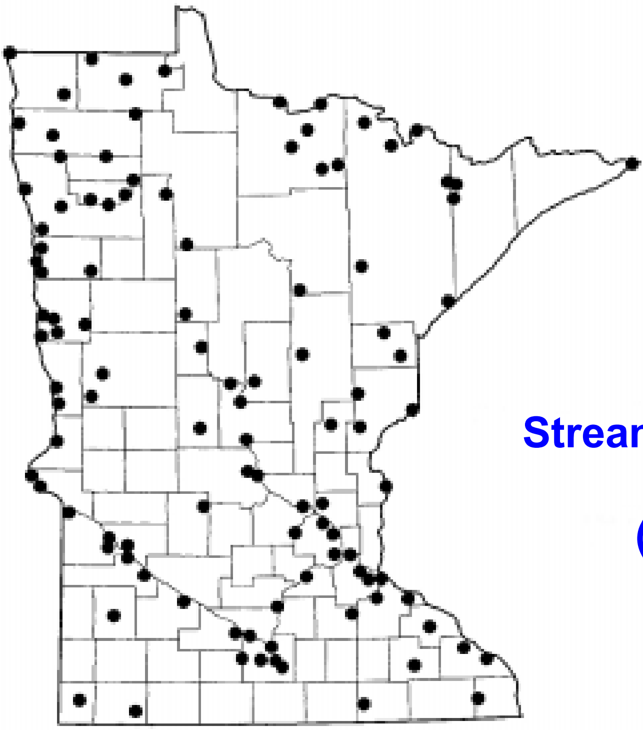
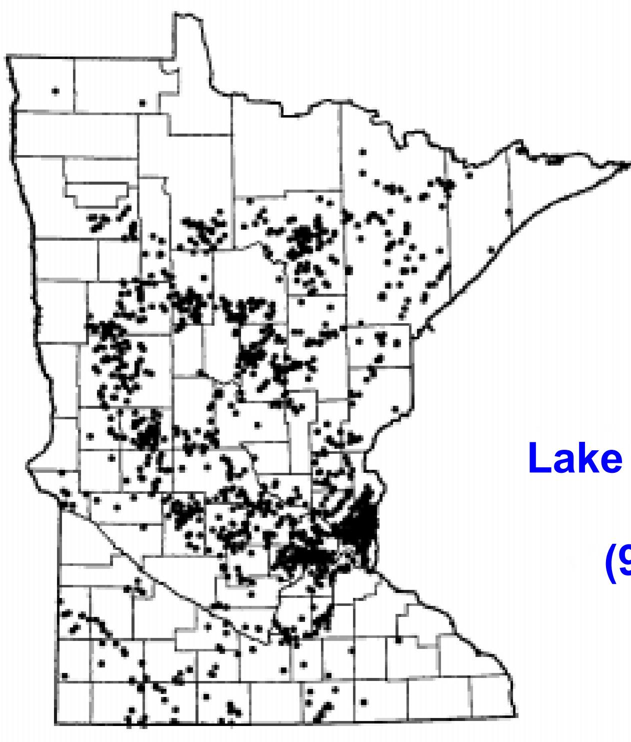
Chapter Two SURFACE WATER



Stream Gage Network
2000
(97 Gages)



Lake Gage Network
2000
(962 Gages)

Stream Flow

Introduction

The Stream Hydrology Unit is responsible for collecting, distributing and analyzing flow data for rivers and streams in Minnesota. Data for these activities comes from a network of stream gages located throughout Minnesota. Figure 1 shows the 81 major watersheds of the state and the location of the continuous recording gages that the DNR uses to monitor statewide watershed stream flow conditions. These gages are used to gather data including historic high and low flows, and information for computing statistics such as flood frequencies and exceedence values (see box below).

Engineers use stream flow data to design the hydraulic capacity of bridges, culverts and control structures. Planners use stream flow data for land use development and to determine water availability for industrial, domestic and agricultural consumption. Biologists use stream flow data to assist in evaluating aquatic habitat potential in streams. Knowing how much water is flowing or available in a stream is very important for flood and drought planning.

Stream Drainage Systems

There are many types of rivers and streams in Minnesota. Along the North Shore of Lake Superior, and along the Mississippi River blufflands in the southeast, are high gradient streams that have scoured channels into bedrock. In the northwest are highly meandered streams that are situated in an ancient lake bed and are prone to flooding. In the southern third of the state, streams are often entrenched with well developed channels and are largely impacted by agricultural practices. North central streams can be impacted by both agricultural and forest land uses.

Minnesota is unique in that two of the three continental divides in North America pass through it. These two continental divides separate river flows into three major drainage basins: the Hudson Bay/Arctic Ocean, the Great Lakes/Atlantic Ocean and the Mississippi River/Gulf of Mexico. Within these three basins are nine major river basins: the Red River of the North, Rainy River, Lake Superior, Upper and Lower Mississippi River, St. Croix River, Minnesota River, Missouri River and the Des Moines - Cedar River (Figure 2).

E X C E E D E N C E V A L U E

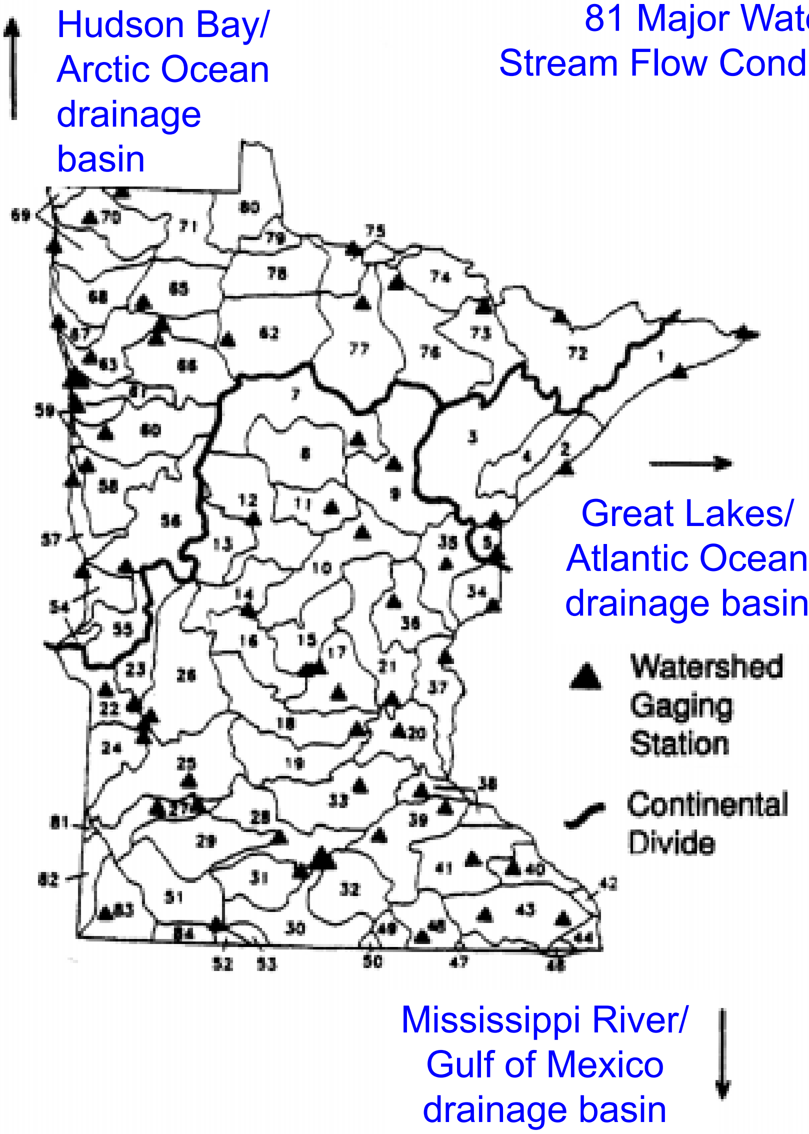
An exceedence value is a statistical parameter, based upon historical discharge records, and is the probability of stream flow *exceeding* a certain value. A 50% exceedence value (Q50) indicates that the discharge at that reporting station has been *equalled* or *exceeded* 50% of the time during a specific period. Exceedence values can be calculated on a daily, monthly or annual basis.

