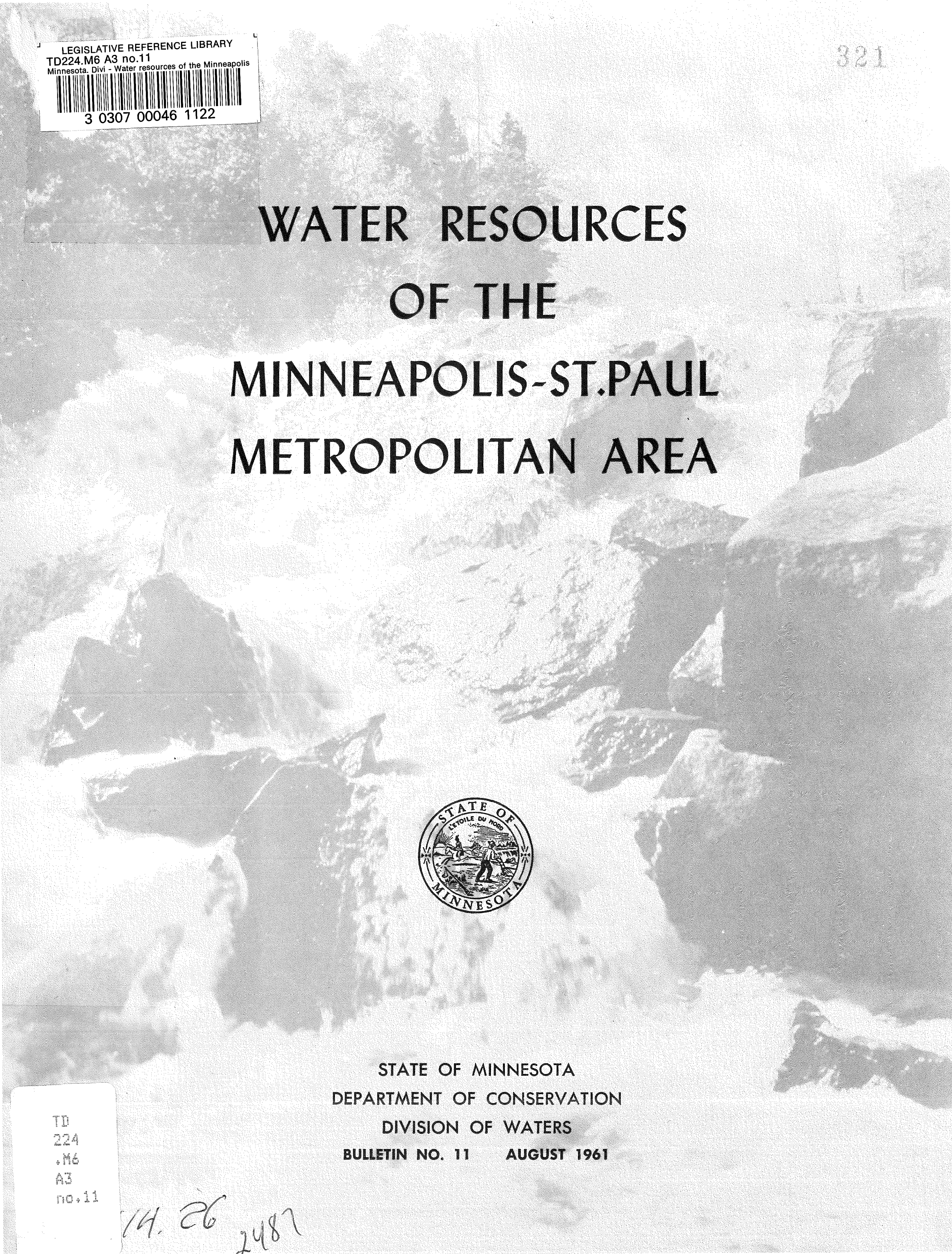

WATER RESOURCES OF THE MINNEAPOLIS-ST.PAUL METROPOLITAN AREA

STATE OF MINNESOTA
DEPARTMENT OF CONSERVATION
DIVISION OF WATERS

BULLETIN NO. 11 AUGUST 1961

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DIVISION OF WATERS

MINNESOTA CONSERVATION DEPARTMENT

WATER RESOURCES OF THE MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

St. Paul, Minn.

August, 1961

FOREWORD

The Twin Cities and their suburbs are becoming increasingly aware of the importance of water to their future growth and development. Midway between the humid east and the arid west, they are not unfavorably situated as regards water supply. Three great rivers bring the water from 45,000 square miles of watershed to their door, and the entire area is underlain by a complex of geologic formations which receive and hold an enormous quantity of water.

The supply, however, is not unlimited. The ground water reservoir can be depleted by pumping continuously at rates higher than the rate of natural replenishment. The flow in the streams is variable and at times has reached a low point which would be dangerous if repeated in the future. Yet the demand for water continues to grow.

This bulletin attempts to evaluate quantitatively the water resources and water needs of the metropolitan area. It is based on records of streamflow collected over many years and on analyses of well records and pumping tests which reveal the characteristics of the deeply buried aquifers. It attempts to define the limits of the water supply, both surface and underground, that is available for all purposes, to estimate the future water needs that an expanding population, industry and commerce will bring about, and to show the relationship between future demand and available supply. This bulletin is intended primarily to furnish the factual basis on which the many difficult administrative, political and economic decisions can be made.

The information in this report has been obtained from field studies and records of the Division of Waters, from the records and published reports of the Minnesota Department of Health, the Minneapolis-St. Paul Sanitary District, the Metropolitan Planning Commission, the U. S. Army Corps of Engineers, the Department of Geology of the University of Minnesota, the Minnesota Geological Survey, the Surface Water, Ground Water and Quality of Water Branches of the U. S. Geology of the University of Minnesota, the Minnesota Geological Survey, the Surface Water, Ground Water and Quality of Water Branches of the U. S. Geological Survey, and from information obtained from municipal and county engineering departments, well drillers, and many other sources. The division is grateful for the excellent cooperation given by all concerned.

ABBREVIATIONS AND DEFINITIONS

Cfs, cubic feet per second. A unit of measurement of the *rate of flow* of water in a stream. It is the volume of water passing a given point in the stream in one second.

Af, acre foot. The volume of water (43,560 cubic feet) which will cover one acre to a depth of one foot. It is a unit commonly used in measuring the contents of reservoirs and lakes.

Mg, million gallons. A unit of volume commonly used in connection with municipal water supply. It is equivalent to 3.07 af.

Mgd, million gallons per day. The *rate* at which water is delivered or used. It is equivalent to 1.55 cfs. A unit of *mgy,* million gallons per year, is also used.

The *watershed* of a stream at a given point is the area of land enclosed by a topographic divide so that direct surface runoff from precipitation normally would drain by gravity into the stream at that point. The terms *drainage basin* and *drainage area* are also used.

Runoff in inches is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface. The term is used for comparing runoff with rainfall, which is also usually expressed in inches.

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STUDY AREA

The area discussed is essentially that of the Metropolitan Watershed Unit, which is no. 33 of 39 such units into which the state was divided and which were defined and briefly discussed in The Hydrologic Atlas of Minnesota, Bulletin no. 10 of the Division of Waters, published in April 1959. These watershed units are natural hydrologic subdivisions of the state, each of which is to be the subject of a separate report on water resources and water problems. This is the first such report to be published.

The boundaries of this unit thus established have been somewhat modified to take in all of the rapidly expanding urbanized portions of the area. For the consideration of surface water problems only, the boundaries have been further extended to include the watersheds of minor tributaries entering the Minnesota River as far upstream as the village of Carver. The area of the surface water study unit is 1,725 square miles and comprises all of Hennepin and Ramsey and parts of Anoka, Carver, Dakota, Scott, Washington and Goodhue Counties.

The ground water study area was determined necessarily by geologic and subsurface hydrologic conditions. It has been extended eastward to the St. Croix River and its boundaries further modified to coincide with those of political townships. Its area is about 2,300 square miles. Population and water use data have been summarized for the ground water study area.

Boundaries of the study areas are shown on the inset, figure 13.

TOPOGRAPHY

The configuration of the land surface in the metropolitan watershed area resulted from glacial and postglacial erosion and deposition superimposed on a deeply incised sequence of marine sedimentary rocks.

The watershed may be described in general terms as a complex basin of minor watersheds tributary to large segments of the Mississippi and Minnesota valleys. The eastern, western and southern boundaries are formed by hilly glacial moraines, whereas the northern boundary is a poorly defined divide on a sand plain. The central region of the watershed is a broad glacial till and outwash plain crossed by hummocky moraines and dissected by wide deep valleys of the trunk streams. The major components of the central area readily visible to the observer are plateau-like uplands at altitudes from 800 to 1,000 feet separated by steep-walled gorges with alluvial floors at altitudes near 700 feet above sea level. The maximum topographic relief is about 600 feet.

The lakes in the area lie in basins of glacial till and outwash on the uplands and of alluvium on the valley floors adjacent to the major streams.

Complete topographic map coverage of the area at scales of 1:24,000 and 1:62,500 is provided by U. S. Geological Survey quadrangles. The area is also shown on parts of the St. Paul and Stillwater maps, prepared by the Army Map Service and published by the U. S. Geological Survey, at a scale of 1:250,000.

GEOLOGY

Aside from Recent alluvial deposits in stream valleys, the youngest geologic formation in the area is Pleistocene glacial drift, consisting of unconsolidated clays, sands and gravels which occur as hilly moraines, rolling till plains and the flat Anoka sand plain. These glacial features resulted from a series of ice advances and retreats during long interglacial epochs.

Of the consolidated bedrock formations, the youngest are Ordovician shales, limestones, dolomites and sandstones. Beneath the Ordovician rocks are older Cambrian shales and sandstones. In the metropolitan area the Ordovician and Cambrian formations were warped into a broad saucer-shaped basin elongated in a northeast-southwest direction. The upper surface of the bedrock was subjected to prolonged erosion and is irregular so that it does not reflect the basin shape of the rocks. In fact, in many places the upper rock formations were eroded away and the irregular surface was covered with glacial drift.

Precambrian pink to red sandstones and shales underlie the Cambrian rocks and are underlain by crystalline basement rock.

Figure 1 is a generalized geologic section near the center of the basin showing most of the formations except the crystalline basement rock. It includes formational names, approximate thicknesses and altitudes above sea level, and brief descriptions of the ground water characteristics of the several aquifers. Away from the center of the basin the upper rock formations have been removed by erosion, and glacial drift covers older rocks.

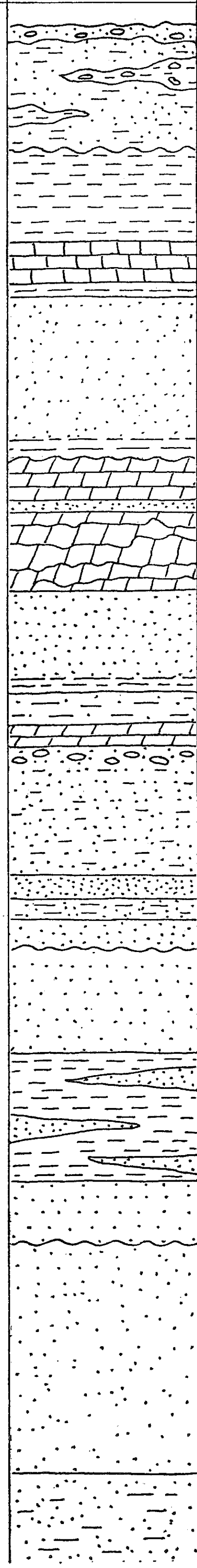
SOILS, AGRICULTURE AND FORESTS

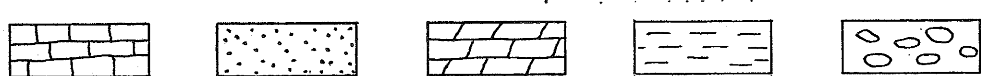
Farm acreage values in the metropolitan area are among the highest in the state. These values are distorted somewhat by the spreading urban real estate market, but agriculturally the area surrounding the Twin Cities contains highly productive soils on which canning vegetables, soybeans and livestock are raised. It is one of the largest commercial vegetable-producing regions in Minnesota because of its favorable agricultural conditions and its proximity to the large fresh vegetable market in Minneapolis and St. Paul.

The morainal and till plain deposits which cover most of the area contain surface materials with a great range of texture, from boulders to fine clay. Much of the morainal region consists of sand deposits; the till plains are dominantly clay. The fertility of the virgin soils depended largely upon the type of natural vegetal cover beneath which the soils were formed. A deciduous forest once covered the morainal region of the watershed, whereas prairie grasslands dominated the till plain region in southern Washington and eastern Dakota Counties. Soil-forming processes on the deciduous forest floor developed dark-colored soils with good fertility. The soils of the prairie grasslands were naturally dark brown or black and rich in organic matter and soluble mineral plant food. Part of the extensive hardwood forest that once covered most of the area remains in its natural condition in the Minnetonka district, but almost all of the rest of the original hardwood forest has been cut.

Figure 1.--Generalized geologic section, Highland Park area, St. Paul, Minnesota

System	Formation and member	Thickness (ft)	Altitude (ft above msl)	Ground water
Pleistocene	Glacial drift	110	1,000	Small to moderate quantities of water available from sand and gravel lenses.
Ordovician	Decorah formation	90	890	Small quantities of water available from fractures, fissures and solution cavities.
	Platteville formation	40	800	
	and Glenwood member	10		
	St. Peter sandstone	150	750	(Water level of Mississippi River below Ford Dam) Small to moderate quantities of water available.
	Shakopee dolomite	40	600	Large quantities of water available.
	New Richmond sandstone	10		
	Oneota dolomite	80	550	
Cambrian	Jordan sandstone	90	470	
	St. Lawrence formation	50	380	
	Franconia formation	190	330	Small to moderate quantities of water available from sandstone beds.
	Reno & Mazomanie members			
	Tomah member			
	Birkmose member			
	Woodhill member			
	Dresbach formation	275	140	
	Galesville member			
	Eau Claire member			
	Mt. Simon member			Moderate quantities of water available.
Precambrian	Hinckley sandstone	220	-135	
	Red Clastic Series	More than 1,000	-355	





CLIMATE

The metropolitan area is characterized by great variation in weather. Climatic disturbances originating in the northwestern and southwestern United States in their eastward migration pass near the Twin Cities and are followed by cooler polar air masses from the northwest and north which produce a cyclonic control of weather causing great and rapid changes.

The temperature range from season to season is quite large. The mean annual temperature for the area is about 45°; the mean for the fall and winter months of October through March is about 27° and for the spring and summer months of April through September it is about 63°. The highest recorded temperature in the watershed is 112° at Maple Plain and the lowest is —40° at Farmington. Maximum daily temperatures of 90° or higher can be expected on about 16 days each year. Minimum daily temperatures of 32° or lower occur about 150 days annually. The extremes of weather are advantageous to two nationally known outdoor events—the St. Paul Winter Carnival and the Minneapolis (summer) Aquatennial.

As the winter season is long with daily mean temperatures below freezing from mid-November to late March, the Mississippi and Minnesota Rivers are frozen over from early December to late March.

The average growing season in the area is about 160 days with the last spring frost occurring between April 30 and May 19 in an average year. The first fall frost usually occurs between October 1 and October 13.

The mean annual precipitation in the area is 27.5 inches, of which nearly 20 inches occurs between April and September chiefly in the form of thundershowers. The maximum annual precipitation of 44.81 inches occurred in the Maple Plain area in 1951. The minimum annual precipitation of 11.59 inches was recorded at Minneapolis-St. Paul in 1910. On July 26, 1892, 7.80 inches of precipitation was recorded in 24 hours at the Minneapolis-St. Paul weather station. Nearly 40 thunderstorms, on an average, occur in the area in a year, but severe storms, such as tornadoes, freezing rain and hail, are uncommon.

GROUND WATER

OCCURRENCE

Ground water is defined as subsurface or underground water that occupies or completely saturates the interstices or voids in the earth's crust. Water that occurs in the soil or subsoil under conditions of capillarity or molecular attraction is subsurface water but is not considered ground water.

A formation that will yield water freely by means of wells or springs is called a water-bearing formation, or aquifer. Some formations of clay or silt are completely saturated with ground water but cannot be considered aquifers because the connected pore spaces are too small to allow sufficient movement of water. Sand, gravel and sandstone with large pore spaces and consolidated rocks with integrated fractures or solution cavities are usually the aquifers that transmit water most readily, although the actual amount of water storage in them is smaller than in beds of silt. This seemingly anomalous condition is possible because the storage capacity of a formation is directly related to the porosity which is relatively high in silt beds of uniform grain size but low in sand and gravel beds of less uniform grain size or in sandstones with some of their pore space occupied by cementing material.

A water-table aquifer contains ground water that is unconfined by overlying relatively impermeable beds of clay, silt or shale. The upper limit of the zone of saturation is the water table and, for all practical purposes, it is represented by the static water levels in wells that penetrate unconfined aquifers. An artesian aquifer contains water that is confined by clay or shale or by other relatively impermeable rock strata that restrict the vertical movement of water to and from the aquifer. Water levels in wells that penetrate an artesian aquifer rise above the top of the aquifer. If the water level in a well rises above the land surface, the well will flow. Accordingly, in an artesian aquifer, wells may be either flowing or nonflowing.

The water levels in artesian wells reflect the hydraulic pressure head in an artesian aquifer. The water level in each individual well represents the pressure head at one point on a water pressure surface which is called the piezometric surface. The piezometric surface may be higher or lower than the water table in the overlying formation.

Both water table and artesian conditions occur in the Minneapolis-St. Paul metropolitan area. Water table conditions are most common in the shallow glacial drift aquifers but also occur in the St. Peter sandstone in some areas. Some of the deeply buried sand and gravel lenses in glacial drift and most of the water-bearing bedrock formations are artesian aquifers.

AVAILABILITY

The major aquifers in the metropolitan area are glacial sand and gravel deposits, the St. Peter sandstone, the Shakopee-Oneota dolomites, the Jordan sandstone, the Franconia and Galesville sandstones, and the Mt. Simon and Hinckley sandstones.

The stratigraphic sequences of the aquifers and other formations in the area is shown on figure 1.

The entire sequence of layered rocks in the area above the St. Lawrence formation is warped in a saucer-shaped basin. The Jordan sandstone is the highest rock stratum in the sequence that is essentially uneroded in the central part of the structure. Some of the valleys eroded in the bedrock extend into the Jordan sandstone, but the total area of the formation in direct contact with glacial drift, other than around the margins of the basin, is insignificant. Accordingly, any wells drilled in the central part of the basin will penetrate the Jordan sandstone if drilled to a sufficient depth. Figure 2 is a map of the structural basin showing contours on the top of the Jordan sandstone.

The quantity of water available from an aquifer on a continuing basis is equivalent to the amount of recharge it receives. In the metropolitan area all aquifers above the St. Lawrence formation are recharged from precipitation on the local upland areas. Part of the precipitation that infiltrates the glacial drift moves laterally and discharges to lakes or streams but most of it descends vertically and provides recharge to aquifers in the bedrock. Practically all of the ground water in the St. Peter sandstone, the Shakopee and Oneota dolomites, and the Jordan sandstone is derived from the overlying glacial drift.

Part of the recharge to the glacial drift that directly overlies the St. Lawrence formation descends to the bedrock and moves laterally to the Jordan sandstone and supplies part of the recharge to that aquifer. When the development of the Jordan produces a shift in the ground water divides to increase the effective recharge area, a larger proportion of ground water in the glacial drift above the St. Lawrence formation will tend to recharge the Jordan.

The principal recharge areas for aquifers below the St. Lawrence formation are located generally north and west of the Twin Cities, where the formations crop out at land surface or are covered only by glacial drift. Only insignificant quantities of recharge water descend through the St. Lawrence formation to the Franconia and Galesville sandstones. Furthermore, the exchange of water between the Galesville and Mt. Simon is restricted by the intervening Eau Claire member so that water in the Mt. Simon and Hinckley sandstones moves into the Twin Cities from recharge areas as much as 100 miles to the north.

Water table and piezometric surface maps indicate that in all aquifers above the St. Lawrence formation ground water moves horizontally as well as vertically and discharges into the Mississippi and Minnesota River valleys. Some ground water from the glacial drift and St. Peter sandstone discharges into tributary streams, such as Nine Mile Creek and Bassett Creek.

Whereas natural discharge from the glacial drift and the St. Peter sandstone is unrestricted where the valley slopes intersect the aquifers, discharge from the Shakopee-Oneota-Jordan aquifer is restricted by overlying valley alluvium and glacial outwash. Ground water discharged from this aquifer must ascend through the outwash and alluvium before it can enter the streams or lakes to be evaporated or transpired by plant life.

The direction of ground water movement in the Mt. Simon-Hinckley aquifer appears to be in a southeasterly direction. However, a detailed analysis of water levels in wells that are cased through all other formations is necessary to determine accurately the flow direction and the areas of natural discharge. On the basis of present information the natural discharge occurs in eastern and southeastern Minnesota to the St. Croix and Mississippi Rivers.

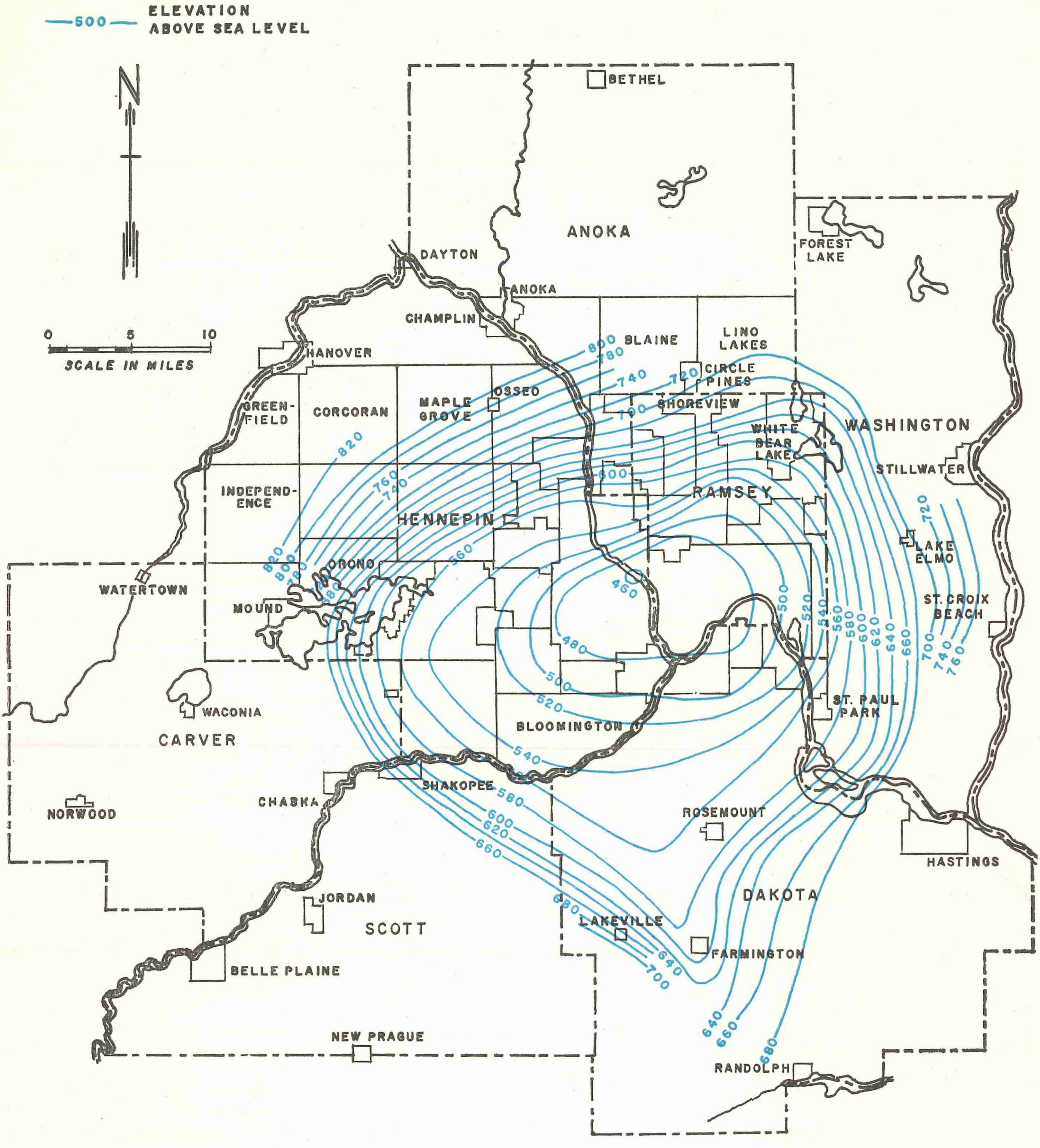


Figure 2.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

STRUCTURAL CONTOURS ON THE JORDAN SANDSTONE
(MODIFIED AFTER SCHWARTZ, 1936)

MINNESOTA CONSERVATION DEPARTMENT
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QUANTITY

The total amount of ground water available in the area is dependent on the average gross recharge to the various aquifers. The recharge can be determined indirectly by ascertaining the ground water discharge to the rivers and to wells from these aquifers. If the recharge is less than the discharge, water levels in wells will decline showing that some water has been removed from storage in the aquifer. Conversely, if the recharge exceeds the discharge, water levels will rise and ground water storage will increase.

The total average effective recharge in the metropolitan area is about 3.5 inches per year. This is the amount that eventually discharges from the aquifers into the streams or supplies part of the water pumped from wells. Part of the water pumped from wells is derived from storage in the aquifers. Some of the precipitation that infiltrates the glacial drift moves laterally to marshes, ponds and lakes in a relatively short time and returns to the atmosphere through the evapotranspiration process. This may be considered recharge to ground water, but it is not effective recharge to aquifers that are usable as water sources.

