Surface Water

photo by Michele Hanson

photo by John Hoxmeier

photo by Michele Hanson

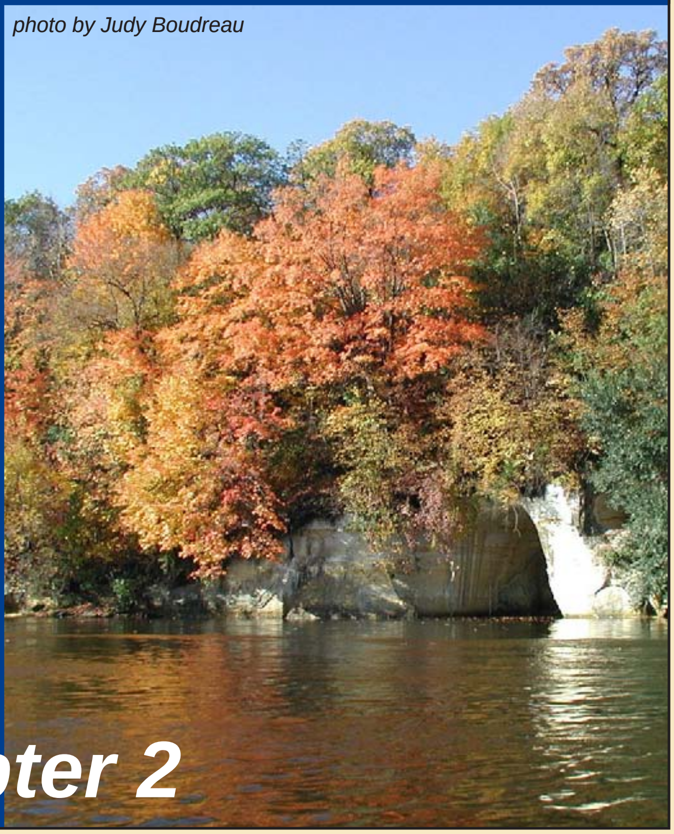


photo by Judy Boudreau

Chapter 2

Stream Flow

Introduction

submitted by Michele Hanson

photo by Michele Hanson

There are many types of rivers and streams in Minnesota. Along the north shore of Lake Superior and the Mississippi River bluff lands in southeast Minnesota, fast flowing streams have scoured channels in bedrock. In the northwest, slow-moving, highly-meandered streams flow through the soft soils of an ancient lake bed and, due to their low gradient, are prone to flooding. In the southern third of the state, streams are often entrenched with well-defined channels, and are highly 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 cross through it, meeting at a point near Hibbing. These Continental Divides separate surface water runoff into three drainage basins (and their major river basins): the Hudson Bay/Arctic Ocean (Red River of the North, Rainy River), the Great Lakes/Atlantic Ocean (Lake Superior) and the Mississippi River/Gulf of Mexico (Upper and Lower Mississippi River, St. Croix River, Minnesota River, Missouri River and the Des Moines – Cedar River). (See Figure 1)

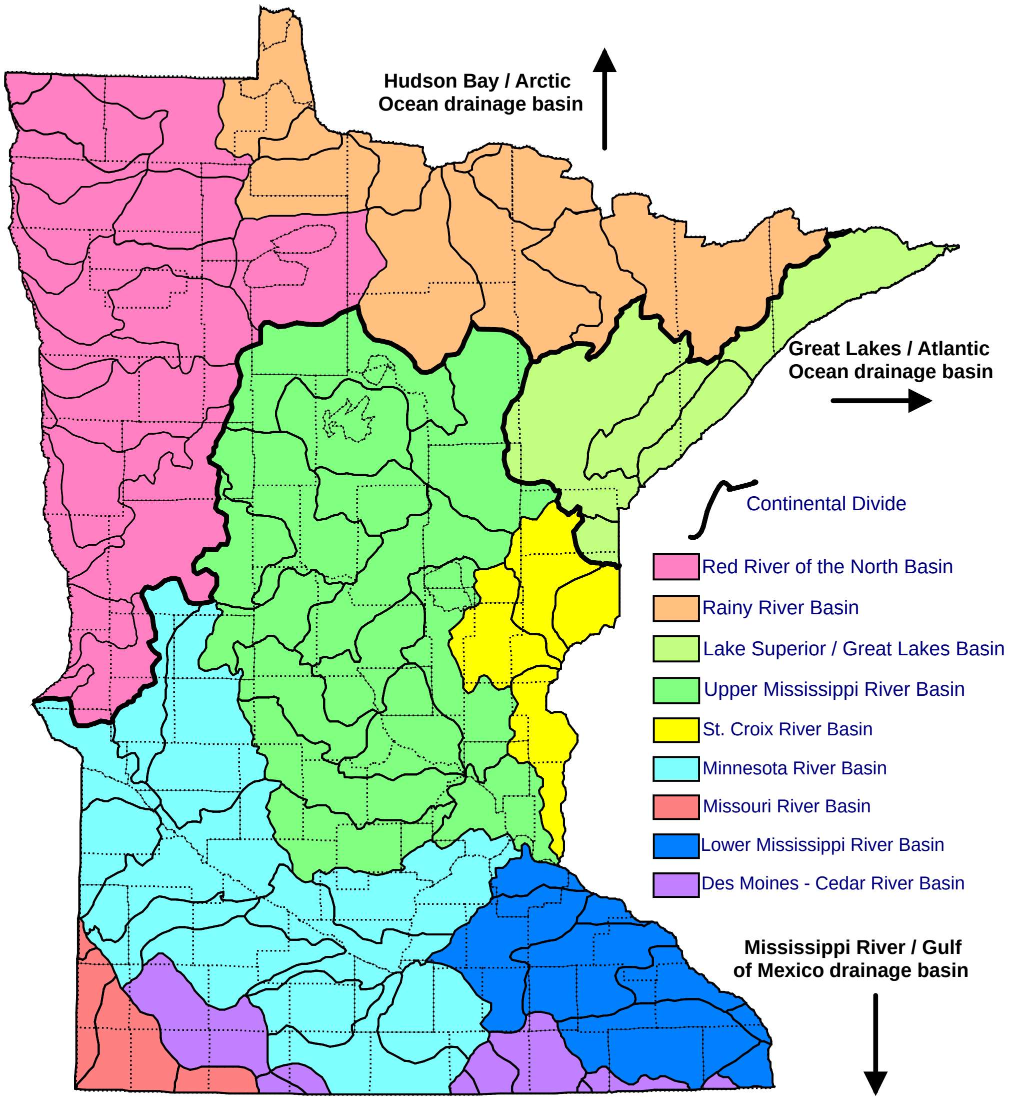
Minnesota is further unique in that very little water flows into the state. Only two rivers receive out-of-state water: the headwaters of the Minnesota River from South Dakota, and the Blue Earth River from Iowa. Minnesota exports large volumes of water via the Red, Rainy, Mississippi (including the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

A standardized set of watersheds was developed by the DNR in 1979. This Watershed Mapping Project delineated 81 Major Watersheds covering the state and approximately 5600 Minor Watersheds that make up these Major Watersheds (Figure 2).

Even earlier in the 1970's, the United States Geological Survey (USGS) and the Natural Resources Conservation Service (NRCS) developed the Hydrologic Unit system (HU for short) to divide and subdivide the U.S. into successively smaller watersheds. This system has been recently expanded and now adopted by the DNR with some modifications for its Lake Watershed Delineation Project (see website for more detail).

Figure 1

Nine Major Stream Basins



Stream Gaging in Minnesota

The United States Geological Survey (USGS) is the primary agency doing nationwide stream gaging. At the present time, the USGS maintains a network of approximately 125 continuously recording stream gages and approximately 400 high-flow and miscellaneous flow gages in Minnesota. However, as needs for additional stream information become necessary, additional agencies and organizations are gaging as well.

