Chapter 2 Surface Water

Eric DeKleyn

Stream Flow

Introduction

Rivers and streams are a defining characteristic of Minnesota's landscape, from the fast flowing streams along the north shore of Lake Superior and the Mississippi River bluffs to the slow flowing streams meandering through the Red River valley and the southwest prairie lands. These rivers and streams all provide a sense of place, each contributing to Minnesota's heritage.

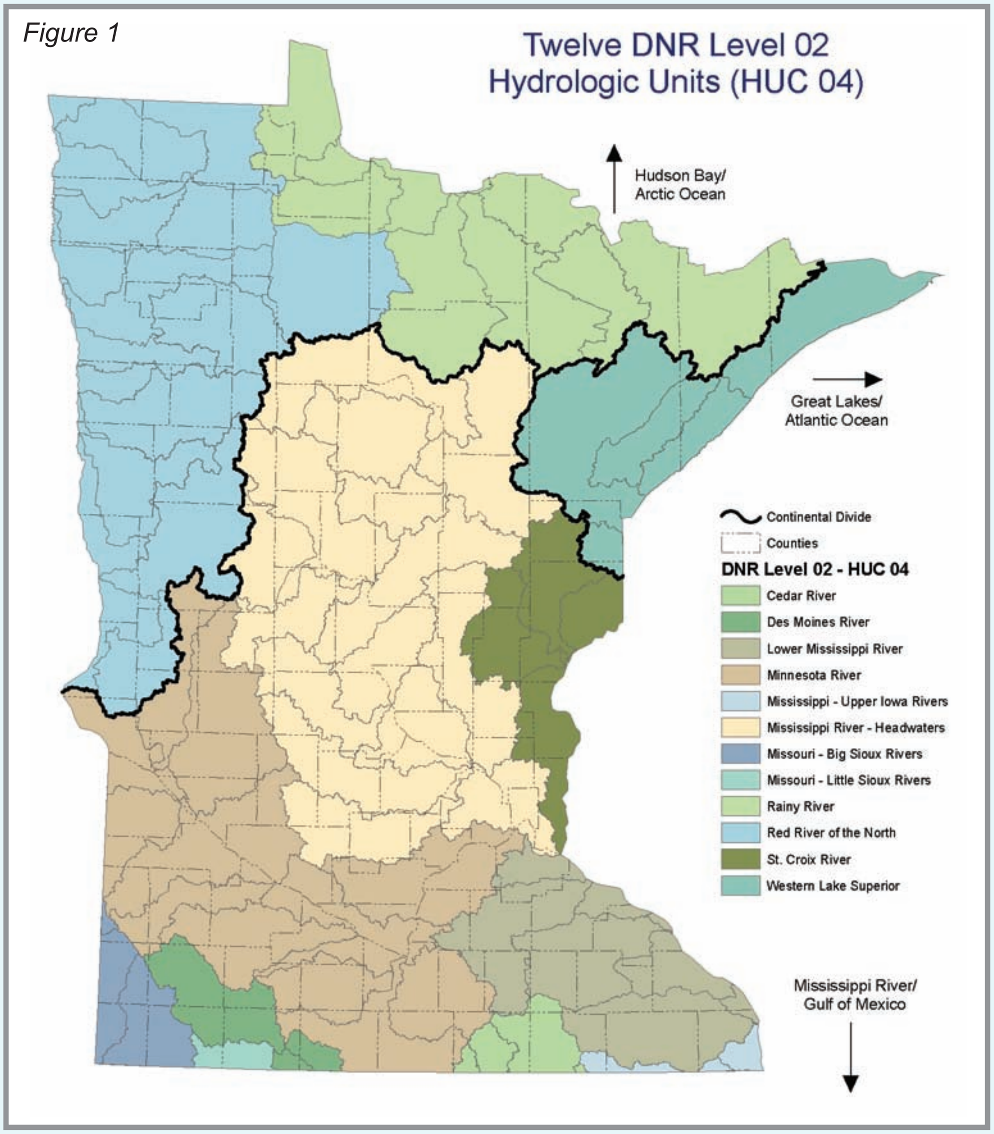
Minnesota is unique in that it exports large volumes of water and receives very little water from out of state. Two of the three Continental Divides in North America cross through the state and meet at a point near Hibbing. These divides route surface water into three separate continental drainage areas: the Hudson Bay/Arctic Ocean, the Great Lakes/Atlantic Ocean and the Mississippi River/Gulf of Mexico (Figure 1). Only two rivers receive out-of-state water: the headwaters of the Minnesota River from South Dakota, and the Blue Earth River from Iowa. This is why it is important for Minnesota to be a good steward of the land to ensure its waters leave the state in optimal condition.

In the 1970s to help understand and manage Minnesota's water, the United States Geological Survey (USGS) and Water Resources Council created a mapping and classification system that partitioned the U.S. into four hierarchically nested watershed levels called Hydrologic Units (HU). In 1979, The DNR developed a standardized set of 81 Major Watersheds that were coincident with the smallest (Level 4) HU division in Minnesota (Figure 2). The DNR proceeded to further divide those Major Watersheds into approximately 5,600 Minor Watersheds. Since these initial mapping efforts, delineations at a higher resolution were required for hydrologic studies. This need was recognized at both the state and national level.

Over the last decade, the DNR Watershed Delineation Project staff worked to develop a high-resolution watershed boundary dataset. New technology and higher quality source data were used to assess the original 1979 delineations and to further subdivide those Minor Watersheds at certain hydrologic points of interest such as lake outlets, dams, and stream gaging locations.

At the national level during this time the USGS, in cooperation with the Natural Resources Conservation Service (NRCS), ramped up efforts to subdivide the HU system into six levels of Hydrologic Units. This expanded delineation system is known as the National Watershed Boundary Dataset. DNR has worked in cooperation with other state and federal agencies to ensure that their products are consistent with the national standardized mapping effort. DNR watershed delineations have been incorporated onto the National Watershed Boundary Dataset (see Watershed Delineation Project website for more detail).

Figure 1



Stream Gaging in Minnesota

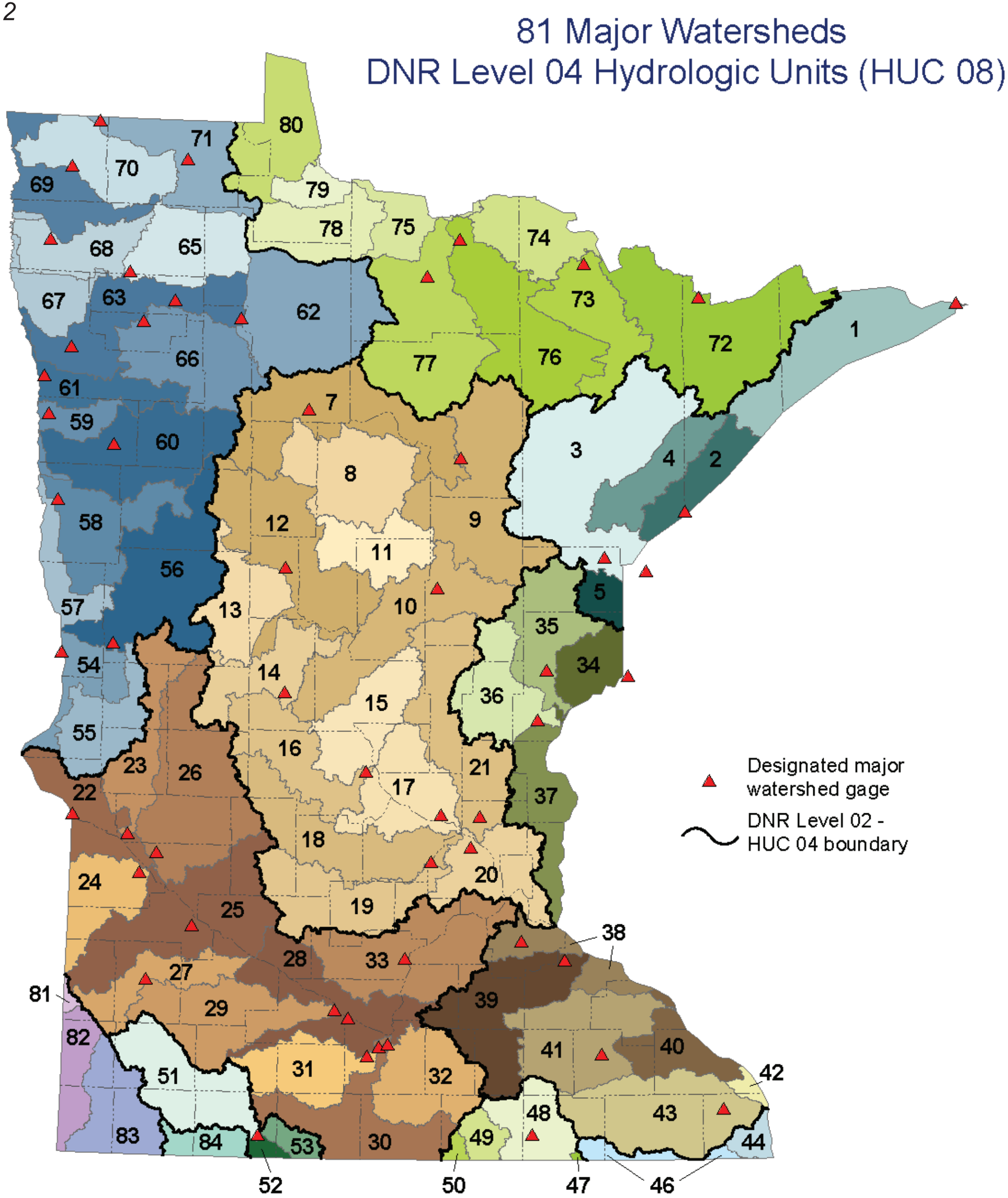
The USGS is the primary agency doing nationwide stream gaging. At the present time, the USGS maintains a network of approximately 135 continuously recording stream gages and approximately 400 high-flow and miscellaneous flow gages in Minnesota. The Minnesota Department of Natural Resources, Division of Waters (DNR Waters) acts as a cooperative funding partner for 34 of the USGS gages. However, as needs for additional stream information become necessary, additional agencies and organizations are gaging as well.