The quantities of ground water discharging from the aquifers in the area has been computed by relating their hydraulic and physical characteristics to the hydraulic gradient indicated on the map of the piezometric surface. The hydraulic and physical characteristics of aquifers are derived from interpretation of pumping test data of existing wells and by study of maps of the surficial and subsurface geology. The piezometric surface of the Jordan sandstone, based on 1958 winter water level measurements, is shown by figure 3.

Computations of the recharge and discharge of ground water have been made for a 900 square mile area for which sufficient information is available for such an analysis.

Ground water discharge from the glacial drift and from the St. Peter sandstone in this area of 900 square miles is about 20 million gallons per day. This is the quantity of water that moves laterally to areas or points of discharge such as springs and seeps. The ground water discharge from the Shakopee-Oneota dolomites and the Jordan sandstone, usually considered to be a single hydrologic unit, is about 130 million gallons per day. An interpretation of the piezometric surface of the Jordan shows that the ground water discharged from the Shakopee-Oneota-Jordan aquifer is derived from the overlying glacial drift and the St. Peter sandstone. Accordingly, the amount of ground water in the glacial drift and the St. Peter sandstone that moves vertically downward far exceeds the amount that moves laterally.

The computed discharge from all aquifers above the St. Lawrence formation for the 900 square mile area totals about 150 million gallons per day. This is equivalent to 3.5 inches of recharge per year. If it is assumed that 3.5 inches of recharge also occurs in the entire ground water study area of about 2,300 square miles, the total ground water discharge is equal to 380 million gallons per day. This is the quantity of ground water that would be available on a sustaining basis under ideal conditions. To obtain an optimum yield that would approach the 380 million gallons per day, wells would have to be drilled throughout the entire area at locations and in aquifers selected on the basis of a comprehensive exploratory program.

The long term effect of local recharge on the availablility of water in the aquifers above the St. Lawrence formation has been estimated by comparing the drawdown that has actually occurred in the Jordan sandstone under the loop area of Minneapolis with the drawdown that would have occurred, due to the known pumpage in this area, had there been no recharge from the overlying aquifers.

At an estimated average rate of 10,000 gallons per minute, as determined from available pumping records, the calculated drawdown in the Jordan sandstone under the loop area during the 30-year period from 1931 to 1960 would have been 135 feet. The calculated drawdown is based on aquifer coefficients determined from pumping tests of wells in the Jordan. Actually the drawdown is only 60 feet. This shows that recharge from the St. Peter sandstone has occurred during this 30-year period to replace some of the water pumped out of the Jordan sandstone. The calculated quantity of water that came from storage in the Jordan sandstone is equivalent to an average pumping rate of 4,500 gallons per minute. The amount of recharge from the St. Peter sandstone then is equivalent to 5,500 gallons per minute, or about 8 million gallons per day. The land area appreciably influenced by the cone of depression produced by this pumping is about 50 square miles. Therefore, the recharge moving from the St. Peter sandstone to the Jordan sandstone is equal to an average of about 3.5 inches per year on the 50 square mile area affected.

Not all of the water removed from storage in the St. Peter sandstone by leakage has been replaced by recharge from the overlying formations, and consequently the water level in the St. Peter formation in the loop area declined about 40 feet during the period 1931 to 1952. The water level in an observation well in the St. Peter near the loop recovered about 10 feet in 1953. Measurements in this well were discontinued in 1953 so that no records are available to show the relationship between declining water levels in St. Peter and Jordan wells in recent years. During 1951 and 1952, however, the water level in the St. Peter fluctuated about 13 feet reaching a high in midwinter and a low in midsummer. Pumpage from wells in the St. Peter caused part of this decline and fluctuation in water levels, but most of it resulted from leakage to the Jordan sandstone and from the effects of sewers and other tunnels.

Aquifers below the St. Lawrence formation generally are not recharged locally from overlying aquifers. The Franconia formation and the Galesville member of the Dresbach formation, which directly underlie the St. Lawrence, are recharged mainly from the glacial drift in Anoka, Chisago, Isanti and Sherburne Counties. The areas of recharge for the Mt. Simon member of the Dresbach formation and the Hinckley sandstone are even farther north of the metropolitan area.

On the basis of the computed available recharge it is evident that ground water withdrawn from aquifers below the St. Lawrence formation must come largely from storage and that only a small part of it will be replenished. The initial yields from properly developed wells penetrating the Franconia formation and Galesville member, acting as a single hydrologic unit, and the Mt. Simon member and the Hinckley sandstone, acting similarly, are about equal to yields from wells in the Jordan sandstone alone.

WATER LEVELS IN WELLS

Changes in water levels in wells may indicate changes in ground water storage, changes in atmospheric pressure, or the arrival of shock waves produced by disturbances such as earthquakes or explosions. Major water level fluctuations are produced

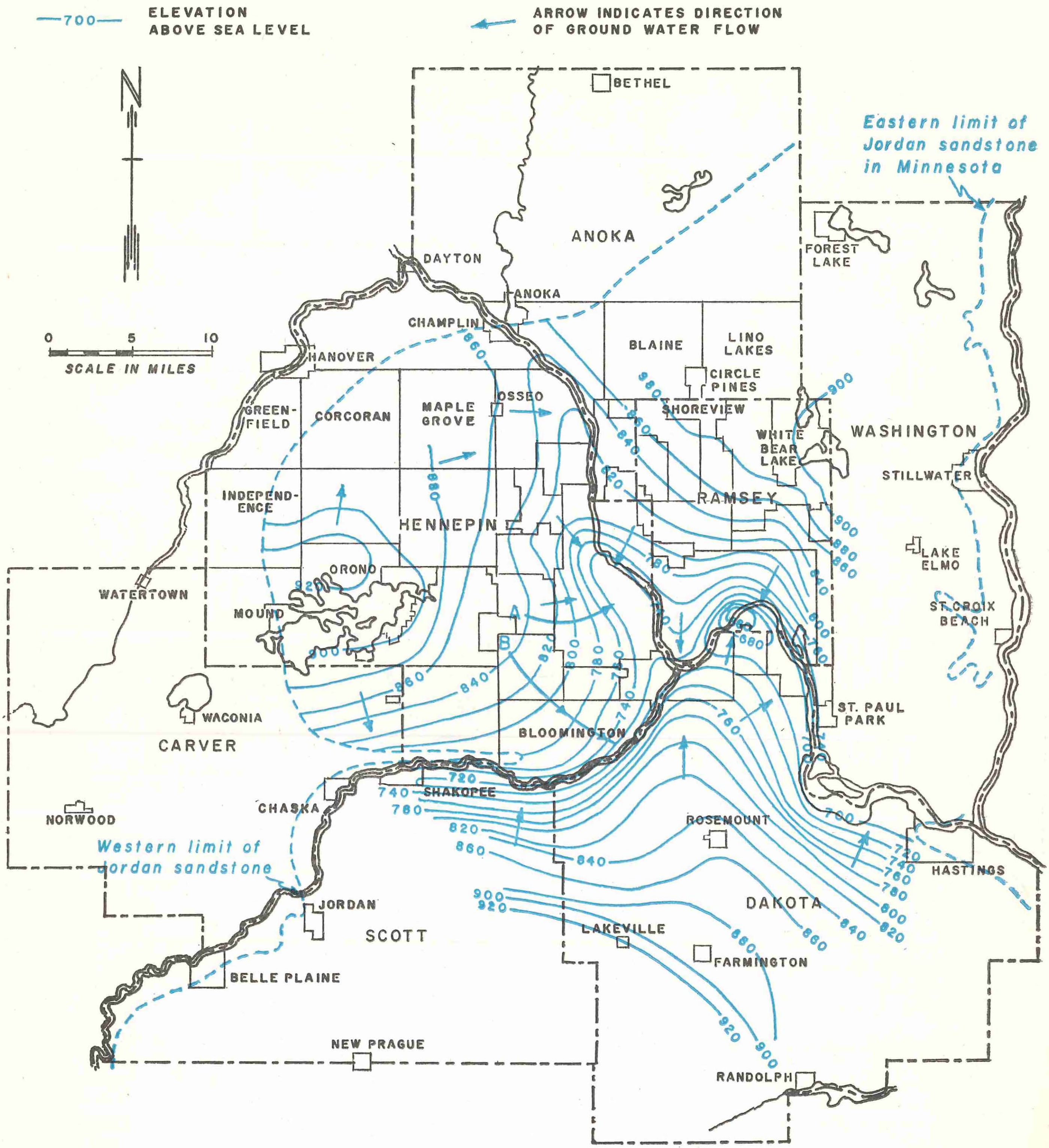

Figure 3.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

PIEZOMETRIC SURFACE OF JORDAN AQUIFER

DECEMBER 1958

MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF WATERS

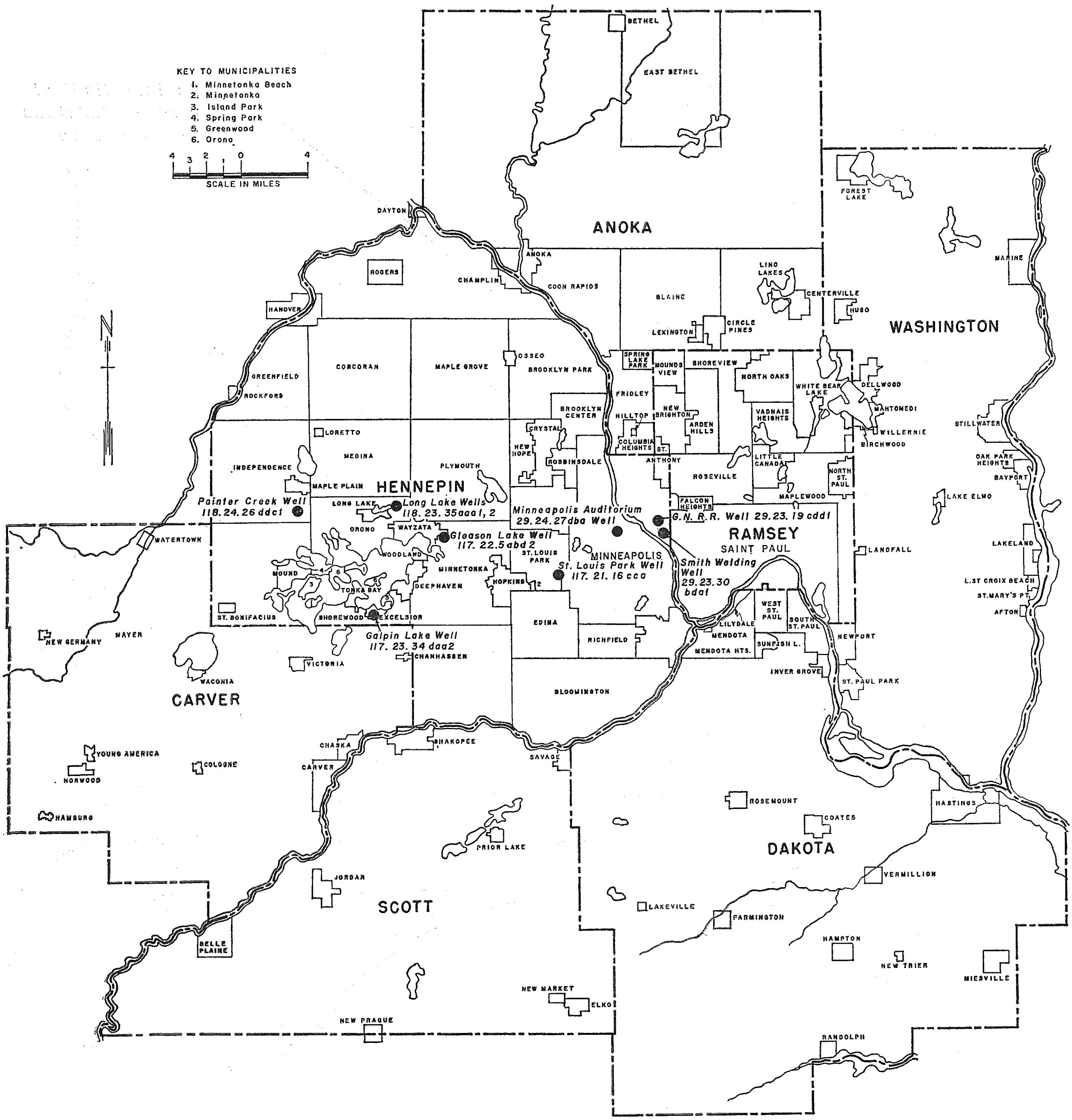

Figure 4.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

OBSERVATION WELLS

● Location of observation well

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by changes in ground water storage and therefore are the only fluctuations interpreted in this report.

The U. S. Geological Survey in cooperation with the Division of Waters, Department of Conservation, and Hennepin County maintains 15 observation wells in the Minneapolis-St. Paul area. Water level records for 9 of these observation wells were selected for analysis. Locations of the wells are shown on figure 4.

Figure 5 is a graph showing water levels in wells in the Minneapolis-St. Paul metropolitan area. The graphs show the fluctuation of water levels in the glacial drift or in the Jordan sandstone at various distances from areas of concentrated pumpage.

A well in Painter Creek Valley (118.24.26ddcl) near Lake Minnetonka penetrates glacial drift to a depth of 13 feet below the land surface. The graph of water levels in this well shows the effects of natural recharge upon a shallow aquifer in a well-defined stream valley and the effects of discharge to a nearby stream. Recharge occurs in direct response to precipitation or snow melt as indicated by the sharply rising segment of the curve. Natural discharge is represented by the more gradual recession of the curve.

A well near Long Lake (118.23.35aaa2) in Hennepin County is also in the glacial drift but extends to a depth of 151 feet below the land surface. The water level in this well responds only slightly to annual variations in precipitation but indicates long term excesses or deficiencies. By comparing this graph with that of nearby Long Lake well number three (118.23.35aaal), which is in the Jordan sandstone, it is apparent that large withdrawals of water from the Jordan, as indicated by the interruption in the graph caused by pumping in 1956, 1958 and 1959, produced leakage from the glacial drift, as indicated by the corresponding declining water level in the glacial drift well.

The remaining graphs represent water level fluctuations in wells in the Jordan sandstone in the Minnetonka area, in St. Louis Park, and in downtown Minneapolis.

Long Lake well number three (118.23.35aaal), the Gleason Lake well (117.22.5abd2), and the Galpin Lake well (117.23.34-daa2) all show slight water level fluctuations caused by pumping wells in the Jordan sandstone in the western suburbs for municipal water supplies and in Minneapolis for industrial and air conditioning water supplies. The declining water levels reflect the increased use of ground water during the summer, and the rising water levels represent recovery as pumpage is reduced during the winter.

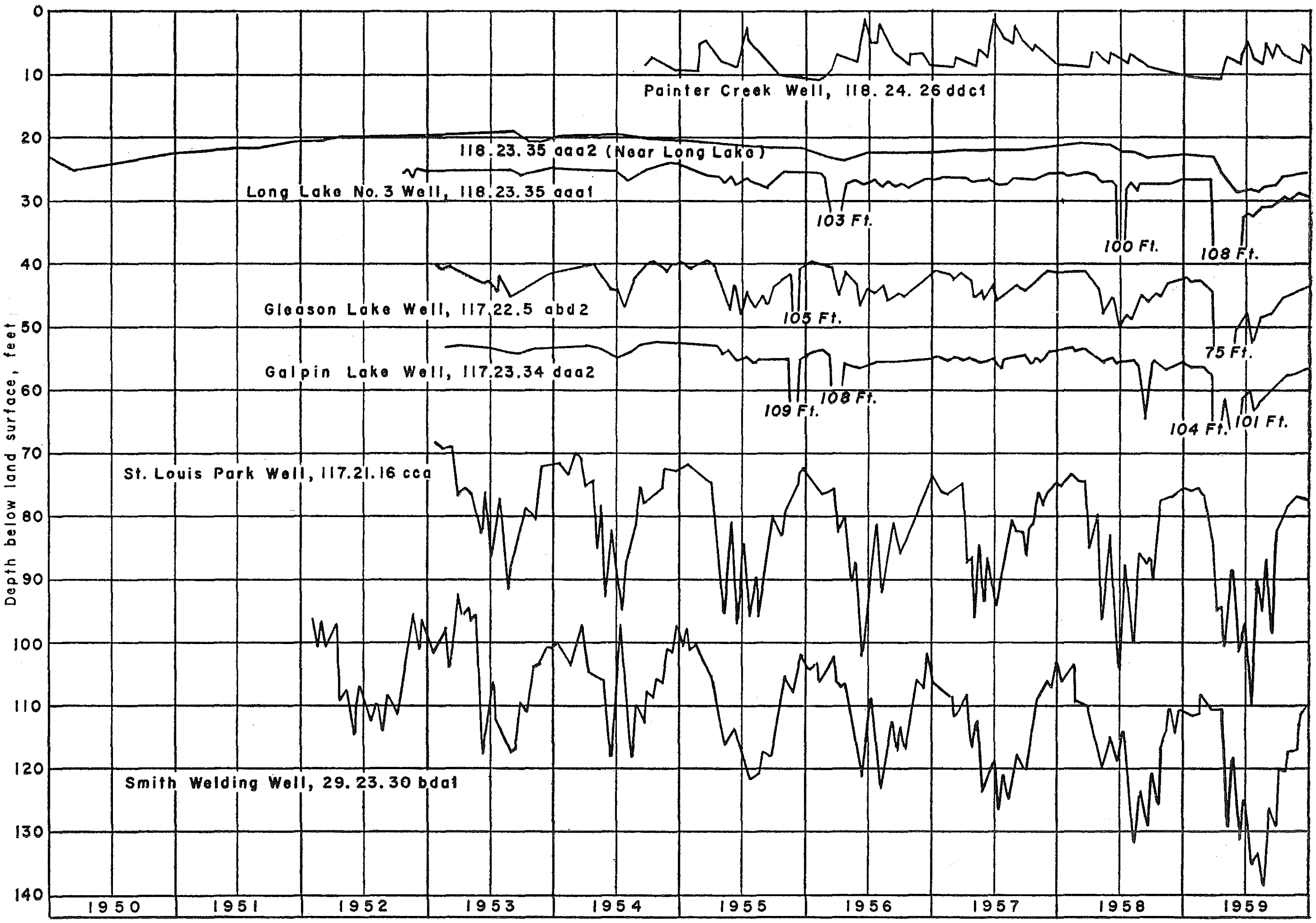


Figure 5. Water levels in wells in the Minneapolis - St. Paul metropolitan area

During 1955 the maximum difference in water levels produced by pumping in the Minneapolis and suburban areas was about 8 feet at Gleason Lake and 2.5 feet at Galpin and Long Lakes. In 1956, 1958 and 1959, the Hennepin County wells used for supplementing the water supply of Lake Minnetonka were pumped and consequently the effects of pumping distant wells is less obvious.

Well 117.21.16cca is an abandoned municipal well in St. Louis Park and well 29.23.30bdal is at Smith Welding Equipment Corporation in Minneapolis. Graphs of water levels in both wells show not only the effect of increased pumpage during the summer but also considerable day-to-day fluctuation produced by nearby pumping wells. The fluctuation in these wells from the high during March to the low in July or August of 1959 is about 30 feet.

The long term trend of water levels in heavily pumped areas is shown on figure 6 which is a graph of water levels in the Minneapolis Auditorium well (29.24.27dba) from 1931 through 1959. The winter or spring water levels have declined at an average rate of about 1 foot per year for the 29-year period. During the period 1945 to 1955, however, the rate of decline was less than 0.5 foot per year, but since 1955 the rate has increased to almost 2 feet per year. The relatively low rate of decline in water levels from 1945 to 1955 is attributed to above average precipitation and a consequent increase in recharge. The increase in the rate of decline in recent years is apparently caused by an increase in the demand for ground water and by less than average precipitation. The effect of increased pumping is indicated by the progressively lower summer levels which are declining at a greater annual rate than the spring levels.

Water levels in the Mt. Simon-Hinckley sandstone have declined rapidly since the development of this aquifer started about 1900. A graph of water levels in well 29.23.19cddl, which penetrates the Mt. Simon-Hinckley sandstone, is shown in figure 7. This well is located in the Great Northern Railway freight yards just north of the University of Minnesota in Minneapolis, and since 1952 when the pump was removed it has been used as an observation well.

The water level graph shows a decline of more than 100 feet from 1912 until 1940. Since 1940 the water level has fluctuated from 5 to 15 feet each year but the trend is no longer downward. This change in trend is attributed to a general decrease in use of water from the Mt. Simon-Hinckley aquifer, as the railroads changed from steam to diesel locomotives.

The present major area of use of ground water from the Mt. Simon-Hinckley aquifer is in the South St. Paul area as indicated by the piezometric surface map (fig. 8). The lowest contour, which is shown at 650 feet above sea level on the map, is closed

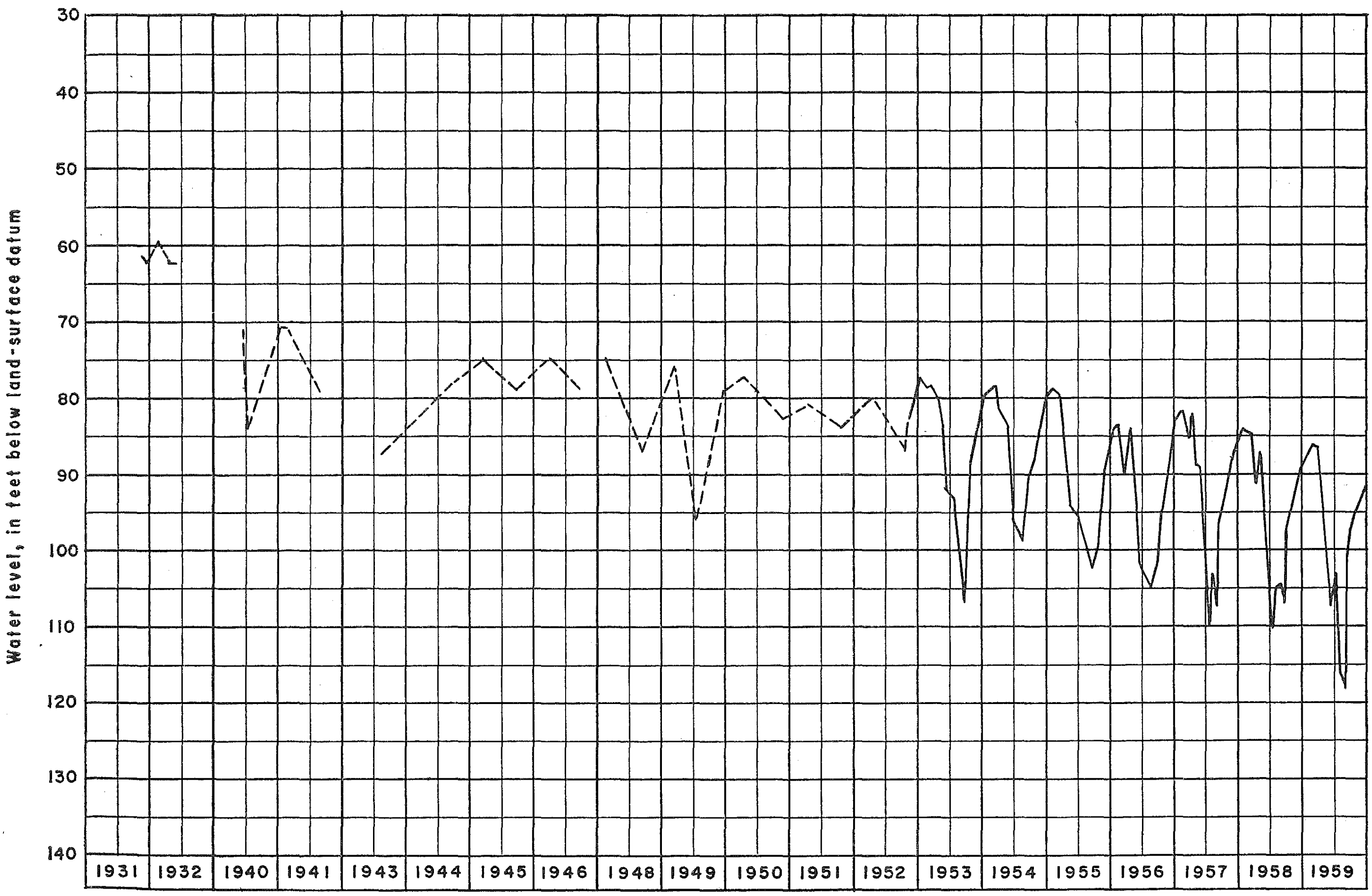


Figure 6. Water level in well 29.24.27 dba, Minneapolis Auditorium
(Periodic measurements, 1931 - Oct. 1952; monthly low water level, Nov. 1952 - 1959)

around South St. Paul and the gradients on the piezometric surface are toward this closed contour.

The effect of the distribution of wells penetrating this aquifer is further demonstrated by the steeper gradient of the piezometric surface directly south of South St. Paul where the aquifer has remained essentially undeveloped until now. For example, the gradient on the piezometric surface is about 5 feet per mile from the north and 17 feet per mile from the south.

CHEMICAL QUALITY

Hardness is a property of water that is caused by certain materials in solution. Calcium and magnesium are the main elements causing water hardness. Aluminum, iron, manganese, strontium, zinc and free acid also cause hardness but generally are not present in sufficient quantities to affect the hardness of the water significantly.

Hard water increases soap consumption to produce a lather, and the common result is a sticky curd. Hardness also produces scale or incrustation in pipes and boilers and so most municipal and industrial waters are softened before use. Many of the domestic well water supplies are softened in the home to reduce consumption and wear on fabrics.