Other federal agencies doing stream gaging in Minnesota include the United States Army Corps of Engineers, with approximately 40 gages, and the National Weather Service.

The Minnesota Department of Natural Resources (DNR Waters Stream Hydrology Unit) is the primary state agency doing stream gaging, with a total of approximately 40 continuously recording gages and 60 seasonal gages. Other agencies having or supporting stream gaging in Minnesota include the Minnesota Department of Transportation and the Minnesota Pollution Control Agency. The Metropolitan Council also has several stream gages to monitor flows for public water supply and the discharge of treated waste waters. In addition, several watershed districts and lake associations operate gages.

Gaging is an essential tool in analyzing stream flows. A stream gage is used to record the water surface 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 volume of flow at that location. Once this relationship is developed, recorded stream elevations can be converted to discharge in cubic feet per second (cfs). Telemetered gages record stream elevations continuously and transmit the data to a central location for conversion to discharge and for use in hydrologic analysis.

There are many uses of information obtained from stream gages. Water surface elevation, the most basic information, assists in the determination of flood elevations, flood plains, and sizing of bridges and is useful for municipal zoning and planning. 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, as well as for the development of municipal and industrial water supplies.

Figure 2 shows the 81 major watersheds of the state and the location of the continuous recording gages that the DNR uses to monitor statewide stream flow conditions. These gages are used to gather data, including historic high and low flow and information for computing statistics such as flood frequencies and exceedence values (below).

A recent trend in stream gages is to include a chemical sampling unit at the gage. The sampler will then measure a chemical in the water, and with the discharge data, calculate how many pounds of that chemical have flowed past that gage. (See discussion on page 21)

If stream gages are lost due to budget constraints, flood prediction and low flow protection can be significantly compromised. The loss of a stream gage with a long-term record can seriously degrade ability to determine stream flow trends, drought and flood frequency calculations and other historical parameters. The long-term goal for DNR Waters is to establish and maintain at least one automated stream gaging station in each of Minnesota's 81 major watersheds to provide water quantity information needed to quantify pollutant loadings and develop Total Maximum Daily Loads (TMDLs).

The USGS has a water science website which includes a section on "How streamflow is measured". Click here for a primer geared toward high school students.

Photo by Lisa Pearson

EXCEEDENCE VALUE

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.

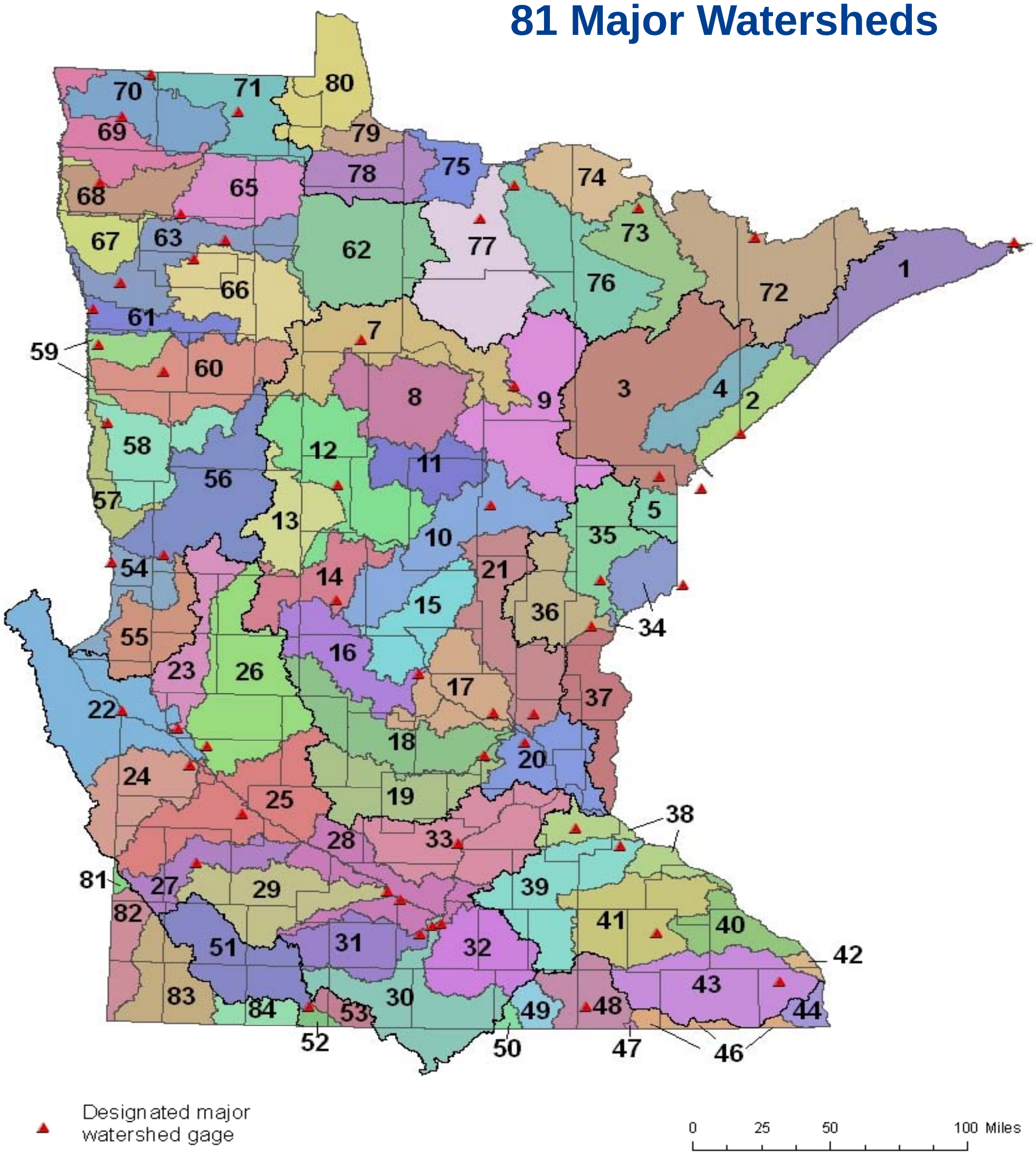
Stream flow reports are based upon the following exceedence values during the open water season.

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

Figure 2

81 Major Watersheds



1. Lake Superior – North
2. Lake Superior – South
3. St. Louis River
4. Cloquet River
5. Nemadji River
6. (none)
7. Mississippi River – Headwaters
8. Leech Lake River
9. Mississippi River - Grand Rapids
10. Mississippi River – Brainerd
11. Pine River
12. Crow Wing River
13. Redeye River
14. Long Prairie River
15. Mississippi River – Sartell
16. Sauk River
17. Mississippi River - St. Cloud
18. North Fork Crow River
19. South Fork Crow River
20. Mississippi River
21. Rum River
22. Minnesota River – Headwaters
23. Pomme de Terre River
24. Lac Qui Parle River
25. Minnesota River - Granite Falls
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 – Stillwater
38. Mississippi River & Lake Pepin
39. Cannon River
40. Mississippi River – Winona
41. Zumbro River
42. Mississippi River - La Crescent
43. Root River
44. Mississippi River – Reno
45. (none)
46. Upper Iowa River
47. Wapsipinican River
48. Cedar River
49. Shell Rock River
50. Winnebago River
51. West Fork Des Moines – Head
52. West Fork Des Moines – Lower
53. East Fork Des Moines
54. Bois de Sioux River
55. Mustinka River
56. Otter Tail River
57. Red River of the North
58. Buffalo River
59. Marsh River
60. Wild Rice River
61. Sandhill River
62. Upper/Lower Red Lake
63. Red Lake River
64. (none)
65. Thief River
66. Clearwater River
67. Grand Marais Creek
68. Snake River
69. Tamarac / Joe Rivers
70. Two River
71. Roseau River
72. Rainy River – Headwaters
73. Vermilion 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 - Medary Creek
82. Big Sioux – Pipestone
83. Rock River
84. Little Sioux River

MDNR/PCA Cooperative Stream Gaging Website

The Cooperative Stream Gaging Website is the final product resulting from over two years of hard work from several individuals within the Department of Natural Resources (DNR), the Pollution Control Agency (PCA) and the National Weather Service (NWS), along with the cooperation of the United States Geological Survey (USGS).