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

DNR Waters is one of the primary state agencies that provide stream flow information through a network of approximately 65 continuously recording gages and 75 seasonal gages. Other agencies that support or monitor stream flows in Minnesota include the Minnesota Department of Agriculture 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, water management organizations and lake associations provide funding support or 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. Measure-

Figure 2



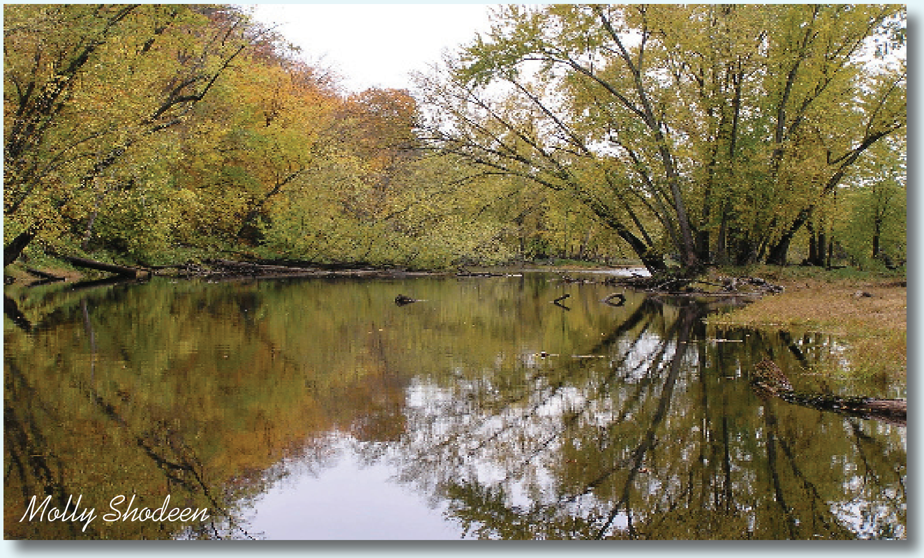
Major Watershed (HUC 08 id)

1. Lake Superior - North (04010101)
2. Lake Superior - South (04010102)
3. St. Louis River (04010201)
4. Cloquet River (04010202)
5. Nemadji River (04010301)
6. (none)
7. Mississippi River - Headwaters (07010101)
8. Leech Lake River (07010102)
9. Mississippi River - Grand Rapids (07010103)
10. Mississippi River - Brainerd (07010104)
11. Pine River (07010105)
12. Crow Wing River (07010106)
13. Redeye River (07010107)
14. Long Prairie River (07010108)
15. Mississippi River - Sartell (07010201)
16. Sauk River (07010202)
17. Mississippi River - St. Cloud (07010203)
18. North Fork Crow River (07010204)
19. South Fork Crow River (07010205)
20. Mississippi River - Twin Cities (07010206)
21. Rum River (07010207)
22. Minnesota River - Headwaters (07020001)
23. Pomme de Terre River (07020002)
24. Lac Qui Parle River (07020003)
25. Minnesota - Yellow Medicine Rivers (07020004)
26. Chippewa River (07020005)
27. Redwood River (07020006)
28. Minnesota River - Mankato (07020007)
29. Cottonwood River (07020008)
30. Blue Earth River (07020009)
31. Watonwan River (07020010)
32. Le Sueur River (07020011)
33. Lower Minnesota River (07020012)
34. Upper St. Croix River (07030001)
35. Kettle River (07030003)
36. Snake River (07030004)
37. Lower St. Croix River (07030005)
38. Mississippi River - Lake Pepin (07040001)
39. Cannon River (07040002)
40. Mississippi River - Winona (07040003)
41. Zumbro River (07040004)
42. Mississippi River - La Crescent (07040006)
43. Root River (07040008)
44. Mississippi River - Reno (07060001)
45. (none)
46. Upper Iowa River (07060002)
47. Upper Wapsipinicon River (07080102)
48. Cedar River (07080201)
49. Shell Rock River (07080202)
50. Winnebago River (07080203)
51. Des Moines River - Headwaters (07100001)
52. Lower Des Moines River (07100002)
53. East Fork Des Moines River (07100003)
54. Bois de Sioux River (09020101)
55. Mustinka River (09020102)
56. Otter Tail River (09020103)
57. Upper Red River of the North (09020104)
58. Buffalo River (09020106)
59. Red River of the North - Marsh River (09020107)
60. Wild Rice River (09020108)
61. Red River of the North - Sandhill River (09020301)
62. Upper/Lower Red Lake (09020302)
63. Red Lake River (09020303)
64. (none)
65. Thief River (09020304)
66. Clearwater River (09020305)
67. Red River of the North - Grand Marais Creek (09020306)
68. Snake River (09020309)
69. Red River of the North - Tamarac River (09020311)
70. Two Rivers (09020312)
71. Roseau River (09020314)
72. Rainy River - Headwaters (09030001)
73. Vermilion River (09030002)
74. Rainy River - Rainy Lake (09030003)
75. Rainy River - Black River (09030004)
76. Little Fork River (09030005)
77. Big Fork River (09030006)
78. Rapid River (09030007)
79. Rainy River - Baudette (09030008)
80. Lake of the Woods (09030009)
81. Upper Big Sioux River (10170201)
82. Lower Big Sioux River (10170203)
83. Rock River (10170204)
84. Little Sioux River (10230003)

ments 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. A well-developed relationship allows recorded stream elevations to be converted to discharge in cubic feet per second (cfs). Once this relationship between stage and discharge is established, regular stream discharge measurements continue to be made in order to verify the relationship and to monitor any changes to the condition or characteristics of the channel. Telemetered gages record stream elevations continuously and transmit the data to a central location for conversion to discharge. These data are used in hydrologic analysis and provide critical real time data for flood warning and forecasting.

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.

A recent trend in stream gages is to include water quality sampling at the gage. Water quality sampling, when combined with discharge data, provides information to calculate how much of that chemical or constituent has flowed past the monitoring site. These data are becoming more available with funding and support of the Clean Water Legacy project. (see discussion on page 20).



Focus: Clean Water Legacy Network

In 2006 multiple state agencies established a plan to expand stream monitoring throughout the state. This was inspired and funded by the passage of the Clean Water Legacy Act (CWL). Two main players in this project are the DNR and Pollution Control Agency (PCA). These two agencies worked together to identify the condition and coverage of the existing gaging network. One goal of this project was to have a telemetered gaging station located at the outlet of all 81 major watersheds in the state. The DNR is responsible for installing new or upgrading existing gaging stations to have real-time telemetry equipment collecting and transmitting stage, precipitation, and water temperature. The PCA is responsible for sampling and testing water chemistry at these locations. The data collected at these sites will be used to track trends and changes in the water quality, frequency and severity of flooding and low flow conditions, and if these changes may be related to land use and climate changes.

Some major watersheds had an existing gage established as part of the DNR Flood Warning Gage network. These stage only real time telemetry gages were used where possible. Other watersheds that did not have adequate gaging were identified and monitoring locations were selected.

During the winter of 2007-08, DNR Waters increased monitoring on the selected Flood Warning Gages by making stream flow measurements throughout the winter and converting these stage only gages to continuous flow.

Beginning in late May of 2008, DNR Waters began an intense schedule of installing new gage equipment. Between May 29 and October 23, crews installed real-time equipment at 16 CWL gages to provide a more complete gaging network.