The hardness of ground water in aquifers above the Eau Claire member of the Dresbach formation generally ranges from about 250 to 400 parts per million. The Mt. Simon-Hinckley aquifer contains water with hardness ranging from about 100 to 200 ppm. City water in both Minneapols and St. Paul is softened to 70 to 80 ppm.

Iron and manganese in combined concentrations exceeding 0.3 of a part per million are probably the most troublesome constituents of ground water. Clothing is stained by excessive iron and manganese and porcelain fixtures and cooking utensils are discolored reddish brown or black. The distribution of ground water containing excessive concentrations of these elements is random, and all aquifers are affected at some places but not at others.

The presence of nitrate in ground water has received a great deal of attention in recent years because an increase in nitrate concentration in water samples from wells in areas where sewage is discharged into the ground indicates that sewage chemicals are entering the aquifer. The nitrates are not injurious to humans except when water containing nitrates (NO_3) in excess of 44 ppm is used for infant feeding. The nitrates appear to be a contributing factor in the incidence of methemoglobinemia, a condition that can be fatal. The nitrate concentration may be measured by

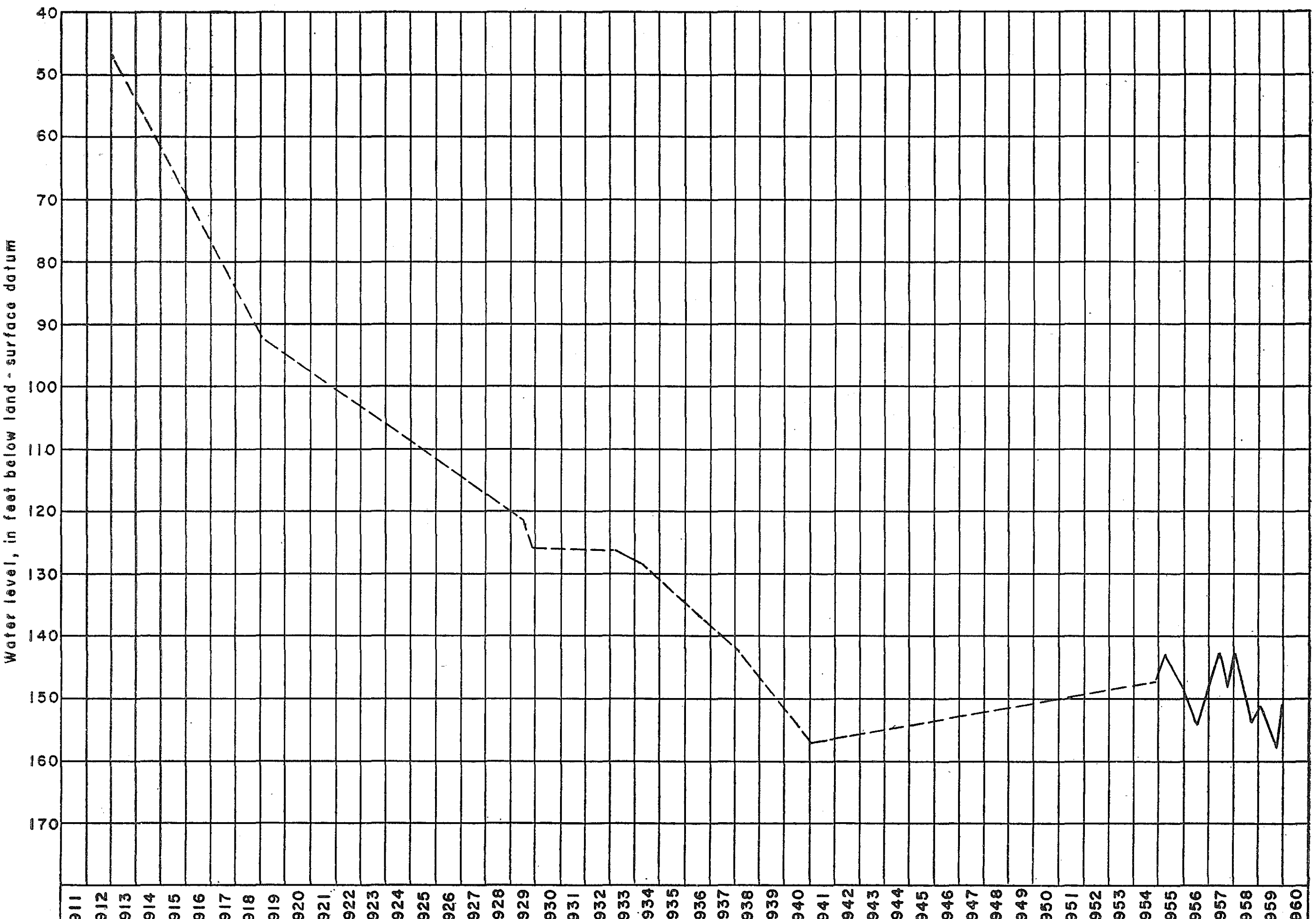


Figure 7. Water level in well 29.23.19 cdd1, Great Northern Railway Co., Minneapolis

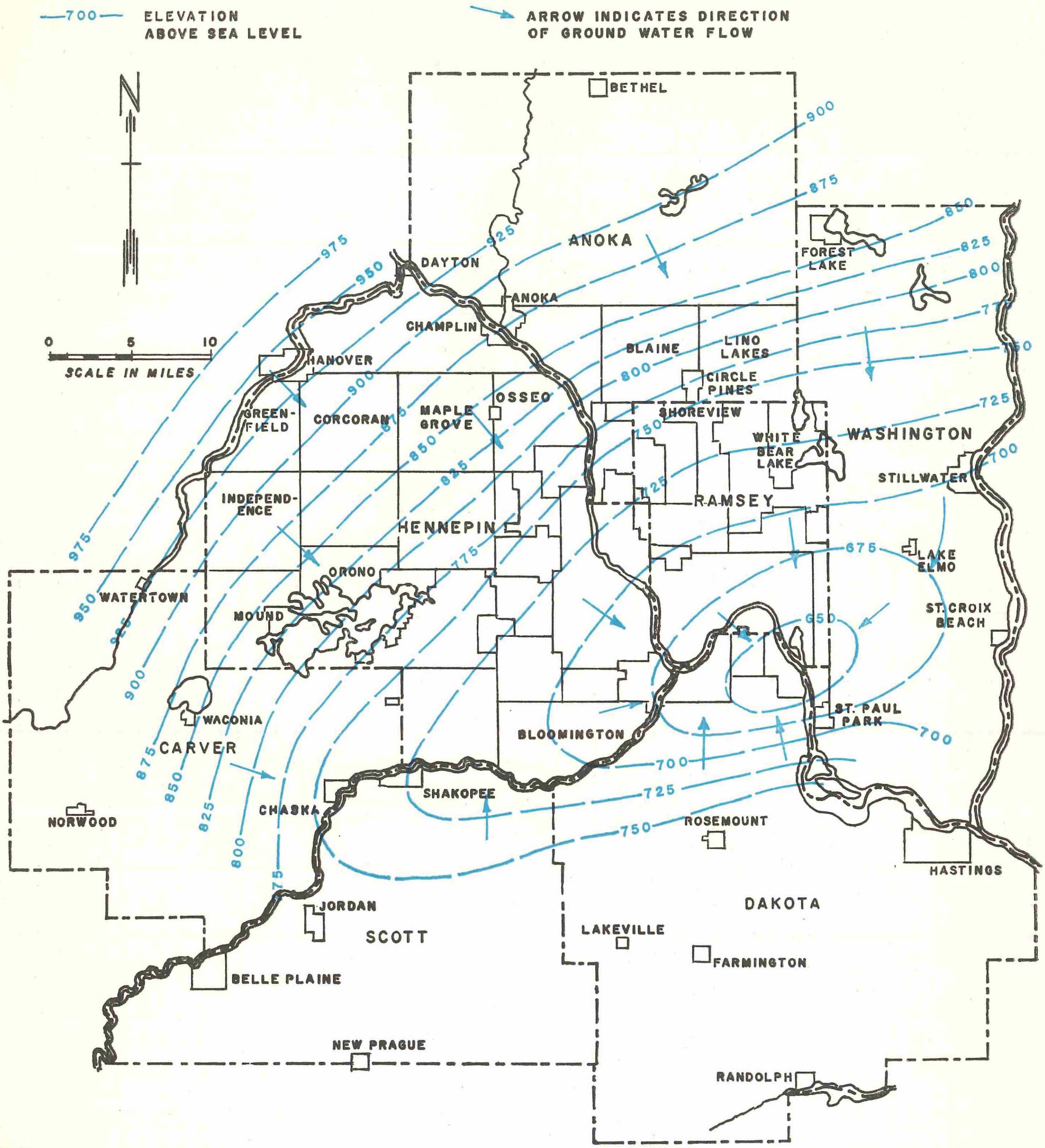


Figure 8.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

PIEZOMETRIC SURFACE MT. SIMON - HINCKLEY AQUIFER

DECEMBER 1959

MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF WATERS

chemical analysis as nitrate (NO_3) or nitrate-nitrogen. One part per million nitrate-nitrogen is equivalent to 4.4 parts per million of nitrate expressed as (NO_3).

TEMPERATURE

Water temperatures in the artesian aquifers are generally within the range of 48° to 55°F, with the higher temperature generally occurring at greater depths. Little, if any, seasonal variation has been noted. Temperatures in the drift are sometimes slightly lower but are more variable, being responsive to temperatures at or near the ground surface at the time recharge occurs. The generally low temperature of ground water makes it especially desirable for cooling purposes, and its lack of variability is important for some industrial uses.

CONCLUSIONS

The most important aquifer in the metropolitan area is that composed of the Jordan sandstone and Shakopee-Oneota dolomites acting as a single hydrologic unit. This aquifer has not only the highest average permeability of all aquifers in the bedrock but also readily receives recharge from overlying formations.

Glacial outwash deposits of sand and gravel represent a very important source of ground water for all types of use, but the random distribution of extensive permeable aquifers is a limiting factor for users of large quantities of water. The large glacial aquifers can be located and investigated by means of detailed geologic mapping and test drilling programs, and individual wells may yield more water per unit of drawdown while pumping than a well in the Jordan aquifer. The continued use of ground water from shallow glacial drift aquifers for domestic or municipal water supplies will depend on its freedom from traces of sewage chemicals. Deep aquifers in the glacial drift and bedrock eventually may be affected by sewage effluent dicharged into the ground if some alternate method of sewage disposal is not adopted. Construction of sewage treatment facilities wherever possible appears to be a rational long range solution to the problem.

Use of water from the St. Peter sandstone is limited by a generally low permeability and relatively small geographic distribution.

The Mt. Simon-Hinckley aquifer yields a relatively soft water, but the permeability of these formations is considerably lower than that of the Jordan sandstone and recharge conditions are much less favorable so that water levels are likely to decline rapidly as development proceeds.

Considering the entire metropolitan area or any portion of it as a unit, the quantity of ground water available in that unit area will become insufficient for municipal water supplies as the population of the area increases. The average annual recharge is not adequate to replace or replenish ground water that would be needed under these conditions, and water levels would decline as ground water is "mined" or pumped from storage and discharged into streams by way of sewerage systems. The amount of water required by a densely populated municipality now exceeds the natural recharge of 3.5 inches, and per capita use is expected to increase so that the rate at which ground water is "mined" will increase in the future.

SURFACE WATER

Three major streams, the Mississippi, the Minnesota and the St. Croix Rivers, converge in the metropolitan area. Their combined watershed area is nearly 45,000 square miles. Mean annual precipitation over this area varies from about 22 inches along the western border of the state to about 28 inches at St. Paul. Annual runoff varies from about 1 inch at the headwaters of the Minnesota to about 10 inches in parts of the St. Croix valley.

The Mississippi River extends for about 500 miles above the Twin Cities and drains a watershed of 19,400 square miles. The northern part is heavily forested, and the entire area has a rather large percentage of forest-covered or uncultivated land. Many lakes, swamps and open bog lands provide temporary storage for some of the surface runoff. Land slopes are generally flat to rolling but with many belts of morainic hills. In the southern part, more of the land is cultivated, although lakes and swamps are still numerous. These conditions are conducive to rather well sustained streamflow and to floods of relatively low peaks but of long duration.

The Minnesota River, rising on the western border of the state, has a total watershed area of 16,900 square miles. The terrain varies from slightly undulating prairie land to rolling or hilly. Most of the area is cultivated and much of the natural storage once provided by sloughs and shallow lakes has been destroyed by agricultural drainage. Floods on the main stem and on the tributaries are frequent and sometimes severe and on the lower part of the river may be of long duration.

The St. Croix River drains an area of about 7,650 square miles, about equally divided between Minnesota and Wisconsin. The northern part is largely forested; the southern part is mostly agricultural lands, both cultivated and grasslands. The headwaters areas of the St. Croix and its tributaries are characterized by many flat, poorly drained, open bogs. The tributaries flow on steep gradients in the lower reaches where they are entrenched in deep narrow valleys in bedrock. The large amount of natural storage provided on the surface and in the ground produces well-sustained flows in all the streams. Floods generally are of short duration and rarely inflict appreciable damage.

The volume of water flowing in these streams is measured and recorded at several gaging stations maintained by the U. S. Geological Survey. A summary of data extracted from these records, which is applicable to water supply problems of the metropolitan area, is shown in table 1.

The Minnesota River is gaged at a point near Carver, about 36 miles above the mouth of the river at Fort Snelling. This station has been operated since September 1934.

The station on the Mississippi River near Anoka, established in 1931, is located below the Coon Rapids dam and above the intakes of the Minneapolis and St. Paul city water systems. At St. Paul the gaging station is located near the Robert Street bridge, and records here represent the combined flows of the Minnesota and Mississippi Rivers. As the entire municipal water supply of Minneapolis and St. Paul is taken from the river above this station and is returned to the river below the sewage plant at Pigs Eye Island, mean daily and annual flows for the St. Paul station are adjusted for this diversion. Streamflow has been recorded at St. Paul since 1892.

Table 1.—Summary of streamflow data.

	Mississippi River near Anoka	Minnesota River near Carver	Mississippi River at St. Paul	St. Croix R. at St. Croix Falls
Period of record	1931-1957	1934-1957	1892-1957	1902-1957
Drainage area ... sq mi	19,100	16,200	36,800	5,930
Mean flow ... cfs	7,070	3,061	9,890	4,047
Mean flow ... mgd	4,560	1,976	6,390	2,615
Maximum flow ... date	4-14-52	4-11-51	4-16-52	5-8-50
Maximum flow ... cfs	75,900	64,100	125,000	54,900
Minimum daily flow ... date	9-10-34	1-21-40	8-26-34	7-17-10
Minimum daily flow ... cfs	602	85	632	75
Minimum daily flow ... mgd	389	55	408	48
Daily flow exceeded 90 percent of time ... cfs	1,640	258	1,920	1,360
Daily flow exceeded 90 percent of time ... mgd	1,060	167	1,240	879
Mean annual flow ... af	5,120,000	2,220,000	7,160,000	2,928,000
Mean annual flow ... mg	1,669,000	722,000	2,333,000	954,000
Maximum annual flow ... af	10,150,000	4,917,000	15,350,000	5,310,000
Maximum annual flow ... mg	3,305,000	1,600,000	5,000,000	1,730,000
Minimum annual flow ... date	1934	1940	1934	1934
Minimum annual flow ... af	1,160,000	498,500	1,400,000	1,270,000
Minimum annual flow ... mg	378,000	163,000	456,000	414,000
Annual flow exceeded 90 percent of years ... mean cfs	2,900	1,220		2,450
Annual flow exceeded 90 percent of years ... af	2,100,000	883,000		1,775,000
Annual flow exceeded 90 percent of years ... mg	684,000	287,000		578,000
Minimum annual runoff 1935-57 ... in.	2.03	0.58	1.37	6.06
Mean annual runoff 1935-57 ... in.	5.47	2.56	4.08	11.07
Maximum annual runoff 1935-57 ... in.	9.96	5.70	7.92	16.82

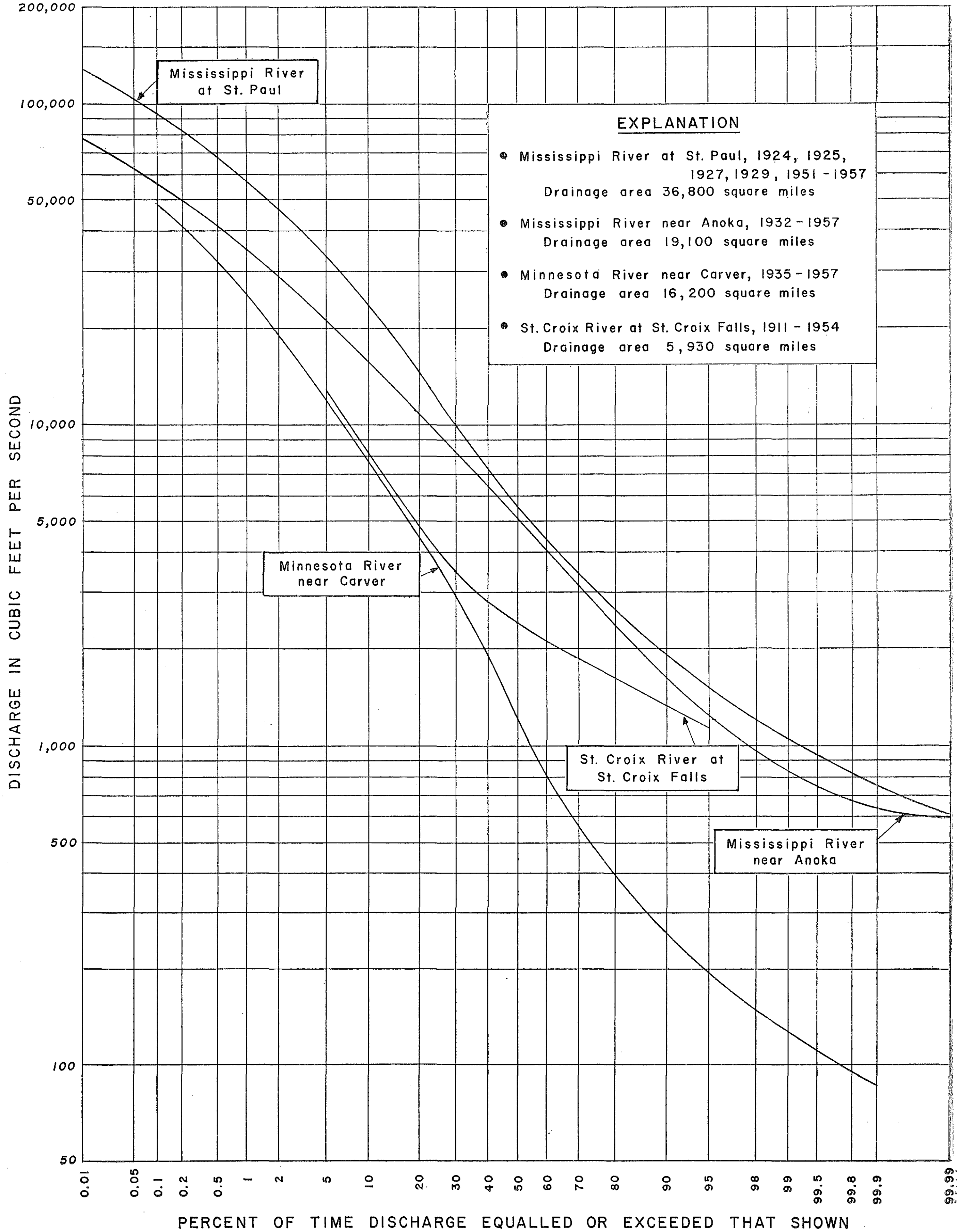


Figure 9. Duration curves of daily river flows

At the gaging station on the St. Croix River near St. Croix Falls, about 52 miles above the mouth, records have been kept since 1902. Streamflow at this station is affected by operation of the power dam a short distance upstream. Below the station, but above Stillwater, the Apple River with a watershed area of about 560 square miles joins the St. Croix on the Wisconsin side.

The flow of any stream varies seasonally and annually. The demand for water for municipal, industrial or agricultural purposes also varies seasonally. It is quite possible that periods of maximum demand may coincide with periods of minimum supply. Where the minimum flows of a stream are inadequate for certain purposes, they may be augmented by storing part of the high flows for release during critical periods or by diverting water into the stream from other sources.

The mean or average flow of a stream represents the theoretical maximum uniform flow which could be developed if all flows above the mean could be stored until needed. Under these ideal but unattainable conditions, the average flow of any one of the three major streams could provide sufficient water for all the foreseeable needs of the entire metropolitan area.

In estimating the adequacy of natural streamflow to meet a specific demand for water, the magnitude, frequency of occurrence, and duration of minimum flows are the determining factors. From these quantities the storage capacity required to augment low flows to a specified minimum may also be estimated.

Flow duration curves for the four gaging stations mentioned above are shown in figure 9. These curves are based on the daily mean flows for the entire period of record and show the percent of time in which any selected flow will probably be equalled or exceeded. The data in table 2 have been extracted from these curves. This table shows that if a flow of 1,500 cubic feet per second were required, it would be available in the Mississippi River near Anoka more than 90 percent of the time; in the St. Croix River at St. Croix Falls more than 80 percent of the time; and in the Minnesota River less than 50 percent of the time.

In general, duration curves with steeper slopes denote streams having a wide range from high flows to low flows. Streams which are subject to regulation by either natural or artificial storage will have curves with flatter slopes. A stream having ample natural storage in lakes, swamps and ground water aquifers will have well-sustained flows during periods of low rainfall. This condition is indicated by a flattening of the lower portion of the curve, such as is seen in the curves of the Mississippi near Anoke and of the St. Croix. The flow of all three streams is, of course, affected to some extent by storage in artificial reservoirs, from which water is released for various purposes such as flood control, power and navigation.

Duration curves do not take into consideration the chronological sequence of low flows, the season in which they occur, nor the duration of continuous low flows. A flow somewhat less than the minimum required may usually be tolerated if it lasts for only a brief period. It may be compensated for by a temporary reduction in consumption, or the shortage may be supplied from local or plant storage. A deficiency in supply for an extended period may have serious consequences and may require that streamflow be augmented by upstream storage or by other means.

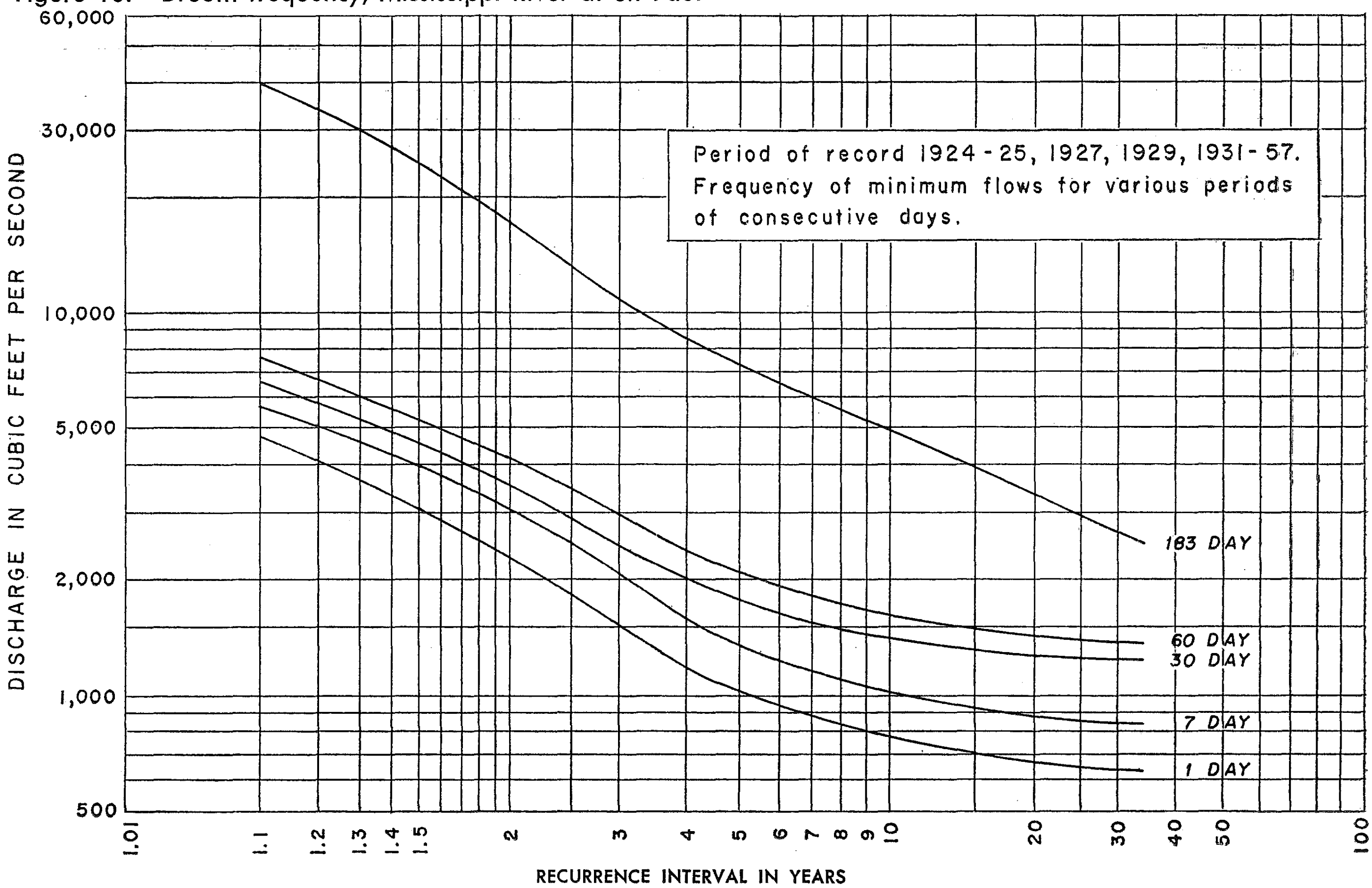
Figures 10 and 11 have been compiled to indicate the frequency of occurrence of flows which remain continuously below a given magnitude for various periods of time. For example, the 30-day curve shows that in the Mississippi at St. Paul a period of 30 days when flow does not exceed 2,000 cfs can be expected to occur once every four years on the average. In the Mississippi River above Minneapolis a flow of the same magnitude and period may be expected once every 3½ years.

