General Weather Conditions and Precipitation Contributing to the 2011 Flooding in the Mississippi River and Red River of the North Basins, December 2010 through July 2011

Chapter B of
2011 Floods of the Central United States

Professional Paper 1798–B

U.S. Department of the Interior
U.S. Geological Survey

Front cover. *Left:* U.S. Geological Survey (USGS) hydrographer Stacey Kinsey measuring discharge on the Musselshell River, Montana, May 27, 2011. Photograph by Tim Morgan, USGS.

Right: Megan VanDenHeuvel (Journeyman Forecaster), Scott Coulston (Journeyman Forecaster), and Gina Loss (Senior Service Hydrologist), National Weather Service (NWS) Great Falls Weather Forecast Office, measuring snow water equivalent in northern Blaine County, Montana, March 7, 2011. Photograph by Ben Schott (Warning Coordination Meteorologist).

Background: View of flooding from Nebraska City, Nebraska, looking east across the Missouri River, August 2, 2011. Photograph by Robert Swanson, USGS.

Back cover. Goose Lake in Custer National Forest, Beartooth Mountains, Montana, looking north, July 3, 2011. Photograph by David Filcher, geologist (retired).

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U.S. Department of the Interior
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Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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By Kevin C. Vining,[1] Katherine J. Chase,[1] and Gina R. Loss[2]

Abstract

Excessive precipitation produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011. The 2011 flooding was caused by weather conditions that were affected in part by a La Niña climate pattern. During the 2010–11 climatological winter (December 2010–February 2011), several low pressure troughs from the Rocky Mountains into the Ohio River subbasin produced large amounts of precipitation. Precipitation was above normal to record amounts in parts of the Missouri River, Red River of the North, and upper Mississippi River subbasins, and mostly normal to below normal in the Ohio River and lower Mississippi River subbasins. During the 2011 climatological spring (March–May 2011), a large low pressure trough over the continental States and a high pressure ridge centered in the vicinity of the Gulf of Mexico combined to produce storms with copious precipitation along frontal boundaries across the Central States. Rain totals recorded during the April 18–28, 2011, precipitation event were more than 8 inches at several locations, while an impressive total of 16.15 inches was recorded at Cape Girardeau, Missouri. Several locations in the Missouri River subbasin had rainfall totals that were nearly one-third to one-half of their 1971–2000 normal annual amounts during a May 16–31, 2011, precipitation event. During June and July, thunderstorm development along frontal boundaries resulted in areas of heavy rain across the Missouri River, Red River of the North, and upper Mississippi River subbasins, while rainfall in the lower Mississippi River subbasin was mostly below normal.

[1]U.S. Geological Survey.

[2]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service.

Introduction

Excessive precipitation produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011. This report, one of a series of reports that documents the 2011 flooding in the Central United States, describes the weather conditions and precipitation in the Mississippi River and the Red River of the North Basins during climatological winter of 2010–11 (December 2010–February 2011), climatological spring of 2011 (March–May 2011), and early climatological summer of 2011 (June–July 2011).

The Mississippi River and Red River of the North Basins encompass about 41 percent of the conterminous United States (U.S. Army Corps of Engineers, 2012b) (fig. 1). The Mississippi River Basin extends from the Rocky Mountains and semi-arid prairies of Montana and Wyoming to the temperate humid areas near the Great Lakes to the subtropical lowlands near the Gulf of Mexico. The Red River of the North Basin lies in the humid continental prairies of Minnesota, North Dakota, and South Dakota (Critchfield, 1974). These differences in climate are indicative of the incongruity of precipitation each of these regions receives each year on average or at any particular time; the lower Mississippi River subbasin may have torrential rainfall from tropical systems at the same time that the Northern Plains face drought. Conversely, as was the case during December 2010–July 2011, the lower Mississippi River subbasin may have drought even though precipitation is above normal in the Northern Plains States. Conditions may also occur such that several regions receive significant precipitation concurrently or in a sequential pattern that results in widespread significant flooding across portions of the United States.