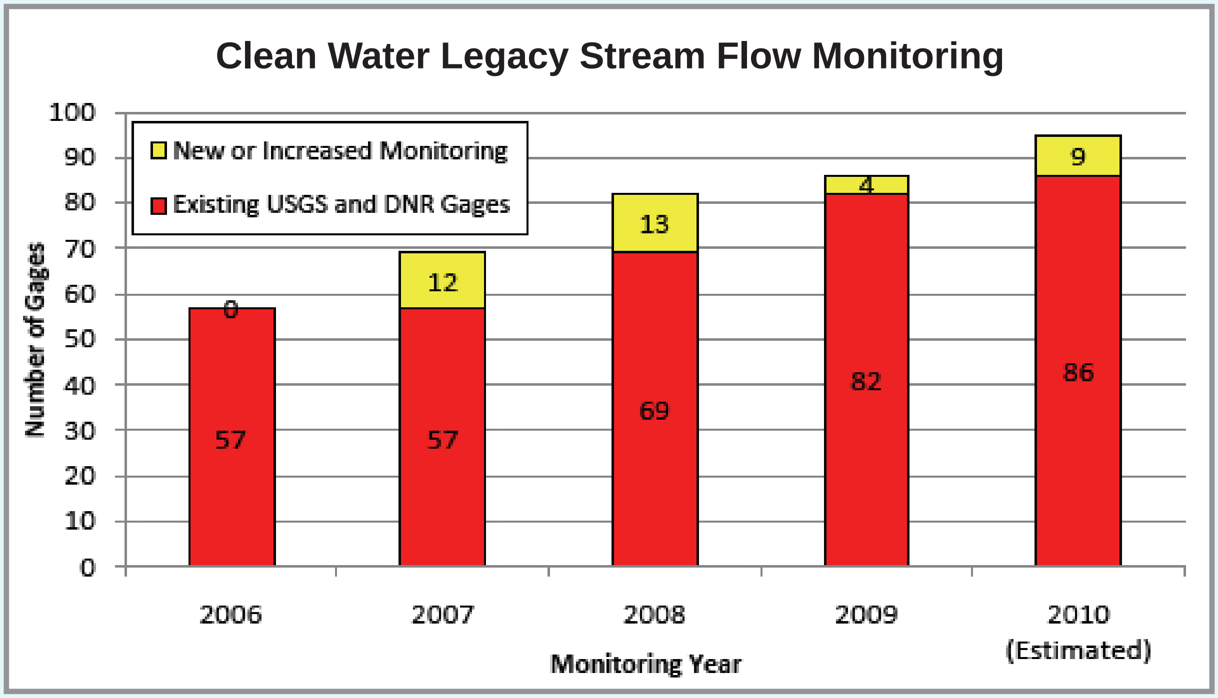
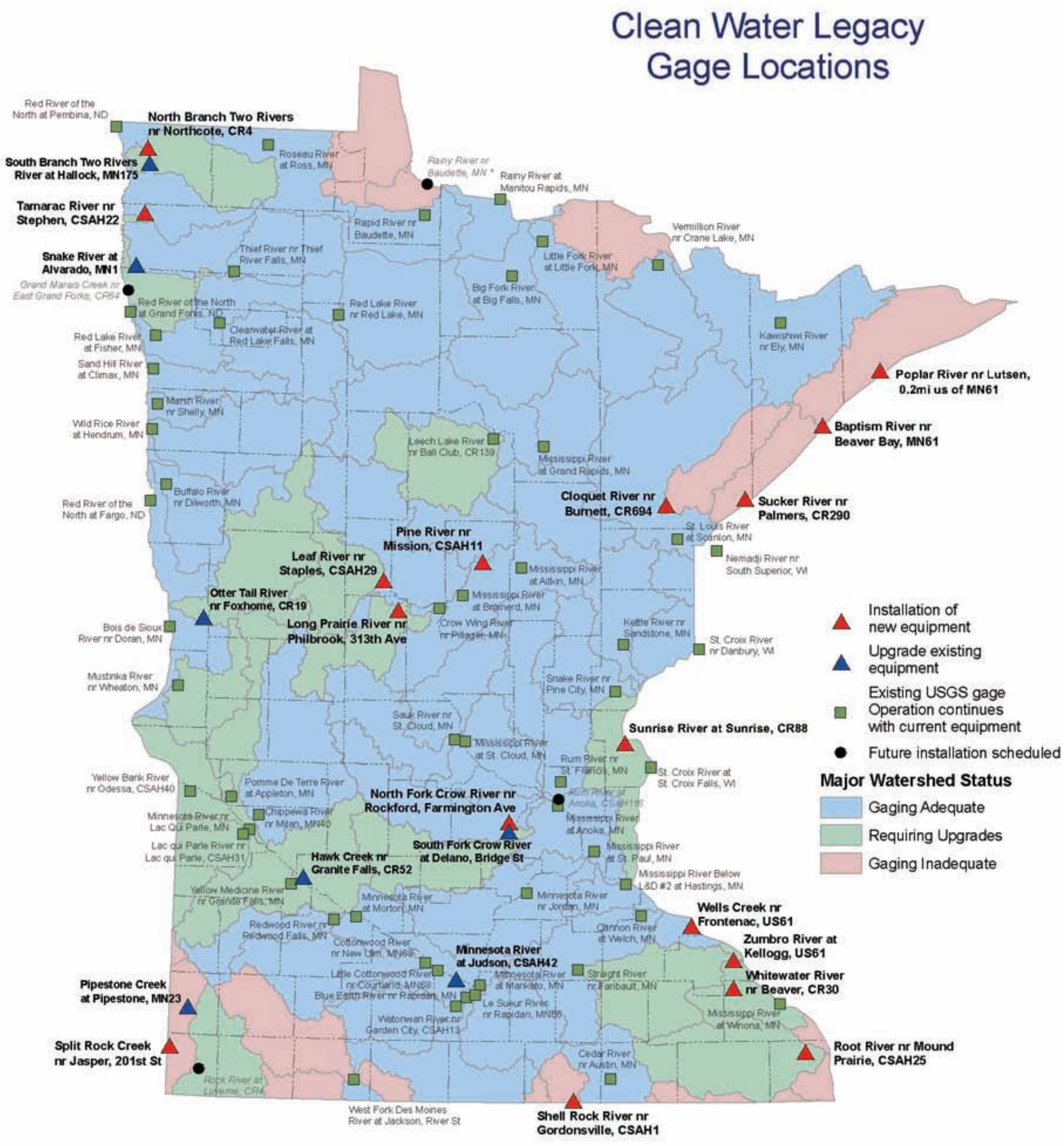


Figure 3



DNR Gage Installations

Station ID	Station Name	Installation date
H01063003	Poplar River nr Lutsen, 0.2mi us of MN61	08/13/2008
H01092001	Baptism River nr Beaver Bay, MN61	08/15/2008
H02031001	Sucker River nr Palmers, CR290	09/25/2008
H04048001	Cloquet River nr Burnett, CR694	09/25/2008
H11051001	Pine River nr Mission, CSAH11	07/02/2008
H13058001	Leaf River nr Staples, CSAH29	10/23/2008
H14034001	Long Prairie River nr Philbrook, 313th Ave	10/22/2008
H18088001	North Fork Crow River nr Rockford, Farmington Ave	07/23/2008
H19001001	South Fork Crow River at Delano, Bridge St	
H25037001	Hawk Creek nr Granite Falls, CR52	
H28054001	Minnesota River at Judson, CSAH42	
H37030001	Sunrise River at Sunrise, CR88	05/29/2008
H38006002	Wells Creek nr Frontenac, US61	06/12/2008

Station ID	Station Name	Installation date
H40016001	Whitewater River nr Beaver, CR30	06/03/2008
H41043001	Zumbro River at Kellogg, US61	
H43007002	Root River nr Mound Prairie, CSAH25	10/09/2008
H49009001	Shell Rock River nr Gordonsville, CSAH1	09/11/2008
H56066001	Otter Tail River nr Foxhome, CR19	
H67014001	Grand Marais Creek nr East Grand Forks, CR64	
H68006001	Snake River at Alvarado, MN1	
H69051001	Tamarac River nr Stephen, CSAH22	06/18/2008
H70018001	South Branch Two Rivers River at Hallock, MN175	
H70021001	North Branch Two Rivers nr Northcote, CR4	06/17/2008
H82015001	Split Rock Creek nr Jasper, 201st St	09/04/2008
H82035001	Pipestone Creek at Pipestone, MN23	
H83016001	Rock River at Luverne, CR4	

Water Year - 2007

In the fall of 2006 (the 2007 Water Year began October 1, 2006), stream flow conditions were low (or below the Q75 exceedence value) in the north-central to northeast part of the state. The remainder of the state was in a normal flow range (Q25-Q75) with a few pockets of higher flows in the west-central part of the state.

While a storm in November brought significant snowfall to the south and southeast, the snow was not sustained throughout the winter. December's above average temperatures caused precipitation to fall as rain, which helped bring low-flow rivers up to normal rankings. Warm temperatures during the beginning of January 2007 and a concurrent "snow drought" reduced remaining snow pack for much of the state. The end of February and beginning of March brought very cold temperatures and a couple of large snowstorms that would affect river levels. Although snow levels were lower than normal for the state overall for the 2006-07 winter, these late snowstorms coupled with quickly rising March temperatures were enough to cause spring runoff flooding problems in western Minnesota.

By early April rivers in the southern two-thirds of the state were open and running at high levels, or above the Q25 exceedence flow. By mid-April, most rivers were ice-free and returning to normal April flows (Q25-Q75). Rivers in the north-central and northeast part of the state that were low in the fall remained lower than those in the south. The spring runoff allowed the northern 1/3 of the state to recover to normal flows conditions.

While many rivers dropped into normal or even low flows in May, the rivers of west-central and southwest Minnesota continued to flow at or above their Q25 exceedence value. This high flow condition rapidly declined as the summer progressed with much of the state slipping into drought conditions.

Throughout May and June, the state began to show a large gap in precipitation distribution. Large rainstorms caused rivers in western Minnesota to swell while other areas of the state saw a shortage and hints of the drought to come.

Below average precipitation in July caused rivers to drop to the Low and Critical Flow range in a band through the northeast, central and south-central part of the state. Western and southeastern Minnesota rivers remained at normal flows levels.

