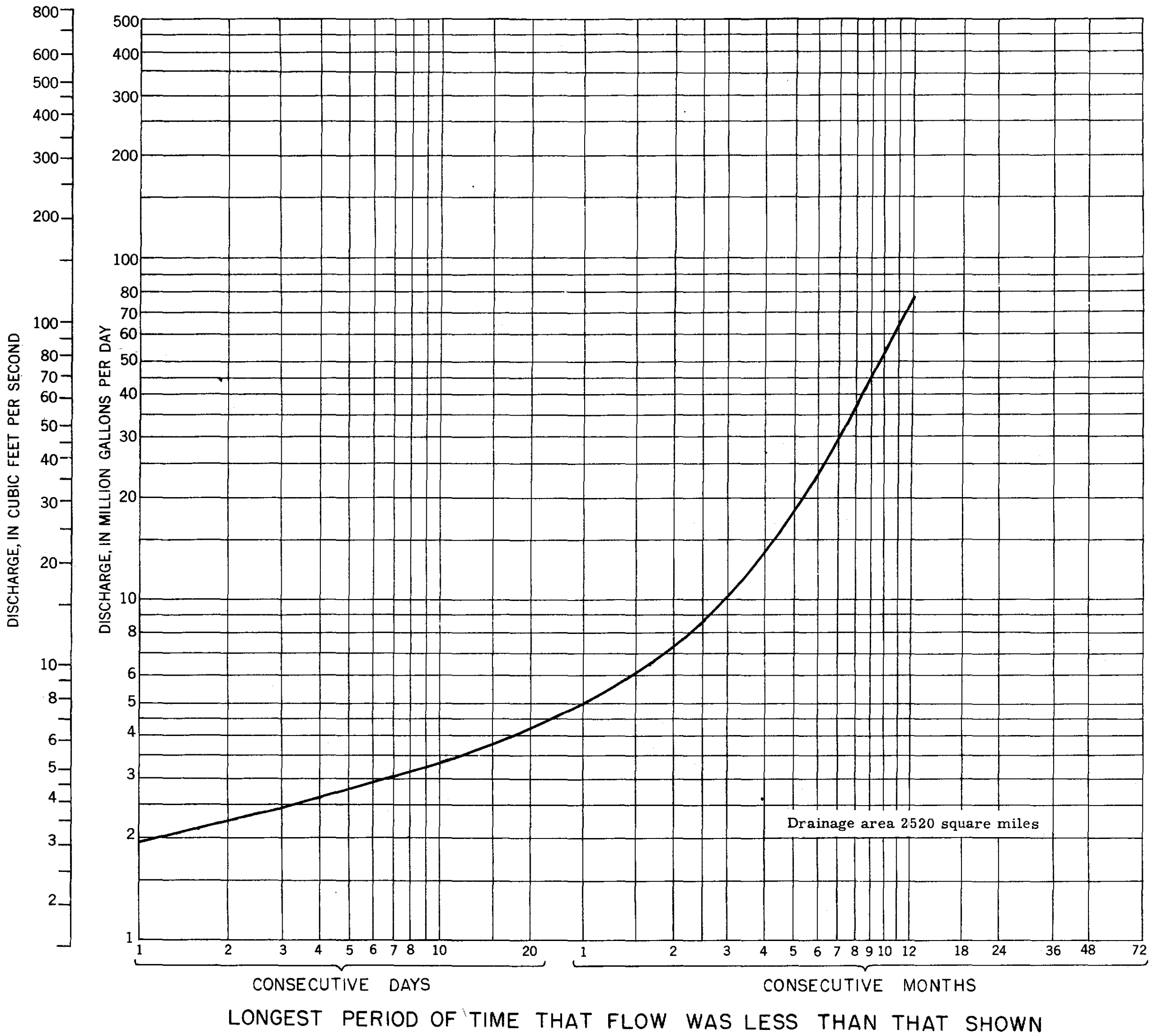

Figure 19.—Maximum period of deficient discharge, Crow River at Rockford, 1909–17, 1929–51.

may be expected to be less than any selected flow may be obtained from figure 19.

Floods.—The maximum discharge at Rockford during the period 1909–17, 1929–52 is 13,900 cfs on Apr. 13, 1952, at a stage of 16.25 feet. This flood has a recurrence interval of about 32 years. (See fig. 20.)

Data on the 7 highest floods of record are given in order of magnitude in table 12.

Chemical quality.—Crow River water was of a moderately mineralized calcium carbonate type at high flow (2,350 cfs) following the record flood of Apr. 13, 1952 (table 13 and plate 2). It had a greater quantity

Table 12.–Selected major floods on Crow River at Rockford, 1916-52

Date	Gage height (feet)	Discharge (cfs)	Recurrence interval (years)
Apr. 13, 1952	16.24	13,900	32.0
Apr. 3, 1916	[1]15.90	10,600	16.0
Apr. 7, 1917	[1]14.50	8,500	10.7
Apr. 16, 1951	12.13	7,720	8.00
Mar. 29, 1948	11.45	7,190	6.40
Apr. 3, 1950	10.72	5,680	5.33
June 21, 1944	10.24	5,600	4.57

1 Former site and datum.

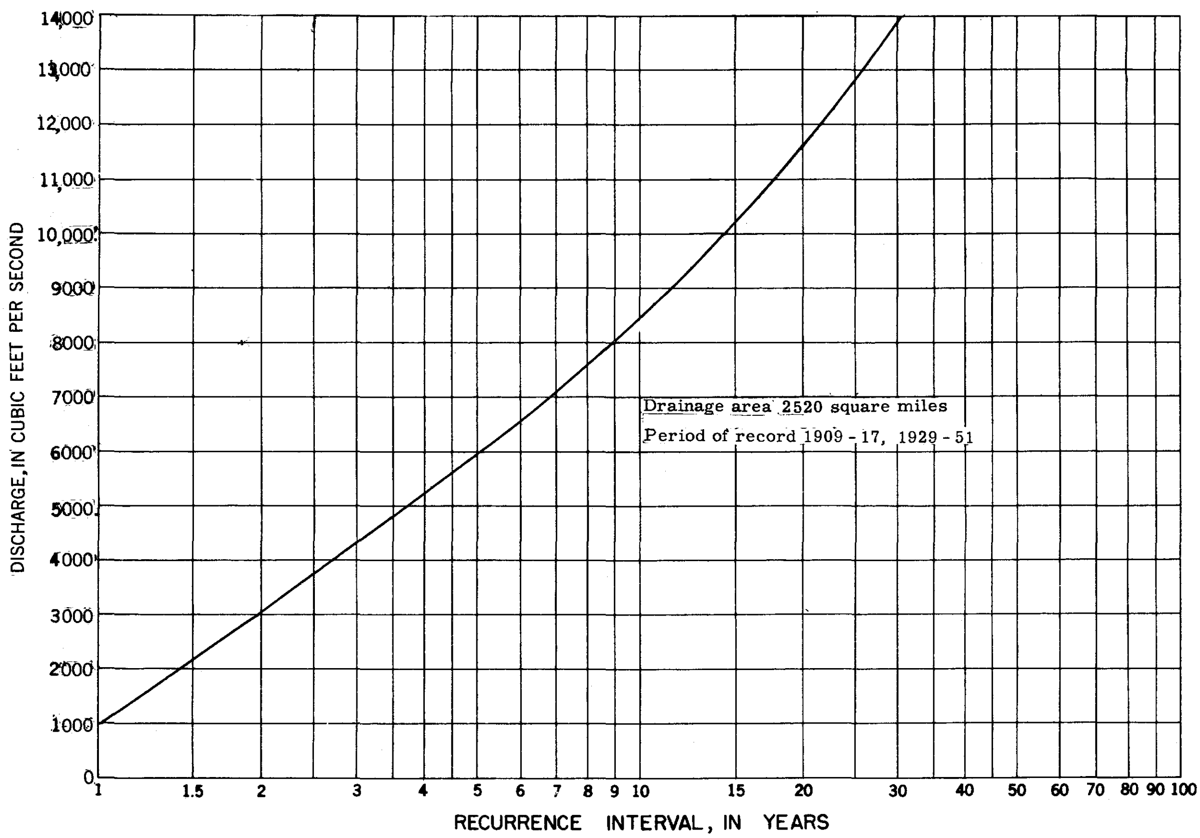

Figure 20.—Flood frequencies, Crow River at Rockford.

Table 13.—Chemical quality of selected surface waters in the Minneapolis-St. Paul area

[Analyses in parts per million]

	Crow River at U.S. 55, at Rockford	Vermilion River at U.S. 61, at Hastings	Bassett Creek at Plymouth Ave.
Date of Collection	May 15, 1952	Apr. 14, 1952	Apr. 14, 1952
Discharge (cfs)[1]	2350	197	135
Temperature (° F)	58	40	38
Silica (SiO_2)	7.9	13	9.0
Iron (Fe)	.06	.06	.04
Calcium (Ca)	56	58	43
Magnesium (Mg)	24	17	12
Sodium (Na)	5.9	2.1	2.2
Potassium (K)	5.2	2.2	3.7
Bicarbonate (HCO_3)	248	219	153
Sulfate (SO_4)	45	36	33
Chloride (Cl)	3.0	2.0	3.5
Fluoride (F)	.2	.2	.3
Nitrate (NO_3)	2.5	6.6	6.8
Boron (B)	.06	.01	.06
Dissolved solids	298	268	214
Hardness as $CaCO_3$:			
Total	238	214	158
Noncarbonate	35	34	33
Percent sodium	5	2	3
Specific conductance (micromhos at 25° C)	469	423	327
pH	7.5	7.4	7.3
Color	31	14	27

1 Preliminary records.

of magnesium and carbonate than waters of other principal tributaries to the Mississippi River in this area. Color (31 ppm) was not as prominent as for a proportionately high flow in the Mississippi River which generally has a color content exceeding 60 ppm during the spring (fig. 11).

A comparison of the chemical composition of waters from several streams is made in figure 21. The samples were collected at high flows and indicate the percentage of each constituent.

Vermilion River

The Vermilion River is the first stream of importance south of the Minnesota River. The drainage area at its mouth is 215 square miles, and its length to the head of the longest tributary is about 35 miles. The most northern tributary reaches to within about 11 miles of the southern suburbs of St. Paul. The drainage basin is comprised mostly of farmlands with gently sloping terrain. The slope of the stream is small, about 5½ feet per mile, throughout most of the basin. In the first 3 miles above the mouth, there is a fall of slightly over 100 feet with a large portion of this being concentrated at the Hastings mill.

Records of stage and discharge were obtained at Hastings half a mile upstream from the mill dam from April 1942 to September 1947. The zero of the gage was 783.59 feet above mean sea level from April 1942 to September 1945 and 781.59 feet above mean sea level from October 1945 to September 1947.

Drainage area.—195 square miles.

Average discharge.—5 years (1942–47), 52.4 mgd (81.1 cfs).

Low flow.—The minimum daily discharge at Hastings during the period 1942–47 was 3.9 mgd (6.0 cfs) on Jan. 3, 4, 1947. The minimum gage height observed was 1.65 feet May 28, 29, 31, 1947.

Floods.—The greatest flood at Hastings in the 5 years, 1942–47, was 1,710 cfs on March 16, 1945, when the stage was 792.7 feet above mean sea level, datum of 1929. A study of flood frequencies in the area shows that a flood of the magnitude of that of March 16, 1945, may be expected to recur at average intervals of between 20 and 30 years. Flooding in the vicinity of Hastings has generally been confined to small areas near the stream where ice jams have caused flooding for short periods.