The USGS Souris River at Foxholm, North Dakota streamgage is half inundated by water about 30 miles northwest of Minot, June 2011. Photograph by Marisa Lubeck, U.S. Geological Survey.

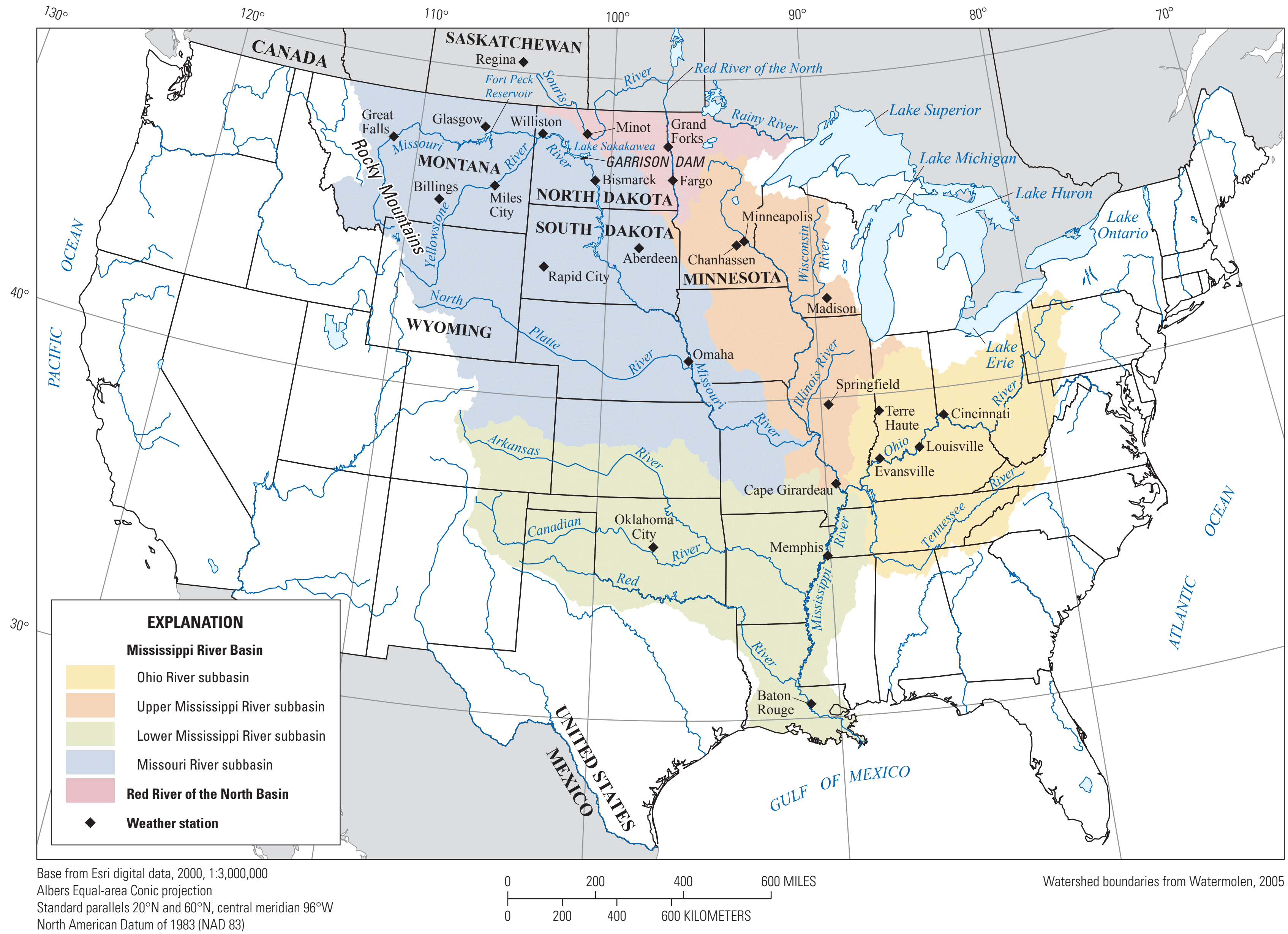


Figure 1. Locations of subbasins and weather stations within the Mississippi River Basin and the Red River of the North Basin.