The maximum period of consecutive days or months for which flows may be expected to remain less than a specified magnitude is indicated in figure 12. For example, from the curves it may be deduced that a flow not exceeding 2,000 cfs may be expected to occur in the Mississippi River at St. Paul for a maximum period of 3⅓ months; in the Mississippi near Anoka for a period of 7½ months; and in the St. Croix River at St. Croix Falls for a period of 5½ months.

Table 2.—Minimum discharges, in cubic feet per second, for selected percentages of total period of record.

Station	Max.	5	10	20	30	40	50	60	70	80	90	95	Min.
	Percent of total time indicated discharge is equaled or exceeded												
Mississippi River near Anoka	75,900	21,000	15,500	10,700	8000	6300	5100	4000	3200	2400	1640	1250	602
Minnesota River near Carver	64,100	12,200	7,600	4,180	2640	1860	1150	777	551	381	258	194	85
Mississippi River at St. Paul	125,000	33,700	23,500	14,700	9900	7330	5590	4410	3460	2660	1920	1515	632
St. Croix River at St. Croix Falls	54,900	12,700	8,230	4,740	3480	2810	2410	2110	1860	1630	1360	1120	—

Figure 10. Drouth frequency, Mississippi River at St. Paul



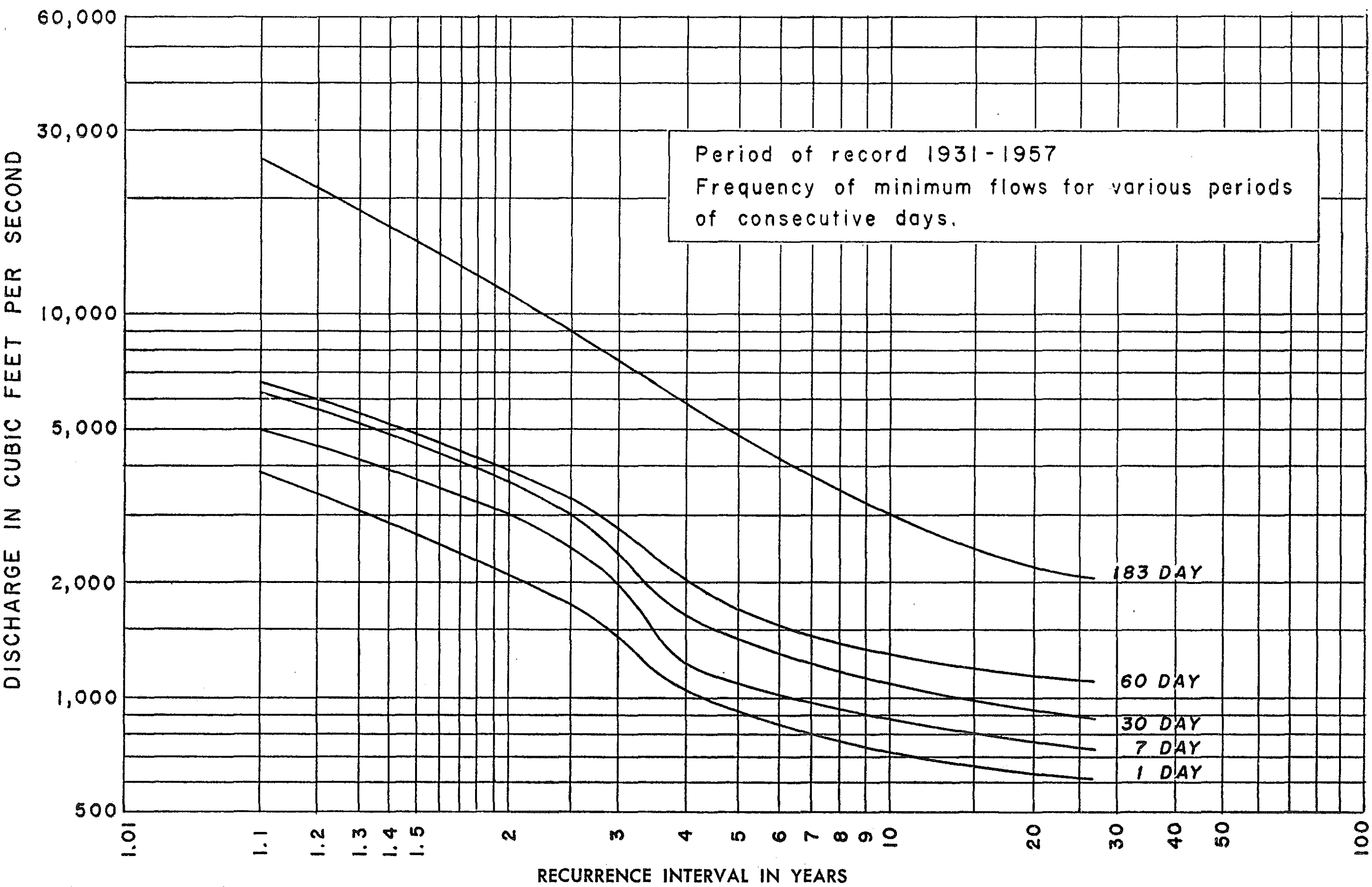


Figure 11. Drouth frequency, Mississippi River near Anoka

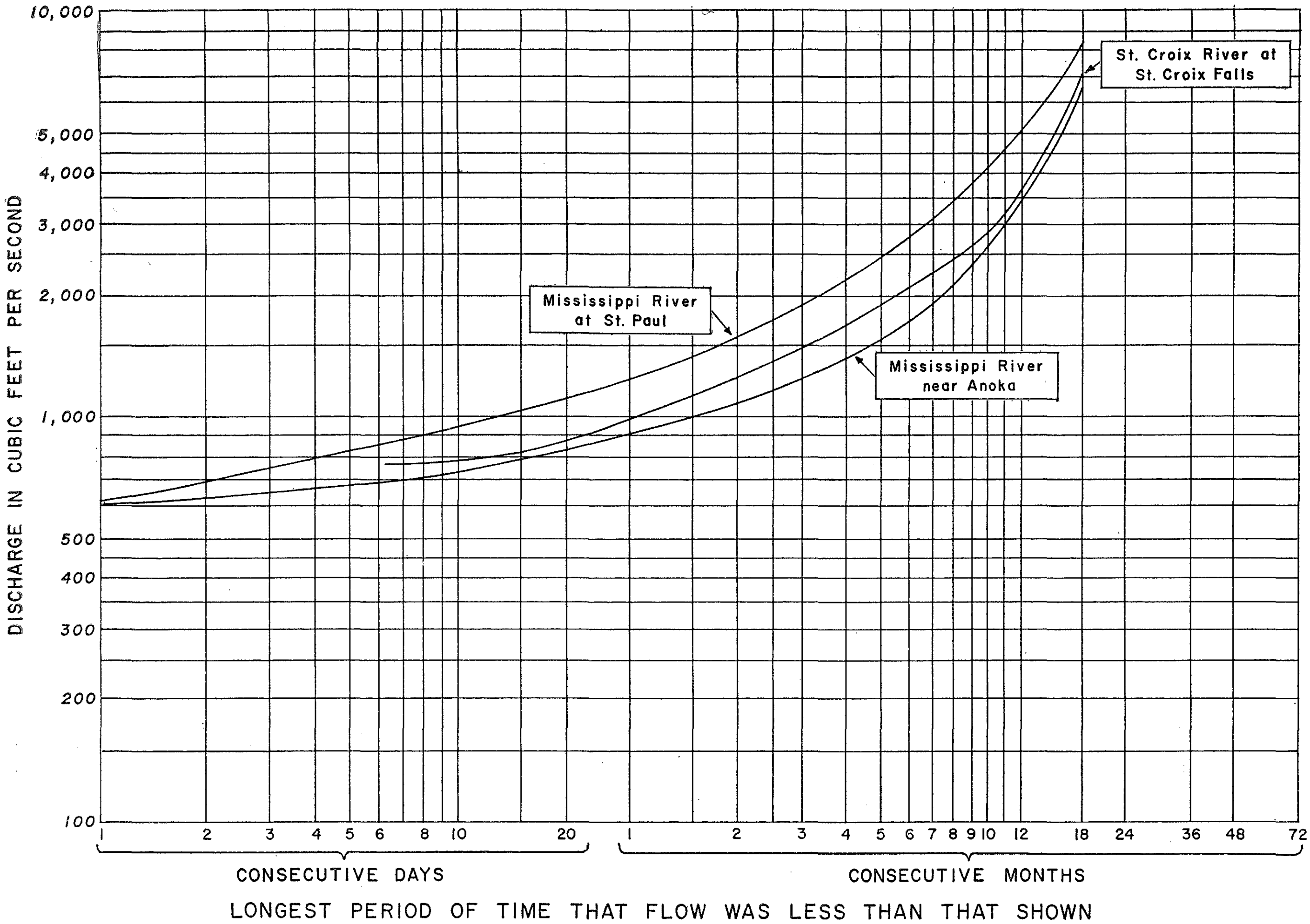


Figure 12. Maximum period of continuous low flows

WATER USE

DOMESTIC AND MUNICIPAL

Of the 114 municipalities in the metropolitan area, 52 have municipally owned water supply systems serving all or most of their residents. Eleven others have partly developed systems serving a small part of their area or have planned systems. (See table 3 and fig. 13.)

The Minneapolis and St. Paul systems use surface water as a source and take their supply from the Mississippi River at Fridley. Parts of 13 adjoining suburban communities purchase water from either Minneapolis or St. Paul. They furnish filtered, purified and softened water to about 58 percent of the total population of the area. All other municipal systems use ground water derived almost entirely from deep wells in the artesian aquifers.

Several suburban municipalities have ordinances requiring that central wells and distribution systems be installed for new housing developments and that these systems become municipal property upon their completion. There are 15 private suburban housing developments and several large apartment buildings with central water systems which presently serve about 12,000 persons and which eventually expect to serve nearly 33,000.

Fifty-one communities have no central water systems. Most of the existing municipal systems have not been extended to the less densely populated areas, and many have not been able to keep up with their rapidly expanding residential areas so that many homes in these areas depend upon private wells for water supply.

Of the total metropolitan population of 1,505,000, approximately 72 percent obtain their water supply for domestic purposes from public or community water systems; 28 percent use water from private wells. Municipal water systems in the area are listed in table 3. The situation is changing rapidly at the present time due to the extension of water systems and the construction of new wells.

Domestic and municipal water use is summarized in table 4. The figures are based, for the most part, on pumping records supplied by municipal water departments. Where pumping records could not be obtained, estimates of per capita water use were made. Commercial and industrial uses have been excluded. Municipal uses include domestic supply, fire protection, street cleaning and losses in the system.

Table 4.—Summary of present water use for municipal and domestic purposes, Metropolitan area.

	Population served	Percent of population	Water use (million gallons) Daily	Annual
From public or community water systems				
Communities with ground water systems	264,000	17.5	18.7	6,826
Communities with surface water systems	798,000	53.0	58.6	21,389
Communities with partly developed municipal water systems	13,000	0.9	0.6	214
Housing developments with central water systems	12,000	0.8	0.5	197
Total	1,087,000	72.2	78.4	28,626
From private wells				
In communities with water systems	56,000	3.7	2.5	912
In communities with partly developed municipal water systems	143,000	9.5	6.4	2,336
In suburban communities without water systems	131,000	8.7	5.9	2,154
In rural areas	88,000	5.9	2.2	803
Total	418,000	27.8	17.0	6,205
Total for Metropolitan area	1,505,000	100.0	95.4	34,831

Table 3.—Municipal water supplies, Metropolitan area

Municipality	Population	Source of water supply	Capacity of water system (mgd)	1958 water use* Daily average (mg)	1958 water use* Annual (mg)	Per capita use* (gpd)	Remarks
Anoka	9,600	3 wells	3.02	1.23	450	128	Includes new well added in 1959.
Bayport	3,000	2 wells	1.37	—	—	—	
Belle Plaine	1,920	2 wells	1.44	0.04	13	22	No large industries; numerous private wells in predominantly farming community.
Blaine	5,960	—	—	—	—	—	A small area is presently served by a ground water system obtained from private developers. By late 1961 at least 50 percent of the village will be served by these and other wells.
Bloomington	46,160	—	—	—	—	—	The densely populated part of the city will be served by a municipal system now under construction which will obtain water from Minneapolis Water Dept. 5 separate ground water systems in outlying areas have been donated to the city by developers.
Brooklyn Center	17,000	2 wells	3.17	1.96	716	115	2 new wells will be added to the system in 1960.
Brooklyn Park	8,300	—	—	—	—	—	A proposed system will eventually serve about 4,000 persons in the village.
Chaska	2,600	3 wells	3.67	0.26	96	100	Includes new well drilled in 1959.
Circle Pines	1,400	2 wells	1.80	—	—	—	Includes new well drilled in 1959.
Cologne	490	2 wells	0.61	0.02	7	41	Small farming community. Many private wells and no industry.
Columbia Heights	14,000	—	—	—	—	—	Served by Minneapolis Water Dept.
Coon Rapids	9,200	—	—	—	—	—	6 central well systems, which serve part of the area, have been given to village by home developers.
Edina	24,000	8 wells	10.08	2.83	1,033	118	Small part of area served by Minneapolis Water Dept.
Excelsior	2,000	2 wells	1.73	0.27	100	135	
Falcon Heights	5,000	—	—	—	—	—	Most of village is served by St. Paul Water Dept.
Farmington	2,200	3 wells	2.59	0.20	73	91	Includes new well drilled in 1959.
Forest Lake	2,300	2 wells	0.72	0.22	79	96	
Fridley	11,000	1 well	1.58	0.51	186	51	4 new wells are planned. Small area served by Minneapolis system.
Golden Valley	12,400	—	—	—	—	—	About 1,200 persons are served by connections to mains of Minneapolis Water Dept.
Hampton	300	1 well	0.14	0.01	2	20	No large industries; numerous private wells in predominantly farming community.
Hastings	8,500	3 wells	3.02	0.65	237	76	Per capita consumption in low because of private wells in outlying areas.
Hilltop	700	—	—	—	—	—	Almost all of the village is served by the Minneapolis Water Department.
Hopkins	10,000	3 wells	6.12	1.12	409	112	Most of the local industries use municipal water supply.
Jordan	1,680	3 wells	1.22	0.04	15	24	No large industries; numerous private wells in predominantly farming community.
Lakeville	850	1 well	0.72	—	—	—	
Landfall	310	1 well	0.14	0.01	3	27	Trailer park.
Lauderdale	1,300	—	—	—	—	—	Served by St. Paul Water Department.
Long Lake	800	1 well	0.50	0.05	17	63	Some private wells in the area.
Loretto	200	1 well	0.14	—	—	—	
Mahtomedi	1,600	3 wells	2.02	0.08	29	50	Many private wells in area.
Maple Plain	650	1 well	0.50	0.03	9	38	No large industries; numerous private wells in predominantly farming community.
Maplewood	16,000	—	—	—	—	—	Community served by St. Paul Water Dept., several housing development water systems, and many private wells.

*Amounts include water used for domestic, industrial and commercial purposes.

Table 3.—Municipal water supplies, Metropolitan area—Continued.

Municipality	Population	Source of water supply	Capacity of water system (mgd)	1958 water use* Daily average (mg)	1958 water use* Annual (mg)	Per capita use* (gpd)	Remarks
Mendota Heights	4,500	—	—	—	—	—	Community served by St. Paul Water Department, several housing development water systems, and many private wells.
Minneapolis	553,000	Mississippi River	150	56.10	20,478	101	
Minnetonka Beach	450	2 wells	0.72	—	—	—	
Morningside	2,000	—	—	—	—	—	Served by Minneapolis Water Dept.
Mound	2,800	3 wells	2.53	0.21	78	75	
Mounds View	5,880	—	—	—	—	—	Part of a new municipal water system was constructed in 1960 and future additions are expected.
New Brighton	4,800	4 wells	4.18	0.20	73	42	Consumption is low because system does not serve entire area. Additions to the system are planned for 1960-61.
New Hope	2,630	—	—	—	—	—	A municipal well was drilled in 1959. A water system with a capacity of 351 mgy is planned.
New Trier	100	1 well	—	—	—	—	
North St. Paul	7,000	3 wells	4.32	0.50	184	71	
Osseo	1,700	2 wells	1.73	0.14	52	82	
Prior Lake	700	2 wells	1.01	—	—	—	
Robbinsdale	16,000	5 wells	6.70	1.20	438	75	
Rockford	500	1 well	0.36	0.04	13	70	
Rogers	300	1 well	0.22	0.02	6	66	No large industries; many private wells in predominantly farming community.
Rosemount	800	2 wells	0.47	0.05	20	63	Do.
Roseville	19,500	—	—	—	—	—	Partly served by St. Paul Water Department and by housing development system.
St. Anthony	3,500	5 wells	3.82	0.24	88	69	Includes new wells added in 1959 and 1960.
St. Bonifacius	500	1 well	—	—	—	—	A municipal well was drilled in November 1958, and a municipal water system was constructed in 1959.
St. Louis Park	40,000	10 wells	14.98	3.74	1,366	94	A new well was added to the system in 1960.
St. Paul	343,000	Mississippi River & Centerville Lakes	120	39.97	14,591	116	
St. Paul Park	2,900	2 wells	1.15	0.11	40	38	No large industries; many private wells in predominantly farming community.
Savage	780	2 wells	0.23	0.12	44	178	New well drilled in 1959 to replace both wells; capacity of system is 0.86 mgd. Per capita use is very high because of a large industry which uses municipal supply.
Shakopee	4,400	3 wells	4.18	0.43	157	103	
South St. Paul	21,500	3 wells	7.12	1.65	601	77	Large industries have private wells. Small area served by St. Paul Water Department.
Spring Lake Park	3,030	—	—	—	—	—	A municipal water system has been considered.
Stillwater	8,400	4 wells	4.82	1.06	387	126	High per capita use is due to industrial use of municipal supply.
Waconia	2,200	2 wells	1.22	0.10	37	45	No large industries; many private wells in predominantly farming community.
Wayzata	2,800	2 wells	2.97	0.44	161	157	High per capita use is due to industrial use of municipal water supply.
West St. Paul	12,000	—	—	—	—	—	Served by St. Paul Water Department.
White Bear Lake	13,500	4 wells	3.17	—	—	—	Includes new well drilled in 1959.

*Amounts include water used for domestic, industrial and commercial purposes.

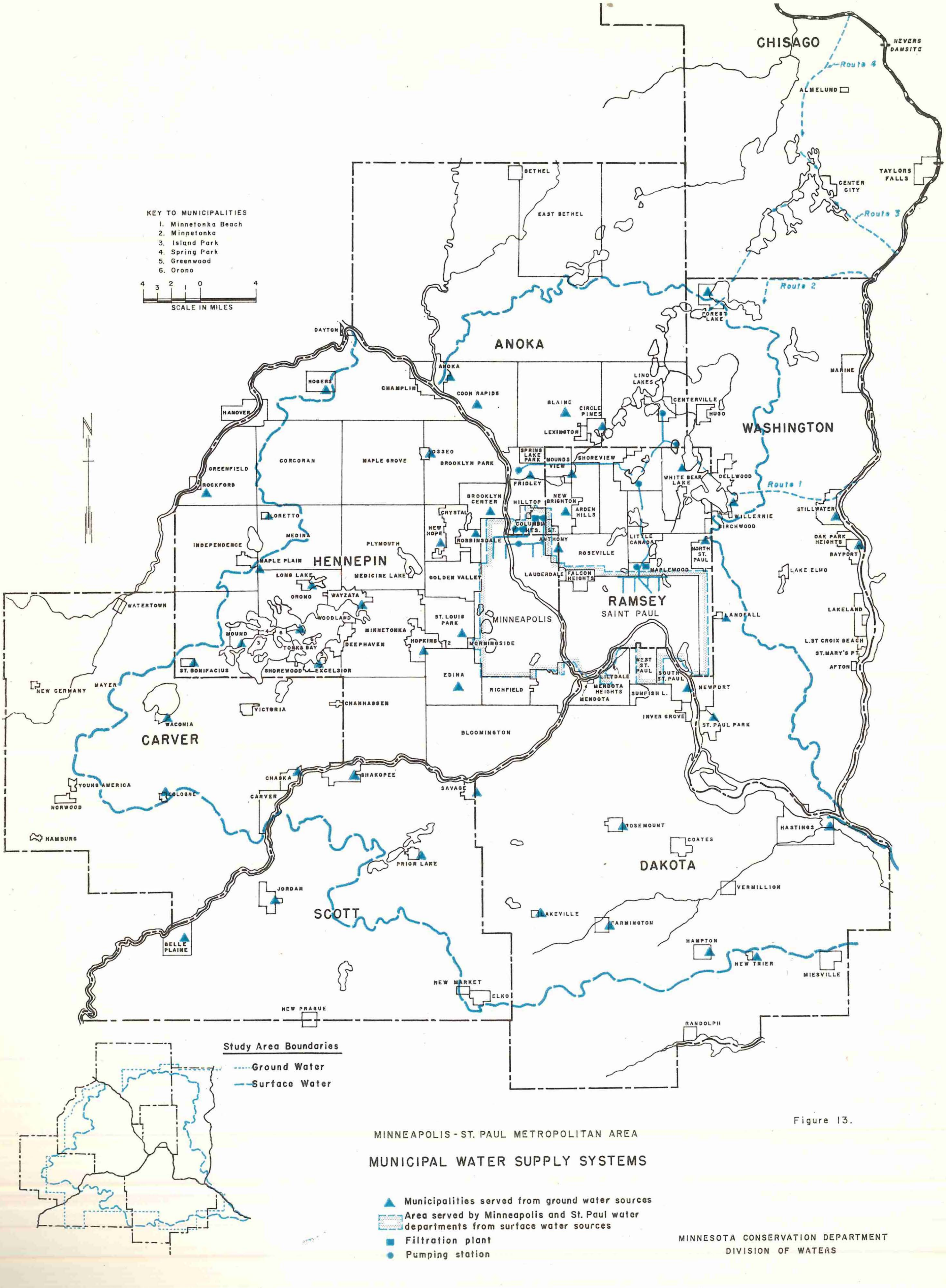


Figure 13.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

MUNICIPAL WATER SUPPLY SYSTEMS

- Municipalities served from ground water sources
- Area served by Minneapolis and St. Paul water departments from surface water sources
- Filtration plant
- Pumping station

MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF WATERS

MINNEAPOLIS WATER SUPPLY SYSTEM

The Minneapolis Water Department pumps water from the Mississippi River at Fridley into a softening plant with a capacity of 120 million gallons per day. Softened water is then pumped to the Fridley treatment plant with a capacity of 80 mgd or to the Columbia Heights treatment plant with a capacity of 78 mgd. Treated water is then distributed to three storage reservoirs located in Fridley, Columbia Heights and Hilltop, which have capacities of 32, 45 and 40 million gallons, respectively. The distribution system is so constructed that either of the two treatment plants could supply the entire service area except during periods of maximum water use.

In 1959 the total water pumped into the Minneapolis water system during July, the maximum month, was 2,658 mg, at an average rate of 85.8 mgd. On the maximum day, pumpage was 129.2 mg.

ST. PAUL WATER SUPPLY SYSTEM

St. Paul has two sources of water supply. Most of the water is taken from the Mississippi River near Fridley where the pumping station has a capacity of 80 mgd. An auxiliary pumping station located at Centerville, which draws water from the Centerville chain of lakes, consists of two pumps with rated capacities of 25 and 15 mgd. These pumps are usually operated only when sufficient water has been stored in the Centerville Lake chain. All of the water pumped from the Mississippi River or from the Centerville Lake chain goes into the Vadnais Lake system from which it is pumped into the McCarron Lake filtration and purification plant, which has a capacity of 100 mgd. Treated water is distributed to three main reservoirs with a total capacity of 68 mg. In addition, six pumping stations, with a combined capacity of 7.7 mg, lift water into seven elevated storage tanks.

Recent improvements in the water supply system include new pumping systems to increase capacities of the Fridley and Centerville stations, a new 60-inch conduit from the Fridley pumping station to the Vadnais Lake chain, and a 90-inch-diameter conduit from Vadnais Lake to the filtration plant. Other improvements were made by enlarging and improving the filtration plant and the storage and distribution system.

In 1959 total water delivered to the St. Paul system during the maximum month was 2,140 mg, at an average rate of 69.0 mgd. Pumpage on the maximum day was 93 mg.

INDUSTRIAL AND COMMERCIAL

Water used for commercial and industrial purposes in the metropolitan area averages 126 million gallons daily and totals 46,000 million gallons annually. Of this total, 75 percent is used within the city limits of Minneapolis and St. Paul. About 70 percent, or 88 million gallons daily, is derived from ground water sources.

For the purposes of this report, commercial use is defined as the water used by stores, office buildings, theaters, hotels, and restaurants for air conditioning, cleaning, drinking and sanitation. Industrial uses include water used for cleaning and processing foods and food products, or for cleaning, cooling, processing or transporting all the varied products of industry, and for other operations in industrial plants. It includes boiler-feed and make-up water used in the production of electric power by steam plants and ground water used for cooling and condensing in industrial power plants. It does not include the large amount of surface water that is withdrawn by power plants for cooling and condensing which is returned directly to the river with little loss.