Stream flow reports are based upon the following exceedence values during the open water season.

Critical Flow = < annual Q90
Low Flow = < monthly Q75
Normal Flow = monthly Q75 to Q25
High Flow = > monthly Q25
Flood Flow = > NWS* flood stage
(or highest monthly Q10)

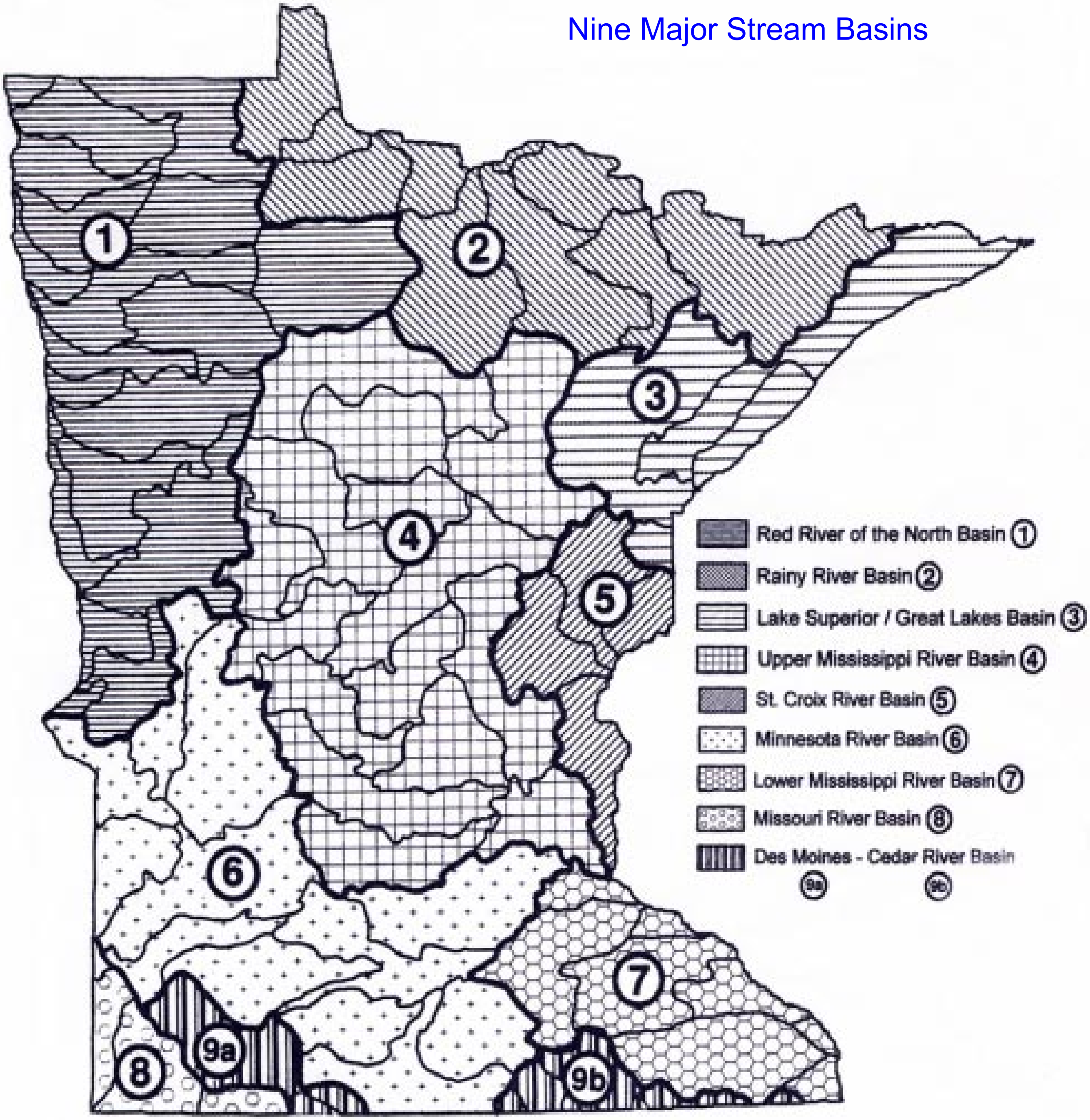
*** National Weather Service**

81 Major Watersheds Stream Flow Condition Network



1 Lake Superior (north) ▲
2 Lake Superior (south) ▲
3 St. Louis River ▲
4 Cloquet River
5 Nemadji River ▲
*
7 Mississippi River (Headwaters, Lake Winnibigoshish) ▲
8 Leech Lake River
9 Mississippi River (Grand Rapids) ▲
10 Mississippi River (Brainerd) ▲
11 Pine River ▲
12 Crow Wing River ▲
13 Redeye River (Leaf River)
14 Long Prairie River ▲
15 Mississippi River (St. Cloud)
16 Sauk River ▲
17 Elk River (Elk River) ▲
18 North Fork Crow River ▲
19 South Fork Crow River
20 Mississippi River (Metro) ▲
21 Rum River ▲
22 Minnesota River (Headwaters)
23 Pomme de Terre River ▲
24 Lac qui Parle River ▲
25 Minnesota River (Montevideo) ▲
26 Chippewa River ▲
27 Redwood River ▲
28 Minnesota River (Mankato) ▲
29 Cottonwood River ▲
30 Blue Earth River ▲
31 Watonwan River ▲
32 Le Sueur River ▲
33 Minnesota River (Shakopee) ▲
34 St. Croix River (Upper)
35 Kettle River
36 Snake River
37 St. Croix River (St. Croix Falls) ▲
38 Vermillion River (Empire) ▲
39 Cannon River ▲
40 Mississippi River (Winona) ▲
41 Zumbro River ▲
42 Mississippi River (La Crescent)
43 Root River ▲
44 Mississippi River (Nevo)
*
46 Upper Iowa River
47 Wapsipinican River (Headwaters)
48 Cedar River ▲
49 Shell Rock River
50 Winnebago River (Lime Creek)
51 West Fork Des Moines River (Headwaters) ▲
52 West Fork Des Moines River (Lower)
53 East Fork Des Moines River
54 Bois de Sioux River ▲
55 Mustinka River
56 Otter Tail River ▲
57 Red River of the North (Headwaters) ▲
58 Buffalo River ▲
59 Marsh River ▲
60 Wild Rice River ▲
61 Sandhill River ▲
62 Upper and Lower Red Lake ▲
63 Red Lake River ▲
*
65 Thief River ▲
66 Clearwater River ▲
67 Grand Marais Creek (Red River of the North) ▲
68 Snake River
69 Tamarack River (Red River of the North) ▲
70 Two River ▲
71 Roseau River ▲
72 Rainy River (Headwaters) ▲
73 Vermillion River ▲
74 Rainy River (Rainy Lake)
75 Rainy River (Manitou) ▲
76 Little Fork River ▲
77 Big Fork River ▲
78 Rapid River
79 Rainy River (Baudette)
80 Lake of the Woods
81 Big Sioux River (Medary Creek)
82 Big Sioux River (Pipestone)
83 Rock River
84 Little Sioux River

Figure 2