Precipitation and the causative weather events are described for subbasins of the Mississippi River and Red River of the North Basins as defined in the report. The lower Mississippi River subbasin includes the areas of the Mississippi River and tributaries downstream from the confluence with the Ohio River. The Missouri River subbasin includes the areas of the Missouri River and tributaries. The upper Mississippi River subbasin includes the areas of the Mississippi River and the tributaries upstream from the confluence with the Ohio River but does not include the Ohio River or Missouri River subbasins. The Red River of the North Basin includes the areas of the Red River of the North and tributaries including the Souris River within the United States.

Preparation of this report required the cooperation of persons in several organizations. The authors are particularly appreciative of the cooperation of personnel at the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) for providing data, written materials, and reviews of the report.

Unless otherwise specified, all climate data presented were obtained from the NOAA National Climate Data Center Web sites concerning the state of the climate (National Oceanic and Atmospheric Administration, 2011a). Descriptions of meteorological phenomena are from the Hydrometeorological Prediction Center (2012) and from the National Weather Service Performance Management Homepage (National Oceanic and Atmospheric Administration, 2012a). Climate normals presented are for the period 1971–2000, because the 1981–2010 normals had not been published when the data for this report were obtained. (The average precipitation for any given 30-year period is termed the "normal" precipitation for the given period.)

General Weather Conditions

The 2011 flooding in the Mississippi River and Red River of the North Basins resulted from weather conditions during December 2010 through July 2011 that were affected in part by a La Niña climate pattern (National Oceanic and Atmospheric Administration, 2011a). The La Niña pattern is characterized by cooler-than-average sea surface temperatures in the central and east-central equatorial Pacific Ocean and a strong high pressure area in the northern Pacific Ocean region. Also during a La Niña, an area of high pressure exists over the south and southeastern regions of the United States. As a result, the northern jet stream can be positioned to bring cooler polar air into the western and northern United States while a southern jet stream brings Pacific moisture into the Rocky Mountain region and the Mississippi River and Red River of the North Basins. The La Niña pattern tends to produce cooler and wetter than normal weather conditions over the western and north-central regions of the Mississippi River and Red River of the North Basins and often warmer and drier than normal weather conditions over the southern Mississippi River Basin. The La Niña pattern developed during mid-2010 and continued well into 2011.

Before the onset of La Niña during climatological winter 2010–11, a news release by NOAA's Climate Prediction Center on October 21, 2010, provided a summary of the potential effects of La Niña on the upcoming winter (National Oceanic and Atmospheric Administration, 2010):

> The Pacific Northwest should brace for a colder and wetter than average winter, while most of the South and Southeast will be warmer and drier than average through February 2011, according to the annual Winter Outlook released today by NOAA's Climate Prediction Center. A moderate to strong La Niña will be the dominant climate factor influencing weather across most of the United States this winter.

From the same NOAA news release, the Climate Prediction Center indicated:

> La Niña is in place and will strengthen and persist through the winter months, providing a better understanding of what to expect between December and February. This is a good time for people to review the outlook and begin preparing for what winter may have in store.