The website features data from over 200 stream gaging locations with near real-time capabilities as well as several hundred gaging stations with historic data operated by the USGS, DNR and PCA.

This website will continue to change over the next year as additional gages and features come on line to support the Clean Water Legacy and as historic data is added to the website.

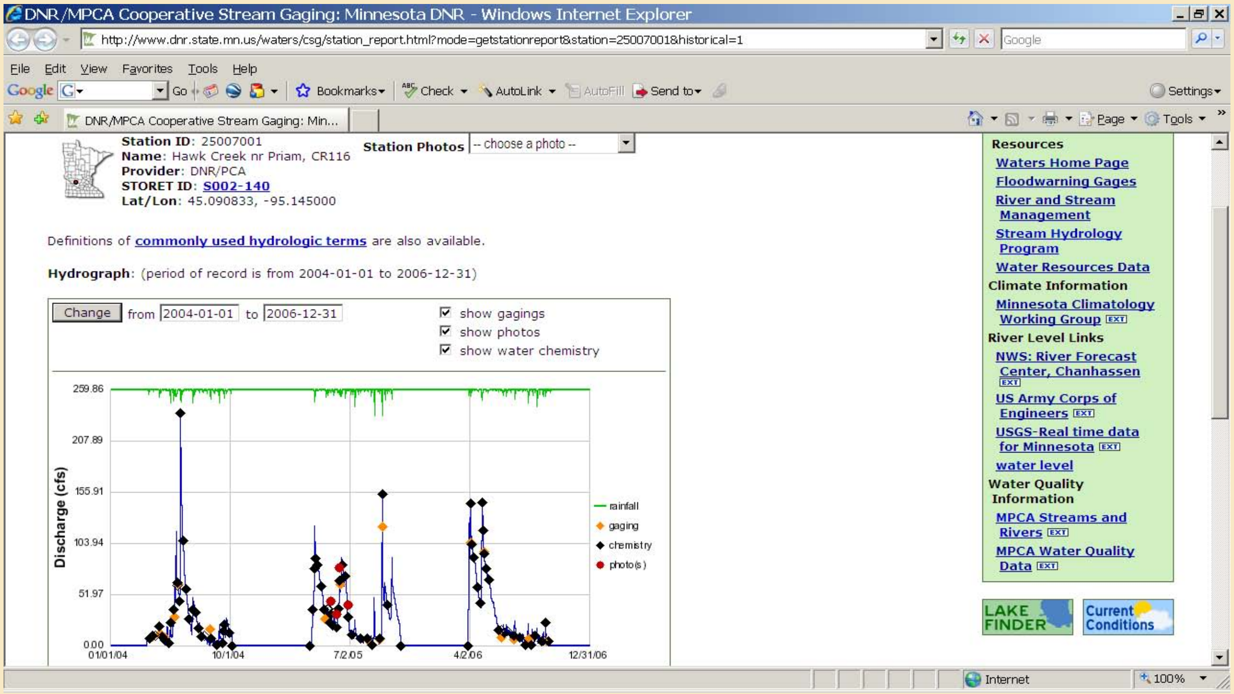
An example of chemical sampling of data can be found at the Hawk Creek (near Priam @ CR 116) website. Check the “show water chemistry” box above the graph and click on “Change” and you will be taken to a new graph which shows water chemistry data when hovering over the black diamonds (see example below).

The Minnesota Stream Flow Report

During the open water season, April 1 to September 30, a weekly Minnesota Stream Flow Report is produced on Mondays. The Stream Flow Report consists of a map showing current stream flow conditions by watershed (Flooding, High, Normal, Low, or Protected) as well as tabular data showing the prior week’s stage and discharge, current stage and discharge, Flood Stage, the protected flow and the Q25 and Q75 exceedence discharges. Once the Stream Flow Report has been generated, it is forwarded to interested users and posted on the Internet for public viewing.

Recipients of the Stream Flow Report use it to monitor current water issues such as flooding, drought, and water availability. The Stream Flow Report also gives a good representation of soil moisture and agricultural conditions throughout the state.

The DNR Division of Waters may use the Stream Flow Report to encourage conservation and a reduction of water use during periods of Low Flow. When the Stream Flow Report identifies a river as having fallen to the Critical Flow Level, DNR Waters may suspend water appropriations in order to maintain some water in the river for downstream public water supplies, power generation and other higher priority uses. This minimal protected flow also provides water to help protected fish and wildlife dependant on the river.



Water Year – 2005

In the fall of 2004 (the 2005 Water Year began October 1, 2004), statewide stream flow conditions were around the Q25. Flows continued around the Q25 through the fall and winter, and into the spring of 2005. For most reporting stations, spring runoff remained near the Q25 exceedence value. However, in the southern half of the state, cold weather persisted and the spring snowmelt occurred as much as 2 weeks later than normal. In the northern half of the state, spring snow melt occurred at the normal time. Spring snowmelt flooding was not widespread, occurring mostly in the northern half of Red River of the North watersheds.

By early May, with the snowmelt passed, the volume of water in many streams dropped to near the Q75 Low Flow level. However, heavy rains in late May and June restored flows throughout the state. In many cases, the May and June storms produced a greater volume of water than the spring snowmelt event. Flows in the mainstem and many tributaries of the Red River of the North exceeded flood stage. These May-June storms provided sufficient water to maintain stream flows in the normal range through the remainder of the water year for much of the state. However, these storms provided less water to the eastern portion of the state, including the Arrowhead region and the St. Croix River watersheds. By early August, Low Flow and Critical Flow conditions could be seen in these two areas.

The 2005 Water Year ended with the southern half of the state in the High Flow range, flows in the northwestern quarter in the normal flow range and flows in the northeastern quarter in the Low or Critical Flow range.

Figure 3 shows the 2005 Average Annual Stream Flow Map. Statewide, all watersheds had an annual average flow greater than the historic average or normal flow.