Minnesota is further unique in that very little water flows into the state. Only two rivers receive out-of-state water: the headwaters of the Minnesota River from South Dakota and the Blue Earth River from Iowa. Minnesota exports large volumes of water via the Red, Rainy, Mississippi, (including the Minnesota and St. Croix Rivers), and through the numerous North Shore streams and rivers.

Stream Gaging in Minnesota

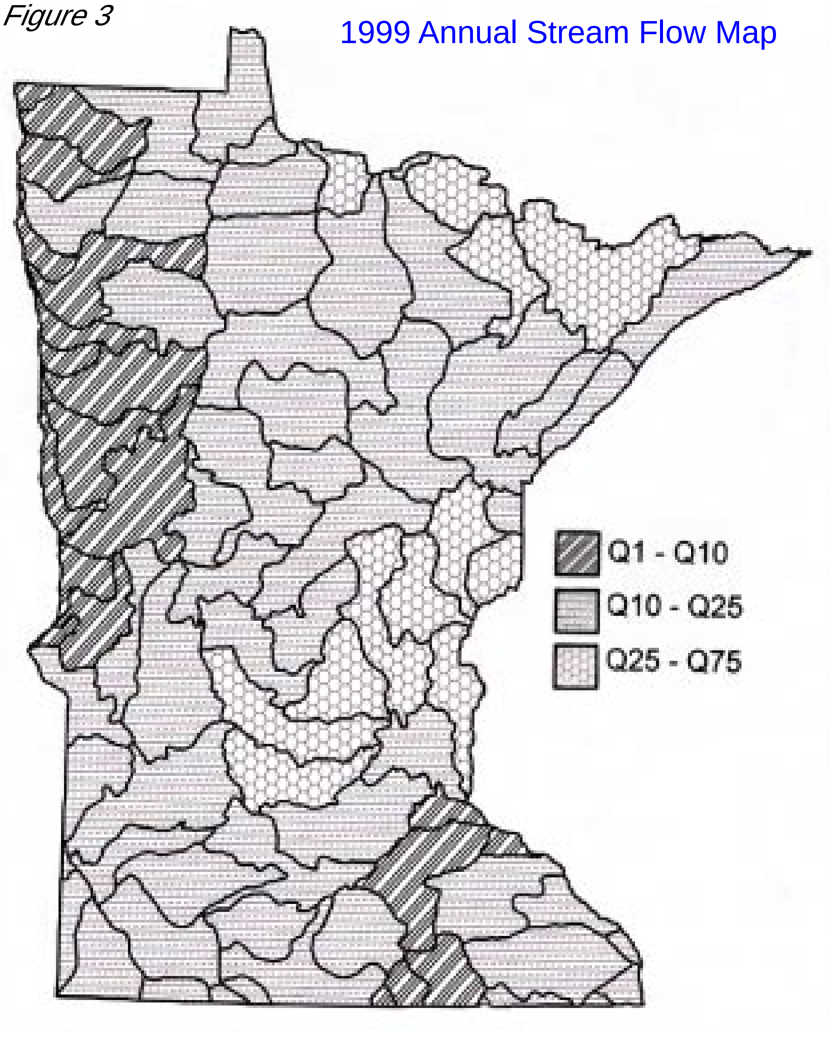
Gaging is an essential tool in analyzing stream flows in Minnesota. A stream gage is used to record the water elevation of a stream at a specific location. Measurements of stream discharge must be made periodically at the gage location to develop the relationship between stream elevation and the quantity of flow in the stream. If this relationship is developed, recorded stream elevations can be converted to discharge in cubic feet per second (cfs). State-of-the-art gages in Minnesota record stream elevations continuously and transmit the data to a central location for conversion to discharge and use in hydrologic analysis.

Most continuous recording stream gages in Minnesota are operated by the United States Geological Survey. DNR Waters supports about one third of these network gages through the USGS's Cooperative Water Resource Data program. In addition, the DNR maintains approximately forty flood warning gages. The USGS has been gaging Minnesota streams for over 100 years.

Currently, there are nearly 100 continuous recording stream gages maintained by the USGS. Additional stream gages are operated and maintained by the Corps of Engineers, the Department of Natural Resources, the Department of Transportation, the Pollution Control Agency, the Metropolitan Council and other state and local agencies, including watershed districts and lake associations.

Unfortunately, at least five stream gages were eliminated in 2000 due to budget constraints and another was destroyed by flooding. The loss of a stream gage can significantly impact flood prediction and low flow protection. The loss of a stream gage with a long-term record also can seriously degrade the historical record of the stream. It is this long-term record that is important in determining stream flow trends, drought and flood frequency calculations and other historical parameters.

Figure 3 1999 Annual Stream Flow Map



Water Year 1999

Water Year 1998 ended with normal to high stream flow conditions throughout most of the state, although low and below protected flow conditions could be found in parts of the Arrowhead and Upper Mississippi River Headwaters regions.