Chemical quality.—Continuous records of chemical analyses are not available for the Vermilion River. An analysis (Apr. 14, 1952) at a moderately high flow, 197 cfs, at Hastings is characteristic of the calcium carbonate type water which is typical of this area (table 13 and plate 2). The water has about the same

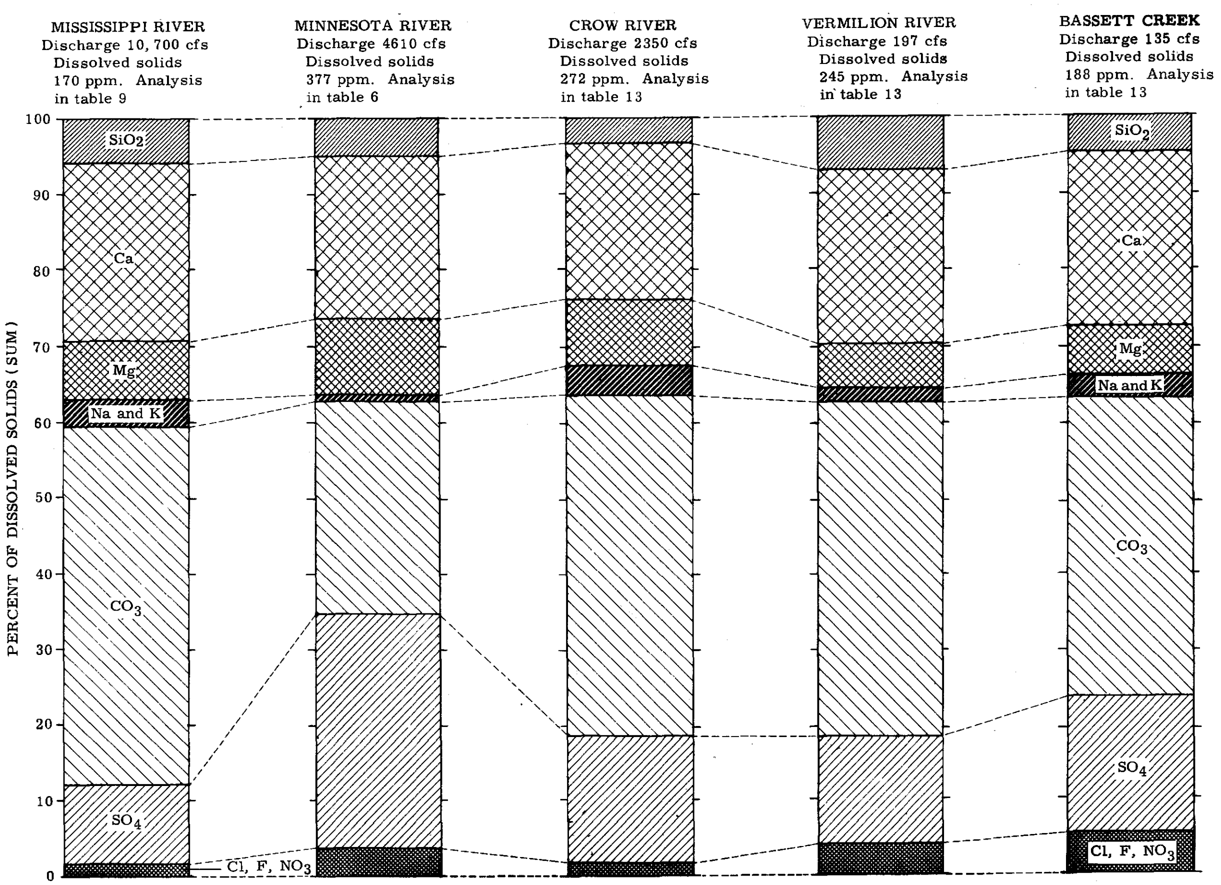

Figure 21.—Composition of dissolved solids in waters from selected streams in the Minneapolis–St. Paul area.

composition and concentration as that for the Crow River, differing principally in the amount of carbonate in solution. (See fig. 21.)

Small Streams

Minnehaha Creek

Minnehaha Creek has its source in Lake Minnetonka. It flows southeastward and enters the Mississippi River just below Twin Cities lock and dam. The drainage area at the mouth is about 206 square miles and the length about 18 miles. The entire length of the stream is contained in the suburban and urban areas of Minneapolis. It follows a meandering course through Hopkins, St. Louis Park, and Edina and enters the Minneapolis city limits in the southwest corner. It crosses the southern part of the city, and, just above the mouth, flows over scenic Minnehaha Falls, made famous by the poet Longfellow.

During much of the year there is no flow, so the stream does not contribute to the domestic or industrial water supply of the area. During prolonged periods of high rainfall, when lake levels generally are raised, excess water from the Minneapolis lakes — Cedar, Lake of the Isles, Calhoun, and Harriet — is discharged into Minnehaha Creek. The creek flows through Lake Hiawatha and is connected by a diversion channel to Lake Nokomis; thus storm runoff can be utilized in replenishing these lakes that are used for recreation.

In Minneapolis, parks and parkways along the course of the stream add to the scenic attraction of the area. In past years, some utilization was made of the stream for sewage disposal; but, with the development of the recreational facilities and the construction of dwellings along the creek, the practice was stopped, and today its use is confined to recreational projects.

There are no gaging stations in the creek basin, so no continuous records of discharge are available.

From a study of flood frequencies in the area, it is estimated that a flood of about 5.8 cfs per square mile will have an average recurrence interval of 10 years.

Bassett Creek

Bassett Creek rises in Medicine Lake about 4 miles west of the city limits of Minneapolis and flows in a meandering course. It enters the city near the northern limits and continues for about 4 miles to the Mississippi River. The total length of the stream is about 12 miles, and in this distance the fall is roughly 90 feet.

At the present (1952), little use is made of this stream except to maintain the elevation of Theodore Wirth Lake, which is in the Minneapolis Park system. Some consideration has been given to a diversion from Bassett Creek to the Minnehaha Creek basin by way of Brownie, Cedar, Lake of the Isles, Calhoun, and Harriet Lakes. By this diversion, help toward maintaining water levels in these lakes would be obtained, and local problems of channel capacity on Bassett Creek during high flows might be alleviated.

No continuous records of discharge have been collected on this stream.

An analysis of Bassett Creek water shows that it is slightly more dilute at high flow than waters from other streams tributary to the Mississippi River. (See table 13 and plate 2.) The principal difference is in the smaller amounts of carbonate and hardness, a characteristic that is probably associated with its source in Medicine Lake and its short length of only 12 miles.

Shingle Creek

Shingle Creek rises in Bass Lake, a little more than 5 miles west of the Minneapolis city limits. It passes through Eagle Lake and meanders eastward to a point north of the city from which it is conducted by ditch to the city limits. At the city limits it is returned to the natural channel and it flows for about 3 miles through the city to the Mississippi River. The length of the stream is about 26 miles and the fall, as measured on topographic maps, is roughly 100 feet. Except for maintaining a swimming pool in Camden Park, no use is made of the water from this stream. The Hennepin County Planning Commission has proposed that the area adjacent to the creek in the city be acquired and converted into park property. No continuous records of discharge are available on this stream.

Coon Creek

Coon Creek has its origin in a large marsh northeast of Anoka. It flows westward and then southeastward in a meandering course and enters the Mississippi River about a mile downstream from the Coon Rapids hydroplant. Throughout the length of the stream, which is about 42 miles, the adjacent land is low and is composed mostly of marshes. The fall from the headwaters to the mouth is only about 50 feet. Except for a diversion to help maintain levels in Crooked Lake, no utilization is made of the water in this basin. An extensive ditch system draining the marshes empties into Coon Creek.

Rice Creek

Rice Creek has its headwaters in Howard Lake in Anoka County. It flows southwestward for about 45 miles, passes through several lakes, and empties into the Mississippi River near Fridley. Its total fall is about 100 feet. During periods of high stages in the natural lakes north of St. Paul, flow is diverted to the city water-supply system by pumping from Centerville Lake which is in the Rice Creek basin. It is estimated by the St. Paul Water Department that in a normal year about 10 percent of the city water is contributed by Rice Creek. In the past, other diversions have been made; but, at present (1952), all the diversion is from Centerville Lake except an occasional diversion from Bald Eagle Lake. In case of an emergency it is possible that more flow could be diverted for a short time.

Lakes

Several lakes lie within the cities of Minneapolis and St. Paul. Recreation is the only use made of these lakes. In addition to the lakes within the city limits, there are more than sixty others in Ramsey and Hennepin Counties and more than one hundred in the adjacent counties covered by this report.

Several lakes north of St. Paul are incorporated into the municipal water system; they serve as reservoirs for the public supply before treatment.

In past years, the surrounding lakes were used as a source of ice for domestic and commercial requirements. With the advent of home refrigeration and the manufacture of ice, the demand for ice from the lakes has decreased so that Lake St. Croix, which furnishes ice for railroads and commercial packing, and Long Lake at New Brighton, where a very small amount is cut and stored for reserve by an ice manufacturing company, are the only sources from which any appreciable quantity is obtained.

The accessibility of such a large number of lakes has induced many people employed in the city to establish homes on the lakeshores outside the corporate limits of the cities.

Within the cities, the lakes are surrounded by parks and picnic grounds which attract large numbers of visitors and residents.

In Minneapolis, the lakes in the southwestern part of the city are regulated at periods of excess precipitation by discharging into the Minnehaha Creek basin. Theodore Wirth Lake, in the northwestern part of the city, is regulated by discharge to and from Bassett Creek, and in the southeast, Hiawatha and Nokomis Lakes are regulated to a small extent by discharge to and from Minnehaha Creek. During periods of deficient precipitation, the level of the Brownie to Calhoun chain of lakes has been restored by flow from the city water system and by the use of stormflow from areas adjacent to the lakes.

Some chemical quality data on lake water have been compiled by the Minnesota Department of Conservation in connection with aquatic and biologic investigations in the State (table 14). Lakes Vadnais and Pleasant are in the St. Paul water-supply chain; therefore the sulfate and chloride would be expected to be comparable to the average for the Mississippi River. Total alkalinity of lake waters, except the maximum of 172 ppm observed for Lake Minnetonka, was generally lower than the average annual alkalinity observed for the Mississippi River waters. This lower alkalinity was due principally to the freshening action of rain and snow on the lake surface during the present wet cycle as well as to the probable precipitation of some of the carbonates of calcium and magnesium resulting from loss of carbon dioxide. Lakes Minnetonka, Calhoun, and Tanners had slightly higher quantities of total nitrogen,

Table 14.—Chemical quality of selected lake waters in Ramsey, Hennepin, and Washington Counties

[Analyses by Minnesota Department of Conservation; results in parts per million]

Lake	Date	Sulfate (SO_4)	Chloride (Cl)	Total phosphorus (P)	Nitrate (NO_3)	Total nitrogen (N)	Total alkalinity as $CaCO_3$
Ramsey County							
Johanna	Aug. 3, 1950	17.5	6.2	0.025	0.18	0.388	122.5
Vadnais	Aug. 30, 1950	18.8	2.8	-	-	-	-
Pleasant	Aug. 21, 1950	12.5	3.2	-	-	-	-
Owasso	Sept. 15, 1948	4.0	2.5	.02	.44	.270	110.0
Snail	Sept. 17, 1948	4.0	.7	.025	.88	.399	87.5
Gervais	Sept. 12, 1948	29.0	14.3	.052	.09	.536	112.5
Turtle	Nov. 5, 1947	16.2	3.2	.023	.09	.242	100.0
Josephine	Nov. 5, 1947	16.0	2.6	.03	.04	.204	125.0
Tanners	May 16, 1947	45.0	5.0	.035	.44	1.010	107.5
White Bear	July 1947	11.0	3.0	.03	.18	.33	100.0
Como	July 15, 1946	9.1	3.4	.12	.31	.40	65.0
Long Lake (New Brighton)	July 30, 1946	22.2	7.7	.03	.35	.213	120.0
Hennepin County							
Minnetonka (ranges in 43 samples)	May 21 to June 13, 1949	0.1- 20.0	0.5- 9.0	0.022- .50	0.00- .62	0.49 4.12	115- 172.5
Hiawatha	Apr. 29, 1948	23.4	9.6	.35	.53	.70	112.5
Calhoun	May 18, 1948	25.0	11.4	.016	.22	2.76	145.0
Cedar	May 20, 1948	19.2	9.98	.02	.31	.251	130.0
Harriet	May 12, 1948	14.5	15.2	.027	.26	.654	135.0
Lake of the Isles	May 21, 1948	17.5	13.9	.05	.31	.499	140.0
Independence	-	9.5	3.6	.025	.22	.405	102.5
Medicine	July 28, 1948	7.0	2.9	.020	.44	.291	130.0
Crystal (Robbinsdale)	Aug. 7, 1946	23.5	19.4	.035	.09	.477	85
Washington County							
Jane	July 27, 1950	4.8	1.0	0.029	0.22	0.33	57.5
Elmo	July 1, 1948	9.9	3.8	.10	.44	.84	112.5
Forest	Aug. 19, 1947	3.0	3.4	.02	.00	.70	127.5

which may be attributed to several sources including waste products and decay of organic material. No color determinations were made for these studies, but some of the lakes are reported to be somewhat high in color.