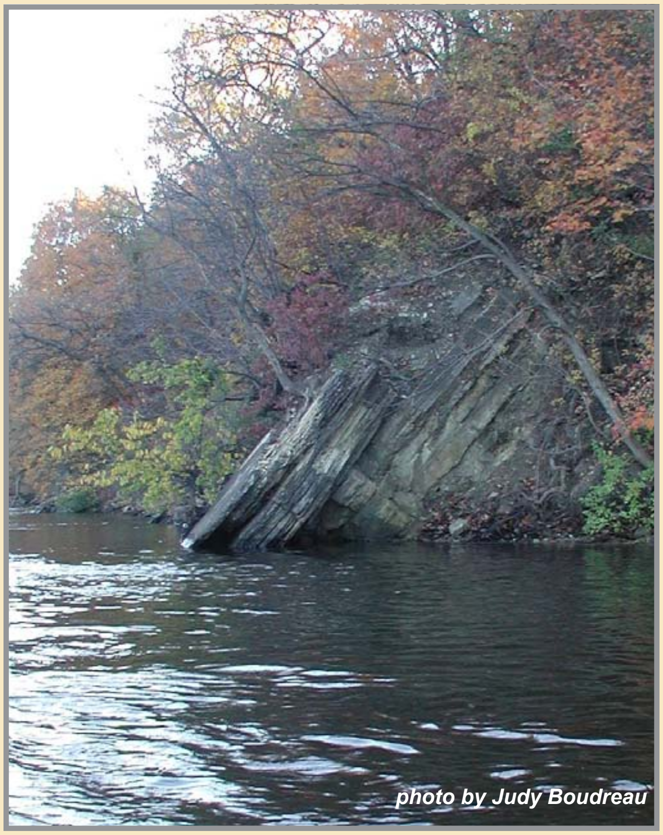


photo by Judy Boudreau

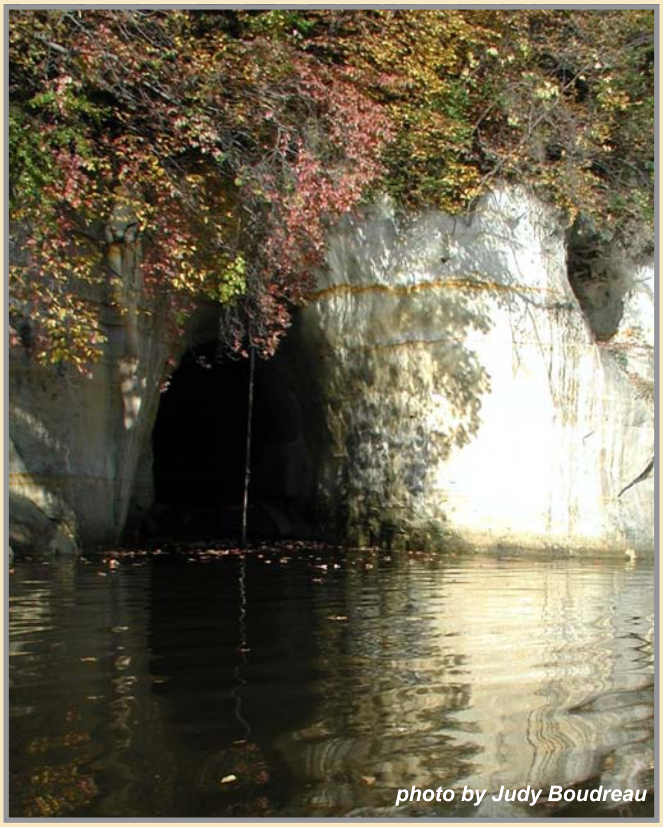
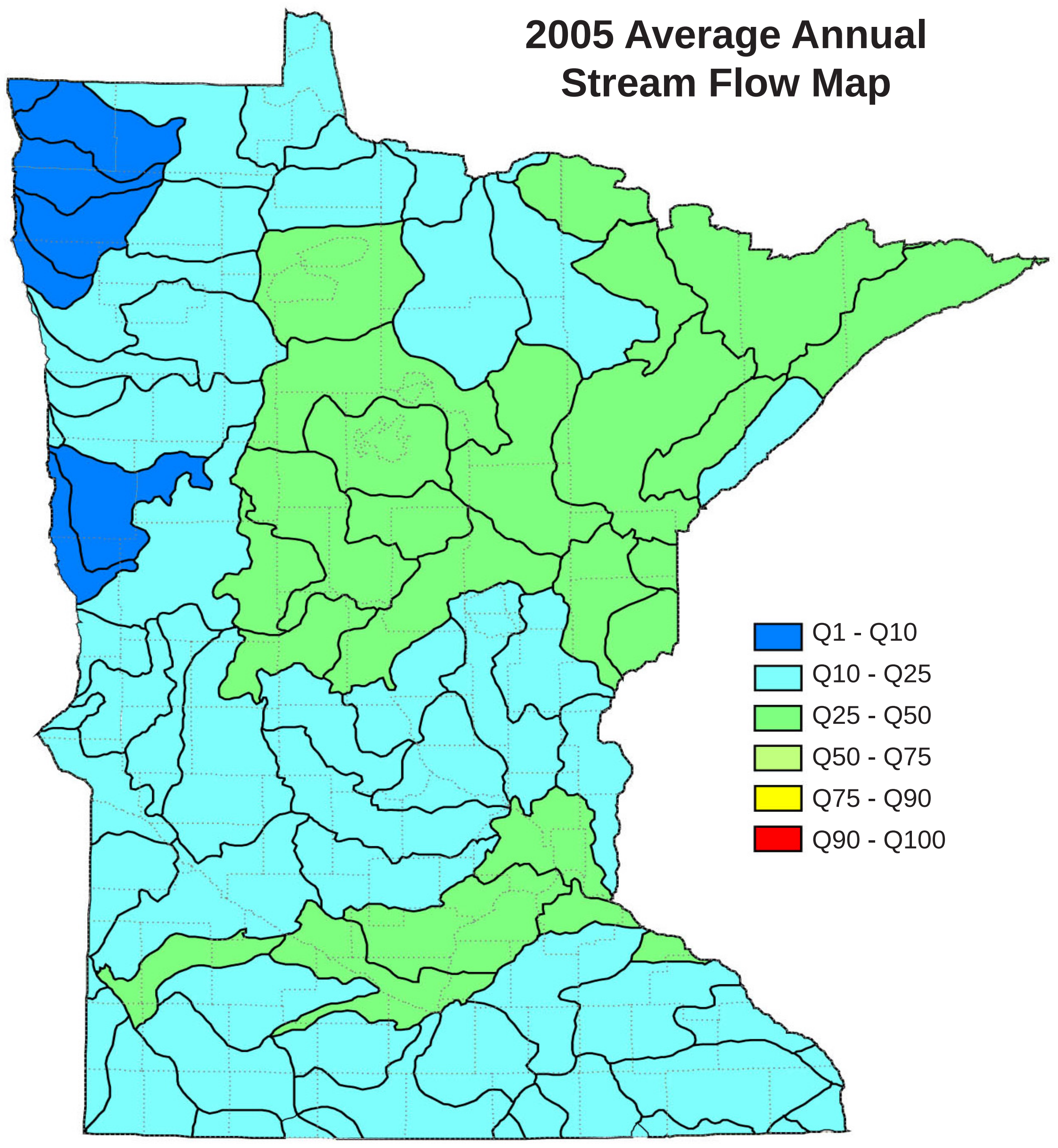


photo by Judy Boudreau

Figure 3


2005 Average Annual Stream Flow Map
Q1 - Q10
Q10 - Q25
Q25 - Q50
Q50 - Q75
Q75 - Q90
Q90 - Q100

Water Year - 2006

Figure 4 shows the 2006 Average Annual Stream Flow map. The 2006 map is very similar to the 2005 map. For the 2006 water year, only one watershed gage, the Mississippi River at Aitken, had average flows below the statistical average or normal value.

The 2006 water year started off with a very large precipitation event covering the southern half of the state. As flows in the southern half of the state were already in the High Flow range at the end of the 2005 water year, this large event provided sufficient water to maintain flows in the High Flow range through the fall of 2005 and winter of 2006. The St. Croix River watersheds also received excessive precipitation from this event and were lifted from the Low/Protected Flow range into the High Flow range through the winter of 2006.

In the southern half of the state and the Red River watersheds, the snowmelt runoff during the spring of 2006 produced a significantly larger runoff event than observed in 2005. Both the peak stage and total volume exceeded that of 2005 and what would be considered normal stage and volumes. Spring flooding was again observed in most of the Red River watersheds as well as in scattered locations in the southern half of the state.

photo by Michele Hanson

In the northeastern quarter of the state, the spring runoff was near normal. Unlike 2005, the timing of the 2006 spring runoff event matched historic normals.