In the spring of 1999, low flow conditions occurred rarely, and then only in the St. Croix River watersheds. The central part of Minnesota experienced near normal flows throughout April while the southern third of the state remained high with an occasional flood flow. The north received heavy rains in early April, concurrent with the spring snowmelt peak. As a result, flooding occurred in parts of the Red River of the North, Rainy River and Mississippi River Headwaters watersheds.

Flows in the northern two-thirds of Minnesota were near normal in early May, although high flows continued in parts of the Red River watershed and in much of the southern third of the state. Heavy rains in mid-May produced flooding in the Upper Mississippi River basin, parts of the Red River and in the Twin Cities Metropolitan Area until early June.

Normal rains in early June maintained high flows throughout Minnesota, with a few exceptions in the Arrowhead, St. Croix and Upper Mississippi River basins. Heavy rains fell in the northwest in late June, however, little precipitation fell during the remainder of the month, and stream flow conditions receded to near normal over much of the state.

July rains pushed stream flows generally into the high range. A major thunderstorm event on July 4-5, 1999 (Figure 3 on page 4) in north central and northeast Minnesota caused flooding in parts of the Mississippi River Headwaters, Rainy River and Great Lakes basins. Many streams in these areas experienced a 10-year to 25-year flood event. Flows remained mostly in the high range throughout August and September, with occasional flood flows and sporadic normal flows occurring in the state.

The annual hydrograph for Water Year 1999 (Figure 3) shows that stream flows were above normal for most of the state and well above normal for much of the Red River. However, flow conditions in the Mississippi River Headwaters, Rainy River and Great Lakes basins would have been near normal for the year without the thunderstorm event in early July.

Water Year 2000

The autumn of 1999 and winter of 2000 featured below normal precipitation and above normal temperatures. Streams, which would normally be frozen, remained open and flowing. By the end of February, nearly all of Minnesota was snow free and, in early March, flows in the southern half of Minnesota were in the low range. Flows in the normal range could be found in the north due to higher ground water levels from prior years and due to a larger volume of water retained as ice over the winter.

By early May, low flows were common in the southwest, east central and northeast watersheds, while the rest of Minnesota was near normal. A series of storms in late May pushed flows into the high range over the southern third of the state. Flows in the southeast would remain high into September in response to excess precipitation.

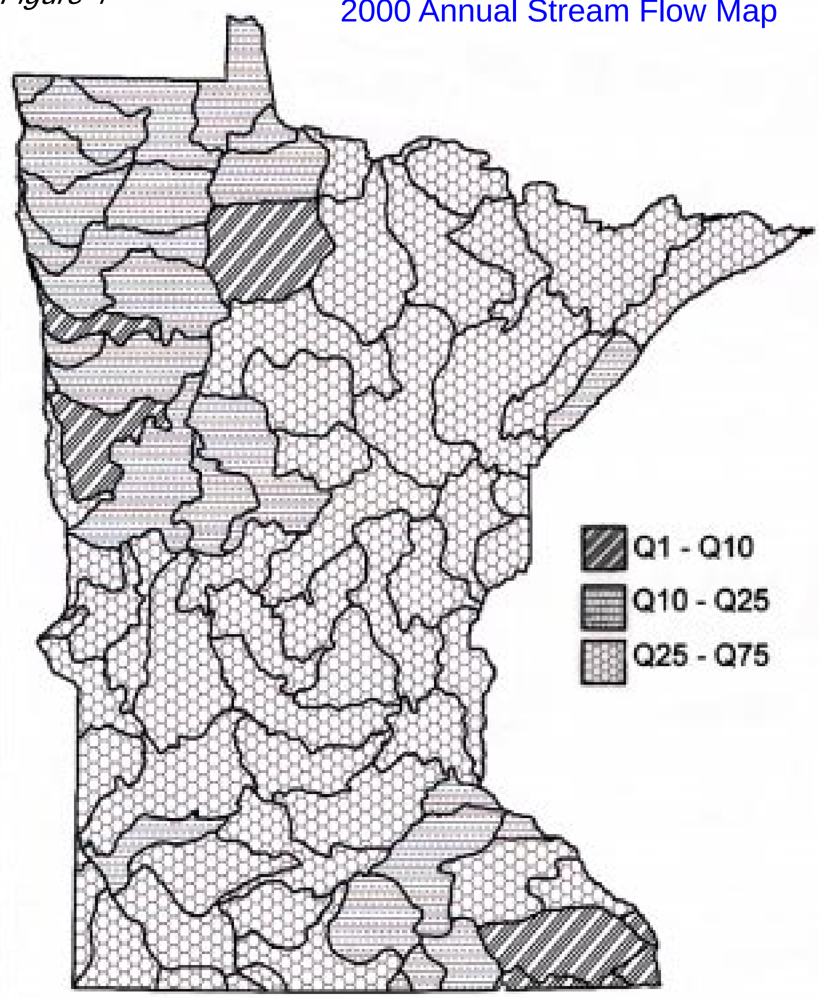
Low to near normal flows were experienced in the northern two-thirds of Minnesota throughout June. A series of storms over the northwest in late June brought many of the Red River watersheds into the high and flood flow categories. Flows remained high in the Red River valley for the remainder of summer.

Normal flows prevailed through July and early August, except in the extreme southeast and in the Red River valley. However, by mid-August, low and below critical flows were found in southwestern and central Minnesota. At the end of the water year in late September, critical flow levels extended from the southwest corner to the northeast corner of Minnesota.

The annual hydrograph for Water Year 2000 (Figure 4) shows that much of the state was near normal. High and very high conditions for the year were observed in the Red River watersheds and in the southeast. However, the low and very low flows observed at the end of the water year are absorbed by the averaging used to produce the annual map.