Regional highlights quoted from the news release described potential effects of La Niña on winter and early spring conditions in parts of the Mississippi River and Red River of the North Basins:

- **Pacific Northwest:** colder and wetter than average. La Niña often brings lower than average temperatures and increased mountain snow to the Pacific Northwest and western Montana during the winter months, which is good for the replenishment of water resources and winter recreation but can also lead to greater flooding and avalanche concerns.
- **Northern Plains:** colder and wetter than average. Likely to see increased storminess and flooding.
- **Ohio and Tennessee Valleys:** warmer and wetter than average. Likely to see increased storminess and flooding.
- **Southern Plains, Gulf Coast States, and Southeast:** warmer and drier than average. This will likely exacerbate drought conditions in these areas.

Precipitation Patterns

The La Niña and its associated weather conditions persisted through climatological winter 2010–11 and climatological spring 2011. Climatological winter 2010–11 was quite active with storms passing through the northern portion of the United States. All the climate divisions in South Dakota had much above normal winter precipitation, and the northeast climate division in Montana had a record wet winter (National Oceanic and Atmospheric Administration, 2011a) (fig. 2). Conversely, the South-Central and areas of the Southeastern United States, especially the lower Mississippi River subbasin, had conditions that were much drier than normal. During climatological spring 2011, much of the northern two-thirds of the Mississippi River Basin continued to have wetter than normal conditions, while the Southern Plains and the lower Mississippi River Basin in Louisiana continued to have much drier than normal conditions, with record dryness observed over much of Texas, Oklahoma, and New Mexico (National Oceanic and Atmospheric Administration, 2011a) (fig. 3).

Precipitation patterns across the Red River of the North and Mississippi River Basins from December 2010 through July 2011 followed the mean position of the jet stream (National Oceanic and Atmospheric Administration, 2011b). During December, January, and February, a southward push of the jet stream steered several low pressure troughs across the country from the Rocky Mountains into the Ohio River subbasin producing large amounts of precipitation (figs. 4–6). As some low pressure systems would develop deep into the southern portions of the United States, they would create a split in the storm track. Low pressure troughs that followed the southern branch of the storm track brought substantial precipitation to the Lower Mississippi River subbasin in January (fig. 5) and also to the Ohio River subbasin in February (fig. 6). From March through May, a large low pressure trough dominated the continental States, and a high pressure ridge was centered in the vicinity of the Gulf of Mexico. This weather combination produced storms with copious precipitation along frontal boundaries that were steered across the Central States before moving to the northeast into the Ohio River subbasin (figs. 7–9). The geographical tracking of these storms brought precipitation into the Missouri River subbasin as well. During June and July, moisture from the southwestern monsoon and the Gulf of Mexico worked its way into the Plains States. Low pressure troughs moving across the country interacted with this moist unstable air; thunderstorm development along frontal boundaries resulted in areas of heavy rain across the Northern Plains States into the Missouri and upper Mississippi River subbasins (figs. 10 and 11). Excessive precipitation that fell on already saturated ground and ran off into already full streams and rivers produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011 (Minnesota Climatology Working Group, 2011). Meanwhile, the high pressure ridge that had built over the Southern Plains kept that area mostly dry.