In 2006, little precipitation occurred during the months of May through September. In the southern half of the state and Red River watersheds, wet antecedent conditions and high ground water levels maintained the flows in the normal range well into summer. However, by mid-June, Low Flows were common throughout much of northeastern Minnesota.

By early July, Low Flows encroached into the central portion of the state, with Protected Flows occurring in the St. Croix Valley.

Dry conditions persisted trough the remainder of the summer and water year with Protected Flows occurring predominantly in the Arrowhead, northern Minnesota, the Mississippi River headwaters and the St. Croix Valley.

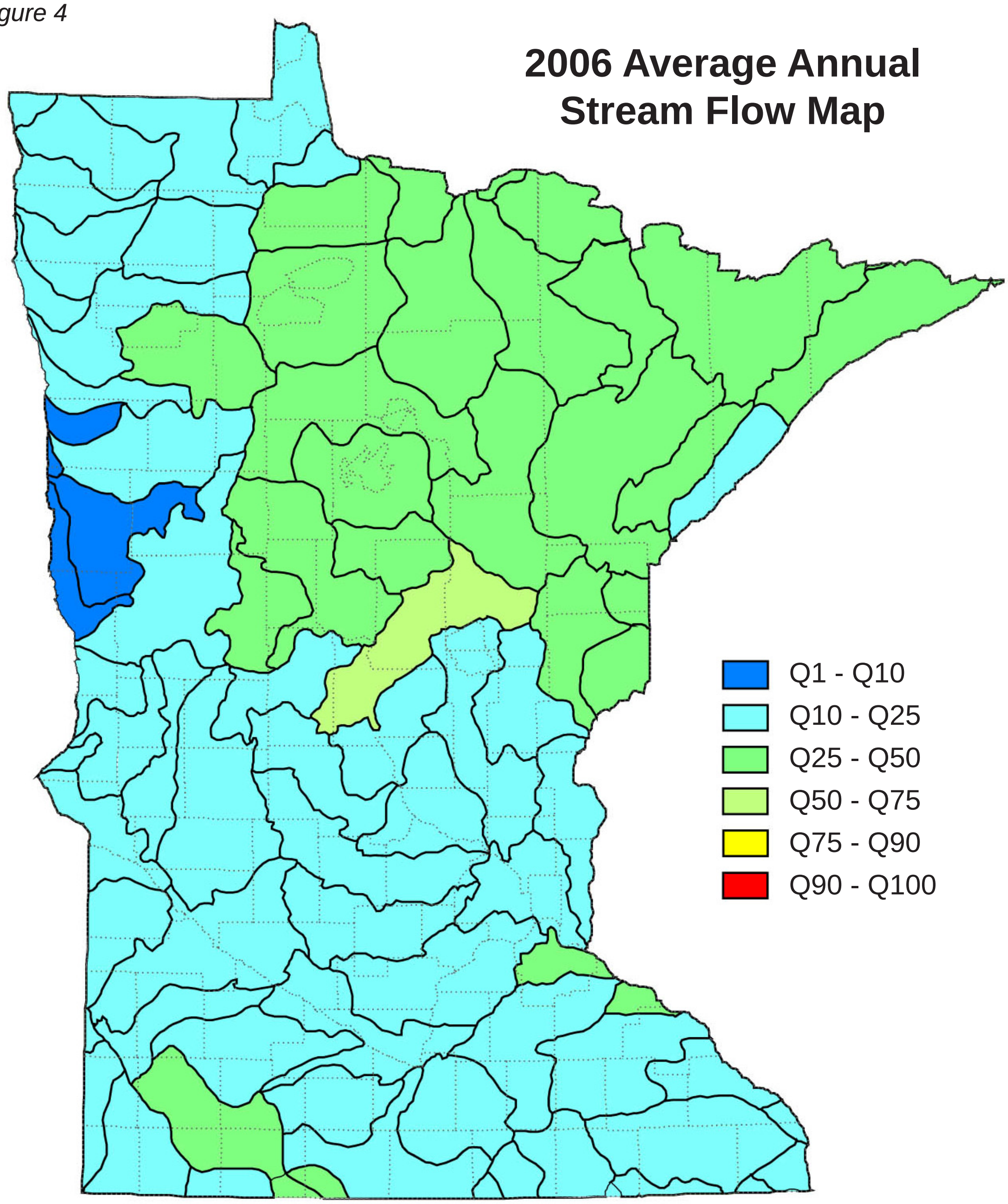
"Who shut the faucet off?"

A phrase often heard during the drought of 1987 and 1988 was "Who shut the faucet off?" or some variant. The question was pointed at the sudden cessation of precipitation.

In June 2006, the faucet was again shut off. While Figures 3 and 4 show that water levels were greater-than to much-greater-than normal for the 2005 and 2006 water years, Figure 4 does not show the sudden drop in water levels and flows that occurred in the last four months of the 2006 water year.

This sudden drop can be observed in the hydrographs in Figures **7** and **9**. Note the drop in water levels to near the Q90 Protected Flow for the months of July, August and September, 2006. (Flows remained at this level for the first four months of the 2007 water year.)