Figure 4

2000 Annual Stream Flow Map



Hydrographs

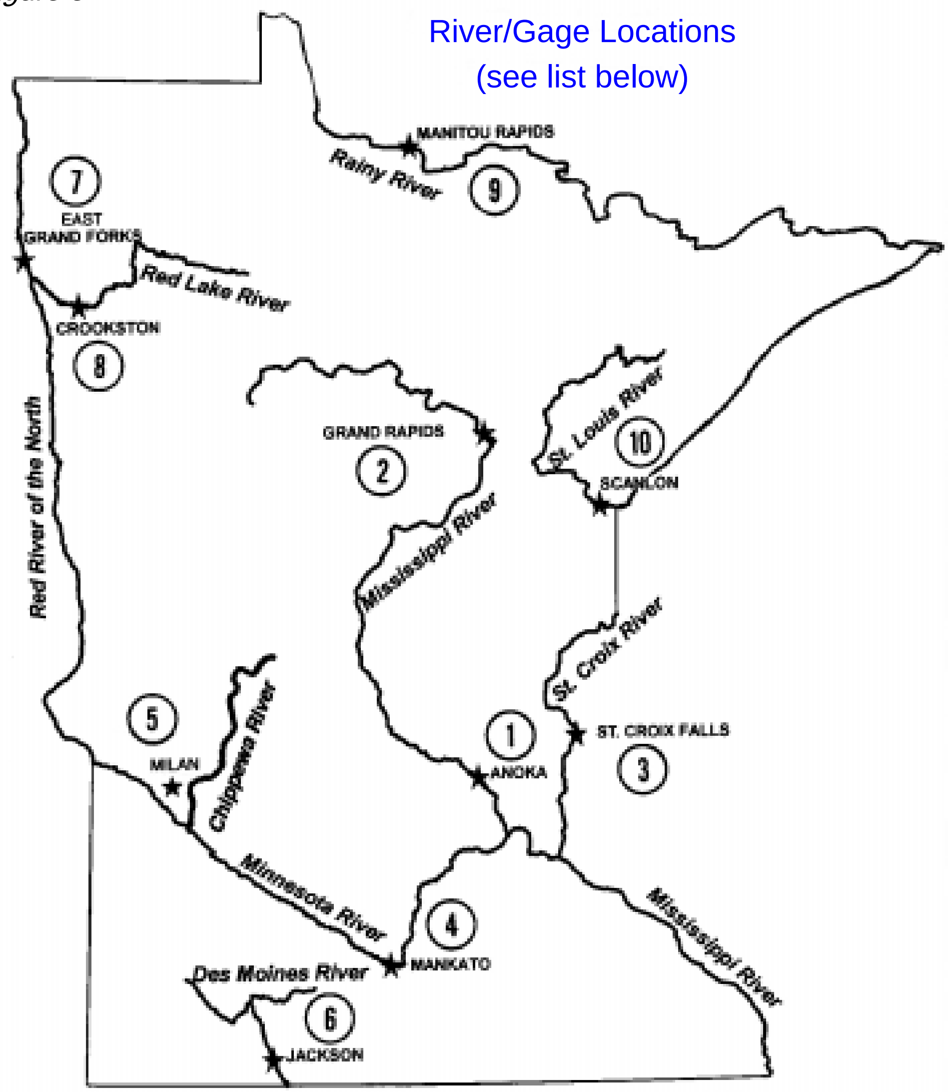
Stream hydrographs show the volume of water discharged during a specific time period. Figure 5 shows the location of ten rivers and stream gaging stations where discharge hydrographs have been created.

Figures 6 and 8 show two-year hydrographs for the ten selected sites. In addition to the mean daily discharge, the daily Q25 and Q75 exceedence levels are shown.

Figures 7 and 9 are period of record hydrographs for the same ten sites. The hydrographs show the average annual volume of water discharged during the water year, the annual Q25 and Q75 exceedence values and a 30-year moving average of the annual discharges. The 30-year moving average shows the trend in the volume of water flowing in a stream.

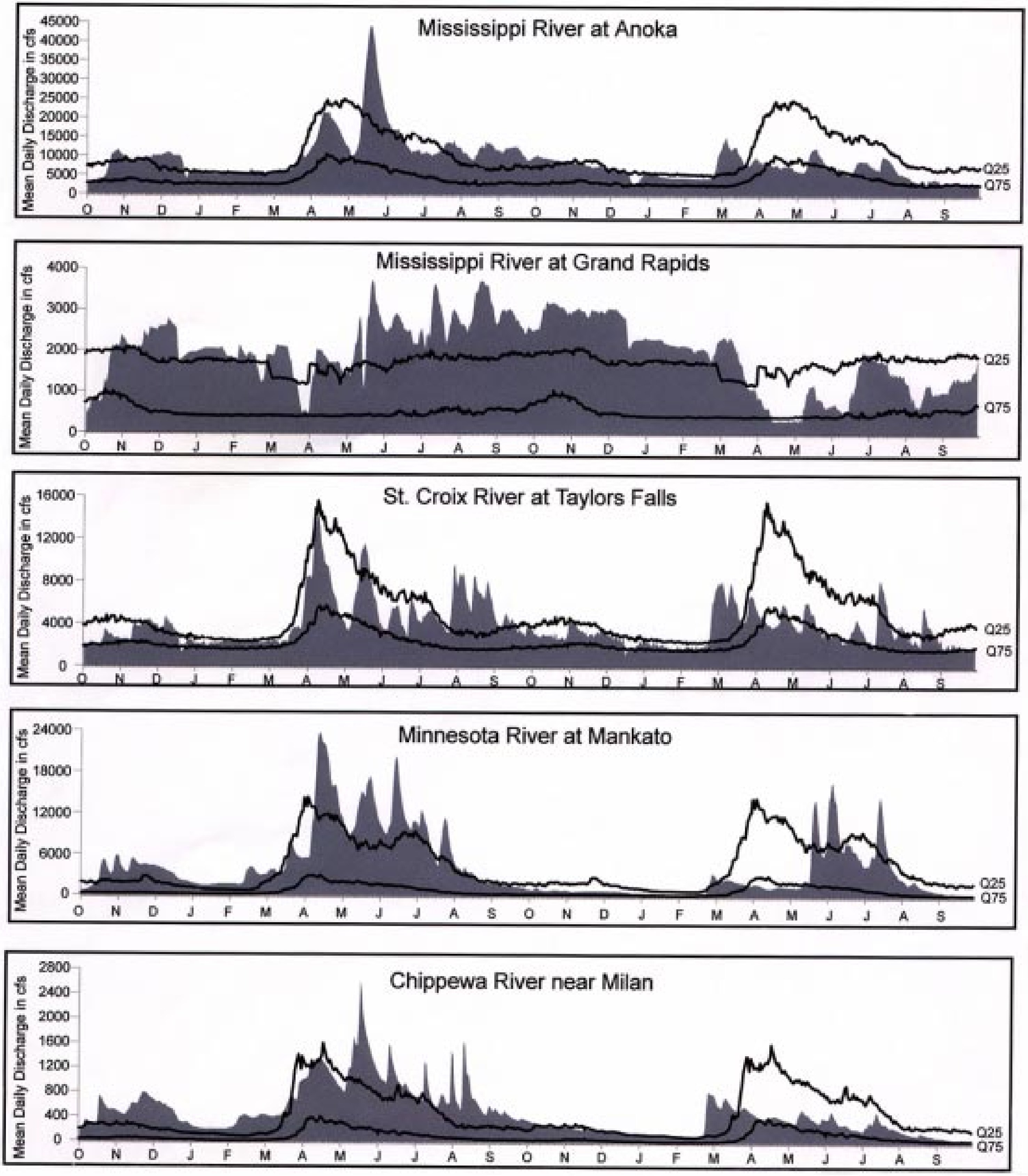
Figure 5

River/Gage Locations (see list below)