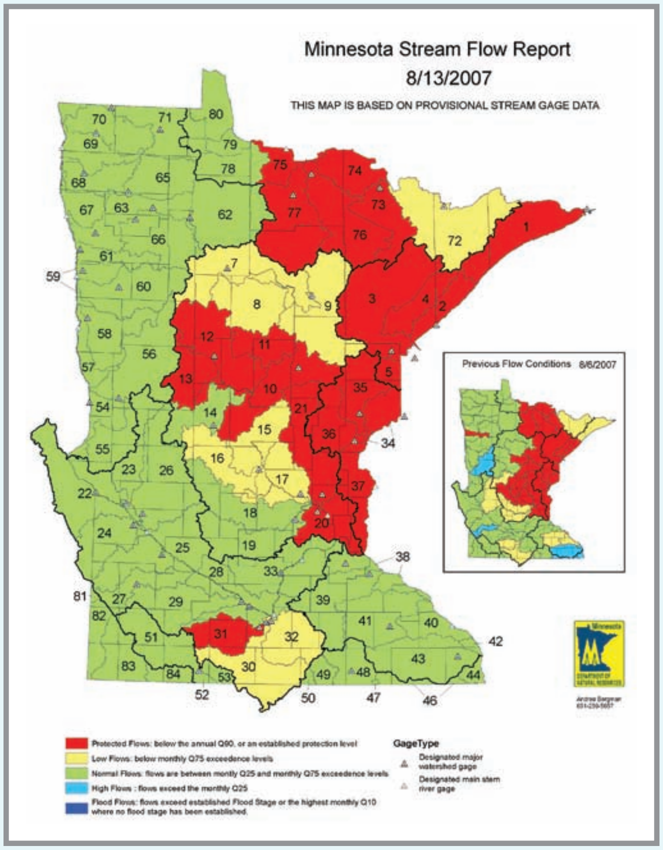
This separation between Normal and Critical Flow levels increased into August with central and northeast rivers falling to very low levels. By mid-August, much of the state was in drought or near-drought conditions. That all changed in southern Minnesota when a storm event on Sunday, August 19th brought up to 18 inches of rain in a matter of hours. Many watersheds quickly flipped from drought to flooding. Rivers in the southeast reported floods at 500-year event (which has a 0.2% chance of occurring in any given year) magnitudes. Severe flooding, mudslides, and damage occurred in many southeast counties (see special section on page 27).

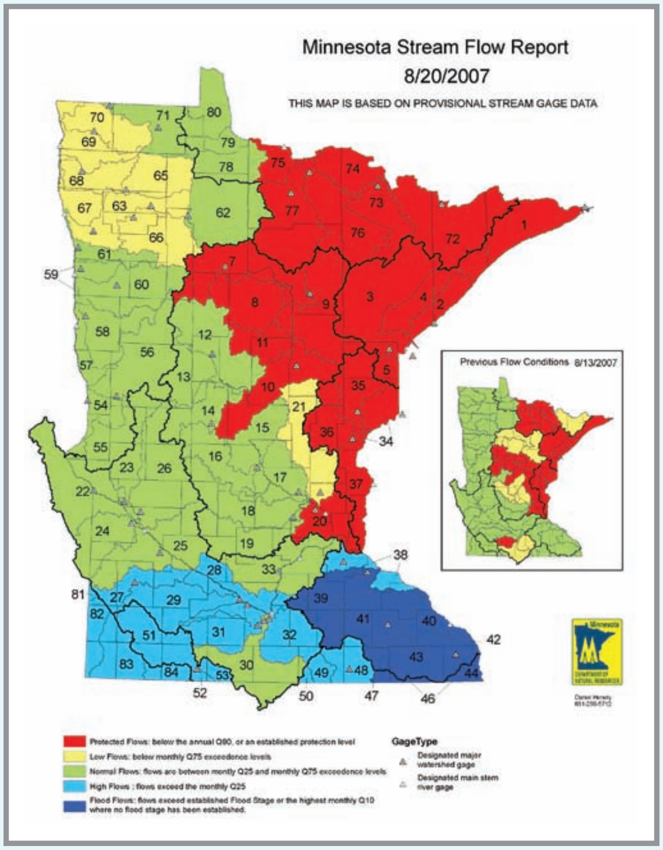
EXCEEDENCE VALUE

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 = > National Weather Service flood stage
(or highest monthly Q10)





September rainfall was higher than normal, welcome in some parts of the state, not so in others. Rivers in the northern part of the state slowly recovered from drought conditions that had plagued them for most of the summer. These rains were unwelcome in southern watersheds where residents were still recovering from the August torrent.

The 2007 Water Year ended with rivers in the arrowhead region and southern Minnesota remaining at the Q25 exceedence level while the rest of the state recovered from drought conditions. Part of north central Minnesota remained below the Q75 exceedence level, while the rest of the state's watersheds were classified

Figure 4

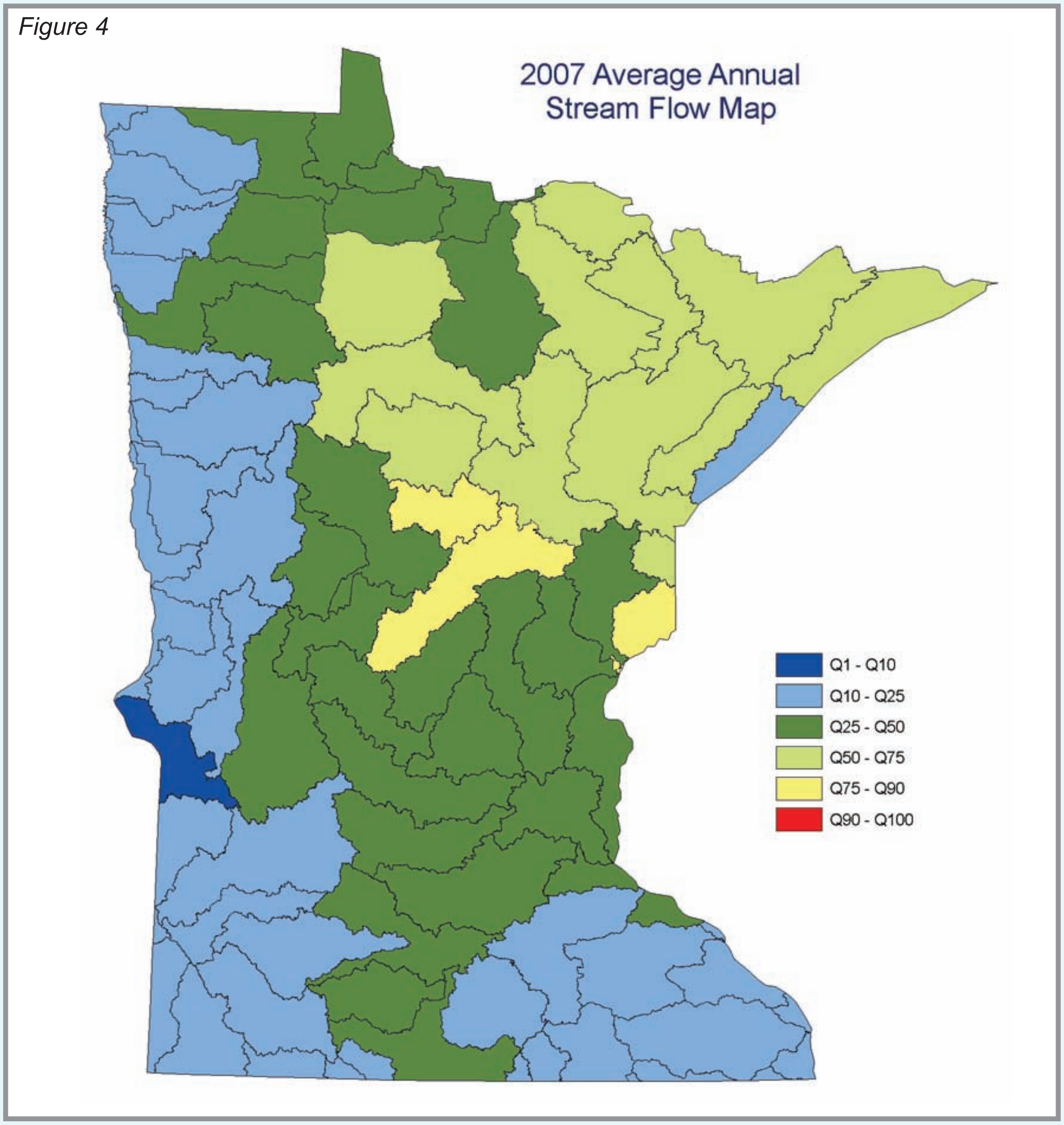
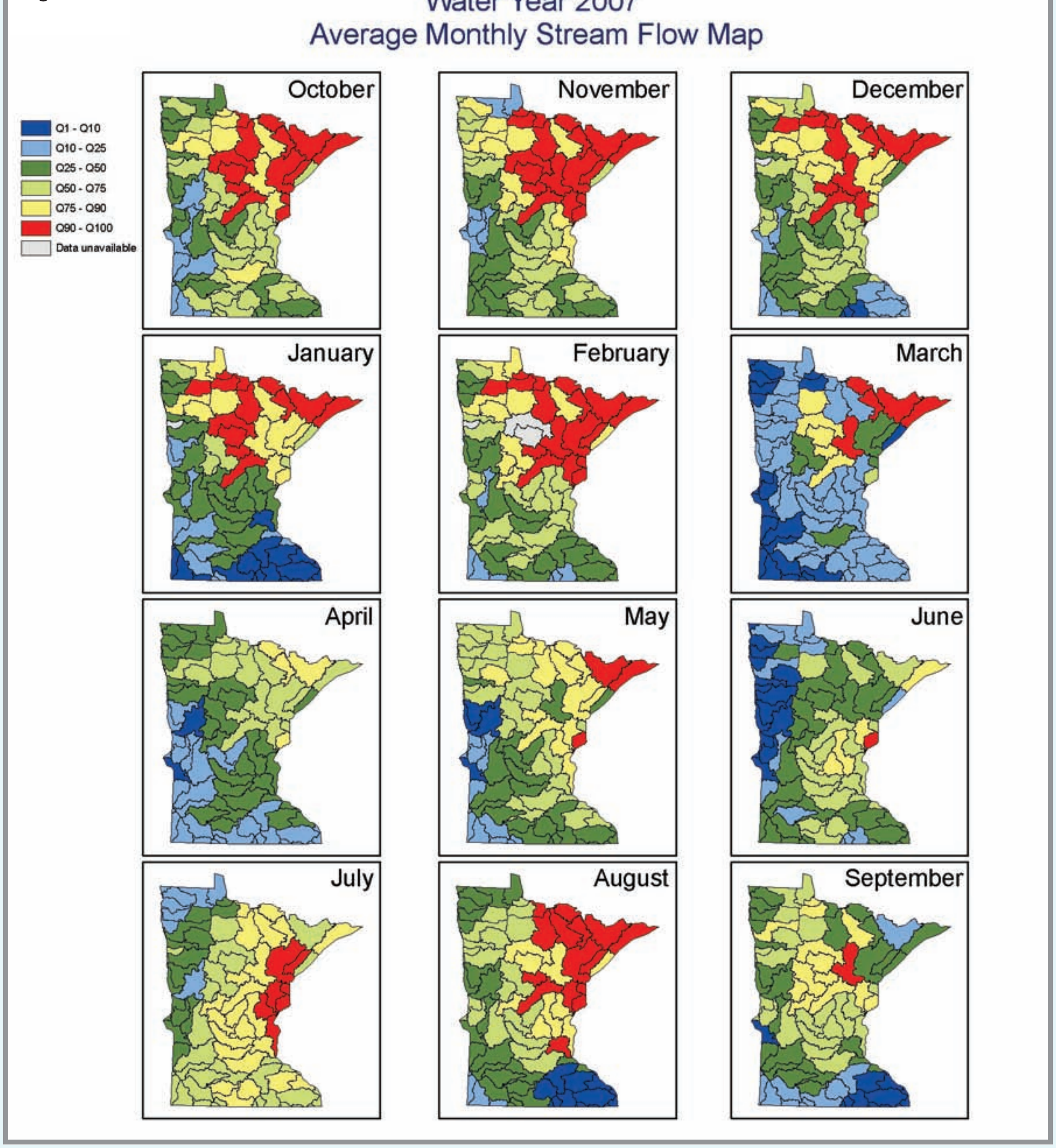