Metered records of ground water withdrawn and discharged to sewers after use are kept by both Minneapolis and St. Paul water departments as a basis for payments to the Minneapolis-St. Paul Sanitary District. Records of ground water pumpage have been obtained directly from the owners of large wells. From these sources a summary of ground water use has been made (table 6).

Records of the use of surface water from the St. Paul and Minneapolis water systems for these purposes are not available. Therefore an estimate of the use of surface water for commercial and industrial purposes has been made by subtracting the known domestic and other uses from the total amount of water delivered by these systems.

Industrial ground water use by type of industry is shown graphically in figure 14. The meat packing, malt beverage, petroleum refining, milling, paper products and stone, clay, and rubber products industries use more than 18 billion gallons of ground water annually; this accounts for two-thirds of the total industrial ground water use in the metropolitan area.

The choice of private wells or city water systems as a source of supply has been determined by factors such as chemical quality, temperature, cost and availability of water. The presence or absence of minute quantities of minerals may seriously affect the suitability of water for such purposes as paper making and the manufacture of malt beverages. Slight seasonal changes in chemical quality or temperature may make product control difficult in some industries.

The uniformly low temperatures of ground water make it ideal for air conditioning, and it is used for this purpose in many installations. Figure 15 shows the commercial ground water use in Minneapolis and St. Paul in 1957. The periods of greatest use occur between June and September and result largely from increased use of water for air conditioning which is estimated at nearly 2 billion gallons for Minneapolis and St. Paul during these four summer months.

Table 5.—Water pumped by Minneapolis and St. Paul water systems.

	Minneapolis			St. Paul		
Year	Annual pumpage (mg)	Average daily pumpage (mg)	Population served	Annual pumpage (mg)	Average daily pumpage (mg)	Population served
1930	20,137	55.2	470,000	9,135	24.2	270,000
1940	18,674	51.0	490,000	7,940	23.2	288,000
1950	20,060	55.0	515,000	12,279	33.1	310,000
1959	21,491	58.9	540,000	15,759	43.2	332,000

Table 6.—Water use for industrial and commercial purposes.

	Industrial use (million gallons)		Commercial use (million gallons)		Total (million gallons)	
	Daily	Annual	Daily	Annual	Daily	Annual
Ground water						
Minneapolis	24.3	8,872	6.5	2,372	30.8	11,244
St. Paul	19.4	7,073	5.9	2,154	25.3	9,227
Suburban communities	28.3	10,388	3.2	1,168	31.5	11,506
Special industrial uses	0.2	74	—	—	0.2	74
Total	72.2	26,357	15.6	5,694	87.8	32,051
Surface water						
Minneapolis					21.1	7,702
St. Paul					16.4	5,986
Suburban communities					0.6	219
Special industrial uses					0.1	27
Total					38.2	13,934
Total, ground and surface water					126.0	45,985

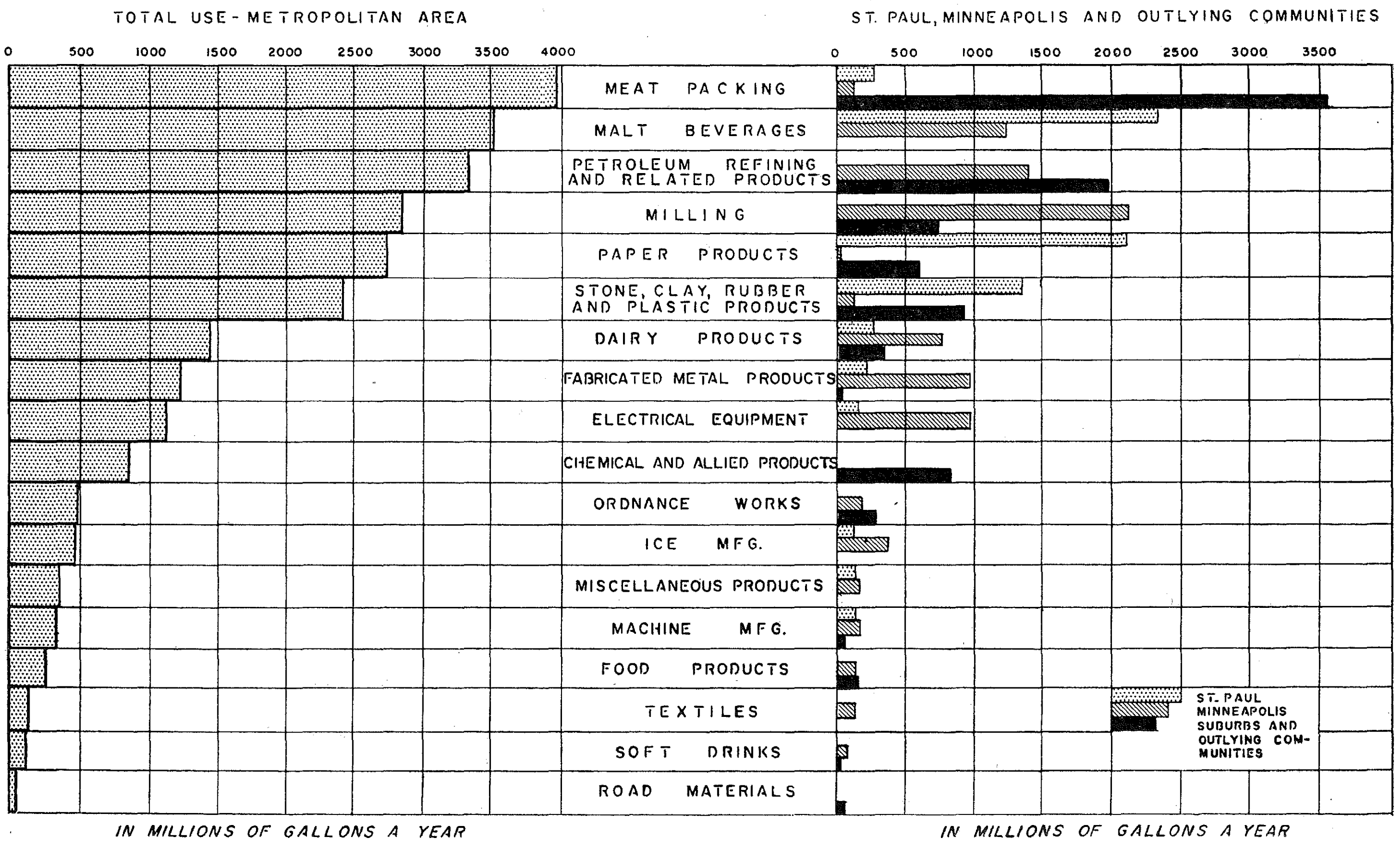


Figure 14. ANNUAL INDUSTRIAL USE OF GROUND WATER IN THE METROPOLITAN AREA

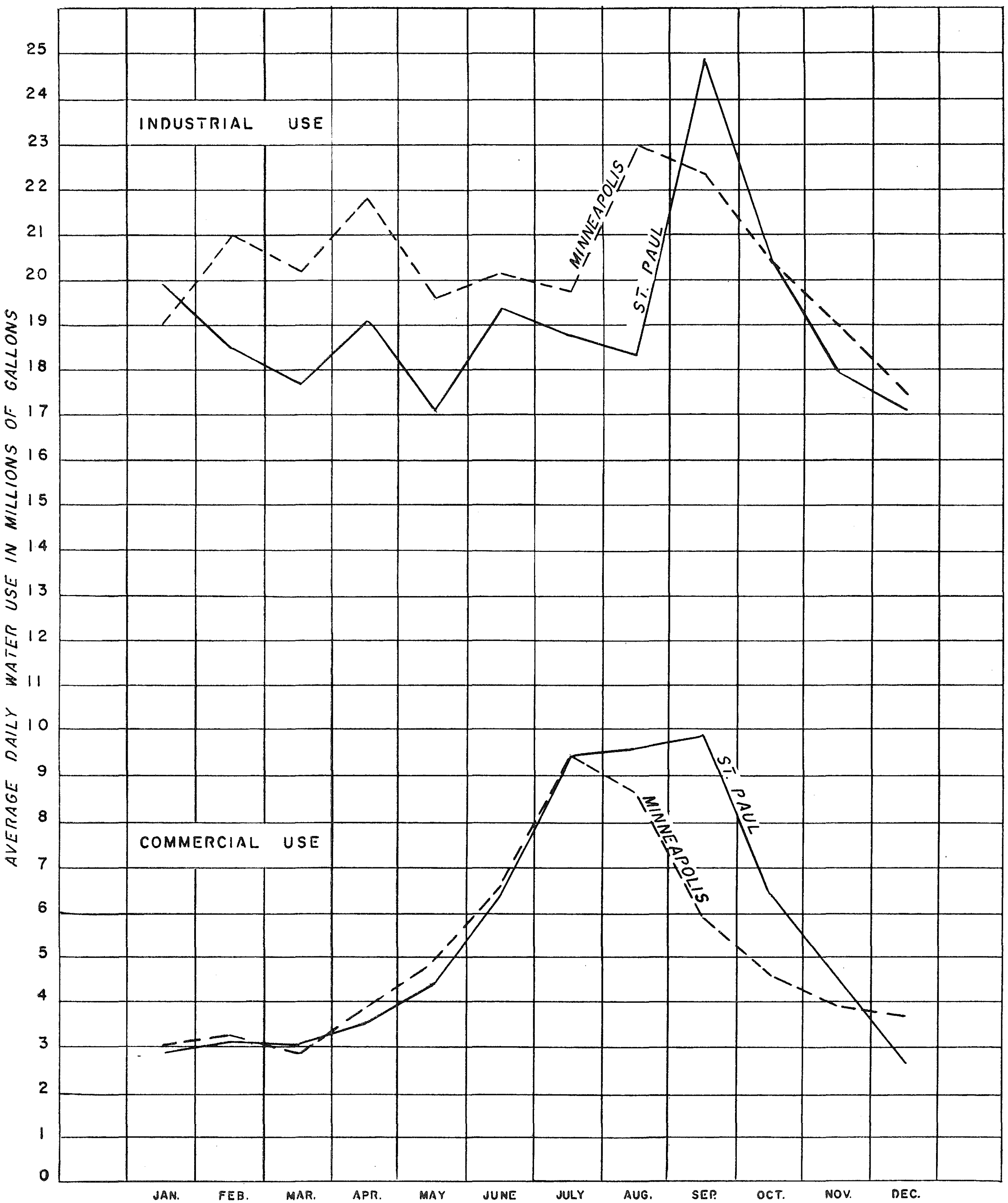


Figure 15. INDUSTRIAL AND COMMERCIAL GROUND WATER USE IN MINNEAPOLIS AND ST. PAUL

Figure 15 also illustrates the seasonal variation in industrial use of ground water in the two cities. The high July use in Minneapolis is attributed to increased use by milling industries, whereas the high September use in St. Paul appears to be caused by increased use by the malt beverage, stone, clay, rubber and plastics industries.

A comparison of present industrial and commercial ground water use with corresponding uses in 1936 shows an increase of over 100 percent, from 42 million gallons per day in 1936 to nearly 88 million gallons per day at the present time.

In 1932, the five Minneapolis industries with the largest ground water use were:

1. Gas manufacturing
2. Dairy products
3. Milling
4. Ice manufacturing
5. Railroads

At present the largest Minneapolis ground water users are:

1. Milling
2. Petroleum refining and related industries
3. Malt beverage
4. Electrical machinery
5. Fabricated metal products

Technological progress has created new large water-using industries to replace those of the 1930's. Gas manufacturing and railroad water uses are no longer important; industrial ice manufacturing has declined with the advent of improved refrigeration techniques; and dairy products industries today require less water for the same amount of production. Only the milling industry remains a large water user. Future technological advances will create new industries or change the water uses of present industries in the Twin Cities. A brief discussion of future industrial water use is included in the section dealing with future water use.

MISCELLANEOUS

Both surface water from the city systems and ground water have been used for many years to maintain certain lakes in the area at more desirable stages. The first well for this purpose in Ramsey County was drilled at White Bear Lake in 1903. Ramsey County now has 15 wells which furnish supplementary water supply to 13 lakes when needed. Hennepin County maintains seven wells from which water is pumped into Minnetonka Lake. Since pumping began in 1938 a total of about 33 billion gallons has been pumped from these wells, about 90 percent in the first five years of operation. Private lake improvement associations and municipalities have permits to appropriate water from wells to improve several lakes in the area.

Appropriations of water for lake improvement vary widely from year to year. For this reason it is difficult to arrive at an average figure for this purpose; the average daily pumpage for 1958, 5.8 mgd, has been included in the estimate of miscellaneous uses in table 7.

Golf courses in the area are estimated to use, on the average, a total of 450 mgy, equivalent to 1.2 mgd.

The water use for supplemental irrigation to increase production of agricultural crops in the metropolitan area is 116 mgy. This estimate is based on a recorded pumpage of 58 mgy for 2,000 acres under permit from the Division of Waters and an estimated pumpage of the same amount for about 2,000 acres not under permit. Most of the acreage not under permit was being irrigated before the law requiring permits was enacted, and records of pumpage on these lands are not available.

On the basis of Bureau of the Census records for 1954, it is estimated that 200,000 cattle and 150,000 hogs were raised in the area in 1958. Agricultural economists estimate that the average daily water use is 7.2 gallons for cattle and 4.5 gallons for hogs. Using these data, the estimated consumptive water use for livestock is 2.1 mgd.

Table 7.—Present water use.

	Ground water (mgd)	Surface water (mgd)	Total (mgd)
Industrial and commercial	87.8	38.2	126.0
Domestic and community	19.8	58.6	78.4
Private domestic	17.0	—	17.0
Miscellaneous	11.6	—	11.6
Total	136.2	96.8	233.0

FUTURE WATER NEEDS

In attempting to estimate the adequacy of the available water supplies to meet the future needs of the area, a number of questions need to be answered:

1. What will be the probable total water demand for all purposes?
2. How much of the area will be served by public or municipal distribution systems?
3. How much of the water supply will continue to be taken from private wells — for domestic, industrial or commercial purposes?
4. Of the public distribution systems, how many will use ground water? How many will use surface water?
5. Can the Mississippi River continue to supply all the surface water needed? If not, what other sources of supply can be used?
6. What means are available for reducing the demand for water?

An estimate of the water needs of the metropolitan area for the years 1980 and 2000 is shown in table 8. The use of predicted population growth combined with estimates of per capita use as criteria, although widely used in regional and national studies, do not furnish a satisfactory basis for predicting future water needs for all purposes for a highly industrialized metropolitan unit. In this study, only increases in domestic and municipal uses are based directly on population. Future water needs for industrial purposes are estimated separately because they are considered to be partly independent of population growth.

Population estimates for the study area are based on the 1960 U. S. census, projected to the year 1980 by applying the same percentage increase factors for each county as were used in the Population Study, Part II, issued by the Metropolitan Planning Commission in February 1961. A further projection to the year 2000 was made by applying to the same population the percentage of growth between the years 1980 and 2000 predicted in the recent report by the Minneapolis-St. Paul Sanitary District, which covers an area reasonably comparable to that used in this study. Using these methods the 1980 population should be 2,277,000, an increase of 772,000 or 51 percent over the present population of 1,505,000. The population in the year 2000 should approximate 2,814,000 or 24 percent greater than the 1980 population.

Table 3 shows that in the municipalities which have central water systems, per capita consumption, based on total annual pumpage, ranges from 22 to 178 gpd. This disparity is explained by differences in living conditions, the amount and nature of local industry, density of population, and the extent of municipal services. Per capita use in St. Paul and Minneapolis has shown a steady but moderate annual increase over a long period. At present the water use for domestic, municipal and public purposes in the two cities, excluding all known commercial and industrial uses, averages about 70 gpd per person. Computations based on the best available records of suburban communities, assuming comparable living conditions and water supply from central water systems, show about the same per capita consumption. As the suburban areas become more urbanized, domestic water consumption should become more uniform over the entire area and should eventually become stabilized.

As the communities which are now suburban or semirural in character become more densely populated, a shift from the use of private wells for domestic water supply to municipal water systems is inevitable. Either depletion of that part of the ground water supply which is available to shallow wells or increasing pollution of the water in shallow aquifers will eventually force adoption of a system in which the requisite quantity of water can be assured and its quality more effectively maintained and protected. The number of persons using water from private domestic wells should decline by 1980 to about 200,000. A population of 2,077,000 should then be served by municipal water systems, and an increase in per capita use to 85 gpd is then to be expected. By the year 2000 about 150,000 persons of a total population of 2,814,000 will use private domestic wells, and the remaining 2,664,000 persons will be served by municipal systems. No further increase in per capita use is anticipated in the period 1980-2000.

The future water requirements for industry will be determined not only by the growth of industry but also by changes in methods of manufacture. Predicted increases may be offset in part by changes in technology which reduce the amount of water required per unit of production and by enforced restrictions on water use in the public interest to conserve the water supply.

Industrial water requirements are herein predicated solely on the basis of anticipated expansion of the industries now established in the area. The greatest increase is expected in the paper, chemi-

Table 8.—Present and future water use, Metropolitan area.

	Present (million gallons)		1980 (million gallons)		2000 (million gallons)	
	Daily	Annual	Daily	Annual	Daily	Annual
Industrial and commercial	126.0	46,000	175	63,900	210	76,650
Domestic and community	78.4	28,600	176	64,200	226	82,500
Private domestic	17.0	6,200	10	3,650	8	2,900
Miscellaneous	11.6	4,200	30	10,950	30	10,950
Total	233.0	85,000	391	142,700	474	173,000
Ground water	136.2	49,700	—	—	—	—
Surface water	96.8	35,300	—	—	—	—

cal and petroleum industries and in the stone, clay, rubber and plastics group. Three of these industries are now among the top five industrial water users in this locality. Some of the most rapidly expanding industries in the area, such as electronics and instruments, do not require much water. It is recognized, however, that new and at present unknown industries may be established here which may increase the use of water beyond the quantity predicted.

Current trends indicate that the use of ground water for air conditioning will be replaced in many buildings by mechanical refrigeration. Present practices in air conditioning make inefficient use of the cooling capacity of ground water which generally has a temperature of about 50°F. It is both desirable and practicable to curtail the present wasteful use of this resource.

Although the number of commercial water users may double by 1980, the total water use for commercial purposes should increase no more than 25 percent to an estimated 20 mgd. No further increase is assumed after 1980.

Of the miscellaneous uses shown in table 7, water pumped for maintaining lake levels accounts for about one-half of the total. Other uses in this category include water for livestock, for agricultural irrigation, and for watering golf courses. The total present withdrawal of 11.6 million gallons daily for these purposes is expected to increase to 30 million gallons by 1980.

THE FUTURE WATER SUPPLY

Any attempt to forecast the future apportionment of the available ground water supply among the many present and potential users is speculative to say the least. Unless a local administrative authority is established to plan and direct these matters, the development of new water supplies during the next few years is likely to be haphazard. Uncontrolled competition for ground water between municipalities and industry, or between the several municipalities, would certainly not be favorable to maximum feasible conservation of this resource.

Ground Water

Of the 126 mgd now being used for industrial and commercial purposes, about 70 percent is ground water. About 25 percent of the 78 mgd now supplied from public water systems for domestic and municipal purposes also comes from this source. Total ground water withdrawal now is estimated to be 136 mgd.

Of the estimated total ground water recharge of 380 mgd it is probable that an ultimate supply of about 250 mgd could be developed without serious lowering of the piezometric surface. This yield can be obtained through an optimum spacing of wells and by limiting withdrawals to an assigned quantity for each well or well field. The major portion of the demand for ground water is, and will remain, localized in certain parts of the metropolitan area. To achieve the optimum well spacing many new wells will have to be drilled and some wells now producing water may have to be abandoned. In view of the legal and political obstacles that must be overcome, the development of a sustained supply of more than 200 mgd in the near future cannot be confidently predicted. Further experience and study of data from wells will determine the ultimate safe yield.

As the rate of pumping from an aquifer increases in any limited area, the cones of depression in the pressure surface produced by each well begin to overlap and interfere with each other. If withdrawals exceed the rate at which water moves into the aquifer, a general lowering of the pressure surface occurs. This condition has existed for some years in downtown Minneapolis and is appearing elsewhere where pumping is heavy and wells are concentrated. Where such lowering is due chiefly to heavy seasonal demands for air conditioning, water levels may be partly or wholly restored during the off season, depending on the relationship between the rates of withdrawal and recharge. Pumping during periods of maximum demand may then be allowed to exceed somewhat the average rate of recharge. Continuous year-round pumping at the rate required for municipal systems would result in a more general and widespread lowering of ground water levels without opportunity for recovery.

Maximum development of ground water resources can be attained only by complete control of water supply and distribution such as would be provided by a single metropolitan water authority. In the absence of such an organization and authority, competition for existing water supplies is certain to increase and the geographical distribution of wells will not be carefully planned to produce the maximum yield.

The additional cost of sinking deeper wells, of lowering pumps, and of lifting water against greater heads, although substantial, should not prevent the fullest development and use of the available ground water supply. An adequate supply of water of good quality is a necessity and must be obtained whatever the cost. A fluctuating ground water level due to changing seasonal demands and variable rates of recharge is to be expected. A moderate lowering of the piezometric surface in an artesian aquifer, even if permanent, may have beneficial results in increasing the water supply available. The increased gradient of the piezometric surface would cause an increase in the rate of horizontal movement of water through the aquifer as well as an outward shift in the ground water divides. Thus, the direction of flow in marginal areas would be reversed and water would flow toward the area of withdrawal instead of away from it. A substantial and ever-increasing lowering of ground water levels over a considerable area, indicating an average withdrawal greater than average recharge, is a condition which should not be allowed to develop.

This, however, is a situation which we may expect when the use of ground water approaches 200 mgd. It should be remembered that this figure is an average daily use. Records of the water departments of both Minneapolis and St. Paul show the maximum daily pumpage, occurring during the months of July, August and September, to be about twice the average daily demand. Municipal systems must have storage capacity in elevated tanks or at ground level sufficient to take care of sudden, short-term increases in demand. To provide enough local storage for a protracted period of excessive demand would be costly and difficult if not impossible. If wells are developed within the urbanized portion of the metropolitan area to supply an average demand of 200 mgd for municipal, industrial and commercial purposes, the daily pumping rates will greatly exceed the average rate for considerable periods of time.

Making allowances for uncertainties and variability in predicted demand and in estimates of available water supply, it appears certain that not more than half the total water demand in 1980 can come from ground water. The remainder, as well as any additional supplies required by future growth of the metropolitan area, must come from surface water.

Surface Water

The demand for surface water for municipal systems in this area will probably increase during the next 20 years to an average of about 200 mgd. Records of the Minneapolis Water Department show that average pumpage during the maximum month in each of the years 1955 to 1959 exceeded the average pumpage for that year by ratios of from 1.3:1 to 1.5:1. In 1959, in both Minneapolis and St. Paul, pumpage on the maximum day was 2.2 times the average daily pumpage, and there were 15 days when Minneapolis pumped more than 100 million gallons from the river. Municipal systems designed to supply an average demand of 200 mgd should, therefore, be capable of pumping about twice that amount, or 400 mgd, from the river for periods of a few days to several weeks.

Converted into units in which streamflow is commonly measured, the predicted average demand for surface water for municipal supply in 1980 is equivalent to 310 cfs, and the maximum demand is equivalent to 620 cfs. After completion of the navigation locks at St. Anthony Falls a flow of about 350 cfs will be required for operation of the locks to accommodate the expected increase in traffic. A flow of about 1,000 cfs in the Mississippi River above Minneapolis will barely meet the maximum requirements for these two purposes alone.

Other needs that are now served by the Mississippi River below the present intakes of the two city water systems are the hydroelectric power plants at St. Anthony Falls, at Lock and Dam No. 1, and at the Riverside steam power plant. The hydro stations would probably not be able to operate when flows above Minneapolis are less than 1,000 cfs. The Riverside plant takes an average of about 340 cfs from the river for cooling and condensing, most of which is returned directly to the river at a higher temperature. Although the quantity of water intake could be reduced by recirculation and other plant modification, the total temperature effect on the river water would not be substantially changed.

Considering the water supply needs of the metropolitan area anticipated for the year 1980, unsatisfactory conditions will exist in the river in its course through the cities whenever the flow is less than 1,200 cfs. A flow of 1,000 cfs in the river above Minneapolis is the absolute minimum necessary to meet these needs. These flows do not take into account the water needed for dilution of the effluent from the sewage treatment plant.

For the year 2000, the average demand for surface water for municipal systems will approach 274 mgd or 425 cfs. The maximum demand would be 550 mgd or 850 cfs. A flow of 1,500 cfs is required for municipal, navigation and power needs if undesirable conditions are to be avoided.

From the curves in figures 9 and 12 for the Mississippi River at Anoka and from other records obtained at this station the following information is extracted:

In 1934 from July 13 to September 23—a period of 72 days—the mean daily flow was less than 1,000 cfs on all but four scattered days.

Flows have not been less than 1,000 cfs since January 1937, nor less than 1,200 cfs since January 1940.

The longest period of time during which the flow has remained below 1,000 cfs is about 1½ months; it has remained below 1,200 cfs for a period of about 2½ months; and below 1,500 cfs for a period of about 4½ months.

Flows will equal or exceed 1,000 cfs about 97.5 percent of the time; 1,200 cfs about 95 percent of the time; and 1,500 cfs about 90 percent of the time.