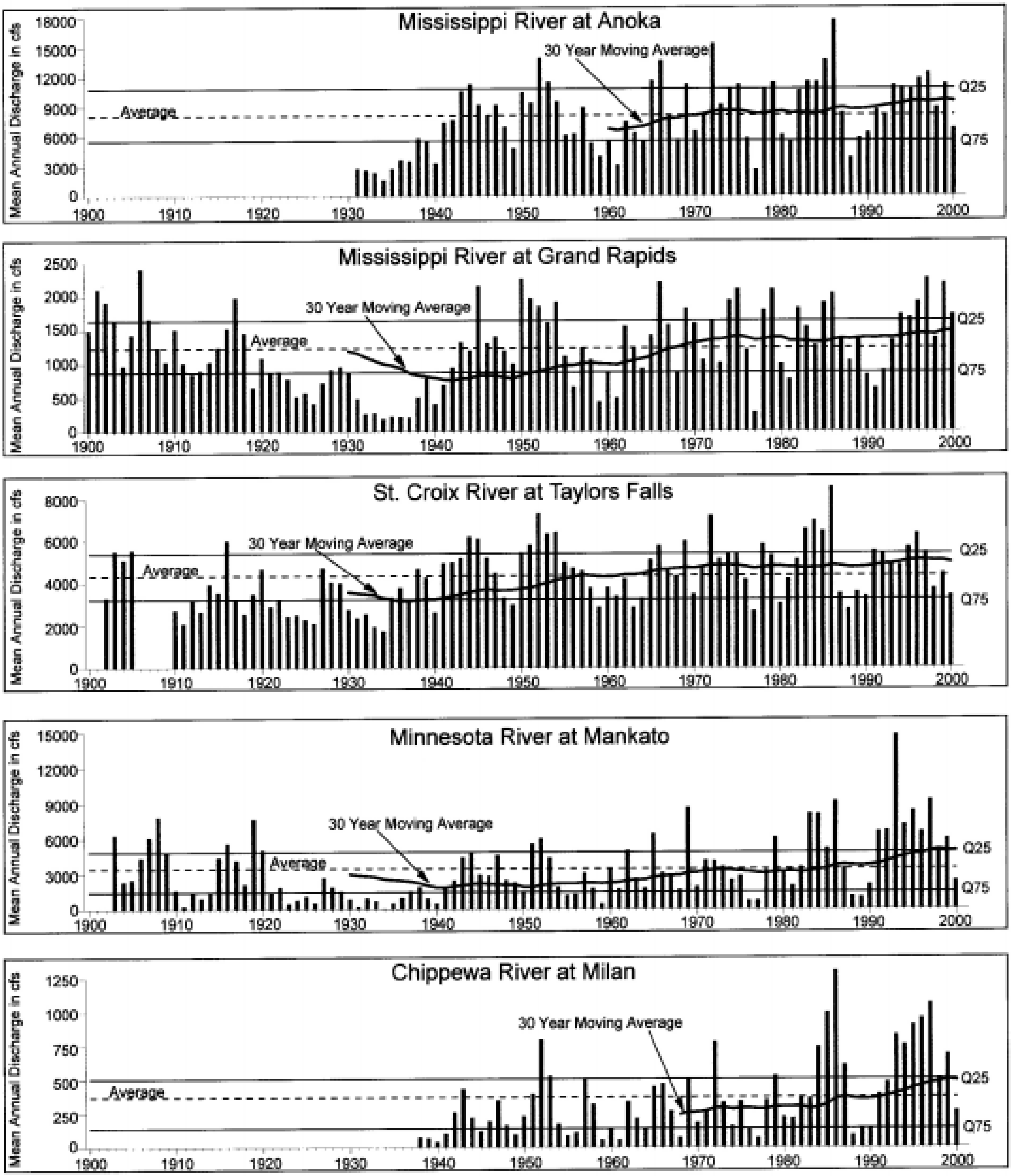
1) Mississippi River at Anoka
2) Mississippi River at Grand Rapids
3) St. Croix River at Taylors Falls
4) Minnesota River at Mankato
5) Chippewa River near Milan
6) Des Moines River at Jackson
7) Red River of the North at East Grand Forks
8) Red Lake River at Crookston
9) Rainy River at Manitou Rapids
10) St. Louis River at Scanlon