Figure 4 shows the 2007 Average Annual Stream Flow Map. Statewide, most watersheds had an annual average flow greater than the historic average or normal flow.

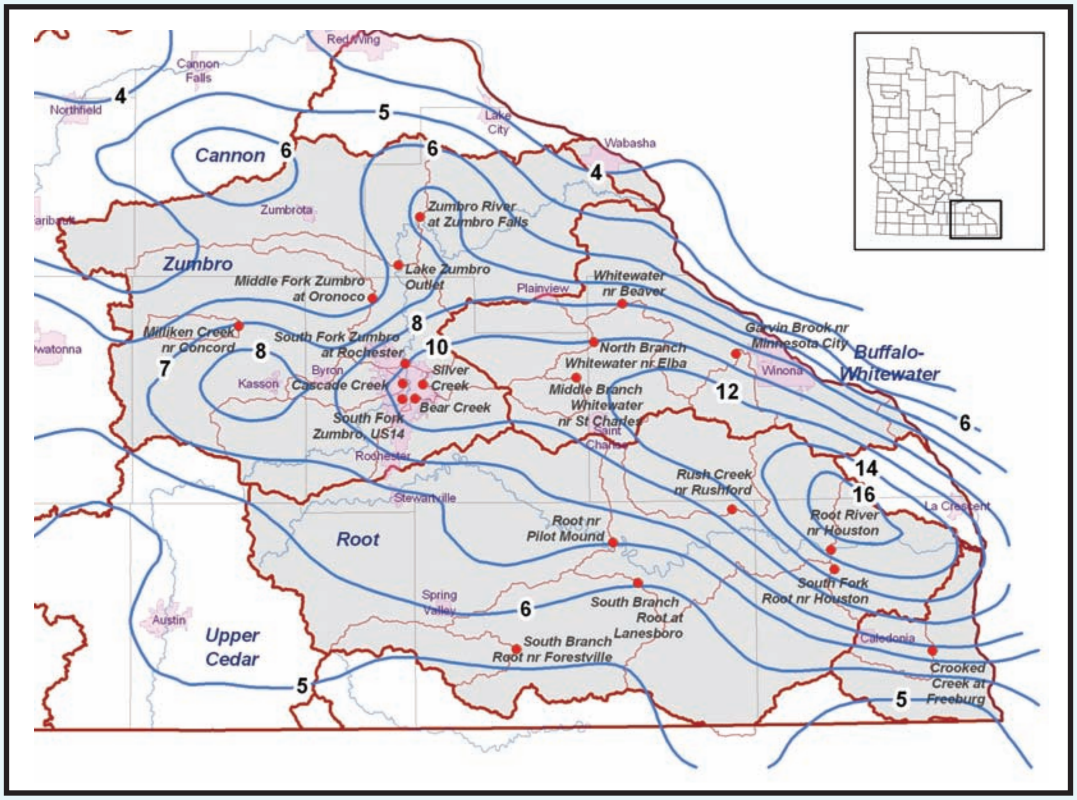
Figure 5


Water Year 2007
Average Monthly Stream Flow Map
Q1 - Q10
Q10 - Q25
Q25 - Q50
Q50 - Q75
Q75 - Q90
Q90 - Q100
Data unavailable
October
November
December
January
February
March
April
May
June
July
August
September


Woodbury Sinkhole
Dale Homuth


Rush Creek
Flood Damage,
Winona Co.
Jeff Green

SPECIAL SECTION: August 18-20, 2007 Flooding

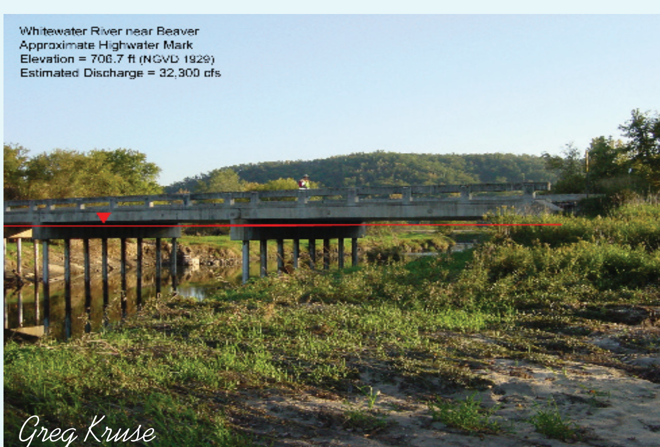


(Data from State Climatology office)

When the rains came on the evening of August 18, 2007, they covered much of southeast Minnesota in record amounts. Rainfall totals ranged from an impressive 6 to a devastating 18 inches over the course of the event.

This event obviously caused a rapid rise in rivers, especially in that part of the state is where geographic relief tends to produce fast flowing, flashy streams. Some streams received such a volume of water, an entirely re-shaped river channel was left in its wake.

Crews from the DNR, USGS, National Weather Service, and Army Corps of Engineers were out collecting data and making stream flow and high water measurements in order to capture this record event. Due to the timing (early Sunday morning) speed and intensity of the event hydraulic models, high water marks and other survey information were used after the flooding to reconstruct the event at many locations where crews were unable to make measurements.



Measured and estimated discharges for affected watersheds:

Watershed	Event magnitude	Event note
Zumbro River Watershed	5-25 year event	
Whitewater River Watershed	500 year event (approximate)	Flood of record
Garvin Brook Watershed	500 year event (approximate)	Flood of record
Root River Watershed	100-200 year event (Houston)	Flood of record
Rush Creek Watershed	200-year event (approximate)	Flood of record

Water Year - 2008

Stream flows were high at the start of WY 2008 due to the flooding and above average precipitation in August and September of 2007. These higher flows continued into October, as precipitation was above average statewide.

Although November was dry, flows were sustained as ice formed and winter 2008 began with higher than normal snowfall amounts in December. However, by January and February, snowfall had dropped to below normal. Low snowfall totals produced a mild spring snowmelt season with no significant flooding events related to spring runoff. Temperatures during this period were also below normal, delaying the spring thaw. It wasn't until late April that most rivers were ice-free. Once the rivers were free of ice they swelled to high flows, at or above Q25 exceedence values, due to significant snow and rain events in April. These high flows did not cause nearly the flood damage seen in the spring of 2007 or other years.

With continued rainfall in May, many watersheds across the state quickly reached Q25 exceedence values by the middle of the month. The remainder of the month was dry and river levels quickly dropped to normal flows. June brought heavy rains to much of the state and caused another rise in stream flows for many watersheds. Two major rain events in the southeast in early June brought about severe flooding and damage. This event was not nearly as significant as the flooding event in August of 2007, but some communities were affected by both major events. By mid-June, most of the rivers in the state flowed at the Q25 exceedence value.

Rainfall dropped off in July and flows declined to Q75 exceedence values. This trend continued into August as watersheds began to dry up, again starting in northeast and east-central Minnesota. The state descended into yet another period of low flow and drought conditions. While considered a drought, it was not nearly as severe as in 2007. Water Year 2008 closed out with dry conditions persisting in the northeast and east-central watersheds, with the remainder of the state in normal flow conditions.