At the present rate of water use the flow of the Mississippi River is sufficient to meet the ordinary requirements of the Minneapolis and St. Paul water systems and the suburban areas now supplied by these systems. If the minimum flow of the river, which has occurred in the past, should occur again, coincident with maximum demands from the city systems, there would be barely enough flow left in the stream below the city intakes for operation of the navigation locks and for cooling water for the steam power plants.

With the metropolitan population expected by 1980 and with a greater proportion of the domestic and industrial requirements then being served by municipal systems using water from the river, there will be periods when the streamflow is not adequate for the combined needs of municipal water supply, navigation and power. As the demand increases, these periods may be of longer duration and occur with increasing frequency. The metropolitan area is approaching a situation where the margin of safety between supply and demand is too small. The necessary steps must soon be taken to insure a sufficient supply at all times.

WHAT CAN BE DONE?

What may be done to keep the supply-demand relationship within safe limits? Three general approaches to this problem appear feasible:

1. Reduce the demand.
2. Provide storage.
3. Develop new sources of supply.

Reduction of Demand

Where a commodity is abundant, cheap, and its use unrestricted, it is to be expected that wasteful practices will become customary, habitual, and accepted without question. The metropolitan area, where water is one of the cheapest commodities, is no exception. Other communities where the scarcity or high cost of water is a controlling factor have found it advisable to reduce the demand for water by eliminating waste. As the demand increases here, it will be profitable to examine closely all possibilities for economizing in the use of water. Some of these possibilities are discussed in the following paragraphs.

The cooling function of air-conditioning systems is performed by some type of heat-exchanger, in which part of the heat energy of the air is transferred to the cooling water. With abundant ground water at a temperature of 47° to 50° available for this purpose, some commercial air-conditioning systems have not been designed to make the most efficient use of the cooling capacity of the water. It is believed to be common practice in this area to waste the cooling water when its temperature has been raised only a few degrees. Some systems, however, are designed to achieve the same reduction in air temperature using a smaller volume of water and resulting in water being discharged at much higher temperatures. Further economies in water use can result from the use of mechanical refrigeration. Where the use of water is limited by its scarcity, by high cost, or by regulation, it is not uncommon to discharge the water from such a system at temperatures approaching 85°.

The amount of water used for "commercial" purposes, which is largely for air conditioning, is only 18 percent of the total water used for industrial and commercial purposes and about 12 percent of the total ground water withdrawal. As this use is seasonal in nature, the high rate of pumping in hot weather makes it desirable to effect all possible economies.

Proposals have been made for returning used air-conditioning water to the aquifer from which it is pumped or to another aquifer. The possibility of contamination, the gradual increase in temperature of the body of ground water, and certain operational difficulties encountered in recharge wells make this of doubtful value on a large scale.

Probably the greatest opportunities for effecting economies in the use of water are in industrial plants, some of which require large quantities of water for cooling, processing, boiler feed water, air conditioning, and sanitation. Each industry or plant presents an individual problem because of wide variations in such water requirements as temperature, purity and other qualities. In some cases water which has been used once for cooling or condensing could be reused in the same plant for processing or washing; or warm water may be cooled by evaporation in cooling towers and used repeatedly for cooling. Recycling—the use of the same water repeatedly for one purpose—or its use successively for various purposes has been remarkably successful in reducing the water requirements in some industries.

A proposal is now being studied for conducting water after it has been used for air conditioning in downtown Minneapolis through storm sewers to a point from which it can be pumped directly into Minneapolis lakes to aid in maintaining lake levels or to ponding areas from which seepage will aid in recharging ground water.

Domestic uses also are wasteful. The practices in some communities of charging a flat monthly rate based on the diameter of the service pipe is not conducive to economy in use. Installation of meters and a sliding scale of charges by which the unit cost is increased with increased consumption might reduce waste.

Possibilities for Storage

Water may be taken from the river during high flows and pumped into storage reservoirs—surface or underground—and retained until needed. Or part of the streamflow may be intercepted and stored in reservoirs built in the stream valley to permit water to be released as required to augment flows.

Artificial surface reservoirs for storing treated water are chiefly of value in equalizing the daily fluctuations in demand, and economies in operating costs of both treatment plant and pumping facilities can be realized through their use. Reservoirs cannot economically provide treated water storage in sufficient volume to relieve long-term deficiencies in supply. The development of surface storage of raw water within or reasonably close to the metropolitan area might provide a partial solution to the water supply problem. Some additional storage capacity could be provided in natural lakes in the vicinity, as is now done by the St. Paul Water Department in the Centerville and Vadnais lake chains. Evaporation losses, which would be large in relation to the volume of storage that could be provided in this manner, would limit the detention period of stored water.

The topography of the area through which the Mississippi River and its tributaries above Minneapolis flow is not favorable to the economical development of large storage reservoirs. The most suitable sites have long since been developed by the federal government or by power companies. Construction of storage reservoirs on the main stem with sufficient capacity to justify the very large land and construction costs does not appear to be feasible. Studies previously made by governmental and private agencies have reported that there are no feasible sites on the tributaries of the Mississippi River which could be economically developed for storage other than those already in use. However, these reports were made with other needs and other economic limitations in mind than those existing today. In view of the increasing importance of augmenting low river flows, a further study and reappraisal of the possibilities for establishing reservoirs in this area might be justified.

The six reservoirs in the headwaters area of the Mississippi River owned and operated by the U. S. Government have storage capacity greater than any that could be developed in the future above Minneapolis. These reservoirs, if operated for this purpose, could maintain the low flows in the Mississippi at Minneapolis at a level high enough to supply all the needs for municipal water supply, cooling water for steam power, and navigation for many years to come. Some change in operating regulations would be required. The possibilities of these reservoirs and the restrictions on their operation are discussed elsewhere in this report.

Aquifers which have been partly unwatered by heavy pumping can provide underground storage for large volumes of water for future use. Artificial recharge may be accomplished by means of injection wells whereby water is taken from the river during high flows, treated and then forced under pressure into the aquifer.

This method has definite advantages over surface storage in that it almost completely eliminates losses from evaporation and prevents contamination during storage over long periods of time. The high cost of large surface reservoirs and the lack of suitable sites for constructing them are additional arguments in favor of underground reservoirs. Some legal rights to store water underground may have to be secured from owners of overlying lands.

The maximum possible rate of recharge is definitely limited by the physical characteristics of the aquifer. Recharge rates show a tendency to drop rapidly after a few hours of operation, due to clogging of the openings in the soil or rock by entrained air or by precipitation of dissolved substances. Temperature changes and other changes in the quality of water may have adverse effects. The rights of other users of water from the same aquifer must be considered. Neither total storage capacity of the aquifer, maximum rates of recharge, nor the best method of injection may be entirely deduced from experiences in other regions. Extensive investigations and research on these problems in the metropolitan area are required.

New Sources of Supply

Supplementary water supplies can be brought into the area from surface water sources other than the Mississippi River. Several possibilities for such diversion have been proposed and studied from time to time. Some of the factors which may determine the choice from among these possibilities are the distance of the source from the Twin Cities, the vertical lift required for pumping, the dependability as to both quantity and quality of the source of supply, and the overall cost.

The variability of both supply and demand requires that storage reservoirs be provided as a part of any system for diverting water from other watersheds. Pumping costs can be reduced by having ample storage capacity for water after it has been pumped to a point from which it can be delivered by gravity to the treatment plant. The acquisition of rights to appropriate from other watersheds and other legal and political problems are obstacles which must be overcome in all proposals for diversion.

Lake Superior.—Lake Superior is a potential source of an abundant supply of water of good quality which has often been mentioned as a possible source for the Twin Cities. It is an interstate and international body of water—one of the Great Lakes which are bordered by eight states and two Canadian provinces. These lakes are subject to the provisions of an international treaty which requires that permission be obtained from the International Joint Commission for any diversion of water out of their natural watershed. Lake Superior is also the immediate concern of the Great Lakes Commission, an association to which seven of the states including Minnesota are now signatory and which has for its main purpose the protection and development of the Great Lakes and of the interests of the various states therein. In view of the adverse effects which a very slight lowering of water levels would have on commercial shipping and the production of hydroelectric power, any proposal for diversion would be certain to meet strong opposition.

It is feasible, from an engineering standpoint, to bring water by pipeline from Lake Superior to the Twin Cities. A total vertical lift from the lake surface of about 520 feet and a pipeline length of more than 160 miles indicate the magnitude and cost of such an undertaking. In view of the high cost and of the nature of the legal and political obstacles, it is not likely to be used as long as more suitable alternatives exist.

St. Croix River.—The St. Croix River is a dependable and adequate source of water of suitable quality favorably located in relation to the Twin Cities. Water can be appropriated at any one of several points on the river, pumped across the divide, then delivered by gravity to a storage reservoir or directly to treatment plants.

Several routes for diversion which have been suggested are indicated on the map, figure 13. Each of these proposals contemplates using natural lakes along the route for storage, which requires controlled fluctuation of water levels. Many of these lakes have suffered at times from abnormally low water levels due to insufficient water supply, a condition which has existed in some cases for many years. These lakes could be substantially improved for recreational purposes if used for storage, by having an assured water supply with their fluctuations held within prescribed limits. Agreement would have to be reached on a desirable range of levels for each lake and easements obtained from all land owners affected.

Route no. 1 would take water from the St. Croix River at a point near Stillwater and convey it by pipeline direct to White Bear Lake. From here it would flow by gravity through Bald Eagle Lake to Otter Lake, where it would connect to an aqueduct which is part of the present St. Paul water system. About 10 miles of pipeline would be required, and the total vertical lift or static head would be about 300 feet. The three lakes mentioned have a total area of about 4,000 acres.

Route no. 2 would follow a route approximately along the north line of Washington County from the St. Croix River to a point north of Forest Lake, thence south to this lake. From this point it could flow by gravity through Clear, Mud, and Howard Lakes which form the headwaters of Rice Creek, which at present feeds into the St. Paul water system at Centerville. The pipeline to Forest Lake would be about 9 miles long with a static head of about 250 feet. Forest, Clear, Mud and Howard Lakes have a total area of about 3,300 acres which would be added to the storage now available on Peltier and Centerville Lakes.

Route no. 3 would take water from the St. Croix River at a point near Osceola, Wisconsin, and convey it through a 6 mile pipeline to South Center Lake near Center City, from which it would flow through Lindstrom, Chisago, and Green Lakes. A channel would conduct the water from Green Lake to Forest Lake, after which it would enter the Rice Creek chain as in route no. 2. The pipeline to Center Lake would have a total static head of about 210 feet, and an additional pumping head of 8 to 10 feet would be needed between Green and Forest Lakes. Connecting channels and culverts would make storage available on all the large lakes of the Chisago chain, with a total area of over 6,000 acres, and would assist in maintaining these lakes at more desirable levels.

Route no. 4 would also bring water into the Chisago Lake chain, but from a point below the mouth of the Sunrise River. A pipeline 11 miles long, with a total static head of 137 feet would bring the water into North Center Lake, after which it would follow the course described in route no. 3. The reduction in pumping head required for this route is due largely to the higher elevation of the river above the power dam at St. Croix Falls. A further reduction in pumping head could result from reconstruction of the Nevers dam on the St. Croix River a few miles below the proposed point of appropriation. This dam, which was partly removed after damage by flood waters, could provide additional storage for water supply, part of which might be used to compensate downstream users for the loss of water by diversion. Total length of this diversion route, from the river to the point where it joins the present St. Paul water system at Centerville, is about 37 miles.

Water brought from the St. Croix River by any of these routes could be made available to either St. Paul or Minneapolis water systems or to both. St. Paul now has conduits from its Mississippi River intake above Fridley to Pleasant Lake north of the city. Pumping equipment could be installed to reverse the flow in these conduits which could be extended downstream to the Minneapolis treatment plant. The St. Croix River water could then be pumped through either system, or it could be used only for St. Paul and the suburbs it now serves, leaving the Mississippi River for the Minneapolis system and some of the suburbs most favorably located. In the event of a calamity such as serious and sudden contamination of either river, neither system would then be entirely deprived of water supply.

The favorable flow characteristics of the St. Croix River, which are discussed elsewhere in this report, and the natural storage which can be developed in the lakes north of St. Paul commend these diversion possibilities for further study.

SEWAGE DISPOSAL

Pollution of the Mississippi River at and below the Twin Cities first became critical in the early 1920's. The dumping of untreated sewage from the sewers of both cities resulted in very offensive conditions locally and impaired the enjoyment and use of the river for many miles below this point. These conditions became noticeably worse during the extended period of low river flows which began in 1929 and were intensified especially in the pool above the Hastings dam after that structure was placed in operation in 1931.

After several years of study by the Metropolitan Drainage Commission, passage of enabling legislation resulted in the establishment of the Minneapolis-St. Paul Sanitary District in 1933. Nine miles of main interceptors were constructed by the district, and 28 miles of principal branch interceptors were constructed by the cities of St. Paul and Minneapolis, all of which conduct the sewage of the two cities to the treatment plant, constructed and operated by the district, at Pigs Eye Island. The network of collecting sewers is constructed and maintained by each of the cities independently of the district. The entire system was placed in operation in 1938.

Although the present Sanitary District includes only Minneapolis and St. Paul, adjacent suburban communities may contract for sewerage service with either of the two cities or with the district. At present contracts are in effect with 24 suburban communities having a total area of 193 square miles, only part of which is sewered at the present time. The Sanitary District now provides service to about 77 square miles in Minneapolis and St. Paul and to about 53 square miles in the surrounding suburbs. In addition several municipalities and private industries within the area have sewer systems and treatment plants which are independent of the Sanitary District. The most important of these is that of South St. Paul, which receives a large volume of sewage of high organic concentration from the packing plants located there.

The sewage treatment plant located at Pigs Eye Island provides at most times only primary treatment consisting of the removal of solids by screening and sedimentation. During periods of low river flows, treatment by flocculation and chemicals resulting in removal of a larger percentage of suspended solids is used. The plant was originally designed to treat an average daily sewage flow of 134 million gallons expected from a population of 910,000 in the year 1945. In 1959 the average daily inflow to the plant was 150 million gallons from a tributary population of 1,021,900.

Unfortunately the sewer systems of both cities were originally constructed as combined sewers, so that a single sewer carries both sanitary sewage and storm water from the streets. Minneapolis has a program of separation of the two types of sewers which has substantially reduced the area served by combined sewers, but about 50 square miles in the two cities is still served in this manner. Spring thaws and heavy rain storms cause a large volume of surface runoff to enter the sewers. When this happens, the total volume of flow exceeds the capacity of the treatment plant, and a large portion of the mixture of sewage and surface water must be bypassed directly to the river at a number of points.

About 342,000 people in the area are at present dependent on individual home sewage disposal facilities, usually consisting of a septic tank with a subsurface drain tile field for disposal of the tank effluent. Most of the population thus served also obtain their domestic water supply from individual shallow wells. Although this method is satisfactory where septic tanks are widely separated and subsoil conditions are suitable and where wells and tanks are constructed according to approved standards, it becomes entirely unsuitable in densely populated areas. Widespread testing of domestic wells in suburban areas in recent months has shown that about 50 percent of the wells are contaminated to some degree by substances originating in domestic sewage. This situation, if continued, will not only result in further pollution of water in the glacial drift but may eventually affect the quality of water in the deeper aquifers.

Neither individual wells for domestic water supply nor septic tanks for sewage disposal can provide a satisfactory permanent solution for the densely populated portions of this area. The effect of inadequate disposal of human and industrial wastes on the quality of both ground water and surface water is serious and far reaching. Not only is a hazard to public health created, but the enjoyment of natural recreational areas is impaired, and land and property values are adversely affected.

As suburban areas surrounding the Twin Cities become more densely populated, they must be provided with central water supply systems and with sewer systems with adequate disposal facilities.

The existing system of joint and branch interceptors is adequate for the present sewered areas, and the area served can be expanded to some extent in certain directions. It does not have sufficient capacity to serve all of the areas now contracted for, when these areas become fully developed.

In order to meet the recommendations of the State Board of Health and of the Metropolitan Drainage Commission for reducing the hazard to public health to a minimum and for reducing the danger to livestock, the Sanitary District set as its initial goal the maintenance of a dissolved oxygen content of 2 ppm for at least 90 percent of the time in the pool above the Hastings dam. For the preservation of fish life it is considered desirable to maintain 4 ppm of dissolved oxygen in the river water below its confluence with the St. Croix River. During the 22 years of operation of the plant it has, for the most part, met these objectives. Recent increases in the sewered area contributing to the system have resulted in occasional overloading of the plant, with substantial increase in the total organic content of the effluent such as would have caused offensive conditions in the river at these times had they coincided with low river flows.

Further extension of the urbanized areas will greatly increase that portion of the metropolitan area requiring central sewerage. Enlargement of the Pigs Eye disposal plant is needed now, with additional facilities to provide secondary treatment of the sewage in order to maintain the quality of the river water at a satisfactory level. Further enlargement of the existing plant or the construction of new plants must accompany the predicted expansion of the sewered area. Additional trunk sewers or interceptors will be required to conduct the sewage to the treatment plant or plants.

The urgency and complexity of this problem indicates the necessity for a unified approach to the planning and construction of the sewage disposal facilities. The metropolitan area is geographically a fairly compact unit. Among other considerations pointing to the need for a single authority having direct responsibility for operating all sewage disposal facilities in preference to independent action by municipalities or small groups of municipalities may be mentioned the following:

1. Lack of coordination of planning and operation by many independent governmental units.
2. Additional costs as a result of duplication of facilities and operating personnel.
3. Economies that could be effected by utilizing the full capacities of the existing interceptors.
4. The desirability of conducting all wastes from the area to a point below the cities before discharging the treated effluent to the river.
5. Difficulties that would be encountered in providing qualified technical staffs for operation of a number of independent treatment plants.
6. The difficulty and high cost of enlarging or replacing interceptors and treatment plants.
7. The need for a plan providing the necessary flexibility for future servicing of areas not now densely populated nor presently included within the boundaries of the municipalities.
8. Sewage disposal for a fast-growing metropolitan area is a long-term ever-changing problem—one that will require continual surveillance, planning, testing, analysis and improvements in operation.

Recognizing that area-wide planning should be done well in advance of the actual needs of the rapidly growing population, the Board of Trustees of the Minneapolis-St. Paul Sanitary District in May 1956 authorized a comprehensive engineering study of the sewage disposal needs, present and future, with the objective of developing a unified master plan for the metropolitan area.

The report resulting from this study considers an area selected on the basis of topography, geology and projections of population growth and suburban development through the next 40 years. The area, recommended as defining the ultimate limits of an expanded sanitary district, is approximately 30 miles by 34 miles, comprising 1,056 square miles, with an additional 114 square miles in the Minnetonka region which was included in the study but not recommended for inclusion within the expanded district. Within the boundaries there are now 82 separate city, village and township units. It is not expected that the entire area within these limits would be developed sufficiently to require sewerage by the year 2000. A sewered population of 2,027,000 is estimated for the year 1980, 2,616,000 by the year 2000.

For the purposes of study and analysis, the area has been subdivided into a core area which generally coincides with the present service area and four regions comprising the more distant suburbs. Four alternate plans are proposed, each providing for modification of existing interceptors and construction of new interceptors to conduct the sewage from the entire area to one main treatment plant and to one or more regional plants. Each plan proposes that sewage from the entire southeast region, lying downstream from St. Paul, be conducted to a new treatment plant to be constructed at Grey Cloud Island. Projects A-1 and A-2 differ in location of interceptors, but both propose that sewage from the entire area except the southeast region be treated at the Pigs Eye Plant. Project B-1 provides two more regional treatment plants, one on the Mississippi River near Fridley and one on the Minnesota River downstream from Savage. Project B-2 is similar but eliminates the plant near Fridley.

A fifth project considers enlargement of the existing plant to provide secondary treatment for all sewage from the present service area, plus a number of community plants, most of which would discharge effluent to lakes or minor streams. The extremely high cost estimated for this project as well as other obvious disadvantages discourage further consideration.

All projects contemplate construction, ownership and maintenance of the system of collecting sewers by the individual municipalities. Only interceptors and treatment plants would be the responsibility of the sanitary district.

Differences in estimated costs alone would not be sufficient to govern the choice between the four A and B projects, each of which appears to offer an acceptable solution to the problem. The obvious advantage of the A projects in discharging all plant effluent from the entire metropolitan area at points downstream from the two cities may well be the deciding factor.

All four plans propose the enlargement of the present treatment plant at Pigs Eye Island and construction of regional plants to provide both primary and secondary treatment. Secondary treatment at the downstream plants would consist of the high-rate activated sludge process. Upstream plants, if built, would probably utilize the conventional type of activated sludge treatment which, although higher in cost, removes a higher percentage of organic material from the sewage.

It is not economically feasible to remove from domestic and industrial wastes all of the contaminating material before it enters the river. After removal of suspended solids by screening and sedimentation, a large part of the organic matter in solution can be removed or rendered harmless by oxidation within the treatment plant by one of several methods. "Complete" treatment generally is limited to the removal of 80 to 95 percent of the material of organic origin, including harmful bacteria. If the bacterial and other organic content of the plant effluent is sufficiently reduced, the natural purification processes of the receiving stream can complete the disposal process.

The ability of a stream to accomplish this result is dependent chiefly on the total amount of dissolved oxygen in the stream, which in turn is determined by the quantity of water flowing and by its dissolved oxygen content. When a stream receives, at any point, a pollutional load that is heavy in relation to the total oxygen resources of the stream, the dissolved oxygen is rapidly depleted and may be totally used up. In the absence of oxygen a different type of decomposition occurs with the formation of obnoxious gases and sludge deposits. Offensive local conditions result, and the pollutants may be carried a long distance until sufficient oxygen is received from tributary streams, from green plants growing in the water, and by absorption from the air, to complete the oxidation.

If the pollution load does not exceed the capacity of the stream to assimilate it, the reduction in dissolved oxygen is more gradual, the oxygen used up is replaced from other sources, and oxidation continues until satisfactory conditions are restored.

At normal and higher flows of the Mississippi River at St. Paul the strength of the effluent from the treatment plant is sufficiently reduced by dilution so that the natural process of stream purification can be completed. At lower flows, more of the oxidizable materials must be removed by treatment within the plant.

At extremely low flows it may be impossible to maintain satisfactory conditions downstream. Balance between the pollution load and the total dissolved oxygen of the receiving waters must be maintained.

Records of the oxygen demand and of the dissolved oxygen content of the river waste under varying conditions and at several points downstream from the present plant indicate that minimum streamflows of about 4,500 cfs in the critical summer months (usually July and August) and of 2,500 cfs in the winter months (January and February) are required for satisfactory dilution of the present plant effluent. At flows below these minimums, the quality of the river water at communities farther downstream may be seriously impaired. While these estimates are based on present conditions, it is not anticipated that the values will change greatly with the expected increases in population and industry even with "complete" treatment.

An index of the monetary value of higher minimum flows in the Mississippi River is contained in estimates, made under the current research project of the Sanitary District, of the savings which may result in plant construction costs and operation costs. These estimates are based on an expected tributary population in the metropolitan area of 2,000,000 by the year 2000 and a population equivalent of all waste waters of 3,600,000. It is estimated that for 1,000 cfs of augmented flow during the four critical months, total annual charges, consisting of fixed charges and maintenance and operating costs, could be reduced by $474,000. Additional flow, if provided, would effect further economies.

These monetary considerations are of value in appraising the function of the river in the sewage disposal process. They should not be interpreted as justifying any lesser treatment than that which will assure the maintenance of satisfactory conditions in the river below St. Paul. It seems probable that the increasing importance of the river for recreation, for municipal water supplies and other uses will, at some time in the future, impose even higher standards for water quality on the entire upper Mississippi River. To maintain such standards, maximum treatment of sewage and adequate river flows are essential.

MISSISSIPPI HEADWATERS RESERVOIRS

The importance of the federal reservoirs at the headwaters of the Mississippi River to the metropolitan area should not be underestimated. For many years low flows in the Mississippi were augmented by the release of water from these reservoirs for the benefit of navigation or for the purpose of providing storage for spring runoff. Such restrictions on reservoir operations have been imposed that the benefits experienced at this point on the river have decreased even as the need for water has been increasing.

Between 1884 and 1912 the U. S. Corps of Engineers constructed the six reservoirs in the headwaters area of the Mississippi River. They were constructed primarily for the benefit of navigation on the river, with incidental benefits for flood control. The six are Winnibigoshish, Leech, Pokegama, Sandy, Pine and Gull, and together they intercept the waters of most of the uppermost tributaries of the Mississippi. Operation of the dams is the responsibility of the district engineer, St. Paul District, U. S. Corps of Engineers.

Most of the land bordering the reservoirs was originally owned by the federal government, and flowage easements were acquired on all other riparian lands. Much of the land owned in fee was later sold, although the government reserved, and still retains, all flowage rights on these lands required for full operation of the reservoirs. All developments of homesites, resorts and commercial establishments which have since been made on the shores of these reservoirs have been made on lands leased from the government or on privately owned lands subject to the government rights.

The need for release of water to aid navigation was greatly reduced by the completion of the 9-foot navigation channel below Minneapolis. With the development of recreation as a business, recreational interests exerted constantly increasing pressure on the government to stabilize water levels in the reservoirs. Successive modifications of the operating regulations were made by which maximum levels were lowered and minimum levels were raised, so that the storage capacity was drastically reduced. Under the original operating limits they had a combined storage capacity of about 2,200,000 acre feet of water. Under the limits of operation designated by official regulations, about 76 percent of the original capacity is theoretically usable. Actual operation at present is governed by "ordinary limits" which reduce the usable capacity to about 37 percent of the original 2,200,000 acre feet.

Actual operation is further restricted by a "desirable summer range" which seeks to limit the range of fluctuation of water levels in the reservoirs to 6 inches or less during the period of intensive recreational use. Operation of the reservoirs with this objective in mind permits almost no water to be released except that which is not needed to maintain these desirable water levels. Some beneficial regulation of streamflow does result from the annual winter drawdown of the reservoirs. This is done to provide storage for spring inflow in order to reduce flood stages in the reservoirs and in the Mississippi River at Aitkin.