Figure 6



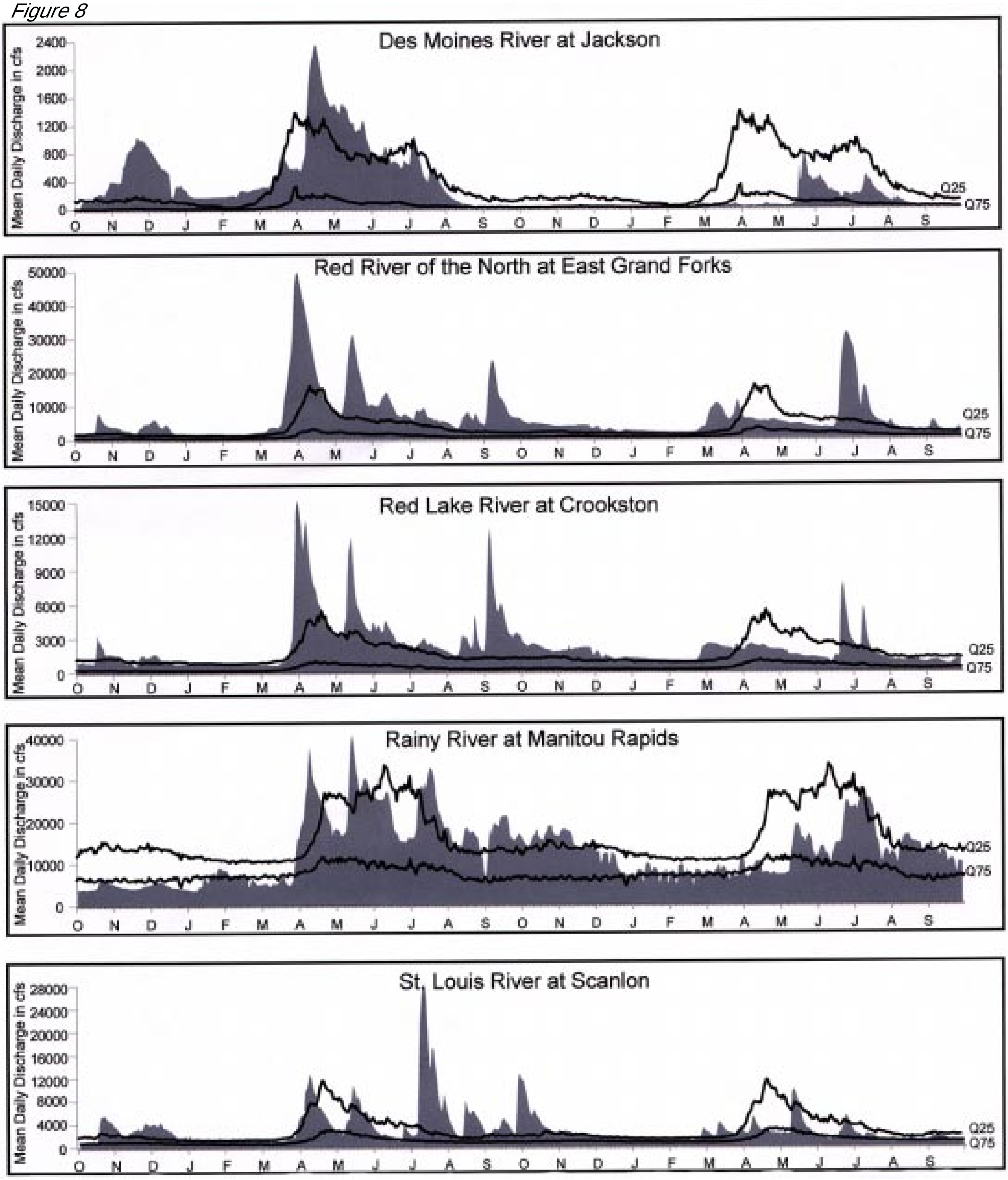
October 1, 1998 to September 30, 2000

Figure 7



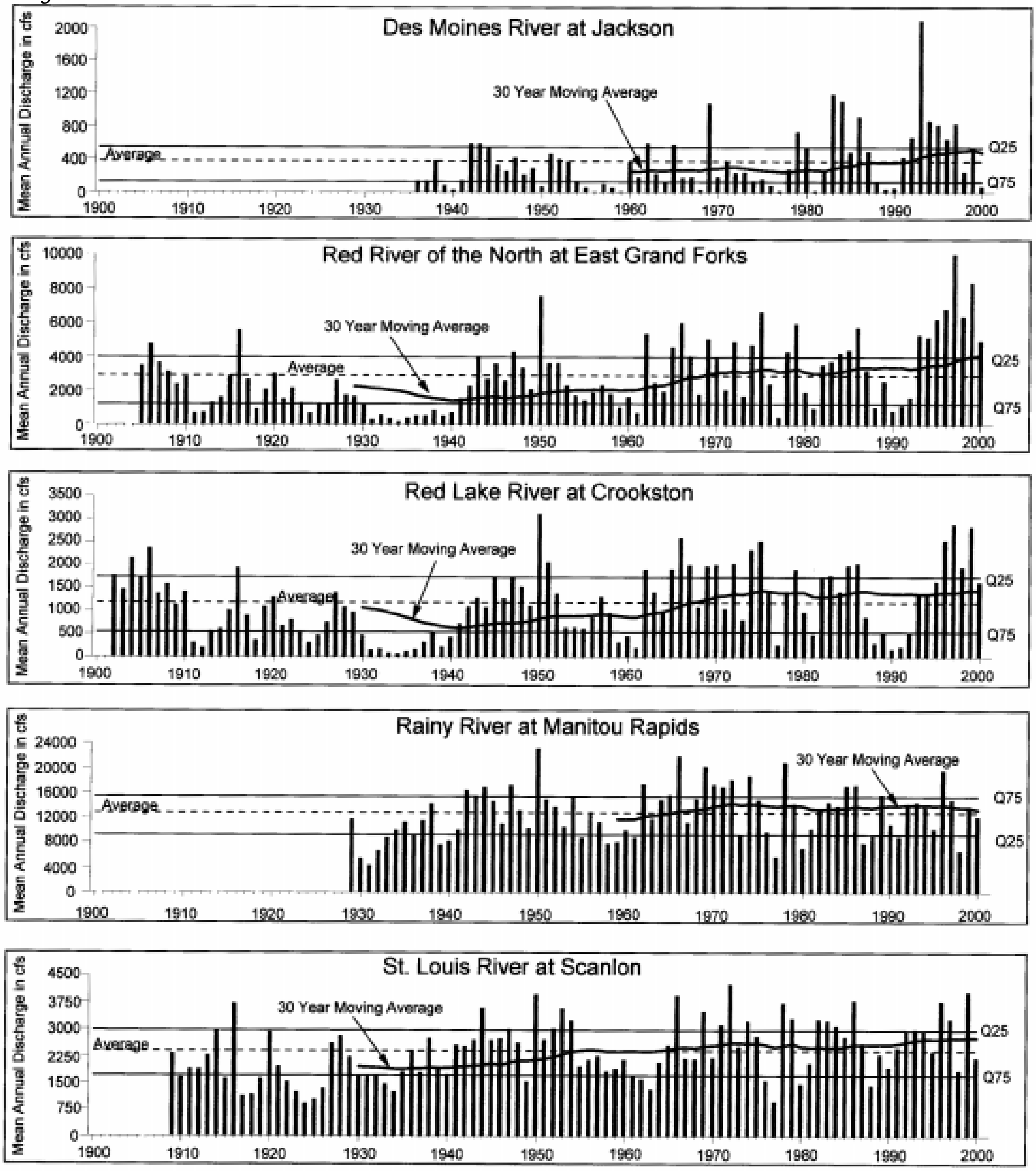
1900 to 2000

Figure 8



October 1, 1998 to September 30, 2000

Figure 9



1900 to 2000

Average Annual Runoff

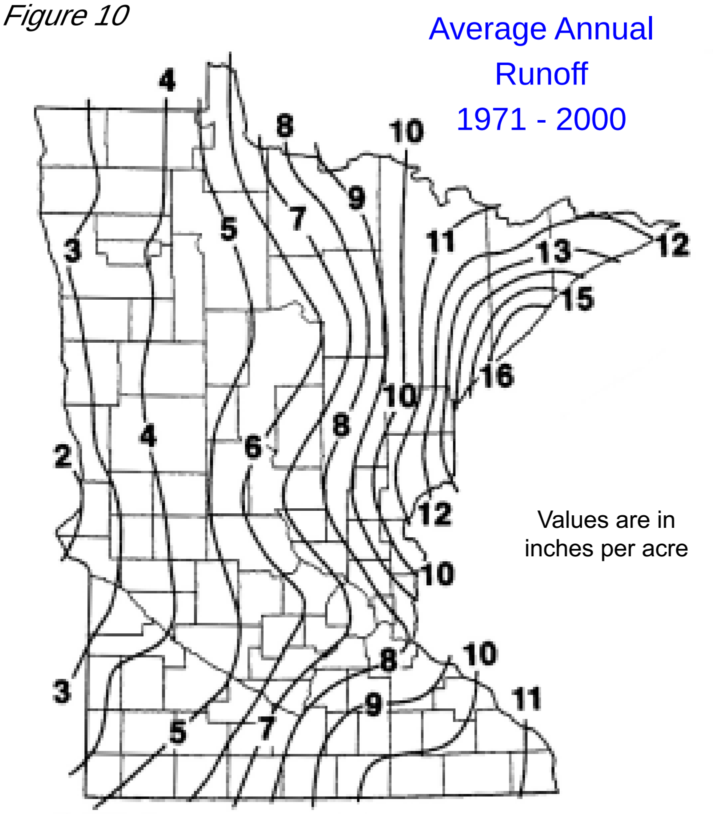


Figure 10

Runoff is the volume of water that, after falling as precipitation (rain and snow), flows off land to lakes, streams, rivers and other drainage features. Nearly all of the water entering major rivers in Minnesota will ultimately flow out of the state.

The amount of runoff is a result of several factors including climatology, surficial and bedrock geology, soil type and land use. Areas of steep slope and shallow soils tend to produce more runoff than areas of deep soil and flat surfaces. Developed areas that contain impermeable features such as roads and buildings tend to have very high runoff. Temperature can also significantly alter runoff by either increasing or decreasing evaporation and transpiration. Spring snowmelt is a major source of runoff in Minnesota.

Figure 10 is a map showing the average annual runoff for the 30-year period 1971-2000. The map was developed by averaging the annual discharge for each of 80 stream gages over the 30-year period. Each value, in cubic feet per second, was then converted to inches per acre for the drainage area of the gage.