Figure 6

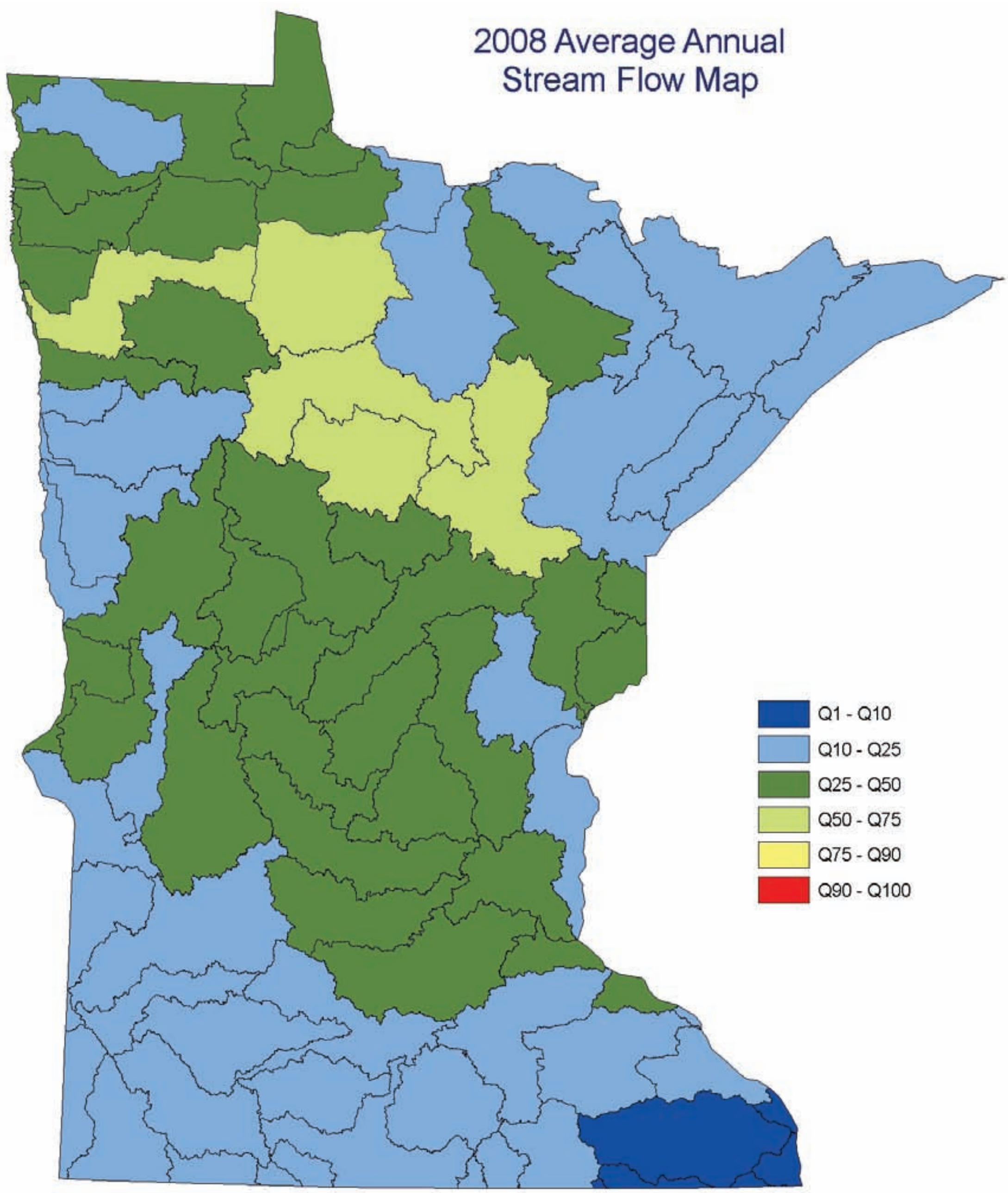
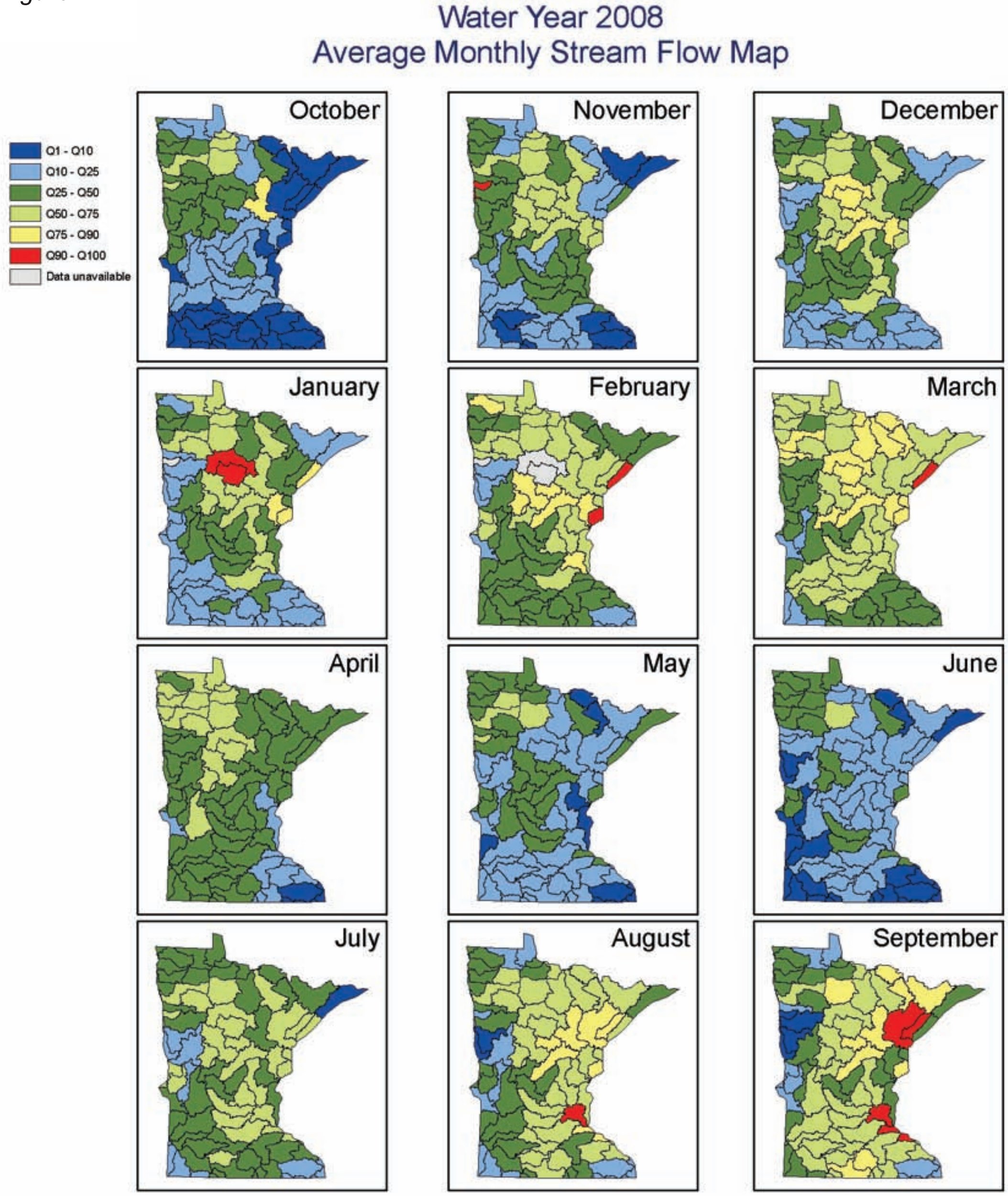


Figure 6 shows the 2008 Average Annual Stream Flow Map. Similar to 2007, watersheds had an annual average flow greater than the historic average or normal flow.

Figure 7

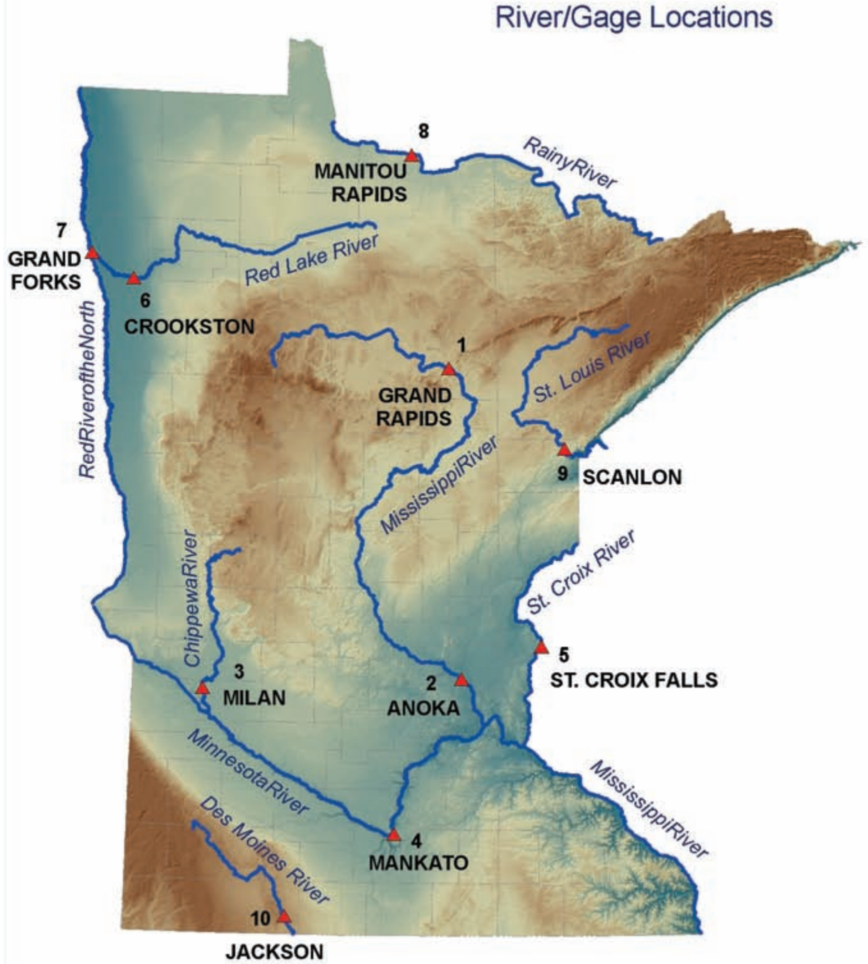



Skip Wright


Molly Shodeen

Hydrographs

Figure 8



Gage Name (USGS ID)