GROUND WATER

Principles of Occurrence

The occurrence of ground water in any area is controlled in large part by the geology. For this reason, a brief geologic history of the Twin Cities area is presented to enable the reader to visualize the processes that gave rise to the water-bearing formations underlying the area.

The oldest known rock in the area is pre-Cambrian granite, which is overlain by ancient lava flows and a series of sandstones and shales which are described later as the so-called red clastic beds. The sandstones and shales were probably deposited in fresh water and were partly derived from the erosion of the lava flows.

After a long interval of geologic time, the sea alternately invaded the area and retreated several times, depositing a thick series of limestones, shales, and sandstones, which are described below as being in the Cambrian and Ordovician systems.

Subsequent to this event, the area was lifted above sea level for an extremely long period and many deep valleys were eroded in the sedimentary rocks. The Pleistocene glacial drift that fills the valleys in the bedrock and mantles practically the whole area was deposited next. If any invasions of the sea occurred between the time of deposition of the Cambrian and Ordovician rocks and the advance of the glaciers during Pleistocene time, the sediments deposited in these seas have been completely eroded.

Glaciers advanced and retreated over the area several times, depositing silt, clay, sand, gravel, and boulders, either directly from the melting ice or in rivers formed by the melting ice. After the last retreat of the glaciers, the present system of rivers and lakes was established, and St. Anthony Falls migrated from near Fort Snelling, at the confluence of the Minnesota and Mississippi Rivers, to its present position.

Ground water is defined as that part of the water under the surface of the earth that is in the zone of saturation, the upper surface of which is called the water table. Below the water table all the connected pores, crevices, and cavities in the rocks are saturated with water.

An aquifer is a rock or stratum that will yield water in sufficient quantity to be of importance as a source of supply.

The primary source of essentially all ground water is precipitation. Water may enter the ground by direct percolation from rainfall or melting snow or from streams and lakes.

Practically all ground water of economic value is moving through the ground from places of intake or recharge to places of discharge. Velocities generally range from a few feet a year to a few feet a day.

In the Minneapolis–St. Paul area, ground water occurs under both artesian and water-table conditions. Under artesian conditions, ground water is confined by an overlying impermeable stratum. When tapped by wells, artesian water rises above the top of the aquifer. If the pressure is sufficient to raise the water above the level of the land, the well will flow. Theoretically, if the artesian system were perfect and there were no frictional resistance between the aquifer and the water, the pressure could raise the water to the same elevation as at the intake area.

Under water-table conditions the water is not confined by an overlying impermeable stratum. Pumping of a well lowers the water table in the form of an inverted cone. The water drains into the well by gravity and the amount released from storage may approach the product of the quantity of aquifer dewatered and the porosity of the aquifer. Porosity is the ratio of the volume of voids to the volume of the whole mass of the material, expressed as a percentage.

Under artesian conditions, pumping lowers the artesian head and water is yielded owing to the expansion of the confined water and compression of the aquifer. The quantity of water released from storage is very much smaller than indicated by the porosity.

If an aquifer is connected directly or indirectly with a river or lake and the river or lake bed is sufficiently permeable, it is possible for a pumping well to induce infiltration or recharge from the body of water.

Geological Structure

In general, the bedrock formations underlying the Minneapolis–St. Paul area form a slightly elongated basin. Plate 3 is a structure-contour map on the upper contact of the Jordan sandstone. The 450-foot contour, near the center of the area, is at the low point in the basin. The average dip of the formations is about 20 feet per mile. The simplicity of the structure is interrupted by an anticline near Afton in the eastern part of the area and by some faulting around Hastings in the southeast.

Mantling the rock formations in practically all the area is an essentially horizontal blanket of glacial drift. Plate 3 also shows east-west and north-south geologic cross sections through the area.

The basin structure is significant because all the bedrock aquifers dip toward the center of the area, thus forming a distinct artesian basin. All the area described in this report lies in the central part of the much larger structural basin.

Water-Bearing Bedrock Formations

The characteristics of the principal formations underlying the area are summarized in table 15.

Hinckley sandstone

The thickness of the pre-Cambrian Hinckley sandstone is somewhat indefinite because it is difficult to distinguish, in well records, the contact of the Hinckley with the overlying Dresbach and underlying sandy shales of the pre-Cambrian Fond du Lac sandstone of Winchell (1899). The lower part of the Hinckley is as red in some places as the underlying Fond du Lac of Winchell,

Table 15. -The principal formations in the Minneapolis-St. Paul area and their water-bearing properties. (After Schwartz, 1936, and Thiel, 1944)[1]

System	Series	Formation	Approximate thickness (feet)	Physical characteristics	Water-bearing properties
Quaternary.	Recent.	Alluvium.	0-150	Clay, silt, sand and gravel.	Yields small supplies of water.
	Pleistocene.	Glacial deposits.	0-400	Clay, silt, sand, and gravel.	Yields small to large supplies of water. It is the source for most farm and domestic wells and a few small industrial wells.
Ordovician.	Mohawkian.	Galena (including Decorah shale member).	0-95	Shale, blue and green, interbedded with thin layers of blue limestone.	Yields little or no water.
		Platteville (including Glenwood shale member).	27-42	Limestone, brown, blue, and gray. Gray and green shale at base.	Yields little or no water. Shale at base is relatively impervious.
	Chazyan.	St. Peter sandstone.	145-165	Sandstone, white and yellowish-brown, fine- to medium-grained, poorly cemented; contains siltstone and shale in lower part.	Yields moderate supplies of water to many wells.
	Beekmantownian.	Shakopee dolomite.	35-60	Limestone, gray to buff, dolomitic, massive to thin-bedded, often cherty and sandy.	Yields small supplies of water to a few wells.
		Root Valley.	0(?)-10	Sandstone, white to yellowish, shaly, and sandy dolomite, probably interbedded and in lenses.	Do.
		Oneota dolomite.	70-90	Dolomite, gray, pink, or buff, thick-bedded; sandy near top.	Yields little water to wells except possibly from solution-enlarged openings.
Cambrian.	St. Croixian.	Jordan sandstone.	80-105	Sandstone, white to yellow to brown, medium- to coarse-grained, loosely cemented.	Yields abundant supplies of water to numerous wells. Most intensively developed aquifer in the area.
		St. Lawrence formation.	35-70	Dolomite, buff, glauconitic, and calcareous gray and buff shales.	Relatively impervious. Yields little or no water.
		Franconia.	100-200	Shales, green silts, and fine-grained, greenish and pink sandstones; about 15 to 40 feet of white, medium- to coarse-grained sandstone at base.	Yields small supplies of water from sandstone beds. Water contains excessive amount of iron.
		Dresbach. Galesville member	250-400	Sandstone, about 50 feet of yellow to white, medium- to coarse-grained, poorly cemented.	Yields large supplies of water to many wells.
		Dresbach. Eau Claire member		Sandstone, about 200 feet of gray, greenish-gray, and buff, with beds of greenish-gray and red shales and siltstones.	Several sandstone strata yield moderate supplies of water.
		Dresbach. Mount Simon member		Sandstone, about 150 to 200 feet of white to pink, and brown, coarse.	Yields large supplies of water to many wells.
Keweenawan.	Lake Superior.	Hinckley.	75-175	Sandstone, yellowish to salmon-pink and red, fine- to coarse-grained.	Do.
		Fond du Lac (red clastic) beds.	1,000-2,500	Shale, dark red, sandy; red to brown sandstone; and conglomerate.	Contains little water.
Pre-Cambrian.			(?)	Basalt flows; granites.	Contains little or no water.

1 Not in accordance with the classification approved by the U.S. Geological Survey.

which has been referred to as the red clastic series.

The sandstone ranges in texture from coarse to fine, although it is usually medium. The red color is probably due to varying amounts of iron oxide.

The formation is tapped by many wells and supplies of relatively soft water are obtained.

Mount Simon and Galesville members [1]

These sandstones described by Trowbridge and Atwater (1934) as members of the Dresbach formation are among the most important water-bearing formations in the area. They crop out at Taylors Falls in Chisago County, which is north of the area under consideration. The Mount Simon member overlies the Hinckley sandstone and is connected hydrologically with it.

Water in the Mount Simon and Galesville is under artesian pressure in practically the whole area, and the pressure is sufficient to lift the water above or nearly to the surface in the valleys of the Mississippi and St. Croix Rivers and some of their tributaries.

Franconia sandstone

The Franconia sandstone crops out along the St. Croix River just north of the area included in this report. Thiel (1944, p. 65) states that the lower part represents a reworking and redeposition of the sands in the upper part of the Dresbach sandstone (Galesville member). Consequently, from drill cuttings it is difficult to distinguish the lower contact. The sandstone in the bottom part of the Franconia is probably connected hydrologically with the Galesville member of the Dresbach formation.

Jordan sandstone

The Jordan is the most important aquifer in the area because of its high yield of water. The formation is exposed in the valleys of the Minnesota River and tributary streams, along the Mississippi River east of the locks at Hastings, and at intervals along the St. Croix River valley (pl. 4). Southwest of Afton, in the eastern part of the area, it is exposed on an anticline. (See pl. 3.)

A glacial or preglacial river, possibly the ancestral Mississippi, eroded a major channel through the overlying formations into the Jordan. In places the river cut completely through the Jordan to the underlying St. Lawrence formation. The channel, which is completely filled with glacial deposits, extends eastward from about the middle of T. 116 N., R. 24 W., to the large bend in the Mississippi River near Pine Bend.

The upper part of the formation is coarser than the lower part. The sand grains are usually well rounded and locally some small quartz pebbles may be found. Also, the upper part is generally more massive and the lower part is thin bedded.

From laboratory tests on specimens of Jordan sandstone, Bass, Meyer, and Norling (1933) estimate the coefficient of permeability for the formation, including a considerable percentage of crevices and cracks, to be about 50 cubic feet per day per square foot for a hydraulic gradient of 100 percent. This is about 375 gpd per sq ft for the same gradient.

In practical terms, this means that 375,000 gallons of water will flow through each mile of the aquifer (measured at right angles to the direction of flow), assuming the aquifer is 100 feet thick and the hydraulic gradient is 10 feet to the mile.

Bass, Meyer, and Norling (1932, p. 100) state that the porosity of the Jordan has been variously estimated at from 12 to 18 percent. It is presumed that they mean the effective porosity. They also state that the effective porosity is probably about 10 percent. The effective porosity is generally defined as the ratio of (1) the volume of water that a saturated material will yield by gravity flow to (2) the total volume of the material.

Recharge to the Jordan sandstone in the Twin Cities area is important in evaluating the ground-water resources of the area.