Figure 4


2006 Average Annual
Stream Flow Map
Q1 - Q10
Q10 - Q25
Q25 - Q50
Q50 - Q75
Q75 - Q90
Q90 - Q100

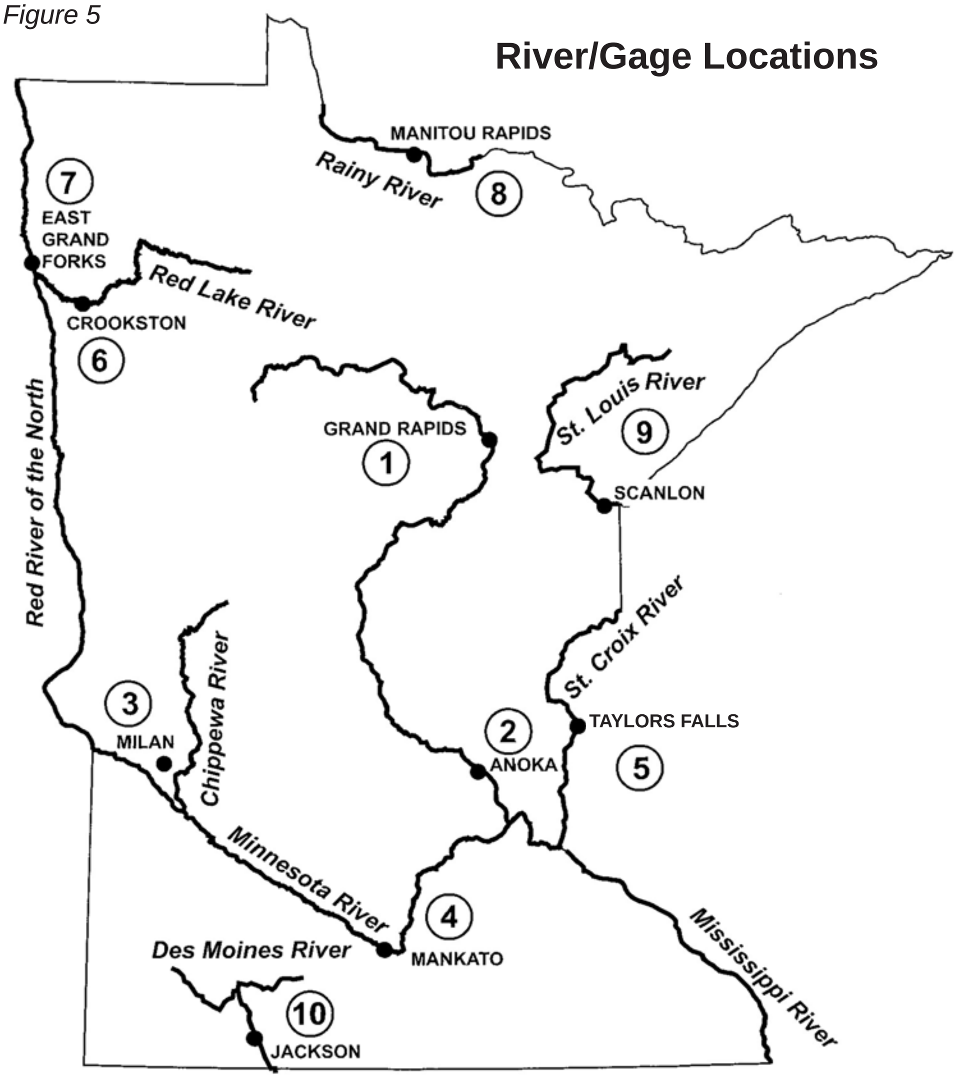
Hydrographs

To give a general summary of flow conditions around the state for the 2005 and 2006 Water Years, discharge hydrographs were created for 10 selected streams. These streams and their locations are shown in Figure 5.

For these 10 selected streams, mean daily discharges are shown in Figures 7 and 9 (pages 28 and 30). Included on those figures are the daily Q25 and Q75 exceedence numbers and the Q90 Protected Flow.

Figures 8 and 10 (pages 29 and 31) show the mean annual discharge for each of the 10 selected sites. In these figures, the graphs, by water year, extend from 1900 to 2010. As with the other figures, the Q25 and Q75 exceedence values are included. Note, however, that these exceedence values are based on annual flows and are different than the Q25 and Q75 values calculated from daily flows. Also included on the graphs is the 30-Year Moving Average, showing the general flow trend.

Figure 5



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

Mean Monthly Discharge

Mean Monthly Discharge was calculated for the 2005 and 2006 Water Years for each of the 10 selected streams shown in Figure 5. These monthly values were then divided by the historic monthly mean. The resultant value is a monthly mean value as a percentage of normal. For example, the January 2005 monthly flow for the Mississippi River at Anoka was 4775 cfs, and the historic average January flow is 4350 cfs. As a percentage, the January 2005 flow is 4775/4350 = 109.8%. For a completely "normal" year, each monthly value would be 100%. The advantage of this technique is that it normalizes the data and allows for the comparison of flows on different streams on the same scale.

Figure 6 is a step graph showing the maximum, minimum, and average monthly value for the 10 selected streams as a group. (The individual streams are not included in this graph as the numerous lines make it difficult to read.)

For the period from October 2004 to June 2006, the average of the monthly flows was above the 100% value. The maximum values for this period were significantly above the 100% level. The monthly minimum values were often below the 100% level, especially during the summer of 2005. However, these minimum values were usually due to one or two streams that had lower flow levels during the water years.

In July 2006, the dramatic fall in flows in these rivers can be observed in Figure 6. For the remainder of the 2006 Water Year (and into the 2007 Water Year), the average flow of the 10 selected streams was 50% of normal, with the maximum at approximately 75% and the minimum at approximately 25%. As the 10 selected streams are scattered throughout the state, the narrow range between minimum and maximum indicates that the Low Flow conditions after July 2006 were statewide.