No matter what maximum and minimum stages are adopted, it is impossible to use the full storage capacity within those limits for the sole benefit of any one interest. The necessary reduction in spring stages to provide storage for spring flood waters limits the amount of water which may be held over a period of years. Additional releases are made to provide minimum flows to protect fish in the streams just below the reservoirs. Wild rice is an annual crop of considerable value in some of the reservoirs and in other areas downstream, and its preservation merits consideration. Evaporation, transpiration and seepage from the reservoirs limit the length of time water may be successfully retained.

The lands adjoining the reservoirs have been developed for summer homes, cabins and resorts, and all of the reservoirs are used extensively for fishing, hunting and boating. Prolonged high stages result in bank erosion in certain locations and in damage to roads and to other improvements such as docks, harbors and boathouses in others. Low stages make navigation difficult. Recreational uses are generally best served by a minimum fluctuation in water stage.

The most severe and protracted drouth experienced in this region since records have been kept occurred during the period 1923-42. During each of the years from 1931 to 1940, inclusive, the flow in the Mississippi River at St. Paul fell well below the flows said to be required for dilution of the effluent from the sewage plant below the Twin Cities. The reservoirs could not have furnished enough water to produce the desirable flows of 4,500 cfs in July and August or of 2,500 cfs during the winter months in most of those drouth years.

The usual plan of operation of the reservoirs was modified to some extent during the years 1931 to 1936 in order to augment streamflow at the Twin Cities during the summer months. A review of the records indicates that if the reservoirs could have been operated primarily for the purpose of increasing streamflows during those years they could have produced even more substantial benefits at the Twin Cities during the critical summer and winter months. Without exceeding the official "limits of operation" then in effect, the present and future requirements for municipal water supply as outlined in this report could have been met even under the extreme conditions of the 1930's. Fluctuations in the stages of the reservoirs would not have been greatly increased, and in general a more desirable range of levels would have resulted.

At no time since 1937 would any special releases from the reservoirs have been required solely for the purpose of water supply for the Twin Cities. No releases for sewage dilution would have been necessary from the end of 1940 until the summer of 1958. At that time a discharge of about 1,600 cfs for 45 days, a total volume of 144,000 acre feet, would have maintained flows at St. Paul above 4,500 cfs during July and August. At the stages existing at the beginning of this period this represents a drawdown of 2.5 feet on Winnibigoshish Reservoir, or a combined drawdown of 1.5 feet on Winnibigoshish and 0.5 foot on Leech. An additional discharge of about 80,000 acre feet during the following December and January would have been necessary to maintain the desired flow of 2,500 cfs at St. Paul during the winter months. The theoretical drawdowns would have been reduced by whatever inflow to the reservoirs occurred during this period and increased by the evaporation which took place.

In view of the large recreational use of the reservoirs today and their importance in the economy of the region in which they are located, restoration of the use of their full capacity of 2.2 million acre feet as intended in the original design is not feasible. The storage capacity defined by the "ordinary operating limits" which now govern their maximum fluctuation is about 787,000 acre feet. This amount of storage could, if releases were timed to provide additional water when most needed at the Twin Cities, assure flows of 1,200 cfs or more. It would fall short of supplying the larger flows required for dilution of sewage.

If the operating limits were increased on Winnibigoshish and Leech sufficiently to provide a total usable capacity of about 1,000,000 acre feet, the desirable minimums of 4,500 cfs in the summer and 2,500 cfs in the winter could probably be reached under all but the most extreme conditions, such as occurred in the prolonged drouth period. The above statements are made with the assumption that the "desirable summer range" permitting a fluctuation in the reservoir levels of only 3 to 6 inches would no longer be adhered to.

Modification of the regulations to permit storage and release of water for the purpose of augmenting low flows in the Mississippi River would have great value for the metropolitan area and for other communities located along the river. This, however, would result in greater fluctuations in the water levels of the reservoirs, a proposal which is vigorously opposed by those who are primarily concerned with recreational values. The diverse interests which the reservoirs are called upon to serve make demands on their operation which are often conflicting and incompatible. Compromise, based on understanding of the relative values of the interests involved and of the possibilities and limitations of the operations of the reservoirs, will be necessary if their usefulness in regulating streamflow is to be restored. All necessary rights for the desired operation would have to be acquired and compensation made for damage to riparian lands.

LAKES AND MINOR STREAMS

Although none of the dozen or so smaller rivers and creeks within the metropolitan area can now be considered as an important single source for public water supplies, each has had and will have a significant effect on the adjacent lands and communities.

These streams flow on glacial drift terrain over most of their courses. Those that are tributary to the Mississippi River above St. Anthony Falls flow in the Anoka sand plain and consequently have low gradients. Local flooding is a common problem of streams in the sand plain, and although channel improvements have been made in many areas, their outlets generally are inadequate to remove storm waters with sufficient rapidity. Total fall of the streams is usually less than 100 feet.

The streams entering the Minnesota River or the Mississippi below St. Anthony Falls usually have a greater total fall; the Vermillion River has a fall of more than 350 feet. In addition to flooding and farm drainage problems in the shallow upstream valleys, erosion problems arise in their lower reaches from their precipitous descent to the deeper valleys of the major rivers.

The natural streamflow characteristics of the streams originating within the metropolitan area have been modified by changes in land use, construction of railroads and highways, public drainage systems and other works of man. The construction of storm sewers and drainage systems across natural divides has, in some cases, changed the area of land contributing water to a stream. Intensified land use tends to increase high stages and to decrease low flows in streams.

Not only are the natural flow patterns of streams affected by a changed environment, but changes in land use bring about new values which must be considered in plans for water management. Damage caused by floods and erosion, which may be tolerated in undeveloped rural lands, become more significant when property adjacent to channels has been developed for residential or industrial purposes. The expansion of urbanization also places a premium on preserving the scenic and recreational values of streams.

In the metropolitan area these problems are made more difficult by the fact that even a small stream may flow through several municipalities and through more than one county. Efforts to improve conditions on one part of a stream may adversely affect conditions elsewhere in the watershed. Counties and municipalities are authorized to make improvements on any body of water under Minnesota Statutes Chapters 106 and 110. Under the joint power statute, M. S., Section 471.59, they may take such actions jointly. It is, however, understandably difficult to reach an agreement where several jurisdictions and conflicting objectives are involved. The Minnesota Watershed Act, enacted in 1955, provides, through the establishment of watershed districts, another approach that can be used to coordinate water projects within an entire watershed.

STREAMS

Nine Mile Creek. — The watershed of this stream includes parts of five suburban municipalities southwest of Minneapolis. The topography is for the most part hilly, but, except for the lower two or three miles, the channels are bordered by wide marshy areas. Flooding of these areas occurs frequently and has been aggravated by construction of streets and storm sewers. Channel improvements and the construction of ponding areas to retain the flood waters have been proposed. The Nine Mile Creek Watershed District was established September 30, 1959, to provide a unified approach to the water and land problems. Although eventual urbanization of almost the entire area may be expected, it has limited but valuable wildlife habitat which should be preserved.

Credit River. — This stream in Scott County joins the Minnesota River at Savage. The topography is rolling to hilly and the watershed is almost entirely rural. The upstream portion has been ditched. The stream has definite recreational and scenic assets which will have increased value as the neighboring areas become urbanized.

Bassett Creek. — This stream, rising in Medicine Lake west of Minneapolis, flows into the Mississippi River in north Minneapolis. Its watershed includes parts of nine municipalities. The upstream portion crosses much flat marshy land where a high water table and inadequate drainage are impeding residential and industrial development. Farther downstream frequent damage from floods is suffered by high value residential and recreational property. In the lower mile and a half the stream flows in a box culvert through residential and industrial areas of Minneapolis. The several municipalities contemplate joint action in solving their common problems.

Shingle Creek and Twin and Crystal Lakes. — Shingle Creek is formed, northwest of Minneapolis, by the confluence of Eagle and Bass Creeks. It circles north, east and south through Brooklyn Park, Brooklyn Center and Minneapolis where it flows into the Mississippi River at Webber Park in north Minneapolis. The watershed of Shingle Creek includes parts of six municipalities and two townships and has an area of 41 square miles. As much of the creek's course is through lakes and marshy areas, the four mile reach through Palmer Lake south to the Mississippi was improved by the construction in 1910 of Hennepin County Ditch 13, the southern part of which was enlarged and in some places relocated in 1959-60.

Twin, Crystal and Ryan Lakes, with areas of 198, 77 and 31 acres, respectively, are in the Shingle Creek watershed area in a locality of increasing urbanization and consequent municipal concern with water levels in these lakes. At present the area is being studied with a view to raising lake levels without damaging lakeshore residences. This can be done by providing additional water to the lakes at times of deficient precipitation from one or more of the following possible sources:

Mississippi River, by pipeline

Diversion from Shingle Creek

Minneapolis city water

Municipal water systems

Wells

Diversion from Gaulke Pond

Providing improved surface drainage of the upstream portions of the watershed to permit its development for residential and commercial purposes is also a problem which is being studied. Deepening of parts of Shingle Creek and the use of Palmer Lake for storage of floodwaters has been given serious consideration.

Elm Creek. — This stream, with its tributaries, Rush Creek and Diamond Creek, has a watershed area of 95 square miles in northern Hennepin County and joins the Mississippi River at Champlin near Anoka. Much of the watershed is gently rolling or flat with rather large marsh and peat areas. Nine county ditches have been established in the watershed for improving agricultural lands. Although about two-thirds of the watershed is within the limits of municipalities, it is generally sparsely populated and rural in character.

Coon Creek. — The watershed of this stream, entirely within Anoka County, is mostly flat with sandy soils. In the eastern or upstream portion are large areas of peat and marshland, and much of the main channel is bordered by marshy lands. Most of the main channel and its tributaries have been straightened and deepened by 72 miles of county ditches established between 1888 and 1920. There are said to be 19,000 acres of good wildlife habitat in the watershed, including 6,000 acres which are part of the Carlos Avery State Game Refuge and Public Hunting Grounds. The character of the area is still predominantly rural. The Coon Creek Watershed District was established May 28, 1959, for the purpose of providing drainage of agricultural land and other land treatment measures.

Rice Creek. — Rising in Clear Lake near the village of Forest Lake, this stream flows southwest through a remarkable chain of lakes to the Mississippi River at Fridley. Its watershed of 185 square miles, in Anoka, Washington and Ramsey Counties, is almost entirely flat to gently rolling and includes extensive marshlands as well as some good farm lands. An extensive system of county and judicial ditches has been established for improvement of agricultural lands. The lakes and marshes in the upstream area have considerable value for fishing and wildlife habitat. The watershed includes the highly developed residential and recreational areas near White Bear and Bald Eagle Lakes and the rapidly growing residential areas of the newer suburbs northwest of St. Paul.

The St. Paul Water Department pumps water from Centerville Lake, which receives water from the upper 80 square miles of the Rice Creek watershed. There is a private seaplane base on Rice Lake.

The watershed includes all or parts of 25 incorporated municipalities and six townships. Future water developments in this area should take into account the interests of agriculture, wildlife and recreation, residential and commercial development, and water supply. Because of the variety of land use, the varied and sometimes conflicting interests to be served, and the many governmental units involved, long-range and comprehensive planning is desirable.

Vermillion River.—This stream rises in eastern Scott County near Lakeville and flows east through flat to rolling agricultural land, passing through Farmington and Hastings. Its watershed of 338 square miles includes a large part of Dakota County. The main channels and tributaries of the upper portion are in wide flat valleys, and many of the channels have been widened and deepened to provide drainage for adjacent farm lands. Flooding has occurred frequently in the valley above Hastings. Several mills were located on the stream in the early days; the Ramsey Mill at Hastings, built in 1857, had a head of 51 feet.

At Hastings the stream falls precipitously to the valley of the Mississippi River and follows the northwest side of this wide valley for about 18 miles until it joins the Mississippi just below Lock and Dam No. 3 near Red Wing. The land along this portion is largely forested and wildlife is abundant. The stream valley here is subject to backwater during high stages of the Mississippi River.

Minnetonka Lake and Minnehaha Creek. — The fame of beautiful Minnetonka Lake, Minnehaha Creek and Minnehaha Falls was widespread even in Minnesota's territorial days. Settlement in the vicinity of the lake began in the 1850's and was followed soon after by the construction of a number of fine resort hotels which flourished for the next 50 or 60 years, drawing their clientele not only from Minneapolis and St. Paul but from distant parts of this country and Europe. Commercial navigation by sail and steam on Minnetonka also began in the 1850's, and the history of a long succession of steamboats carrying passengers, freight and mail indicates the importance of this traffic in the life of the growing communities along its shores. Both Minnetonka Lake and Minnehaha Creek have been declared to be navigable waters of the state.

A dam constructed in Minnehaha Creek at Minnetonka Mills in 1853 furnished power, first for a sawmill and later for a flour mill, and made navigation by steamboat possible from the lake to the mill. After its destruction, the Grays Bay dam was built at the lake outlet by the county in 1897 and reconstructed in 1944. Farther downstream a mill was built at Edina, and the reconstructed dam at this point now impounds water to form Edina mill pond.

The matchless beauty of Minnehaha Falls was preserved through the establishment of Minnehaha State Park in 1889, and its acquisition that year by the Minneapolis Board of Park Commissioners. This was followed by the acquisition of other parcels of land along Minnehaha Creek by the Board.

Minnetonka Lake has a total area of 14,386 acres. Excluding the area of 15 islands, it has a water area of 13,832 acres, or about 21.5 square miles; an average depth of 25 to 30 feet and a maximum depth of 101 feet; and an exterior shoreline of about 86 miles. Most of the shoreline is rolling to hilly and well timbered, containing some of the last unspoiled remnants of the Big Woods, which once covered much of this part of the state. The adjacent lands, in some places to a distance of a mile or more from the lake, are now highly developed residential areas.

The watershed area tributary to the lake is about 100 square miles or about five times the area of the lake. This area does not always contribute enough surface runoff to the lake to compensate for the losses from evaporation and seepage. As a result, the water level of the lake is subject to a considerable range of fluctuation. The elevation of the crest of Grays Bay dam is 929.4, sea level datum. Records of lake levels which have been kept continuously since 1881 show that the all time high of 932.7 occurred in 1882, and the all time low was 922.7, reached in 1937 and 1938. Since the dam was built in 1897, there has been outflow from the lake less than half the time. The longest continuous period when the lake level was below the crest of the dam was from June 1929 to May 1942, a period of 13 years. In September 1951 a stage of 931.4 was reached, causing substantial damage to lakeshore property.

Minnehaha Creek, from its source in Minnetonka Lake, flows east for about 20 miles to is junction with the Mississippi River just below Lock and Dam No. 1. For most of its course, before it reaches Minneapolis, it flows through broad marshy bottomlands. Thereafter, its valley is narrower and its channel well defined. It receives water from the chain of lakes in Minneapolis, bypasses Nokomis Lake which is connected to it by a short channel, flows through Hiawatha Lake and over Minnehaha Falls, a drop of 55 feet. Throughout its length, encroachment on the flood plain by residential and commercial developments has occurred over a long period of years, restricting in places the capacity of the valley to carry flood flows and increasing the susceptibility to flood damage of adjoining property. Much of the flood plain west of Minneapolis is still in private ownership, and the present rapid spread of urbanization in this area threatens further restrictive encroachment.

The area of the watershed tributary to Minnehaha Creek below Grays Bay dam is about 65 square miles. Although this area alone can cause flood flows in the creek after heavy rainfall, surface runoff from the area is not generally sufficient to sustain satisfactory minimum flows. When there is no outflow from Minnetonka Lake, the creek becomes dry. On the other hand, floods have frequently occurred, and during prolonged periods of high stage on Minnetonka damage has been considerable. In 1951 and 1952, flows of about 300 cfs were measured at Minnetonka Mills; flood conditions start at about 50 cfs in certain reaches of the creek.

The problems of Minnetonka Lake and of Minnehaha Creek are interrelated and inseparable. Essentially, they may be defined as the problem of maintaining desirable minimum levels on the lake, preventing extreme high stages of the lake, preventing damaging floods on the creek, providing minimum flows, especially in the summer months, adequate to maintain good appearance of the creek and the falls, and improving the appearance and utility of the bottom lands along the creek. Also closely related is the problem of providing adequate water supply for the lakes in Minneapolis which are tributary to the creek.

Many studies have been made and plans proposed for the improvement of the lake and stream, among which may be mentioned the following:

Diversion of floodwaters of the Crow River to Minnetonka Lake by gravity flow.

Diversion from the Mississippi River by pumping through a pipeline to the lake or to some point on the creek.

Construction of dams in the creek to form a series of ponds in the valley between Minnetonka Mills and Minneapolis.

Pumping from wells directly into Minnetonka Lake or into connecting lakes.

Pumping from wells to some point on the creek.

Abandonment of Grays Bay dam and construction of a new dam a short distance above Minnetonka Mills, extending the lake to that point and providing some control of the outflow from the lake.

Channel improvements to enable Minnehaha Creek to carry flood flow from the lake without excessive damage to property.

Hennepin County pumped 30,148 million gallons of water from a series of deep wells into Minnetonka Lake from 1938 through 1942. This was equivalent to 6.7 feet of water on the lake. Since then the wells have been used only when the lake stage was at least 1.5 feet below the crest of Grays Bay dam. In 1957 a permit was granted to the Board of Park Commissioners to divert surplus waters by pumping from Bassett Creek to Brownie Lake to provide additional water supply for the chain of lakes. Both pumping operations make some contribution to flows in Minnehaha Creek.

Not only have physical conditions changed, but changing land use and rising property values have accentuated the water problems in the area. Fourteen separate municipalities are adjacent to Minnetonka, and the creek flows through four more. In an effort to provide a unified approach to the solution of some of these problems, a Minnetonka Watershed District has been proposed. Clearly concerted action by the various governmental units involved is required.

LAKES

The metropolitan area watershed contains 517 lakes each having an area of more than 10 acres, of which 110 have been lowered or completely drained by public and private drainage systems. The total area of these lakes is 76,500 acres or 120 square miles. This is equivalent to one acre of lake for each 14 acres of land.

Most of these lakes were formed or had their origin during the periods of extensive glaciation tens of thousands of years ago. The chains of lakes in or near the Twin Cities are located along buried preglacial and interglacial river valleys.

The largest lake, Minnetonka, has an area of 14,386 acres. Other large lakes are: Waconia 3,196 acres, White Bear 2,410 acres, Long Meadow 1,425 acres, and Bald Eagle 1,046 acres.

The abundance of lakes affords excellent recreational facilities and their accessibility and desirability as home sites have resulted in intensive residential development along their shorelines. In addition to their recreational values, several lakes in northern Ramsey County, the Vadnais and Centerville chains of lakes, are used as storage reservoirs for water supply by the City of St. Paul.

The general decline of water levels in the glacial drift, which discharges water to many of the lakes, and seasonal climatic variations including high evapotranspiration rates during the summer months, have necessitated the use of supplementary water supply to sustain lake levels in some areas. Methods used include: pumping from wells, use of water from municipal water systems, and diversion of surface water. A plan to use waste water from air-conditioning wells in downtown Minneapolis in the Calhoun-Harriet chain of lakes in southwestern Minneapolis has been proposed.

RECREATION

The Mississippi and Minnesota Rivers, more than a dozen small streams, and the many lakes provide excellent fishing, swimming and boating facilities. Minneapolis has 153 parks, totaling 5,317 acres in area, approximately one acre for each 100 inhabitants. The 78 parks in St. Paul have an area of 1,625 acres, about 0.2 acre for each 100 inhabitants. In addition, there are small roadside parks and public beaches at many of the lakes.

William O'Brien State Park, consisting of 256 acres of wooded, rolling land fronting for almost a mile on the St. Croix River, is located two miles north of Marine-on-St. Croix in Washington County. A future state park will include part of Fort Snelling, Pike Island and adjacent parts of the Minnesota River valley. Part of the Crosby farm, located in St. Paul along the left bank of the Mississippi River below Fort Snelling, may become a new city park.

Probably few, if any, metropolitan centers have such varied and delightful opportunities for pleasure boating as does this area. To the more than 400 lakes in the area may be added at least 50 miles on the St. Croix River to Taylors Falls and 55 miles on the Mississippi from Lock and Dam No. 3 to St. Anthony Falls. For long distance travel, the Mississippi leads either to the Gulf of Mexico or through the Illinois waterways to the Great Lakes.

The U. S. Corps of Engineers maintains a navigable channel of 4-foot depth in the Minnesota River from the mouth to Shakopee, a distance of about 25 miles. Snag removal and other improvements to the channel above Shakopee will begin in July 1961 under a Conservation Department project authorized by the legislature and should make many more miles of this river navigable to small pleasure boats.

Minnetonka Lake, with more than 12,000 acres of surface area, is one of the most intensively used playgrounds in the state. Excursion steamers were common on Minnetonka Lake and White Bear Lake in Civil War days and continued to do a flourishing business on these lakes and on the rivers for many years. Sail boating also got an early start and continues to be a major sport on the larger lakes and on St. Croix Lake. The development of internal combustion motors brought about lower costs and private ownership of power boats, and the number and variety of these craft found on local lakes and streams have increased steadily for many years.

Small boat harbors have been constructed as federal projects at Hastings and at Harriet Island in St. Paul. Numerous marinas, boat works and other servicing facilities have been constructed along all the major streams.

The number of pleasure boats passing annually through Lock and Dam No. 2 at Hastings increased from 980 in 1954 to 5,297 in 1959. The number of lockages for pleasure boats at this lock in 1959 was 2,594, more than twice the number of commercial lockages.

It is generally recognized by municipal officials, civic groups and planning commissions that the recreational facilities of the area are inadequate for today's population. Increased mobility due to greater use of the automobile and improved highways, while it has brought more distant parks and wilderness areas within easy reach, has not resulted in decreased use of local parks and playgrounds. If the recreational needs of an expanding population having increased leisure time, as predicted, are to be provided for, more space must be preserved for this purpose in or near centers of population.

Most of the land developed for outdoor recreational use is associated with water areas. The recreational values of the bodies of water so abundant in the metropolitan area cannot be fully utilized by the public unless ample areas of the adjacent lands are acquired or reserved to provide access and space for facilities such as bathing beaches and boat landings. The pressure which is being felt today for development of such lands for residential and other private uses makes it imperative that acquisition of the lands which will eventually be needed for public recreation should not be delayed.

PUBLIC DRAINAGE

There are over 90 public drainage systems which affect an estimated 69,000 acres of land within the metropolitan area. Figure 16 is a map of the seven-county area showing, as well as can be determined from existing records, the lands affected by these enterprises. The most extensive drainage has been in Anoka County, western Hennepin County, and western Carver County. Records are not available for most drainage systems in Dakota County.

Nearly all of these ditches were intended to benefit agricultural lands. Unfortunately in many cases the expected benefit was not realized, either because adequate drainage of the lands was not achieved or because the lands were not suitable for cultivation even when drained. In urbanized areas the ditches have been supplanted by municipal storm sewer systems; others have been allowed to deteriorate.

Within the study area a total of 110 natural lakes, originally having a total water area of nearly 15,000 acres, have been either wholly or partly drained. The extent of the marshy areas and those intermittently covered by water, which were capable of supporting abundant wildlife, has been greatly reduced.

Much of the drainage has been beneficial to agriculture; in some cases it has resulted in the improvement of lands which are now suitable for residential or commercial developments. Some lands are not usable for either purpose. The changes in land use which inevitably accompany urbanization bring about a change in values which may make it desirable and possible to restore some of the wetlands and open water areas.