Schwartz (1936, p. 113) states that the Jordan is unable to conduct water from the east beyond the St. Croix River; from south of Afton to Point Douglas, the Afton anticline prevents any east-west movement. This interpretation seems to be correct, owing to the fact that the Jordan sandstone crops out in the St. Croix valley above river level.

The piezometric map given on plate 4 is helpful in studying the direction of movement of ground water in the Jordan and the various factors involved in the recharge of the aquifer. The contours connect points of equal elevation on the artesian-pressure surface, that is, the surface to which water will rise in cased wells tapping the Jordan. The contours as shown relate to conditions as they were in the spring of 1949. The position of the contours may shift with seasonal changes in pumping, as well as long-term trends. Water moves at right angles to the contours, in the direction of the hydraulic gradient.

The closed circular contours near downtown Minneapolis indicate the approximate location of the center of pumping in that area. As a result of the lowering of the artesian pressure, water is moving in locally from all directions. North of the center of pumping, a valley or trough has been developed in the pressure surface. The contours at the head of the valley point in a northerly direction and the axis of the valley trends due north or a little west of north. Thus, at some distance from the center of pumping water seems to be moving toward the cone of depression from all directions except the southeast.

Depressions in the pressure surface are evident near downtown St. Paul and around South St. Paul, but the data are relatively meager in those areas.

Bradley (1949, p. 12) mentions that, north of New Brighton, the Jordan is recharged locally from glacial deposits filling a preglacial valley that was cut into it.

[1] The subdivision of the Dresbach formation is not approved by the U. S. Geological Survey.

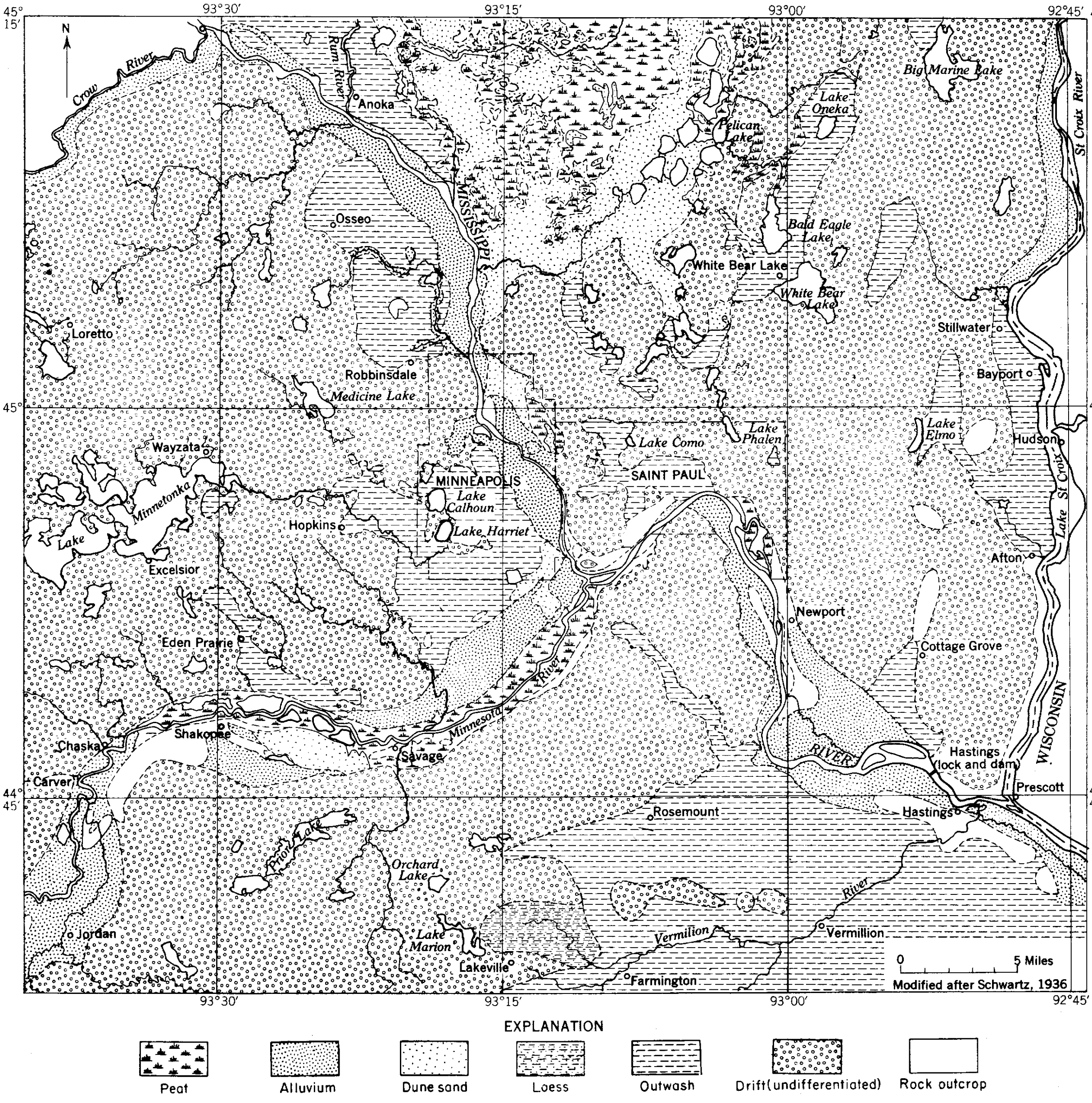

Figure 22.—Map of the Minneapolis–St. Paul area showing the alluvium and glacial deposits.

In the western part of the area, around Lake Minnetonka and to the north where the Jordan is in direct contact with the glacial deposits, water levels are relatively high, indicating an area of recharge. However, the contours do not appear to be much affected by the heavy pumping to the east in the metropolitan area. This may mean either that relatively little water has moved from here to supply the wells in the cities, or that a condition of equilibrium has been reached or is being approached.

In the southern and southwestern parts of the area the pressure surface appears to slope toward the valley of the Minnesota River from both the north and the south, indicating that the Minnesota River valley is an area of ground-water discharge. Schwartz (1936, p. 117-119) mentions large springs along the north bank of the Minnesota River in the valleys of tributaries and also at the foot of the main bluffs. He also states that the largest springs in the Minneapolis–St. Paul area are at Pine Bend. This is where the large glacial or preglacial channel that was cut into the Jordan sandstone intersects the present valley of the Mississippi River. It is possible that the Jordan is contributing to the spring discharge in these areas, for the sandstone is exposed in the Minnesota valley and is also overlain by the glacial fill in the old channel.

According to Bass, Meyer, and Norling (1932, p. 102), the Shakopee and Oneota dolomites are somewhat permeable formations, and they may not confine the water in the Jordan very effectively. If this is correct, it may be possible that some recharge is occurring relatively near the centers of pumping through the lower part of the St. Peter sandstone and the Shakopee and Oneota dolomites. Owing to the paucity of data, it is almost impossible to state whether ground water moves from the St. Peter to the Jordan via natural openings in the formations. However, in the downtown area at least, there is probably some movement of water from the St. Peter to the Jordan through wells that have been completed in both formations and probably through the leaky casings of old or abandoned wells that had cased off the St. Peter and tapped the Jordan.

St. Peter sandstone

The St. Peter sandstone crops out in the valley of the Mississippi River, and it is either exposed at the surface or lies directly beneath the glacial deposits in most of the central, east-central, and south-central parts of the area considered in this report.

The St. Peter was eroded by glacial or preglacial rivers, and several valleys, cutting completely through the formation, were subsequently filled with glacial deposits.

In upland areas the St. Peter is completely saturated, but adjacent to the river valleys the upper part has been drained. Water in the upper part often occurs under water-table conditions. Approximately the lower third of the formation is confined by strata of shale or siltstone and the water is under artesian pressure. The confining layers are below the bed of the Mississippi River.

According to laboratory tests (Corps of Engineers, U. S. Army, 1939) on quarried blocks of sandstone, the coefficient of permeability of the upper part of the St. Peter at the Ford sand mine in St. Paul is about 19 gpd per sq ft under a hydraulic gradient of 100 percent at a temperature of 60 F. In practical terms, this means that about 29,000 gallons of water will flow through each mile of aquifer (measured at right angles to the direction of flow), assuming the aquifer is 150 feet thick and the hydraulic gradient is 10 feet per mile.

Water-Bearing Glacial Deposits

The surface distribution of the glacial deposits in the area is shown in figure 22.

Outwash and terrace deposits

Outwash consists of beds of clay, sand, and gravel that were deposited by streams that issued from the melting glacier. In this area the outwash deposits range in thickness from about 15 to 75 feet, and they generally contain adequate water to supply farm and domestic wells. Large water supplies may be obtained from the outwash, but test drilling should precede any such development.

Where streams have cut their valleys into the glacial river deposits, the glacial deposits have been sculptured into terraces. These terraces are commonly underlain by water-bearing sand and gravel. Like the outwash, these deposits supply water to many farm and domestic wells. However, they are dry in many places along the edge next to the stream. The terrace deposits are as much as 200 feet thick at some places.

Drift (undifferentiated)

The undifferentiated drift, as used in this report, consists of deposits of several glacial stages. The material is largely glacial till and associated sand and gravel deposits. Glacial till is composed mainly of clay, but it contains sand, pebbles, cobbles, and boulders in a heterogeneous mixture. (See fig. 22.)

Enclosed in or associated with the relatively impervious till are lenses and layers of water-bearing sand and gravel. Most of the farm and domestic wells in the area obtain water from these sources. The water occurs under both water-table and artesian conditions.

Presumably it should be possible to drill a well almost anywhere in the glacial drift and penetrate beds of water-bearing sand and gravel. However, many wells have been drilled and abandoned because no water-bearing materials were found. In most of these places, the desired small supplies have been obtained by locating new wells a short distance away. Large supplies can be developed in the drift, but a series of test holes is usually needed to determine the thickness and lateral continuity of the sand and gravel strata. Some beds of sand and gravel in the drift may be, for all practical purposes, completely cut off from natural sources of recharge. Initial yields from such wells may be as high as those from wells in aquifers having adequate recharge, thus giving the impression that an abundant perennial supply is available.

Dune sand

According to Schwartz (1936) dune sand underlies a large segment of the north-central part of the area (fig. 22). However, Thiel (1944, p. 81) states that belts of dune sand derived from glacial outwash occupy only a small part of this sand plain. Presumably, the area is underlain largely by outwash and valley-train deposits of glacial Mississippi River. The dunes themselves are 10 to 20 feet high and contain little or no water. However, the dunes may serve as intake areas to recharge the underlying formations.

Water-Bearing Alluvium

The distribution of the alluvium is shown on figure 22. Supplies for farm and domestic wells can be obtained from these deposits along the Mississippi River and along the valleys of the larger creeks. The permeability of the alluvium is generally low, owing to the presence of silt.

Well Construction

Types of wells

Dug and bored wells for homes and farms are constructed in alluvium or glacial deposits, where the water table is near the surface. Wells are driven where unconsolidated glacial deposits or sandy alluvium occur. A few wells on farms and residences in the rural areas have been drilled with hydraulic rotary rigs, but most wells are drilled by the cable-tool method. Nearly all of them completed in unconsolidated materials are screened.

In the rock formations cable-tool rigs are used almost exclusively, and practically all the wells are of the open-hole type.

Methods of completing wells

Before about 1910 many wells were drilled to the bottom of the St. Peter sandstone and were usually cased to the top of the first limestone layer, either the lower part of the Galena dolomite or the Platteville limestone. Some wells were drilled through the Shakopee and Oneota dolomites to the Jordan sandstone. In Minneapolis and St. Paul the average depth of the wells in the St. Peter is about 290 feet. Those tapping both the Jordan and St. Peter are about 500 to 600 feet deep.