Figure 6

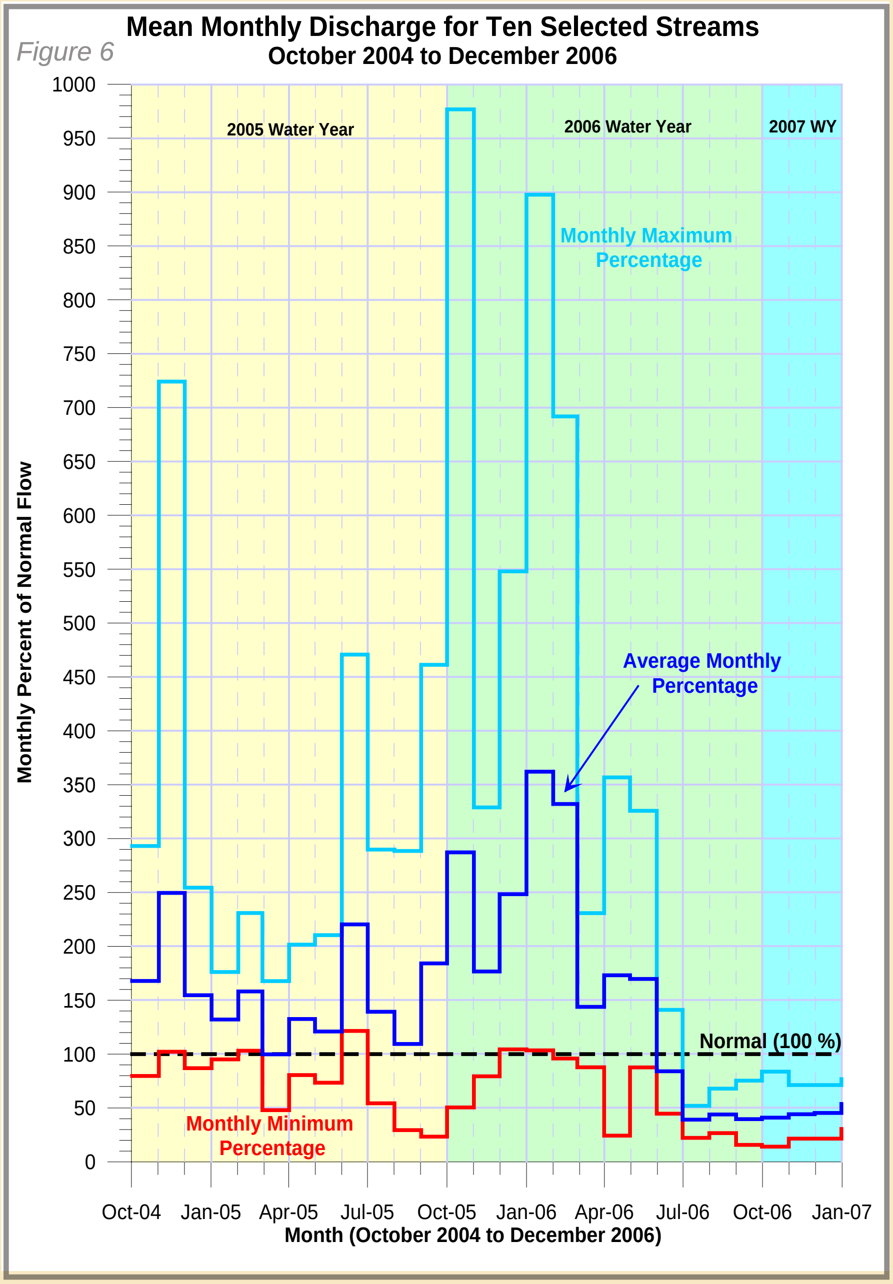


Figure 7

Mean Daily Discharge

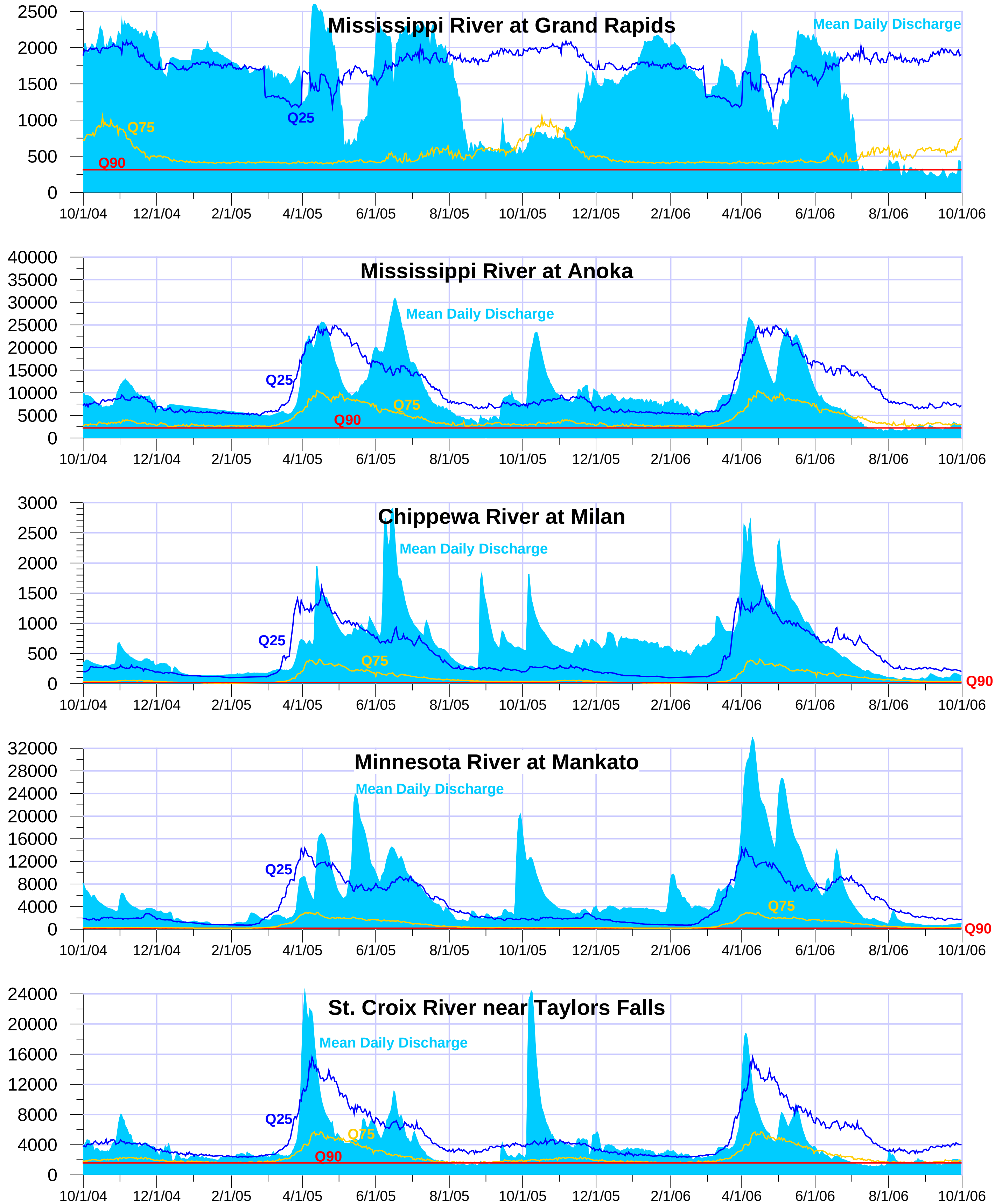


Figure 8

Mean Annual Discharge

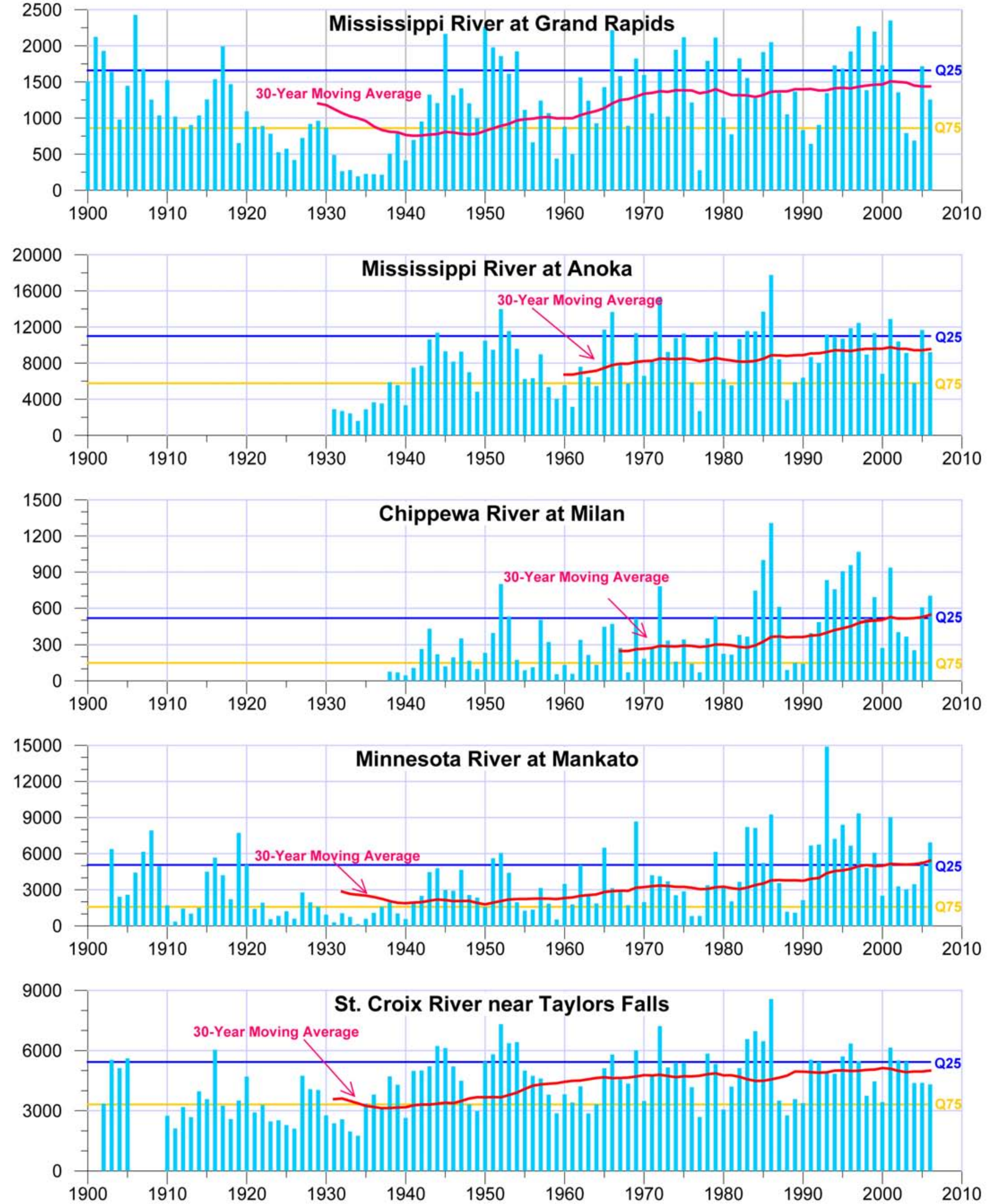
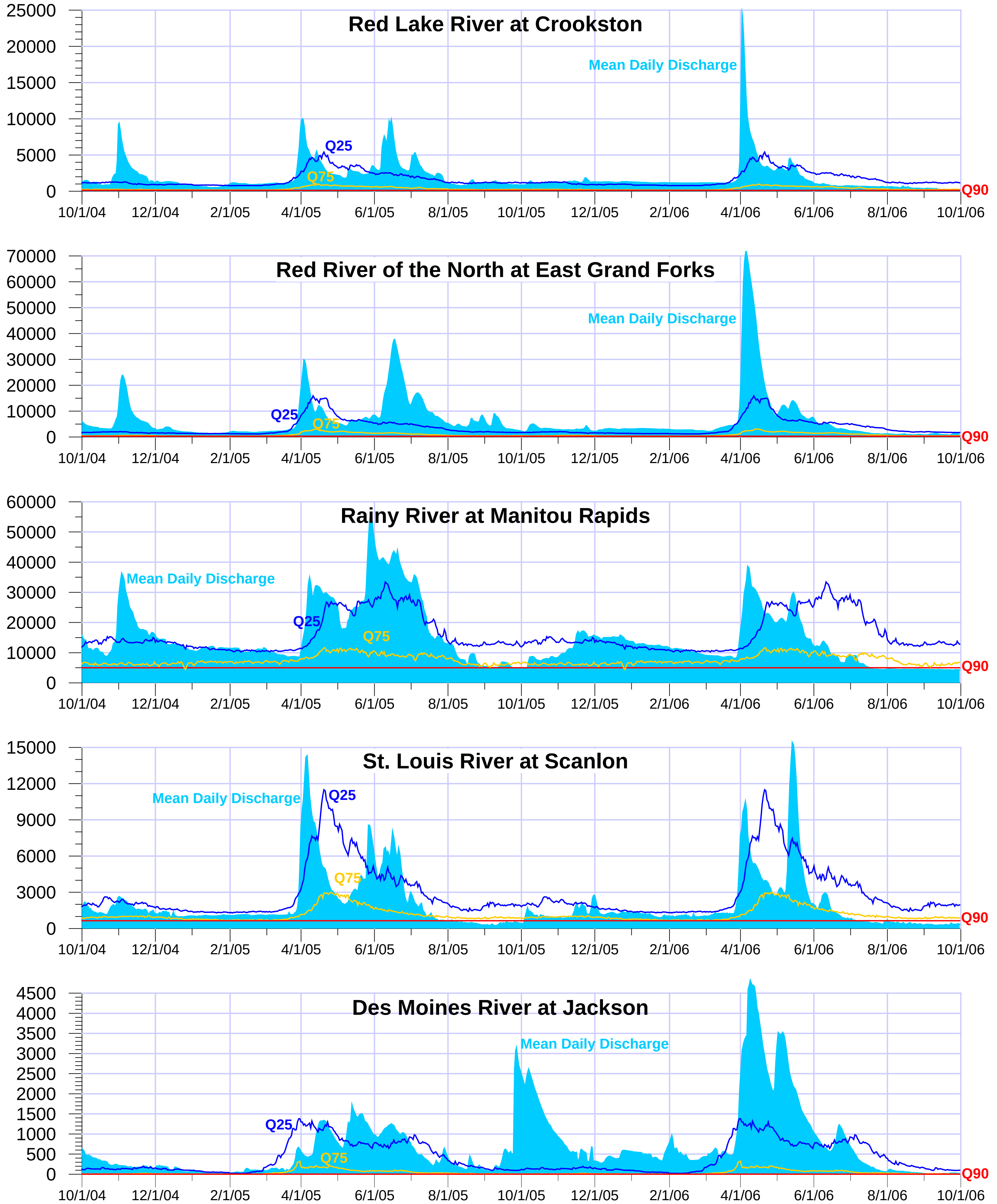