1) Mississippi River at Grand Rapids, MN (05211000)
2) Mississippi River near Anoka, MN (05288500)
3) Chippewa River near Milan, MN (05304500)
4) Minnesota River at Mankato, MN (05325000)
5) St. Croix River at St. Croix Falls, WI (05340500)
6) Red Lake River at Crookston, MN (05079000)
7) Red River of the North at Grand Forks, ND (05082500)
8) Rainy River at Manitou Rapids, MN (05133500)
9) St. Louis River at Scanlon, MN (04024000)
10) Des Moines River at Jackson, MN (05476000)

To give a general summary of flow conditions around the state for the 2007 and 2008 Water Years, discharge hydrographs were created for 10 selected streams. These streams and their locations are shown in Figure 8.

For these 10 selected streams, mean daily discharges are shown in Figures 9 and 10 (pages 32 and 33). Included on those figures are the daily Q25 and Q75 exceedence values and the Q90 Protected Flow.

Figures 11 and 12 (pages 34 and 35) 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 average 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 9

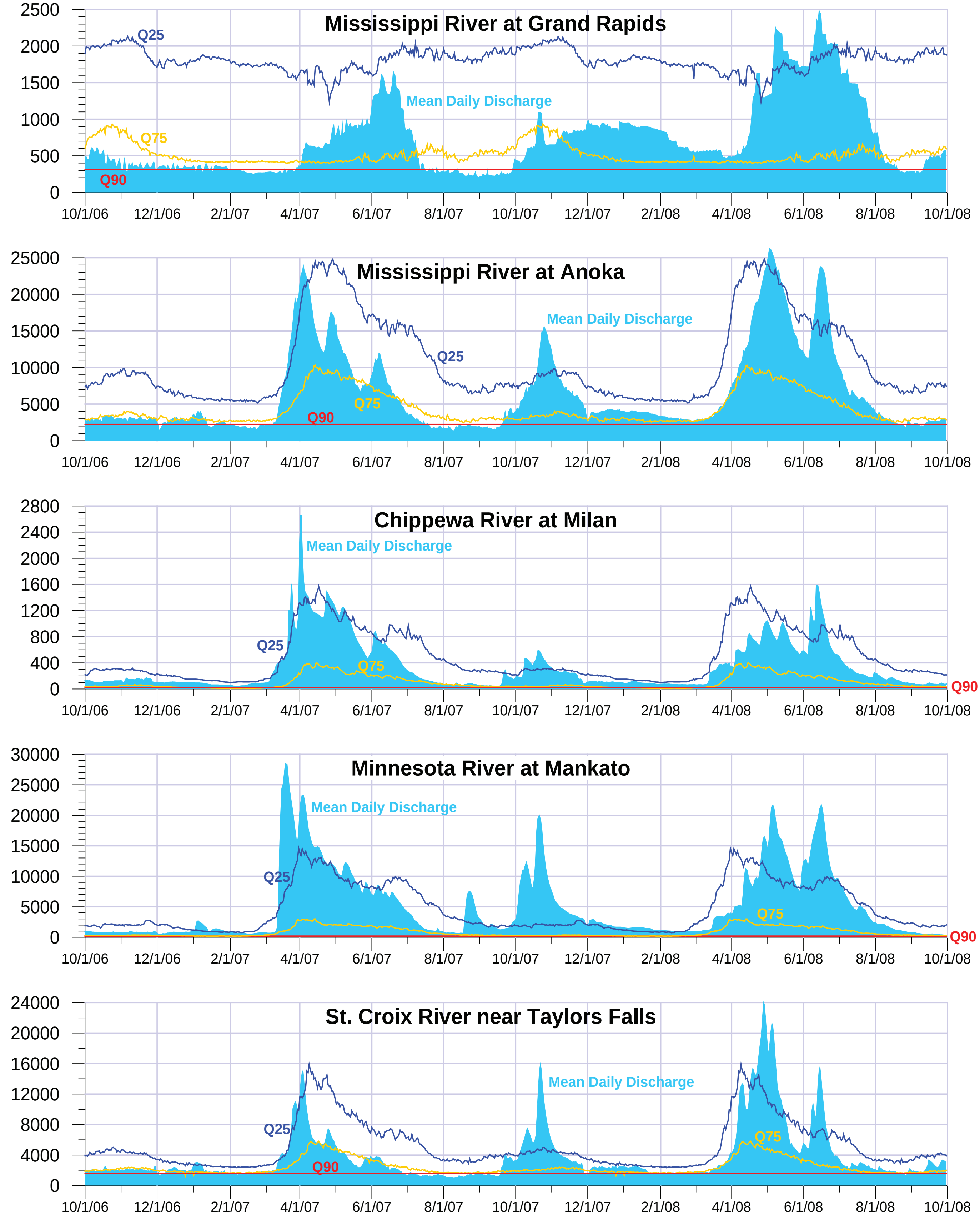

Mississippi River at Grand Rapids
Q25
Q75
Q90
Mean Daily Discharge
2500
2000
1500
1000
500
0
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07
8/1/07
10/1/07
12/1/07
2/1/08
4/1/08
6/1/08
8/1/08
10/1/08
Mississippi River at Anoka
Mean Daily Discharge
Q25
Q75
Q90
25000
20000
15000
10000
5000
0
Chippewa River at Milan
Mean Daily Discharge
Q25
Q75
Q90
2800
2400
2000
1600
1200
800
400
0
Minnesota River at Mankato
Mean Daily Discharge
Q25
Q75
Q90
30000
25000
20000
15000
10000
5000
0
St. Croix River near Taylors Falls
Mean Daily Discharge
Q25
Q75
Q90
24000
20000
16000
12000
8000
4000
0