Since about 1910 many wells have been cased to the Shakopee dolomite in order to seal off the St. Peter, and they are open to the Jordan alone or to the Jordan, Franconia, and upper part of the Dresbach (Galesville). A few wells tap the St. Peter, Jordan, Franconia, and upper part of the Dresbach. In the metropolitan area the average depth of wells extending to the upper part of the Dresbach is around 750 feet or possibly more.

The so-called Hinckley wells, which are usually cased down to around 800 feet, are probably open to the Mount Simon member of the Dresbach, the Hinckley sandstone, and in some wells, to sandstone strata in the Fond du Lac. Some of these wells also have been left uncased opposite the Jordan, Franconia, and upper part of the Dresbach.

The practice of completing wells in two or more formations containing waters of different quality and under different artesian pressures presents serious problems. The formations containing water of better quality, for example, softer or less highly mineralized water, may be contaminated to a certain extent by waters of less desirable quality. Also, the exchange of waters between formations produces complicated piezometric surfaces and makes it difficult to interpret ground-water conditions and therefore it is difficult to make reliable estimates of the adequacy of this important resource.

Yields of Wells

Very few statistical data have been assembled on the yield of wells in the area.

Several wells in the metropolitan area, tapping the lower part of the St. Peter, have yielded as much as 250 gpm. However, a well owned by the city of St. Louis Park is reported to yield about 1,200 gpm from this aquifer. It is probable that, in the vicinity of St. Louis Park, the St. Peter is completely saturated.

Yields of as much as several thousand gallons per minute are obtained from the Jordan sandstone. Bass, Meyer, and Norling (1932, pl. 40, p. 119) present graphical drawdown data for a well in Minneapolis tapping only the Jordan. Several tests were made for pumping periods of about 1 to 3 days. The specific capacity of the well is about 110 gpm per ft of drawdown.

A well, owned by the city of Stillwater, tapping only the sandstone known as the Galesville member of the Dresbach, is reported to have been tested at about 780 gpm. After 16 hours of pumping, the drawdown was about 109 feet, so that the specific capacity is a little more than 7 gpm per ft of drawdown.

A well in South St. Paul, tapping the Hinckley sandstone, and possibly the Mount Simon sandstone member of the Dresbach, is reported to yield 2,000 gpm with about 80 feet of drawdown after a long period of pumping. The specific yield of this well is 25 gpm per ft of drawdown. Other wells in the Hinckley in South St. Paul are reported to yield from about 1,400 to 3,000 gpm.

A good many large-capacity wells in the Jordan sandstone and several in the Hinckley sandstone are continually pumping fine sand and silt. Occasional cave-ins have been reported in some wells in the Jordan. Depending on the extent of the hole collapse, the yield may merely be reduced or the well may be completely plugged, in which case the sand has to be bailed out. Reducing the yield, and thus the velocity of the water in the well, should lessen the amount of sand and silt being pumped because most of this material is eroded from the walls of the well.

Changes in Ground-Water Levels

Natural fluctuations

Under natural conditions, the amount of water in underground storage is constantly changing. The changes are reflected by fluctuations of water levels and artesian pressures.

The water table fluctuates constantly in response to several natural factors. In shallow aquifers in this area it is generally lowest during the winter because the ground is frozen and covered with snow and little or no water percolates downward, whereas natural discharge continues and supplies most of the streamflow in the winter. In the spring, when the ground thaws and the snow melts, water levels rise as a result of additions to the water table. Thus, the peak water level for the year is often obtained in the spring. During the summer, except for periodic rises of the water table as a result of heavy rains, water levels generally drop because of the increased rate of evaporation and transpiration by plants. Fall rains coupled with low rates of evaporation and transpiration may cause the water table to reach a secondary peak or, sometimes, to attain the highest level for the year.

Artesian pressures also fluctuate in response to various natural forces but the changes are slight.

Effect of pumping

Precise data on water-level fluctuations in the heavily pumped metropolitan areas are generally lacking. It is difficult, therefore, to make a reliable evaluation of the effect of pumping on the lowering of the artesian head.

In the downtown areas of Minneapolis and St. Paul the daily water-level fluctuations during the summer correspond with changes in air temperature because of the large volume of water pumped for air conditioning. Where the wells are closely spaced, the interference among them is rather serious especially during a prolonged period of hot weather. Pumping lifts during the summer may vary from 175 to more than 200 feet.

Bradley (1949, p. 8-9) states that in downtown Minneapolis the maximum measured difference between summer and winter static water levels is 60 feet for wells in the Jordan sandstone and the Dresbach and Jordan sandstones combined. Also, pumping levels during the summer ranged from 15 to 50 feet below the static levels. He mentions that in Robbinsdale there is a difference of 2 feet from summer to winter, in Edina and St. Louis Park the difference is 6 to 8 feet, and in Hopkins it is about 4 to 5 feet.

Bass, Meyer, and Norling (1932, pl. 28, p. 97) state that the static water level in wells in the St. Peter in Minneapolis dropped 30 feet from 1886 to 1931, or about 0. 7 foot per year. For wells in the Jordan and Dresbach they report a lowering of 25 feet in the period 1910–31, about 1. 2 feet per year. For wells in the Hinckley they state that the water level lowered 40 feet in the period 1925–31, about 6. 7 feet per year. Bradley (1949, p. 15) mentions that the water level in a well in the Hinckley, owned by the Great Northern Railway Co., in St. Paul dropped 100 feet from 1932–49, or about 6 feet per year.

Bradley (1949, p. 7) also tabulates water-level data for a well owned by the Dayton Co. in Minneapolis which taps the Jordan and Dresbach. For the period 1933–49, the net lowering was 20 feet or about 1. 2 feet per year. He states that the static water level (in wells tapping the Jordan and the Dresbach and Jordan combined) in downtown Minneapolis has dropped on the average of 1 foot per year for the past 60 years. Since 1940, however, he indicates that the rate of decline has been less.

Regarding the downtown area of St. Paul, Bradley states (1949, p. 12-13) that there has been a drop in the static level (in wells tapping the Jordan and the Dresbach and Jordan combined) of 50 feet in 46 years. He mentions that at South St. Paul water levels are between 50 and 100 feet below the surface, whereas 25 years ago they were near the surface. However, these figures are not particularly significant because he does not relate them to any single aquifer or group of aquifers.

Quality of Ground Water

Knowledge of the quantity of dissolved minerals and the chemical composition of ground water, including artesian water, is important in evaluating the water supply for domestic and industrial uses. In addition to sanitary aspects, the domestic well owner is concerned with the hardness, mineralization, and amounts of fluoride, iron, or manganese in his specific supply, as these determine how satisfactory the supply is for general use. Likewise, for the industrialist who requires large amounts of water for cooling or processing his products, a high-quality supply of uniform temperature that requires little or no treatment is a tremendous asset. Quality-of-water standards for industries differ widely, and for many products rather exacting quality requirements must be met.

A few incomplete chemical analyses of ground water have been accumulated by industries and State and Federal agencies that are interested in ground water in the Minneapolis–St. Paul area. Unfortunately, the currently available data, though considered representative of the various sources of supplies, must be used with reservation when attempting to evaluate the over-all quality of these specific sources. Although there are appreciable differences in the chemical composition of water from the various aquifers, the wells frequently are not cased to a single formation and the water is a mixture representing two or more sources. Hydrologic factors must be considered also; for example, the chemical quality of water in the Jordan sandstone may be affected by localized lowering in artesian head which may result in movement and mixing of water of different quality from other sources, for example, the overlying St. Peter sandstone. Analyses of samples of water from several formations are given in table 16. The quality of water is variable within each of the several bedrock aquifers, which makes it difficult to detect trends or changes of the bedrock waters until the Hinckley sandstone is reached.

Adolph F. Meyer reports that the average hardness for water in the Hinckley sandstone is about one-third that of water from the St. Peter sandstone; however, the mixed water from the Jordan and Dresbach sandstones seems to be slightly harder than water from the Jordan alone. Table 17 shows data furnished by Adolph F. Meyer and published in a report by the Minneapolis Chamber of Commerce (1950) giving the average hardness of artesian water from the different formations.

A wide variation may be expected in the chemical quality of water (table 16). For example, water from the St. Peter sandstone in Ramsey County (Northern Pacific Railway well) was softer and more dilute than the water from the Hinckley sandstone (Armour & Co. well) which normally is a source of softer water in this area.

The quality of ground water in the Minneapolis–St. Paul area is affected in those areas where ground and surface flow is interrelated. For example, the quality of water in the alluvium along the Mississippi River is probably modified by recharge from the river at high flow, and it would be expected that water from wells near the river would be more dilute than ground water at greater depth or adjacent to the bluffs. Likewise, if the Mississippi River or the large lakes recharge the bedrock reservoirs by induced infiltration then water of better quality can be expected near the zone of recharge. However, as the water moves down gradient it tends to become more mineralized.

Because of generally lower hardness, water from the Hinckley sandstone is the preferred ground water for commercial laundries and other establishments where large amounts of soap are consumed. Troublesome quantities of iron are commonplace in water from bedrock, and periodic treatment is required of some public-supply wells for removal of iron encrustations. Alkalinity and hardness of ground water, other than that from the Hinckley sandstone, are considerably higher

Table 16.—Chemical quality of water from selected wells in bedrock, Minneapolis-St. Paul area

[Analyses in parts per million except as indicated]

	Northern Pacific Ry.	St. Louis Park well 3[1]	Average of 8 wells	Edina Composite of 4 wells	Average of 14 wells	Village of Mound
Source of data	U.S. Geological Survey	U.S. Geological Survey	Minnesota Geological Survey Bull. 31	U.S. Geological Survey	Minnesota Geological Survey Bull. 31	U.S. Geological Survey
Source of water	St. Peter sandstone	St. Peter sandstone	St. Peter sandstone	Jordan sandstone	Jordan sandstone	Franconia sandstone
Date of collection	May 20, 1952	May 30, 1951	-	May 31, 1951	-	May 29, 1939
Temperature (°F)	50	49	-	-	-	52
Depth	85	290	-	400-500	-	509
Silica (SiO_2)	15	20	12	18	6.3	20
Iron (Fe)	.08	.18	[2]2.4	.52	[2]2.6	.58
Calcium (Ca)	53	81	56	70	58	78
Magnesium (Mg)	21	32	22	28	22	51
Sodium (Na)	3.4	3.6	8.6	3.9	6.8	26
Potassium (K)	1.2	1.7	-	1.8	-	3.4
Bicarbonate (HCO_3)	265	320	293	335	278	490
Sulfate (SO_4)	2.0	52	1.8	8.0	6.0	60
Chloride (Cl)	4.0	16	6.4	6.0	5.0	1.5
Fluoride (F)	.1	.1	-	.1	-	.2
Nitrate (NO_3)	.2	7.3	-	1.9	-	2.4
Dissolved solids	231	432	254	310	246	[3]484
Hardness as $CaCO_3$	-	334	-	288	-	406
Specific conductance (micromhos at 25°C)	412	620	-	536	-	802
pH	7.7	8.0	-	7.8	-	8.0
Color	-	5	-	5	-	-
Turbidity	-	2	-	7	-	-

	Vadnais Lake artesian well	Average of 6 wells	Donaldson Co.	Northwestern Natl. Bank	Armour & Co.
Source of data	Minnesota Geological Survey Bull. 31	Minnesota Geological Survey Bull. 31	Northern States Power Co.	Northern States Power Co.	U.S. Geological Survey
Source of water	Dresbach sandstone	Dresbach sandstone	Hinckley sandstone	Hinckley sandstone	Hinckley sandstone
Date of collection	1899	-	Sept. 14, 1931	Feb. 14, 1931	May 20, 1952
Temperature (° F)	-	-			51
Depth	-	-	-	-	904
Silica (SiO_2)	15	8.1	3.0	-	18
Iron (Fe)	1.7	[2]2.2	7.0	2.1	.91
Calcium (Ca)	58	52	41	47	70
Magnesium (Mg)	22	20	12	4.6	28
Sodium (Na)	8.0	10	29	32	37
Potassium (K)	-	-	-	-	2.8
Bicarbonate (HCO_3)	306	252	208	196	328
Sulfate (SO_4)	-	4.1	6.0	5.8	19
Chloride (Cl)	1.3	5.3	38	30	58
Fluoride (F)	-	-	-	-	.1
Nitrate (NO_3)	-	-	-	-	4.2
Dissolved solids	257	236	239	217	400
Hardness as $CaCO_3$	-	-	154	137	288
Specific conductance (micromhos at 25° C)	-	-	-	-	708
pH	-	-	-	-	7.4
Color	-	-	-	-	-
Turbidity	-	-	-	-	-

1 Treated at well with polyphosphate for iron stabilization.
2 As Fe_2O_3 and Al_2O_3.
3 Total manganese (Mn) 0.34 ppm.

Table 17.–Hardness of artesian water in the Minneapolis area

[Minneapolis Chamber of Commerce, 1950]

Source	Average hardness as $CaCO_3$ (ppm)
St. Peter sandstone	393
Jordan sandstone	325
Jordan and Dresbach sandstones (includes Franconia sandstone)	359
Hinckley sandstones	137

than that of water in the Mississippi River, even at low flow, and in the lakes in the area.