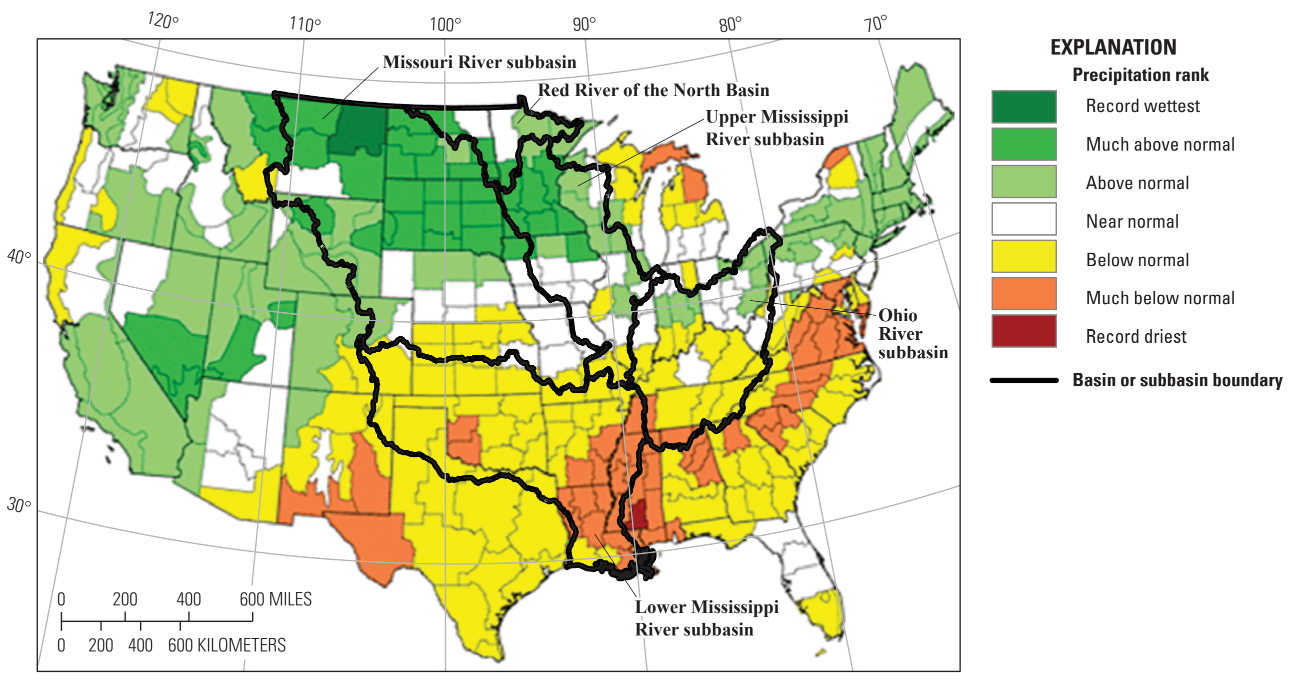


Figure 2. Climate-division precipitation ranks for climatological winter 2010–11 (December 2010–February 2011) based on about 116 years of record.

Precipitation on the Mississippi River Basin

Climatological winter 2010–11 was characterized by the passage of several deep low pressure troughs, each of which allowed for the infiltration of cold, continental polar air. The combination of moisture associated with these troughs and cold air set the stage for significant snowfall across the Rockies and northern portion of the Mississippi River Basin. At the end of December 2010, Montana, Wyoming, North Dakota, South Dakota, Minnesota, Colorado, and most of Nebraska were covered with snow (National Oceanic and Atmospheric Administration, 2011c). By the end of February, the snow water equivalent (SWE) in the mountains was near to a little above average; southwestern Montana had approximately 17 inches SWE, the plains on the eastern side of the Rocky Mountains approximately 20 inches SWE, central Montana mountains approximately 18 inches SWE, and the mountains of Montana and Wyoming, which contain headwaters of the Yellowstone River, approximately 12 inches of SWE. On the plains of eastern Montana, North Dakota, and South Dakota, the series of snowstorms created a widespread, deep snowpack with some areas receiving nearly three times their average annual snowfall. At the end of the climatological winter, SWE over the plains ranged from 4 to 12 inches. South Dakota and Montana recorded their fourth and ninth wettest winter periods, respectively (National Oceanic and Atmospheric Administration, 2012b).