Figure 9

Mean Daily Discharge



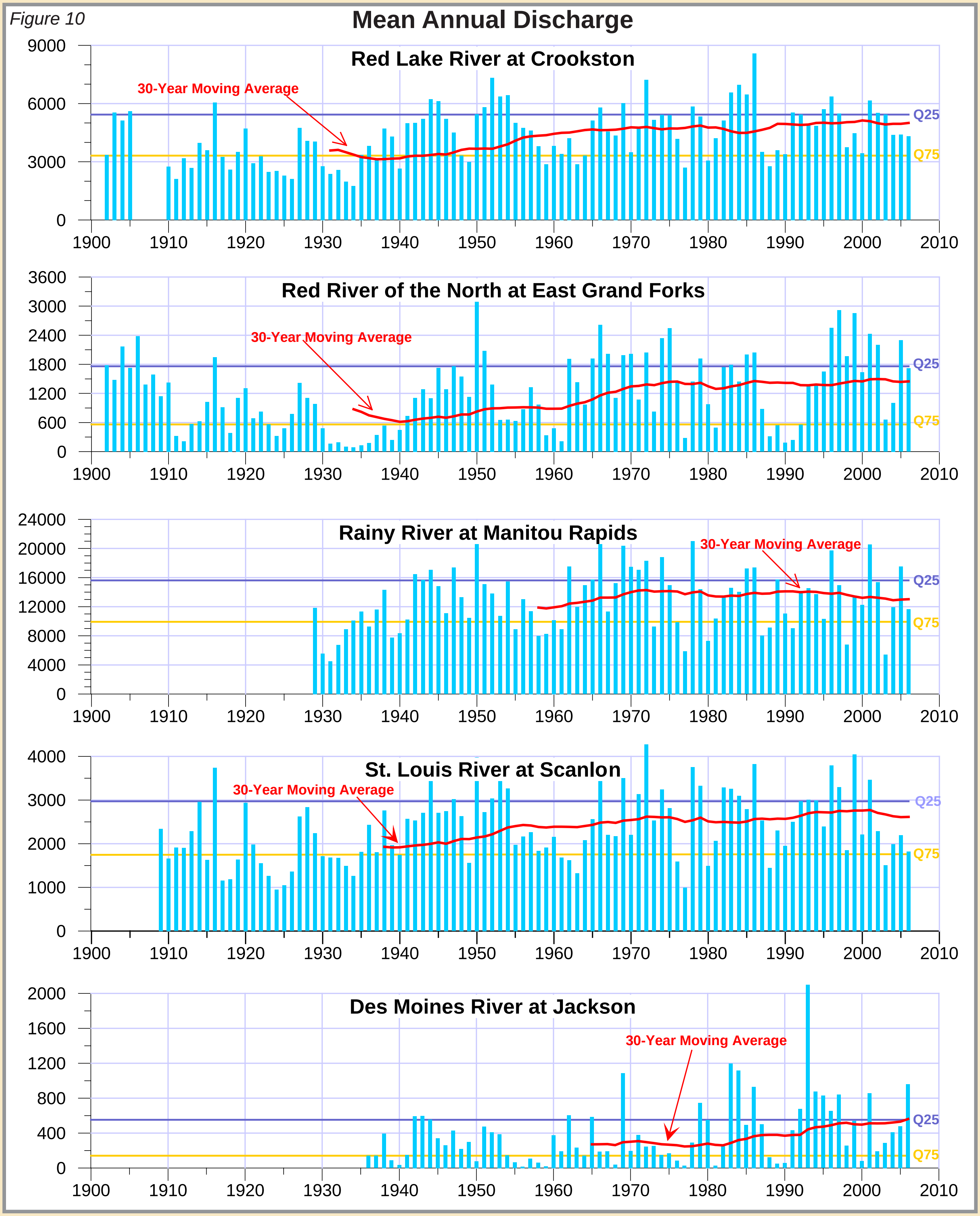


Figure 10
Mean Annual Discharge
Red Lake River at Crookston
30-Year Moving Average
Q25
Q75
Red River of the North at East Grand Forks
30-Year Moving Average
Q25
Q75
Rainy River at Manitou Rapids
30-Year Moving Average
Q25
Q75
St. Louis River at Scanlon
30-Year Moving Average
Q25
Q75
Des Moines River at Jackson
30-Year Moving Average
Q25
Q75