Waters from the drift deposits are generally hard and show the effect of the calcareous composition of these materials. Available analyses show that the iron content in water from drift is frequently much greater than the suggested upper limit of 0.3 ppm in drinking water.

In addition to general use in industry and business establishments, ground water is being pumped in ever-increasing quantity during summer for air conditioning. Collins (1925) states that the temperature of ground water at a depth of 30 to 60 feet is approximately the same as the mean annual air temperature, which is about 45 F for Minneapolis and St. Paul. Below 60 feet, the earth's temperature generally increases about 1 F for each 50 to 100 feet of depth. Temperatures of nonthermal artesian waters rise slowly with increasing depth and the following temperatures may be considered representative of artesian supplies (Schwartz 1936):

Depth (feet)	Main aquifer	Temperature (°F)
100	St. Peter ss	49
290	St. Peter ss	[1]49
370	St. Peter ss	45
431	Jordan ss	50
529	Jordan ss	53
509	Franconia ss	[1]52
904	Hinckley ss	[1]51
1,068	Hinckley ss	53

[1] U. S. Geological Survey.

PUBLIC WATER SUPPLIES

Minneapolis

Ownership.—Municipal; also supplies about 11,000 people outside the city limits and about 3,700 at other places. Total population supplied, about 536,400.

Source.—Mississippi River.

Treatment.—Prechlorination, softening with lime and soda ash, coagulation with ferrous sulfate, and Flerrifloc as required, clarification stabilization with alum, carbon dioxide or Ferrifloc or a combination of these as required, rapid sand filtration, postchlorination, and ammoniation.

Rated capacity of treatment plants.—Fridley softening plant, 120 mgd; Columbia Heights Filtration Plant, 78 mgd; Fridley Filtration Plant, 80 mgd.

Use.—Average daily use in 1951, about 55 million gallons. Maximum daily use in 1950, 102.1 million gallons.

Raw-water storage.—None.

Finished-water storage.—61,000,000 gallons.

System.—The public supply of Minneapolis is obtained from the Mississippi River at the Fridley pumping station No. 5 north of the city. (See table 18.) After the water is softened at the Fridley water softening plant it is divided for filtration. Centrifugal pumps deliver part of the water to the Columbia Heights Filtration Plant from which after filtration and sterilization finished water is supplied to the city by gravity from the covered finished-water reservoir. The other part of the water is pumped by low service pumps to the Fridley Filtration Plant from which the finished water is pumped directly into the mains from the covered reservoir. The western half of the city is supplied by direct pumping into the mains and the balance is served by gravity. The Columbia Heights Plant generally serves the entire city from midnight to 5 o'clock in the morning.

St. Paul

Ownership.—Municipal; also supplies 10,000 people outside the city limits. Total population supplied, about 325,000.

Source.—Although the principal source of water for St. Paul is the Mississippi River, the flow plan differs from the Minneapolis system because the water is impounded for several weeks before treatment. Water from the Mississippi River is pumped to the Vadnais storage reservoir through Charles and Pleasant Lakes. Vadnais, Pleasant, Otter, Charles and Sucker Lakes form the principal impounding reservoirs of the present water-supply system. They are contained in a watershed area of 27 square miles, have a combined water surface of 1,500 acres, and a total available water storage of approximately 6.8 billion gallons. Water storage in the Vadnais impounding system may be augmented by the Centerville Lake system, consisting of 4 principal lakes lying 18 to 20 miles north of the city. This watershed has an area of about 81 square miles, a water surface of 2,200 acres, and available storage of several billion gallons. Water is pumped from the Centerville watershed to the Vadnais watershed.

Water from Otter Lake and the overflow from Bald Eagle Lake may be taken by gravity into the Vadnais system, as a reserve source. Two artesian well fields are held in reserve. One field which has 28 wells with an average depth of 400 feet is along the shores of Centerville Lake. The other field which has 6 wells ranging in depth from 700 to 1,000 feet is at McCarron Station.

Table 18. -Chemical analyses of Mississippi River water (yearly averages), Fridley Treatment Plant, Minneapolis, 1943-49

[Analyses by city of Minneapolis; analytical results in parts per million except as indicated]

	1943		1944		1945		1946		1947		1948		1949		Average 1943-49	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
Temperature (°F)	50.0	-	50.1	-	51.8	-	50.4	-	50.4	-	51.0	-	51.3	-	50.7	-
Silica (SiO_2)	8.86	2.64	9.61	-	8.56	3.43	7.90	4.17	9.45	5.41	9.20	6.08	10.84	6.32	9.20	4.67
Iron (Fe)	.18	.02	.24	.01	.16	.01	.17	.02	.19	.03	.15	.04	.17	.046	.18	.03
Aluminum (Al)	.43	2.04	.42	1.39	.23	2.01	.23	1.27	.33	.84	.17	.50	.226	.45	-	1.21
Manganese (Mn)	.05	.00	.04	.00	.03	.00	.02	.00	.03	.00	.03	.00	.05	.00	.04	.00
Calcium (Ca)	42.32	17.75	41.65	18.86	41.00	17.22	41.62	17.69	42.15	16.11	41.42	15.73	41.48	18.41	41.66	17.40
Magnesium (Mg)	16.27	5.42	14.90	6.07	14.20	5.36	14.04	5.81	15.28	7.62	14.52	7.98	14.22	7.03	14.78	6.47
Bicarbonate (HCO_3)	-	23.6	-	27.1	-	-	-	31.4	-	36.3	-	39.3	-	41.1	-	33.1
Sulfate (SO_4)	15.31	54.93	13.11	55.19	11.19	43.97	12.08	41.78	11.92	32.14	12.84	30.19	13.04	35.21	12.78	41.92
Chloride (Cl)	2.3	4.5	1.6	5.0	1.5	5.3	1.9	5.5	1.08	6.17	2.24	6.60	2.2	6.8	1.83	5.7
Total residue	233	142.4	225	144	209	121	209	124	210	116	206	119	209	129.8	214	128.0
Hardness as $CaCO_3$ (calculated)	172.5	66.6	165.2	72.1	162.0	76.3	162.9	75.1	168.2	76.18	164.1	74.78	168.4	76.3	166.2	73.9
Alkalinity as $CaCO_3$	158.2	-	148.9	-	193	-	194	-	-	-	-	-	151	-	-	-
pH	7.9	8.71	7.9	8.5	8.0	8.72	8.0	8.58	8.1	8.47	8.1	8.32	8.07	7.96	8.0	8.46
Color	-	8.6	-	8.7	-	6.9	-	7.1	-	5.4	-	4.3	-	6.1	-	6.7
Turbidity	12.7	-	16.1	-	12.5	-	11.0	-	10.4	-	10.3	-	9.6	-	11.8	-
Dissolved oxygen	9.3	9.6	-	9.8	-	10.0	-	9.6	-	9.76	-	9.48	-	9.1	-	9.6

Untreated Water

	1943		1944		1945		1946		1947		1948		1949		Average	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Color	165	21	150	20	90	23	83	18	110	18	110	13	150	13	122	18
Temperature (°F)	80	32	79	32	79	33	77	33	80	33	82	33	83	33	80	33

The pumping stations of the supply system have a total capacity of 42 mgd, which, combined with the normal runoff from the watershed, is sufficient to maintain the lake levels. The present conduit capacity from Vadnais Lake is 80 mgd.

Treatment.—Treatment at the St. Paul plant consists of aeration, coagulation with alum, softening with lime, recarbonation for pH stabilization, rapid sand filtration, and postchlorination.

The storage of the river water in the impounding lakes has some effect on the quality of the water. (See table 19.) The lakes afford opportunity for settling of silt and clay, the death of some forms of bacteria, and some reduction in color. However, there is some increase in low forms of animal and vegetable growth. The main value of the lakes is that they tend to equalize the daily fluctuations in the quality of the river water and act as a raw-water storage reservoir to guarantee a constant source of supply.

Rated capacity of treatment plant.—70 mgd.

Use.—Average daily use in 1951 about 30 million gallons. Maximum daily use in 1950, 62 million gallons.

Raw-water storage.—6, 750, 000, 000 gallons.

Finished-water storage.—70, 000, 000 gallons.

St. Louis Park

Ownership.—Municipal.

Source.—6 wells (1 to 6). Wells 1, 2, and 3 are 290 feet deep; wells 4, 5, and 6 are 500 feet deep. The yield of the wells is reported as follows: Wells 1 and 2, 930 gpm, each; wells 3, 4, 5, and 6, 1, 200 gpm, each.

Treatment.—Chlorination, polyphosphate for stabilization, and aeration in surface storage tank. The iron content is reported to range from 0.8 to 3.4 ppm, and there is a continuous problem with Crenothrix.

Raw-water storage.—None.

Finished-water storage.—Elevated tank, 1, 600, 000 gallons; steel surface tank, 1, 500, 000 gallons.

South St. Paul

Ownership.—Municipal.

Source.—3 wells (2 to 4), 982, 340, and 960 feet deep. The yield of the wells is reported to be 1, 200, 1, 900, and 2, 000 gpm. The water is pumped directly to the mains and to storage.

Treatment.—None.

Storage.—2, 400, 000 gallons.

Robbinsdale

Ownership.—Municipal.

Source.—3 wells (1 to 3), about 630 feet deep, for main supply; broken connection to Minneapolis supply for auxiliary supply. The yield of the wells is reported to be 900, 1, 050, and 1, 200 gpm. One well supplies the town during winter. In the summer, two wells are used continuously, and a third is used intermittently. All pump directly into the mains.

Treatment.—Chlorination and sodium phosphate for water stabilization.

Raw-water storage.—None.

Finished-water storage.—Elevated storage, 150, 000 gallons.

Edina

Ownership.—Municipal.

Source.—4 wells (1 to 4), 400, 450, 475, and 500 feet deep. The yield of the wells is reported to be 700, 1,000, 1, 000, and 1, 000 gpm.

Treatment.—None.

Storage.—Elevated tank, 75, 000 gallons.

Other Water-Supply Systems

Details of the physical features of the smaller systems in the area were not obtained, and a summary of the available data is given in table 20.

The extent of the iron problem and the general level of hardness in ground water in several municipal supplies in the area are shown with other chemical data in table 21. Bar diagrams on plate 2 illustrate the areal distribution of hardness in representative municipal water supplies. Of these supplies, only those from Minneapolis and St. Paul are from surface sources and are softened before delivery to the consumer.