The weather pattern that dominated during climatological winter 2010–11 continued through climatological spring 2011 (National Oceanic and Atmospheric Administration, 2011a). Texas recorded its driest spring on record, with statewide-averaged precipitation of only 2.66 inches (table 1), almost 5 inches below normal. Nearby, Louisiana had its sixth driest spring on record while Arkansas had its tenth-wettest spring on record. As the jet stream continued to flow over the Northern United States, several low pressure troughs were steered along its path. Frequent storm systems continued to bring precipitation to the northern Rocky Mountains and Northern Plains. Storm systems also developed in the mid-Mississippi Valley and moved northeastward across the Ohio Valley region. The divisional ranks of precipitation for spring (fig. 3) show that southern Missouri and northern Arkansas into the Ohio River subbasin and many locations in the Missouri River subbasin recorded above normal precipitation. Above-normal spring precipitation fell in the Ohio River subbasin during late April and in the Missouri River subbasin during late May (National Oceanic and Atmospheric Administration, 2011a). Details about these precipitation events are discussed in the sections about each subbasin. Monthly precipitation totals for December 2010 through July 2011 for selected weather stations across the Mississippi River Basin are presented in table 2.

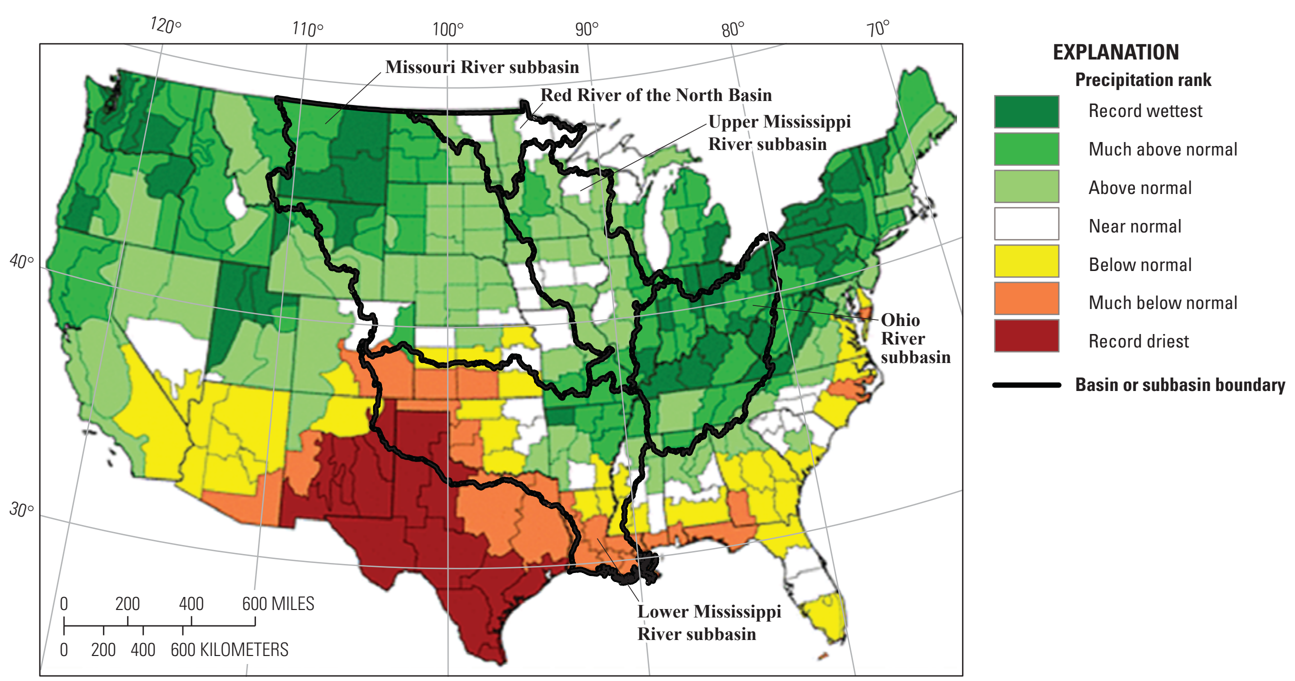


Figure 3. Climate-division precipitation ranks for climatological spring 2011 (March–May 2011) based on about 116 years of record.