To identify changes in average annual runoff, values for the 30-year period 1951-1980 were calculated. A comparison of the difference between the 1951-1980 period and the 1971-2000 period (Figure 11) shows that there has not been a notable change in runoff for much of the northerly two-thirds of Minnesota during the last 50 years. However, the southerly third of the state has experienced a significant increase in the volume of runoff. A primary reason for the increased runoff is that average annual precipitation has increased by approximately two inches in the south during the 50-year period. Precipitation in the north has increased by an average of approximately one inch, with some parts of the Arrowhead approaching a two-inch increase.

Figure 11 Change in Average Annual Runoff 1951-1980 vs. 1971-2000

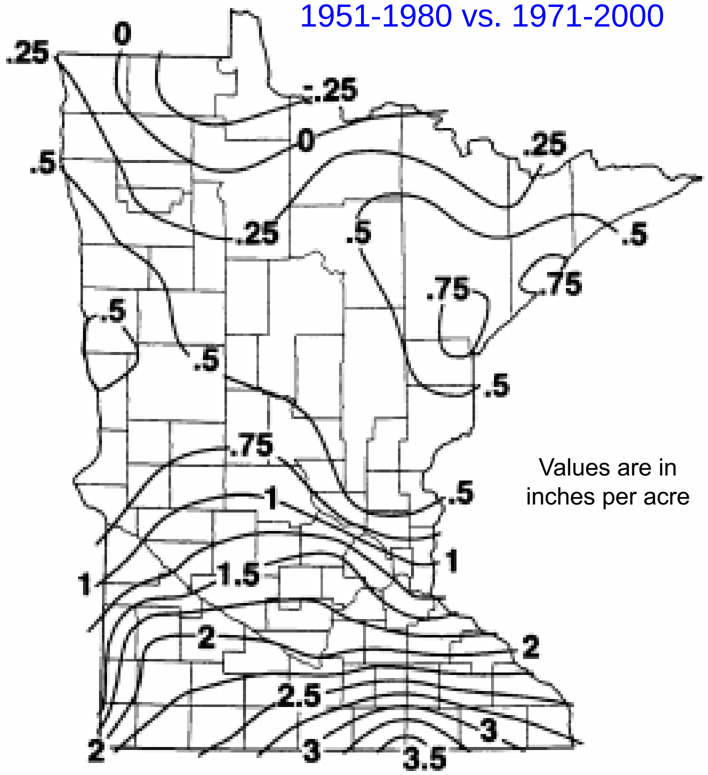
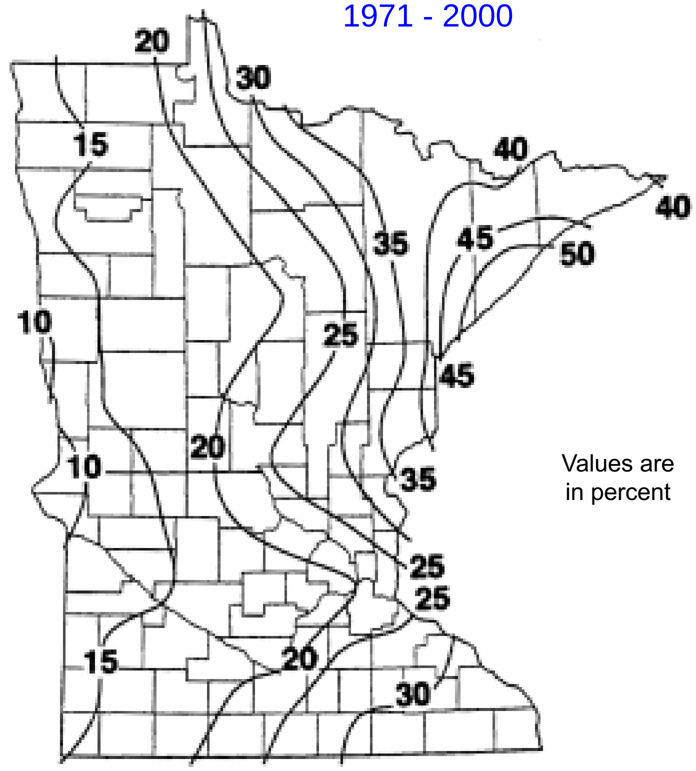


Figure 12 shows the volume of water running off the land as a percent of precipitation. The volume of precipitation that becomes runoff varied from 15 percent to 40 percent during the 30-year period of 1971-2000. However, it is possible for runoff to be less than 10 percent of precipitation in dry years or greater than 50 percent in wet years.

The very high values of runoff (50 percent or greater) along the north shore of Lake Superior are due to several factors including steep slopes, shallow soils with bedrock outcrops and heavier amounts of precipitation.

Figure 12 Runoff as a Percent of Precipitation 1971 - 2000



One of the consequences of a greater volume of runoff is that rivers must handle the additional water. Figures 7 and 9 on pages 21 and 23 clearly show that the annual hydrographs for the Minnesota River at Mankato, the Chippewa River near Milan and the Des Moines River at Jackson are now noticeably higher than they were in the mid-twentieth century.