Five of the municipalities listed that obtain their supply from ground water sources provide some treatment for iron either by aeration or by stabilization with polyphosphates directly at the well.

PRESENT USE OF WATER

Surface Water

As previously noted, both Minneapolis and St. Paul utilize the Mississippi River as a source of public water supply. Each city has an intake just upstream from Minneapolis. Water for Minneapolis in the amount of about 55 mgd is pumped directly to the softening plant; water for St. Paul in the amount of 30 mgd (fig. 23) is

Table 19. -Chemical analyses of Mississippi River water, St. Paul Treatment Plant, 1940-49

[Analyses by city of St. Paul; analytical results in parts per million except as indicated]

	1940		1941		1942		1943		1944		1945		1946		1947		1948		1949		Average 1940-49	
	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P	R	P
Temperature (°F)	52	52	53	52	52	54	53	52	51	54	50	50	52	52	52	53	54	54	53	53	52	53
Silica (SiO_2)[1]	9.29	3.74	10.31	5.46	9.63	5.46	10.70	3.92	8.30	4.90	8.02	3.66	8.92	3.23	11.73	5.61	6.83	4.04	6.76	2.70	9.0	4.27
Iron (Fe)	.36	tr	.39	.04	.31	.06	.168	.03	.35	.07	.23	.036	.17	.03	.54	.02	.25	.01	.18	.05	.30	.04
Aluminum (Al)	.44	.49	.91	.63	1.05	.57	1.04	.66	.87	.57	.62	.46	.47	.29	.70	.50	.60	.31	.51	.23	.72	.47
Manganese (Mn)	.16	tr	.08	nil	.07	0	.06	0	.09	tr	.060	.00	.09	.00	.10	.02	.10	.03	.14	.02	.10	-
Calcium (Ca)	46.98	17.15	44.40	15.50	46.0	16.7	44.7	19.9	41.7	19.9	41.42	20.55	43.80	18.72	43.04	16.82	42.61	15.80	40.62	17.51	43.53	17.86
Magnesium (Mg)	17.37	9.51	17.28	9.60	18.6	7.1	15.6	8.17	15.03	7.1	14.55	8.07	14.38	8.62	15.06	7.88	14.95	7.53	14.21	6.99	15.70	8.06
Sodium and potassium as Na	7.19	5.81	5.54	6.18	2.7	4.4	2.9	3.13	4.15	4.00	1.48	2.78	1.16	3.71	1.76	4.15	1.91	4.25	1.62	3.73	3.04	4.21
Sulfate (SO_4)[2]	18.78	23.40	19.32	21.57	20.4	23.4	13.8	18.0	16.8	21.0	13.1	17.8	12.7	15.7	14.0	17.3	17.0	15.1	12.8	15.9	15.87	18.92
Chloride (Cl)	2.86	3.59	2.44	3.78	3.7	4.2	4.00	4.08	2.96	4.30	3.42	4.59	2.29	3.38	3.31	4.13	2.62	4.28	2.29	4.60	2.99	4.09
Fluoride (F)	-	-	-	-	-	-	-	-	-	-	-	-	.24	.20	.16	.12	.14	.12	.13	.11	-	-
Nitrate (NO_3)[3]	.22	.14	.26	.44	.62	.35	.51	.36	.80	.61	.35	.75	.57	1.01	.44	.35	.22	.48	.22	.52	.42	.50
Residue	235	121	247	132	252	117	259	131	246	132	221	125	239	116	237	109	234	100	240	104	241	119
Hardness as $CaCO_3$	192	85	192	89	199	74	182	87	173	83	169	87	172	84	175	77	173	72	163	74	179	81
Alkalinity as $CaCO_3$	169	61	158	59	177	52.5	162	69	158	66	154	68	158	70	159	62	155	60	150	59	160	63
pH	8.1	8.2	7.9	7.8	8.0	8.4	8.0	9.0	8.1	8.8	8.3	8.5	8.1	8.5	8.2	8.4	8.3	8.5	8.3	8.5	8.1	8.5
Color	46	8	92	8.2	73.8	11.0	90	10.6	62.0	6.5	52.0	7.8	59	8	48.9	5.1	41.0	3.8	60.0	3.0	62.5	7.2
Turbidity	6.0	.30	3.8	-	7.3	.2	17.0	0	15.0	nil	9.8	0.0	8	0	7.9	0	8.0	0	8.3	0	9.1	0
Dissolved oxygen	9.5	9.4	8.4	7.9	9.9	8.4	8.6	7.95	9.5	7.5	10.3	7.8	9.8	7.5	10.4	7.6	9.7	7.2	10.3	9.1	9.6	8.0

R River water.
P Plant effluent.
1 Silica calculated from Si to SiO_2.
2 Sulfate calculated from S to SO_4.
3 Nitrate calculated from N to NO_3.

Table 20.–Public water supplies in the Minneapolis-St. Paul area

Municipality	Population (1950)	Source	Treatment	Average consumption (gpd)	Date of pumpage records
Anoka	7,396	Wells	Iron removal	534,000	1949-50
Bayport	2,502	do	None	[1]150,000	1951
Chaska	2,008	do	Iron removal	183,000	1950-51
Circle Pines	[2]1,000	Well	None	[1]9,500	1950
Edina	9,744	Wells	do	[1]800,000	1950
Farmington	1,916	Well	do	[1]77,000	1951
Forest Lake	1,766	Wells	Chlorination and addition of polyphosphate.	[1]48,000	1951
Hastings	6,560	do	None	[1]450,000	1951
Hopkins	7,595	do	Chlorination and addition of polyphosphate.	697,000	1949-50
Jordan	1,494	do	Chlorination	[1]80,000	1951
Lakeville	628	Well	do	[1]100,000	1951
Lauderdale	1,033	do	None	[1]25,000	1951
Long Lake	399	do	do	[1]40,000	1952
Loretto	179	do	Chlorination	[1]5,000	1951
Mahtomedi	1,375	Wells	None	[1]46,000	1951
Maple Plain	479	Well	Chlorination	53,000	1949
Minneapolis	[3]521,718	Mississippi River.	Prechlorination, postchlorination, softening, coagulation, clarification, filtration, and ammoniation.	[1]55,000,000	1951
Mounds	2,061	Wells	None	[1]70,000	
New Brighton	2,218	do	do	90,000	1950-51
North St. Paul	4,248	do	do	211,000	1951
Osseo	1,167	do	Chlorination	37,800	1951
Prior Lake	536	do	None	[1]4,000	1951
Robbinsdale	11,289	do	Chlorination and addition of polyphosphate.	843,000	1950-51
Rosemount	567	do	None	[1]60,000	1951
St. Louis Park	22,644	do	Chlorination, aeration, and addition of polyphosphate.	1,557,000	1949-50
St. Paul	[3]311,349	Mississippi River and lakes. Wells held in reserve.	Aeration, coagulation, softening, recarbonation, sedimentation, filtration, and chlorination.	30,000,000	1951
Savage	389	Wells	Chlorination	[1]55,000	1951
Shakopee	3,185	do	do	[1]175,000	1951
South St. Paul	15,909	do	None	970,000	1950-51
Stillwater	7,674	do	Chlorination and ammoniation.	1,008,800	1947-49
Wayzata	1,791	do	Chlorination	346,500	1951
White Bear Lake	3,646	do	None	[1]250,000	1950

1 Estimated.
2 Unincorporated.
3 Not including suburban areas.

Table 21. -Chemical analyses of typical municipal ground-water supplies, Minneapolis-St. Paul area

[Analyses by Minnesota Dept. of Health; results in parts per million except as indicated]

Municipality	Date	Turbidity	Color	pH	Iron (Fe)	Manganese (Mn)	Chloride (Cl)	Sulfate (SO_4)	Fluoride (F)	Nitrate as N	Alkalinity as $CaCO_3$	Total hardness as $CaCO_3$	Treatment
Anoka Well 2......	Aug. 17, 1947	2.6	8	7.8	0.9	0.18	22	-	-	0.08	220	230	Iron removal.
Well 4....	Aug. 17, 1947	3.5	2	8.2	.85	.02	13	2.4	0.09	.1	220	200	Do.
Bayport..	Oct. 10, 1947	2.6	4	7.6	.37	0	1.1	0	.02	.1	220	230	None.
Chaska..............	Jan. 30, 1951	1.0	2	7.6	.06	0	6.5	140	.07	1.4	380	510	Iron removal.
Farmington.	Sept. 19, 1938	1.5	0	7.9	.4	0	2.5	4.8	0		270	280	None.
Forest Lake.	Mar. 7, 1932		10		2.4						372	359	Chlorination and phosphate for iron stabilization.
Hastings Well 1(old)	Aug. 15, 1947	.6	3	7.8	.02	0	4	2.4			220	230	None.
Well 2 (new).....	Aug. 15, 1947	.3	2	7.6	.05	0	6	41	0	3.3	220	250	Do.
Hopkins Well 1.....	Nov. 27, 1946	3.1	6	7.8	.6	.05	4.4	14	.1		300	300	Do.
Well 2....	Nov. 27, 1946	6.5	7	8.0	1.6	.05	6.9	33	.1		310	320	Do.
Jordan Well 1..	Sept. 21, 1949	80	32	7.5	7.5	.2	0	84	0	.1	360	370	Do.
Well 2....	Sept. 23, 1947	1.3	14	7.8	.85	.05	4	130	0	.1	350	410	Do.
New well..........	Feb. 14, 1951			7.7	1.2	.14	100			.1	380	450	Do.
Mahtomedi.	Jan. 31, 1944	1.2	2	7.2	.1	.23	3.8	2.4	.05		280	190	Do.
Mound Well 1.......	Mar. 20, 1948	3.3	6	7.5	.26	.62	0	69	0	.1	410	420	Do.
Well 2....	Mar. 20, 1948	15	14	7.7	4.8	.24	0	2.6	.08	.1	400	380	Do.
New Brighton........	Jan. 7, 1942	2.0	2.0	7.9	.3	.05	4	5	0		240	220	Do.
Do..........	July 16, 1947			7.7	.35	.38	1.5	0		.05	300	290	Do.
North St. Paul Well 2....	Feb. 27, 1933	80	40	7.4	.14	.30					230	230	Do.
Osseo.................	Sept. 23, 1946	56	25	8.1	7.2	.1	5.4	9.4	.2		200	180	Do.
Rosemount...........	Oct. 10, 1947			7.9	.05	0	2	4.8		.55	230	240	Do.
Shakopee.............	June 1, 1943	2	5	7.4	.6	.05	65	5.6	.5		250	190	Chlorination.
Well 1 (old).	Oct. 22, 1948	28	10	7.9	4.3	0	15	0	.15	.02	250	210	Do.
Well 2 (new)......	Oct. 22, 1948	14	3	7.6	2.3	0	8.5	5.6	.15	.37	270	240	Do.
Stillwater Well 2 shallow...	May 6, 1948	34	6	7.6	0.83	0.03	2	0	0.08	0	220	170	Do[1].
(Spring well)......	Sept. 1, 1949	.15	2	8.0	.002	0	7	4	.1	2.7	210	220	Do[1].
Owens St. well...	Sept. 1, 1949	5	10	7.8	.46	.06	2	3	.05	.1	210	200	Do[1].
Second St. well..	Sept. 1, 1949	53	30	7.6	3.6	.09	1.5	1	.2	.1	230	220	Do[1].
Wayzata.	Oct. 15, 1942	20	5	7.55	2.1	.17	12	35	0		330	360	Do.
White Bear...........	Apr. 3, 1941	5	6	7.7	1.56	.15	5.6	5.0	.20		180	200	None.