Figure 10

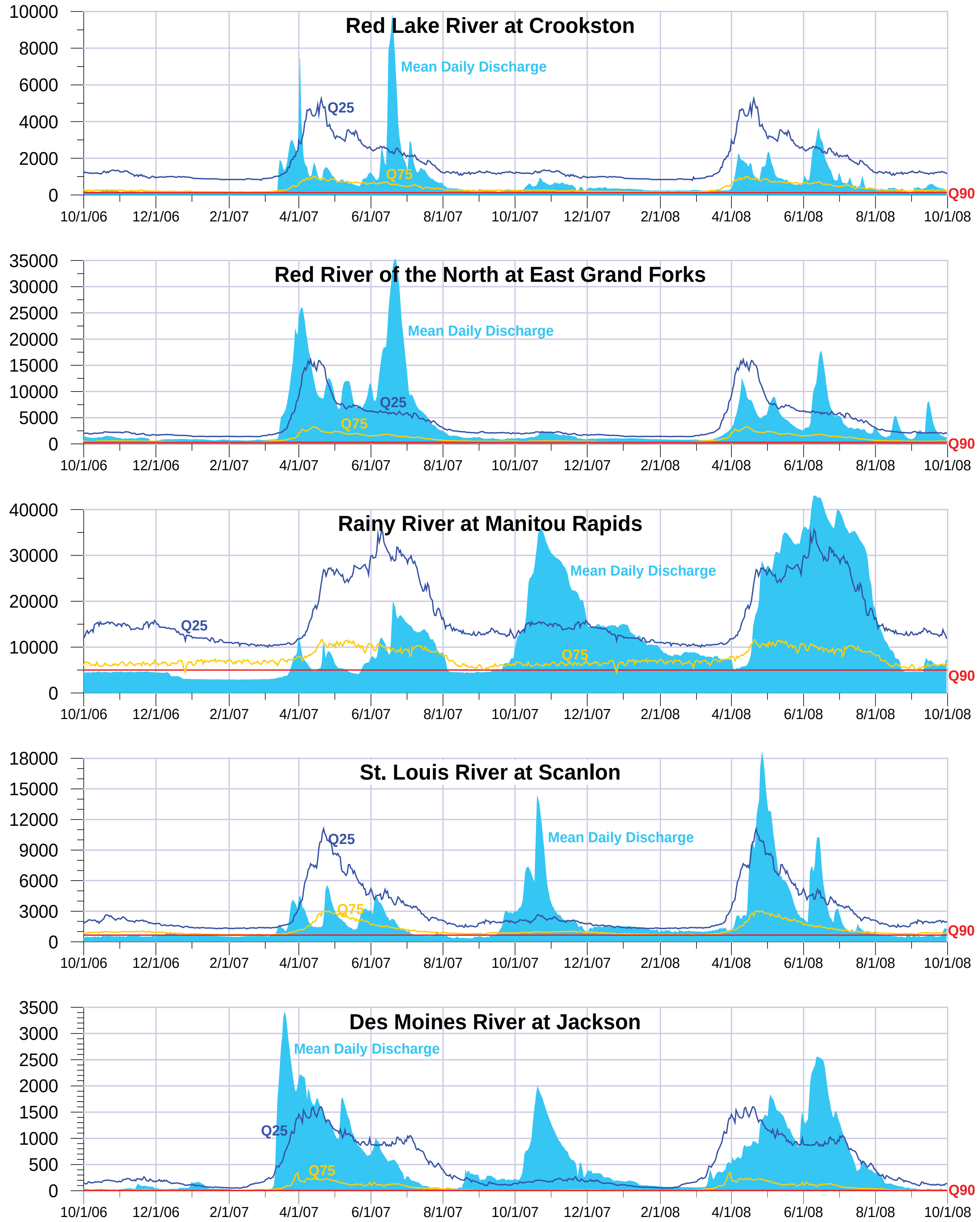

Red Lake River at Crookston
Mean Daily Discharge
Q25
Q75
Q90
10000
8000
6000
4000
2000
0
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07
8/1/07
10/1/07
12/1/07
2/1/08
4/1/08
6/1/08
8/1/08
10/1/08
Red River of the North at East Grand Forks
Mean Daily Discharge
Q25
Q75
Q90
35000
30000
25000
20000
15000
10000
5000
0
Rainy River at Manitou Rapids
Mean Daily Discharge
Q25
Q75
Q90
40000
30000
20000
10000
0
St. Louis River at Scanlon
Mean Daily Discharge
Q25
Q75
Q90
18000
15000
12000
9000
6000
3000
0
Des Moines River at Jackson
Mean Daily Discharge
Q25
Q75
Q90
3500
3000
2500
2000
1500
1000
500
0

Figure 11

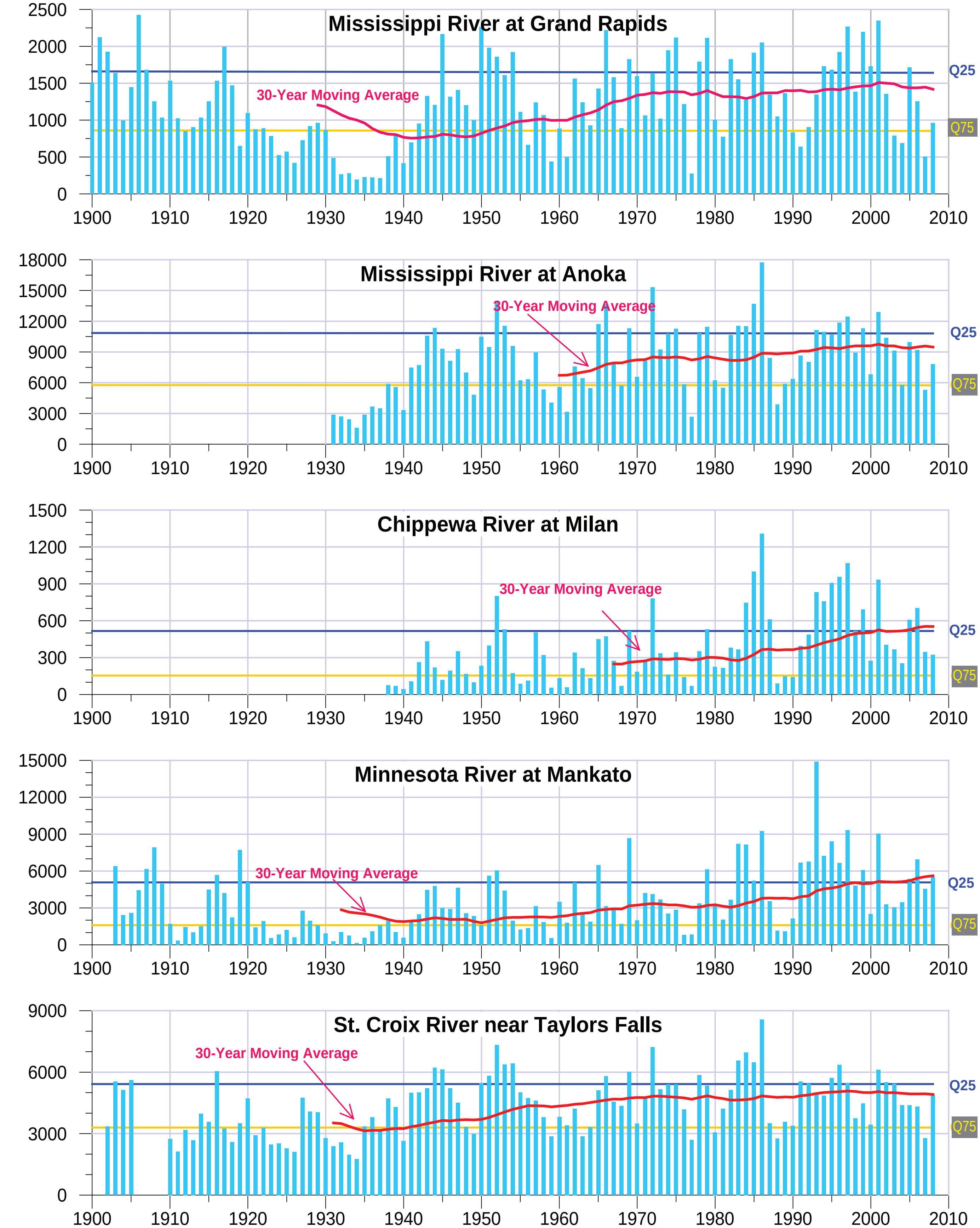
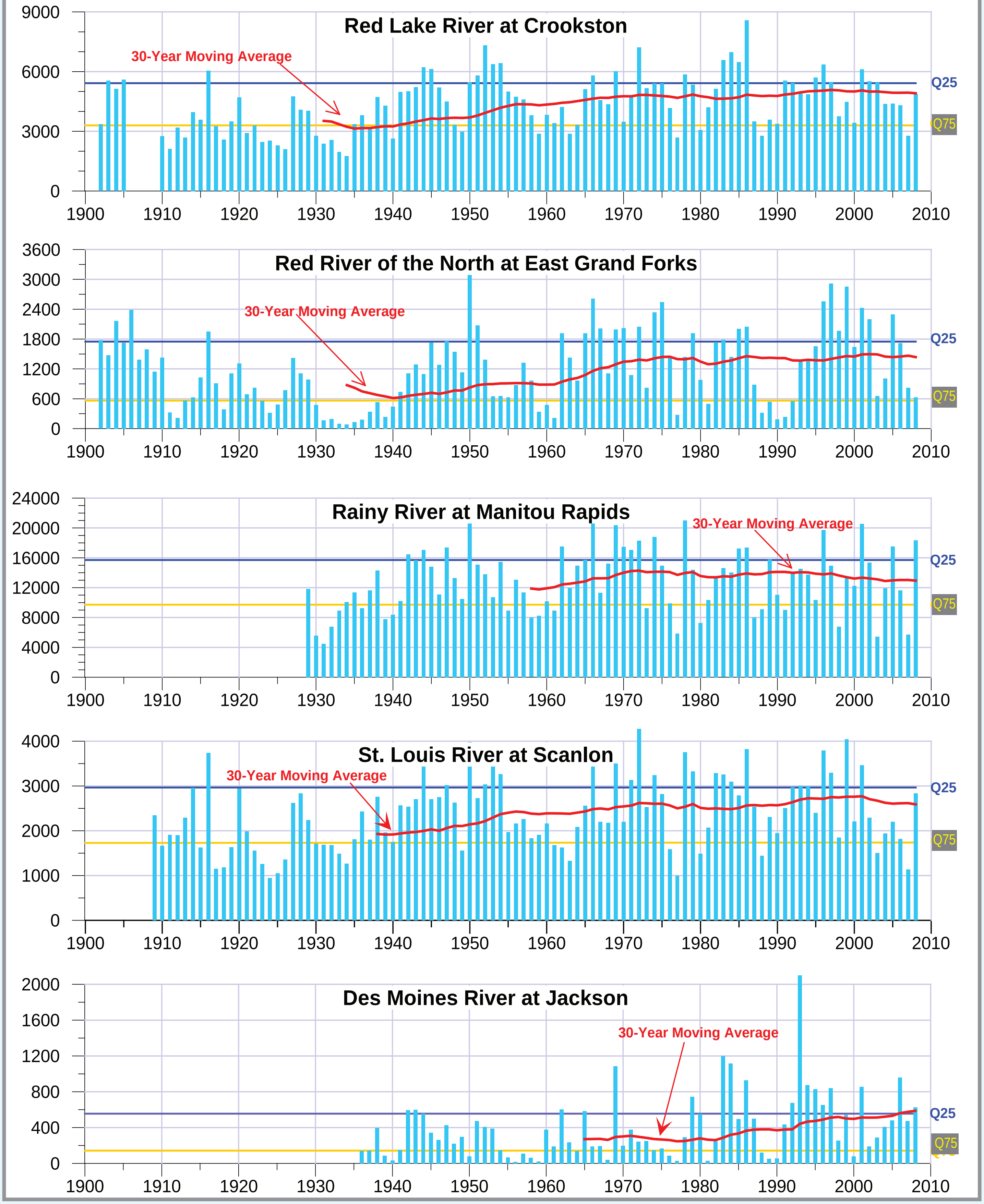

Mississippi River at Grand Rapids
30-Year Moving Average
Q25
Q75
Mississippi River at Anoka
30-Year Moving Average
Q25
Q75
Chippewa River at Milan
30-Year Moving Average
Q25
Q75
Minnesota River at Mankato
30-Year Moving Average
Q25
Q75
St. Croix River near Taylors Falls
30-Year Moving Average
Q25
Q75

Figure 12


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