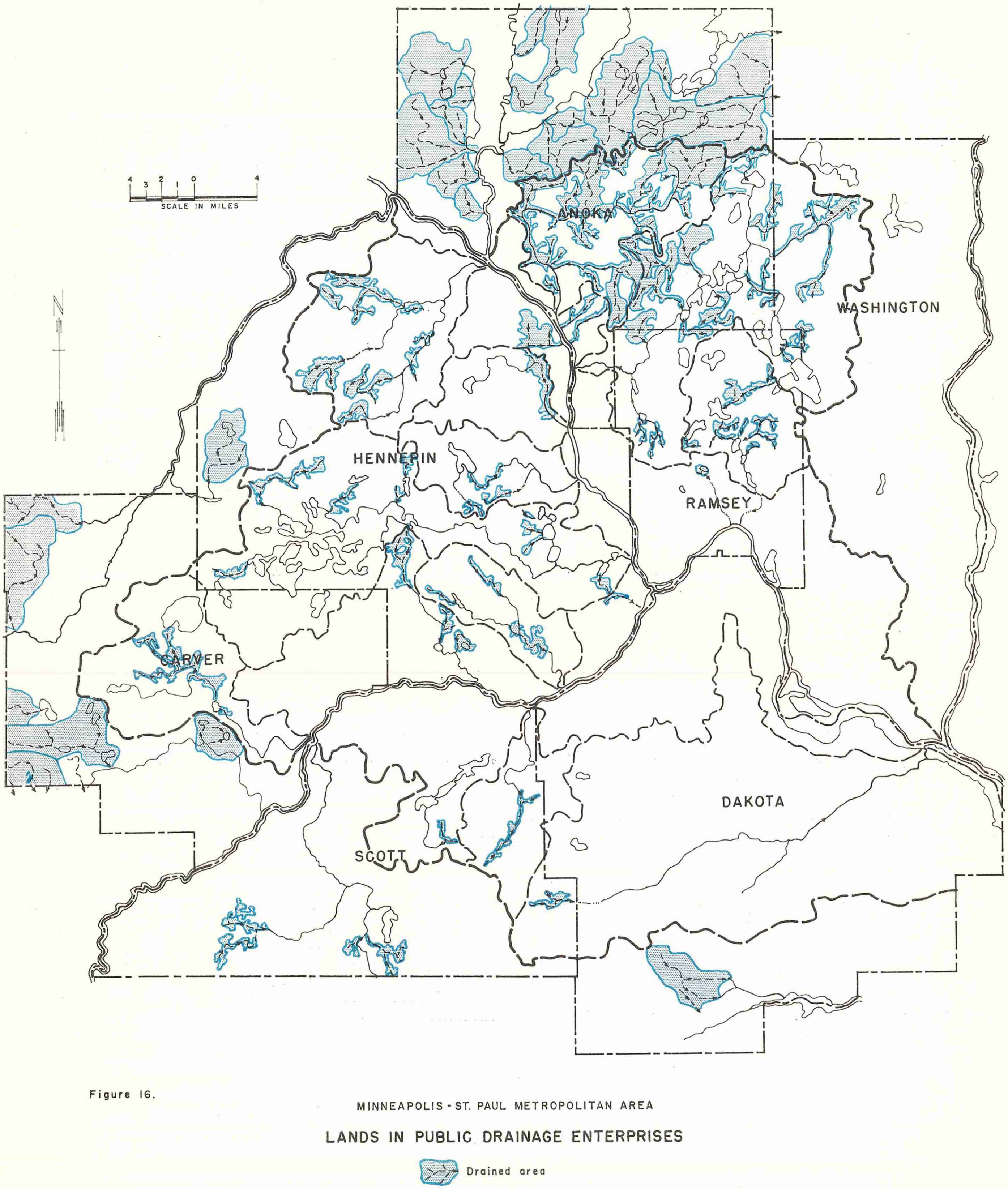


Figure 16.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA

LANDS IN PUBLIC DRAINAGE ENTERPRISES

MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF WATERS

COMMERCIAL NAVIGATION

The Twin Cities metropolitan area is a major marketing, distribution and transportation center. It is ideally situated in relation to the heavy industrial centers to the east, the agricultural-industrial complex to the south and southeast, the agricultural plains region to the west and northwest, and the timber and mineral resources found to the north. Its primary trade area includes all of Minnesota, the Dakotas and Montana.

The industry of the area is primarily light manufacturing, transportation and trade. Most prominent of the industries are food processing, including meat packing, malt beverages and flour milling, electronics and instruments, machinery and fabricated metals, abrasives, plastics, chemicals and petroleum products, and printing and publishing. The large number of persons employed in transportation and warehousing and in wholesale and retail trade contribute to the generally stable economy and steady employment situation. The mineral resources of the area are used in glass, architectural stone, brick, and concrete products manufacturing.

The trunk lines of nine major railroads converge here, and four of these have their headquarters in the Twin Cities. The area is served by an excellent system of primary and secondary highways, over which more than 100 authorized motor freight carriers operate. Adequate terminal and transfer facilities exist for both railroad and truck cargoes and for the interchange of freight between the various systems. Fast freight and passenger transportation is provided by seven scheduled airlines using the Minneapolis-St. Paul International Airport at Wold-Chamberlain Field. Pipelines from the Kansas-Oklahoma, North Dakota, Indiana and Canadian fields bring crude petroleum, refined petroleum products and natural gas to the area.

Certainly the cities of St. Paul and Minneapolis owe much of their early growth to their situation at the head of navigation on the Mississippi River.

Transportation of both passengers and freight on the Mississippi River flourished in Minnesota's territorial period but with the coming of railroads declined rapidly. The growing need for dependable low-cost transportation of bulk commodities resulted in the authorization by the Congress in 1930 of the 9-foot navigation channel in the Mississippi River from St. Louis to the Minneapolis harbor just below St. Anthony Falls. This channel, constructed and maintained by the U. S. Corps of Engineers, has been in operation since 1940. In 1937 Congress authorized the extension of the 9-foot channel a distance of 4.6 miles upstream from St. Anthony Falls. This work, now nearing completion, required the construction of a lock and a new dam at the lower St. Anthony Falls, modification of the dam and construction of a lock at the upper falls, dredging of channels and of a turning basin near the upstream end of the project at the Soo Line Railroad bridge.

Locks in the river below St. Paul are generally 110 by 600 feet. Dam No. 1, known as the Ford dam, has twin locks, each 56 by 400 feet, and the single locks at St. Anthony Falls will be 56 by 400 feet, with provisions for auxiliary locks to be constructed when needed.

In the Minnesota River a 4-foot channel from the mouth to Shakopee was completed by the Corps of Engineers in 1931. In 1942 a 9-foot channel from the mouth to Savage, 13.2 miles, was dredged by private interests so that naval tankers and towboats constructed at Savage could be taken downstream. Improvement of this channel and its extension for 1½ miles upstream has now been authorized by the Congress. The Lower Minnesota Watershed district, established in March 1960, will provide the required local sponsorship for federal navigation projects on the Minnesota River.

The St. Croix River has a channel depth of 9 feet in the reach of 23.5 miles from the mouth to Stillwater and a depth of 3 feet for 27.5 miles from Stillwater to Taylors Falls.

Commercial harbors have been developed by the Corps of Engineers at St. Paul and Minneapolis. In the foreseeable future a harbor at Pigs Eye Lake in St. Paul will become a reality. Extensive dock and loading facilities have been constructed privately on the Mississippi River at Minneapolis, St. Paul, Newport and Spring Lake. Port Cargill is a private installation on the Minnesota River at Savage.

At present about 75 percent of the commercial river traffic consists of commodities shipped into the area, chiefly petroleum products and coal. Local shipments of sand and gravel into St. Paul account for a substantial share of the receipts at that port. Grain and soybeans make up the bulk of the shipments out of the area. Due to ice conditions in the river, navigation is usually limited to the period from late March to early December.

Table 9.—Barge traffic, in tons, in the Metropolitan area in 1959.

	Receipts	Shipments	Receipts and shipments
Port of Minneapolis	740,514	155,625	896,139
Port of St. Paul	2,767,094	639,337	3,406,431
Minnesota River	412,424	489,510	901,934
St. Croix River	38,449	0	38,449
Total	3,958,481	1,284,472	5,242,953

FLOODS

Flood damage on the Mississippi River within the metropolitan area is generally restricted to the reaches below its confluence with the Minnesota River. Most of the large floods occur during the spring, usually in April, but major floods have occurred during other months. The magnitude of spring floods is affected by the accumulation of snow, depth of frost in the ground and the rate of thawing and rainfall, although heavy rainstorms are rare during snow melt periods. Occasionally severe floods are caused by summer storms. The slow rise and fall of flood crests in the Mississippi River in the area is characteristic of streams with large watersheds in relatively flat areas.

The major flood of record, in April 1952, resulted from a record flood on the Mississippi above St. Paul and a near record flood on the Minnesota which occurred simultaneously. Extensive damage was caused to both public and private property in the Upper Levee, West Side and Holman Airport areas in St. Paul. In South St. Paul emergency dike construction at the stockyards prevented damage in that area.

The U. S. Weather Bureau flood stage for the Mississippi River at St. Paul is 14.0 feet. At a stage of 15.4 feet the Minneapolis-St. Paul sewage plant becomes inoperative. Flooding of Warner Road and Holman Airport occurs at stage of 18.0 and 18.5 feet, respectively. Emergency protection is needed at the South St. Paul stockyards when a stage of 13.3 feet is reached.

Floods along the Minnesota River within the watershed are generally not as damaging, although floods occur on an average of once a year. High flood flows affect the U. S. Highway 169 crossing at Shakopee, cause damage to rural property along the valley and to urban residential areas in parts of Shakopee. Industrial and commercial property located near the river is subject to flooding at Carver, Chaska, Savage and Shakopee.

Flood damage is not usually severe along the St. Croix River. During very high flows residential flooding may occur at Afton, Bayport and St. Croix Beach. Minor flooding may cause some damage to commercial and industrial establishments in Stillwater.

Improvement of the Mississippi River within the St. Paul-South St. Paul reach by the construction of levees, flood walls, drainage facilities and pumping plants for the purpose of flood control is authorized and construction by the U. S. Corps of Engineers is a future certainty.

Table 10.—Major floods of the Mississippi River at St. Paul

Date	Stage* (feet)	Discharge (cfs)	Duration (days)
April 22, 1867	17.4	84,700	
July 23, 1867	18.6	92,000	
March 1870	19.4	104,700	
April 16, 1875	18.0	86,200	
April 29, 1881	19.7	107,000	10
April 6, 1897	18.0	86,200	19
June 29, 1908	16.8	73,000	26
April 6, 9 1916	16.6	73,500	24
April 16, 1951	18.79	92,800	15
April 16, 1952	22.02	125,000	23
June 29, 1957	16.68	78,400	7

*Flood stage is 14.0 feet.

POWER

The water power of St. Anthony Falls has been used since 1821 when the United States government built a sawmill there. A wooden flume and an overshot wooden water wheel furnished the power. In 1823 a government-owned gristmill was erected near the sawmill. The first privately owned mill was completed on the east side of the river in 1848.

As the need for power increased and additional plants were installed, there was much controversy about priorities in the use of water. In 1856 the various owners of lands adjacent to the falls pooled their interests and formed the St. Anthony Falls Power Company on the east side and the Minneapolis Mill Company on the west side. These companies apportioned the available water equitably to the various users on each side of the river. The Northern States Power Company acquired both companies in 1923 and at present is the only company operating at the falls.

Originally the power from the turbines was transmitted directly to the mills by mechanical means, but all of the installations now produce electric power.

A summary of hydroelectric power plants now in operation in the metropolitan area is given in table 11.

Most of the steam-electric power produced in the metropolitan area is generated by the Northern States Power Company at four plants located on the Mississippi River and one plant on the Minnesota River. Slightly less than 310 billion gallons of river water is used annually for steam generation, condensing and cooling by the four plants on the Mississippi River and the Black Dog plant on the Minnesota River. The latter plant recirculates the cooling water through Black Dog Lake, which also serves as a reservoir during extreme low flow periods.

About 94 percent of the water withdrawn from the river by steam-electric plants is used for cooling and condensing and is thereafter returned to the river unchanged except for an increase in temperature. The portion used for boiler-feed water and converted to steam is included under "special industrial uses" in table 6.

Table 11.—Hydroelectric power plants, Metropolitan area.

Location and licensee	Head (feet)	Installed capacity (hp)	Installed capacity (cfs)	Generating capacity (kw)
Coon Rapids.................. Northern States Power Co.	20	11,040	6,075	8,240
Lower St. Anthony Falls....... Northern States Power Co.	24	11,680	5,350	8,000
Upper St. Anthony Falls....... Main Street plant of Northern States Power Co.	49	2,000	450	960
Upper St. Anthony Falls....... Hennepin Island plant of Northern States Power Co.	49	15,300	3,450	9,900
Lock and Dam No. 1.......... Ford Motor Co.	34.5	18,700	5,960	13,930

Table 12.—Water demand of steam power plants, Metropolitan area.

Name	River	Rated capacity (1,000 kw)	River water demand Max (mgh)	River water demand Min (mgh)	Annual river intake 1960 (mgy)	Annual river intake 1961 (mgy)
Riverside..................................	Mississippi	262	20.4	13.7	79,500	79,500
Southeast Minneapolis.....................	do.	30	1.5	0.8	Standby[1]	—
Island (St. Paul)..........................	do.	20	0.7	0.4	Standby[1]	—
High Bridge...............................	do.	423.25	19.2	14.1	112,816	112,816
Black Dog.................................	Minnesota	260[2]	16.5	9.9	84,600	109,700

[1]Standby stations run only during peak load conditions.
[2]New unit installed in 1960 adds 160,000 kw to the rated capacity.

SUMMARY

The discussions in this report have demonstrated the manifold and complex nature of the water problems of the area. Ground water and surface water are closely related and interdependent, and both are affected by the climate, geology, and topography of the region, and by the use and development of the land surface. Similarly, the problems of water supply and waste disposal cannot be entirely separated. What one community within the area does concerns the surrounding communities. Heavily pumped wells in one area adversely affect the pumping levels in wells elsewhere. The quality of water flowing in the rivers is directly related to sanitation practices in upstream communities, and the metropolitan area as a whole has a serious responsibility in maintaining the quality of river water so that it is fit for further use downstream.

The need for water continues to grow, but its supply varies seasonally and from year to year. As the total amount of water used approaches the supply now available, increased regulation and control will be required if recurrent shortages and excessive costs are to be avoided. And the problems will not be solved, once and for all, even with competent planning, foresight and the construction of facilities needed in the next 20 to 40 years. Records of consumption, analyses of the quality of water, appraisals of the quantities available, and expansion of facilities for supply, treatment and distribution must be continuous.

Coordination of sources of supply and the construction of facilities for treatment and distribution sufficient for the present and the near future can probably be achieved through expansion of the St. Paul and Minneapolis water systems and by voluntary cooperation of small groups of municipalities. Long-term planning and development to assure the future water supply of all of the area can hardly be expected to result from such a fragmentary approach to the problem. Areas which are now only sparsely populated may require large amounts of water in the future, and neighboring communities cannot now assume the responsibility for providing the water such areas will need.

It is suggested that the establishment of a single metropolitan water authority be considered. It should include approximately the same territory now being considered for an expanded metropolitan sanitary district. The authority should be empowered to acquire and operate all facilities for the supplying and storage of raw water and all water treatment plants. It should have the sole responsibility for supplying finished water to all municipalities in the area on a wholesale basis. It should have regulatory powers over all private, industrial and commercial water supplies and control the locations of new wells for such purposes. Local distribution systems should remain the property of the municipalities and be operated and maintained by them but be interconnected by mains constructed by the district authority in order to minimize the risk of serious disruptions of service and to make sure adequate pressure will be maintained for fire protection.

The metropolitan area is a physical and geographic unit, requiring an integrated approach to many of its problems. The complexity and difficulty of its water supply and waste disposal problems and their close inter-relationship indicate that their eventual solution will require a degree of coordination and control in both planning and operation which can be obtained only under a single administrative authority. Legislation leading to the establishment of such an authority is certain to be required in the foreseeable future. The educational campaign for such a change should be inaugurated by civic groups now.

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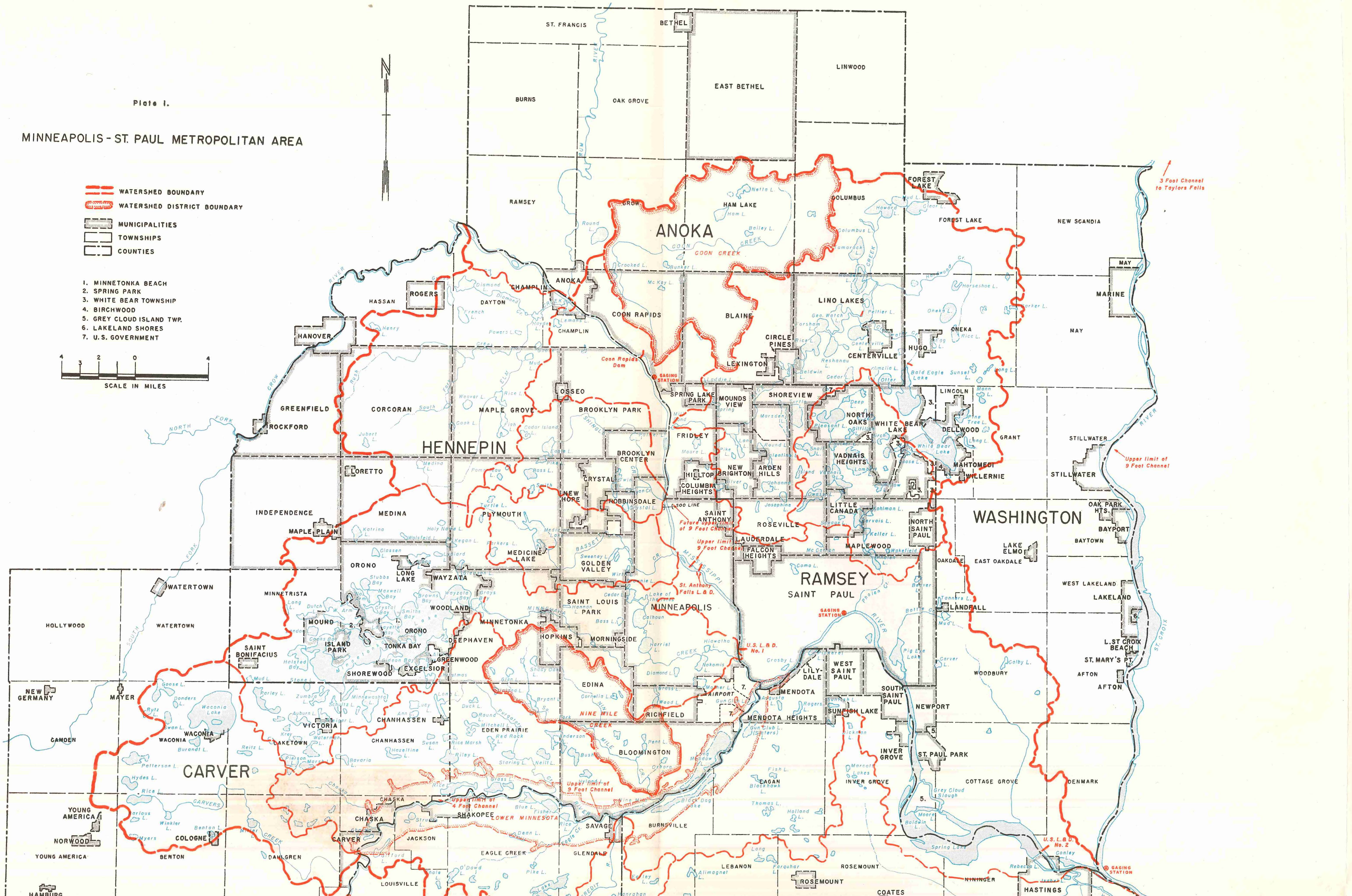
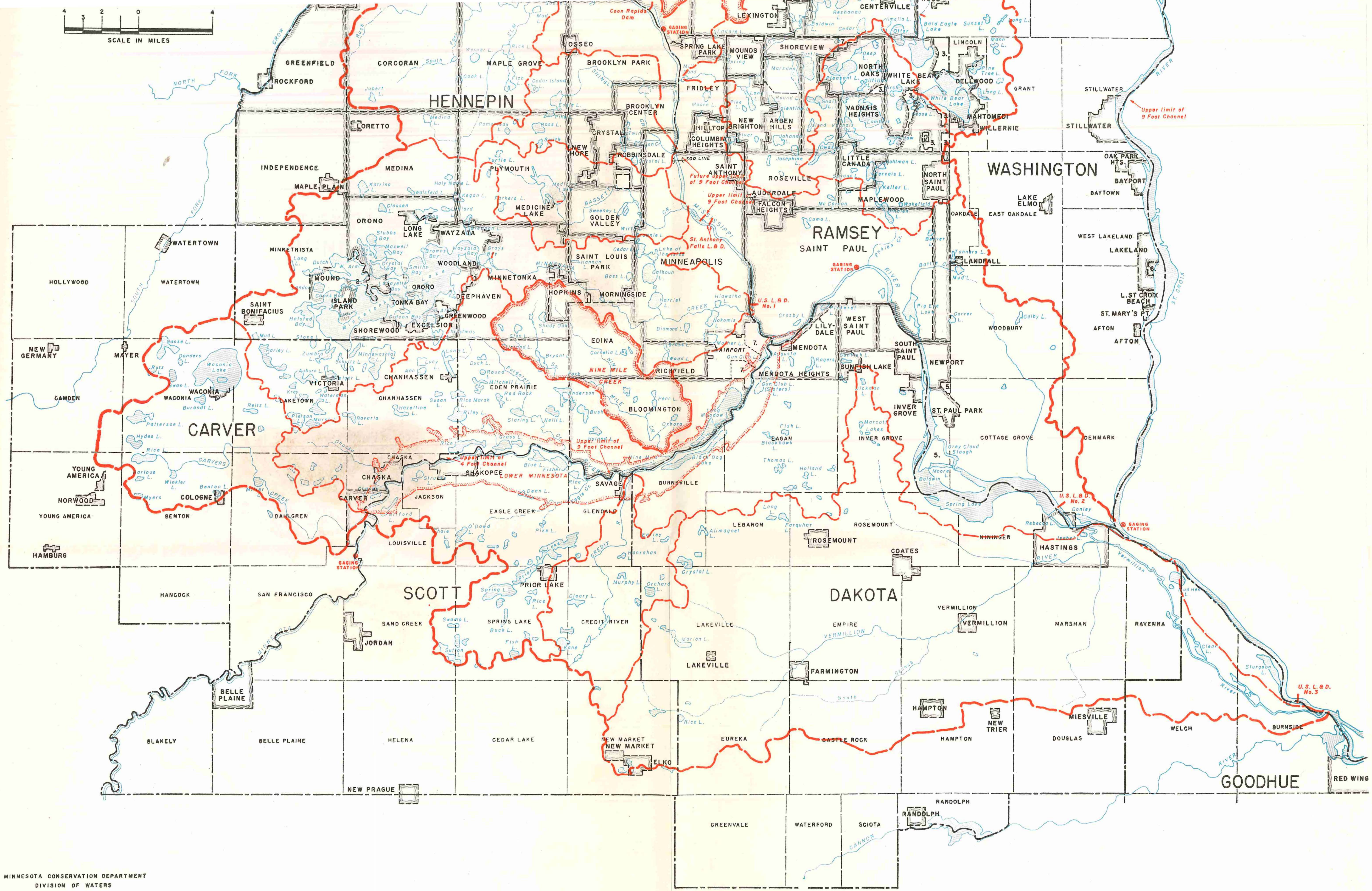
Plate I.

MINNEAPOLIS - ST. PAUL METROPOLITAN AREA





4 3 2 0 4
SCALE IN MILES
HENNEPIN
RAMSEY
SAINT PAUL
WASHINGTON
CARVER
SCOTT
DAKOTA
GOODHUE
MINNEAPOLIS
GREENFIELD
ROCKFORD
CORCORAN
MAPLE GROVE
BROOKLYN PARK
OSSEO
LEXINGTON
CENTERVILLE
SPRING LAKE PARK
MOUNDS VIEW
SHOREVIEW
NORTH OAKS
WHITE BEAR LAKE
LINCOLN
DELLWOOD
GRANT
STILLWATER
FRIDLEY
BROOKLYN CENTER
NEW BRIGHTON
ARDEN HILLS
VADNAIS HEIGHTS
MAHTOMEDI
WILLERNIE
LORETTO
CRYSTAL
HILLTOP
COLUMBIA HEIGHTS
NEW HOPE
ROBBINSDALE
SAINT ANTHONY
LITTLE CANADA
ROSEVILLE
NORTH SAINT PAUL
OAK PARK HTS.
BAYPORT
BAYTOWN
INDEPENDENCE
MEDINA
PLYMOUTH
MAPLE PLAIN
LAUDERDALE
FALCON HEIGHTS
MAPLEWOOD
LAKE ELMO
OAKDALE
EAST OAKDALE
ORONO
LONG LAKE
WAYZATA
MEDICINE LAKE
GOLDEN VALLEY
WATERTOWN
MINNETRISTA
WOODLAND
SAINT LOUIS PARK
WEST LAKELAND
LAKELAND
LANDFALL
HOLLYWOOD
MOUND
MINNETONKA
HOPKINS
MORNINGSIDE
ISLAND PARK
TONKA BAY
DEEPHAVEN
L. ST CROIX BEACH
ST. MARY'S PT.
AFTON
SAINT BONIFACIUS
EXCELSIOR
GREENWOOD
SHOREWOOD
EDINA
LILYDALE
WEST SAINT PAUL
WOODBURY
NEW GERMANY
MAYER
VICTORIA
CHANHASSEN
RICHFIELD
MENDOTA
MENDOTA HEIGHTS
SOUTH SAINT PAUL
NEWPORT
SUNFISH LAKE
EDEN PRAIRIE
CAMDEN
WACONIA
LAKETOWN
BLOOMINGTON
INVER GROVE
ST. PAUL PARK
COTTAGE GROVE
DENMARK
EAGAN
YOUNG AMERICA
NORWOOD
CHASKA
SHAKOPEE
SAVAGE
BURNSVILLE
COLOGNE
CARVER
JACKSON
EAGLE CREEK
GLENDALE
BENTON
DAHLGREN
LEBANON
ROSEMOUNT
NININGER
HASTINGS
LOUISVILLE
COATES
HAMBURG
PRIOR LAKE
HANCOCK
SAN FRANCISCO
SAND CREEK
SPRING LAKE
CREDIT RIVER
LAKEVILLE
EMPIRE
VERMILLION
MARSHAN
RAVENNA
JORDAN
FARMINGTON
BELLE PLAINE
HAMPTON
NEW TRIER
MIESVILLE
WELCH
BURNSIDE
BLAKELY
HELENA
CEDAR LAKE
NEW MARKET
ELKO
EUREKA
CASTLE ROCK
DOUGLAS
RED WING
NEW PRAGUE
RANDOLPH
GREENVALE
WATERFORD
SCIOTA
MISSISSIPPI
MINNESOTA
RIVER
ST. CROIX
CANNON
Coon Rapids Dam
GAGING STATION
Upper limit of 9 Foot Channel
Future upper limit of 9 Foot Channel
St. Anthony Falls L. & D.
U.S. L. & D. No. 1
U.S. L. & D. No. 2
U.S. L. & D. No. 3
Upper limit of 4 Foot Channel
LOWER MINNESOTA
NINE MILE CREEK
MINNESOTA CONSERVATION DEPARTMENT
DIVISION OF WATERS