1 Chlorination and ammonia (chloramine).

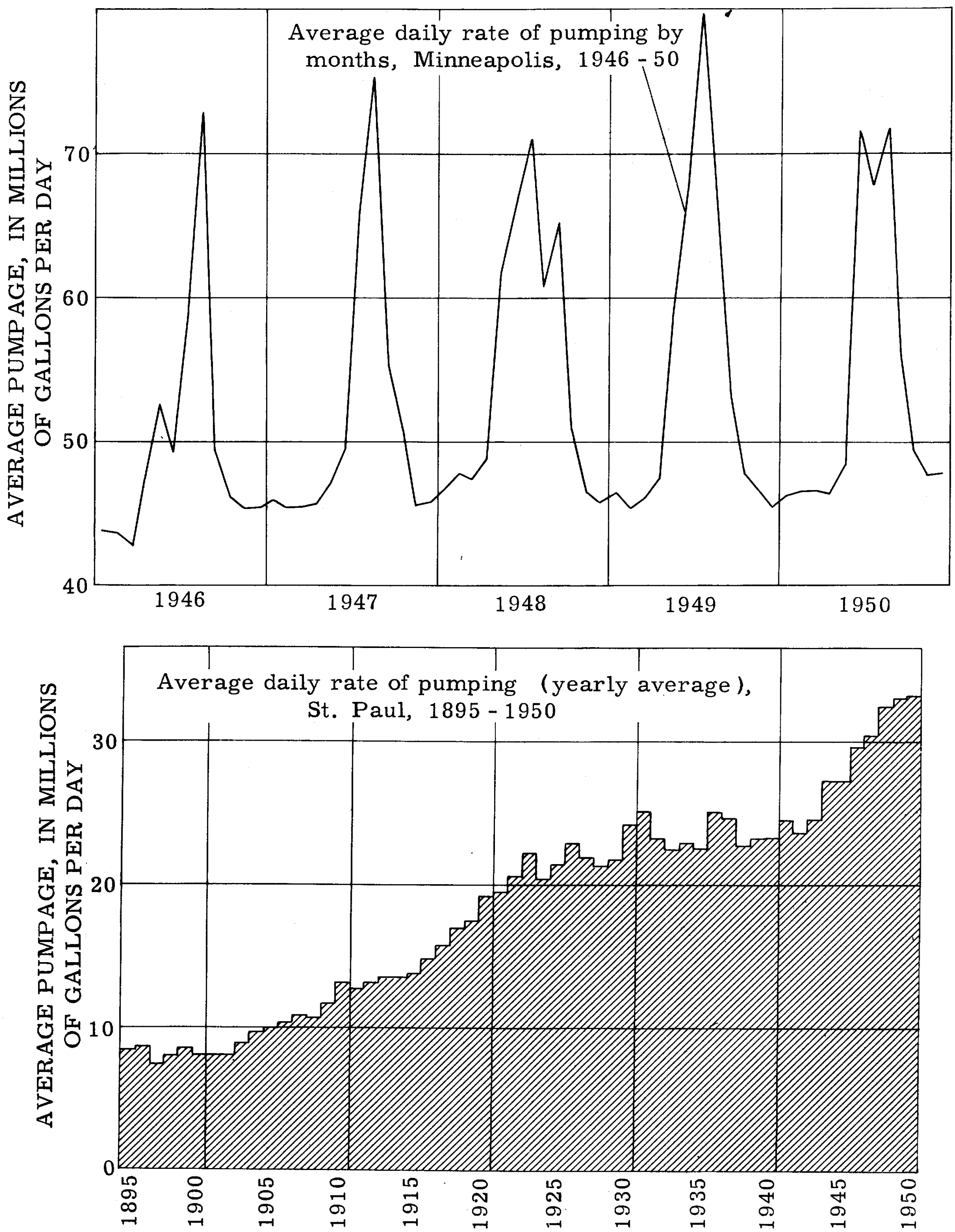

Figure 23.—Average rate of pumping, Minneapolis and St. Paul.

pumped into a series of lakes through which it flows by gravity to the St. Paul filtration plant. The amount pumped by St. Paul is, therefore, augmented to a small extent by the runoff from the lake basins through which it flows. In a normal year this increase is estimated by the City Water Department as 10 percent of the water pumped.

Cooling water is used by 4 steam-electric generating plants in the Minneapolis—St. Paul area. Of these, 3 are in regular use, and 1 operates intermittently as a standby plant. The water at each is returned to the river; the discharge from the upstream installation becomes available for use by the plants downstream, so the maximum requirement—that needed at the largest plant—is only 475 mgd in summer and 346 in winter. The amount of water consumed in the production of steam for the various generating plants is negligible, amounting to only 34,000 gpd.

The use of water for irrigation in the area is negligible. The Minnesota Conservation Department estimates this use for the year 1951 as about 233 million gallons. It is estimated that two-thirds of this amount is from surface water. Professor Even R. Allred, of the University of Minnesota, has classified the Minneapolis—St. Paul area as being conducive to the successful use of irrigation. Therefore, the use of water for this purpose will undoubtedly continue to increase.

Ground Water

In order to arrive at the approximate order of magnitude of the quantity of ground water being pumped in the area under consideration, a partial inventory of pumpage was made. Fairly good pumpage records for Minneapolis and St. Paul are maintained by each city for levying sewer taxes. For the area outside of the cities, the pumpage was obtained from records of estimates of waterworks officials and representatives of the larger industrial establishments. No attempt was made to classify the pumpage by aquifers. It was not possible to obtain pumpage for the smaller industries and commercial establishments.

To estimate the rural consumption of ground water for domestic and stock use, it was assumed that practically all the farms and residences had wells. The total human consumption of ground water in rural areas was estimated by assuming 55 gallons as the per capita use. The 1950 Census of Agriculture was used to obtain the stock population. Following is the estimated average per capita use by livestock in this area:

Livestock	Use (gpd)
Cattle and calves	7.2
Horses and colts	7.2
Mules and Mule colts	7.2
Hogs and pigs	4.5
Sheep and lambs	1.9

The areal distribution of the combined industrial and municipal pumpage and piezometric contours for the Jordan sandstone are shown on plate 4. The average daily ground-water pumpage in the Twin Cities and South St. Paul is estimated to be about 58.6 million gallons. The center of the cone of depression in Minneapolis approximately coincides with the weighted center of pumpage for the same area.

The estimated average daily ground-water pumpage in the cities of Minneapolis, St. Paul, and South St. Paul and the nearby communities of New Brighton, Lauderdale, Columbia Heights, Robbinsdale, St. Louis Park, Hopkins, Edina, Newport, and North St. Paul is about 71.9 million gallons.

For the area as a whole, it is estimated that an average of about 90 million gallons is pumped daily.

POTENTIALITIES

Surface Water

The surface-water supply in the Twin Cities area is sufficient to supply all foreseeable industrial and domestic needs. Under the most adverse conditions of record, the maximum combined water demand of Minneapolis and St. Paul was less than one-half of the flow of the Mississippi River above the Minnesota River. The combined maximum daily use of water by the two cities in 1950 was 164 mgd and the lowest momentary flow of the river was 379 mgd, of which about 65 mgd was stored water released from the headwater reservoirs. Thus only 43 percent of the lowest river flow known is required to supply the combined maximum demand of both water-supply systems. Assuming that the demand should equal the present installed pumping capacity of the two systems (225 mgd), only 59% of the low flow of record would be required. The number of days when the natural flow as low as 314 mgd (379—65) might be expected are few; therefore, it is very probable that, if the demand should reach the point where the supply proves to be insufficient under natural conditions of flow, at least 65 mgd could be obtained by regulation of the headwater reservoirs. It can be assumed, therefore, that without provision for increasing the flow of the Mississippi River by special regulation of the headwater reservoirs by more than 65 mgd, the daily combined pumpage of the two systems could be more than doubled.

The outstanding use of surface water in the area is for public water supply as most industrial plants either use the public supply or wells. Little utilization has been made of other streams in the area, and it is evident that a large potential supply from this source awaits development.

Owing to the utilization of the lakes in the Minneapolis area for recreation, they cannot be considered as a potential source of water supply except in a war emergency resulting from complete destruction of the present system. Most of the lakes in the St. Paul area are considered as part of the public water-supply system, and have been used in the past during periods when the pumps at Fridley were shut down. Utilization of other lakes in the area covered by this report is controlled by State law to the extent that industrial use of the waters would probably be too much opposed to the public interest to be considered.

Ground Water

In general, ground water is abundant in the area and considerable additional development is possible.

In the glacial drift, which is practically everywhere, small wells can almost always be completed and large developments can be planned after adequate exploration and testing.

The rock formations below the drift include several prolific aquifers, the most important of which are the Jordan sandstone, the basal Franconia sandstone, the Galesville and Mount Simon members of the Dresbach, and the Hinckley sandstone.

Heavy pumpage in several concentrated areas has resulted in a serious lowering of artesian pressures. If pumpage is increased in these areas, water levels will continue to drop if the aquifers are not sufficiently permeable to transmit the required quantities of water from the intake areas to the points of withdrawal. Unfortunately, practically no reliable data are available on the permeability characteristics or storage coefficients of the formations.

The most favorable areas for developing additional supplies of ground water from the bedrock aquifers are those removed from the areas of concentrated pumpage. If large developments are contemplated, an exploratory and testing program should be undertaken as an aid in locating areas where recharge to the bedrock aquifers from glacial or preglacial channel is favorable.

The available data are inadequate for satisfactorily evaluating the maximum amount of ground water that can be developed in the area. However, for the purpose of indicating the general order of magnitude of the quantity of water in storage in the Jordan sandstone alone, the following assumptions have been made. North of the center line of T. 116 N. the area enclosed by the upper contact of the Jordan (pl. 4) is roughly 800 square miles. Using an average thickness of 90 feet and an effective porosity of 10 percent, the formation in this area theoretically could yield about 1.5 trillion gallons, if unwatered. At the current average daily rate of withdrawal of ground water, the quantity stored in the aquifer and without recharge would be enough to supply the ground-water use for the entire area for about 45 years.

Quality

The treated and moderately soft water supplied by the cities of St. Paul and Minneapolis will be in continued demand by industries requiring water of those specific characteristics. Where temperature is a factor, as for air conditioning or as a coolant, the ground-water sources will offer some advantages during the summer season when ground waters normally are uniformly cooler. Economic factors will largely determine to what extent combination ground and treated surface-water sources will be used.

Continued activities directed toward pollution abatement upstream in the Mississippi and Minnesota Rivers will further protect these sources for potentially much greater use by public water-supply systems and industries obtaining water directly from the river.

Further increase in ground-water pumping will cause some change in the chemical quality of the various sources. However, because of the wide variation in quality that is observed for the present supplies, and because of similarity in type of water, the over-all effect will probably not be especially apparent unless excessive lowering of head results in movement of hard water into the deep moderately soft-water sources, such as the Hinckley sandstone. In general, the ground water in the area, because of extreme hardness, will not be attractive to industries requiring process waters of low mineral content and hardness. However, the ground-water potential is greater where induced infiltration of the better quality Mississippi River water is practicable.

WATER LAWS

Control of the public waters, both surface and ground, in the State of Minnesota, is vested in the State and administered by the Commissioner of Conservation.

Owing to the complexity of the water law, the Commissioner is charged with the responsibility of investigating applications and issuing licenses for many types of activities in connection with the public waters of the State. Some of the most important responsibilities are reviewing applications and issuing permits for all water supplies except small domestic installations serving 25 individuals or less and reviewing plans and issuing permits for any construction affecting the course, current, or cross section of a public waterway. In the administration of the various phases of the law, the Division of Waters, a branch of the Minnesota Department of Conservation, acts as an investigating and advisory agency in matters dealing with the use of public waters as well as with problems of public drainage.

Water pollution is under the control of the Water Pollution Control Commission which is charged with the responsibility of holding public hearings on questions arising from discharge of waste material into public waters. If, after the hearings, it is found expedient, the Commission may issue an order for the offending party to take corrective measures.

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INT.-DUP. SEC., WASH., D.C. 49773