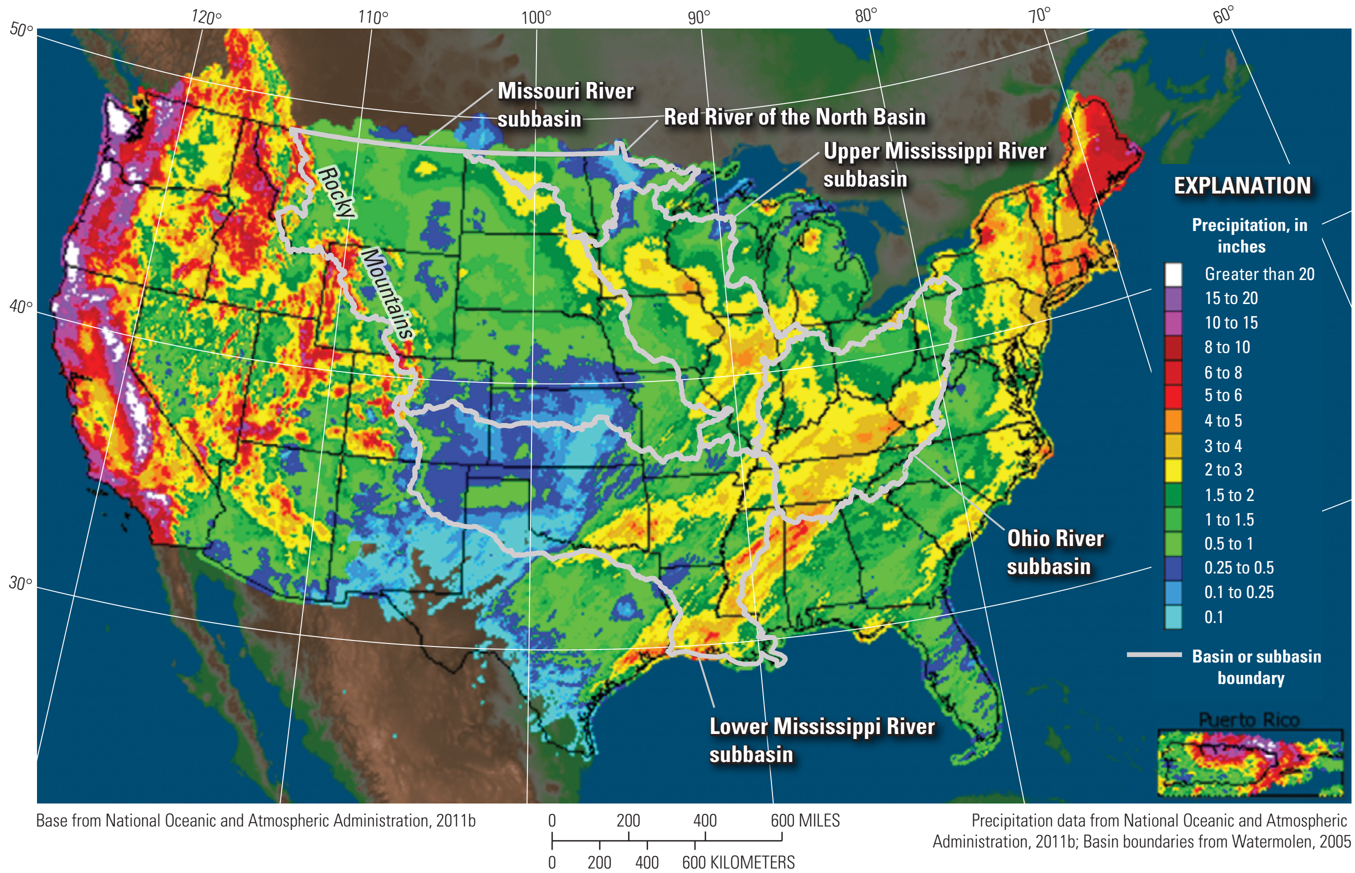


Figure 4. December 2010 observed precipitation.

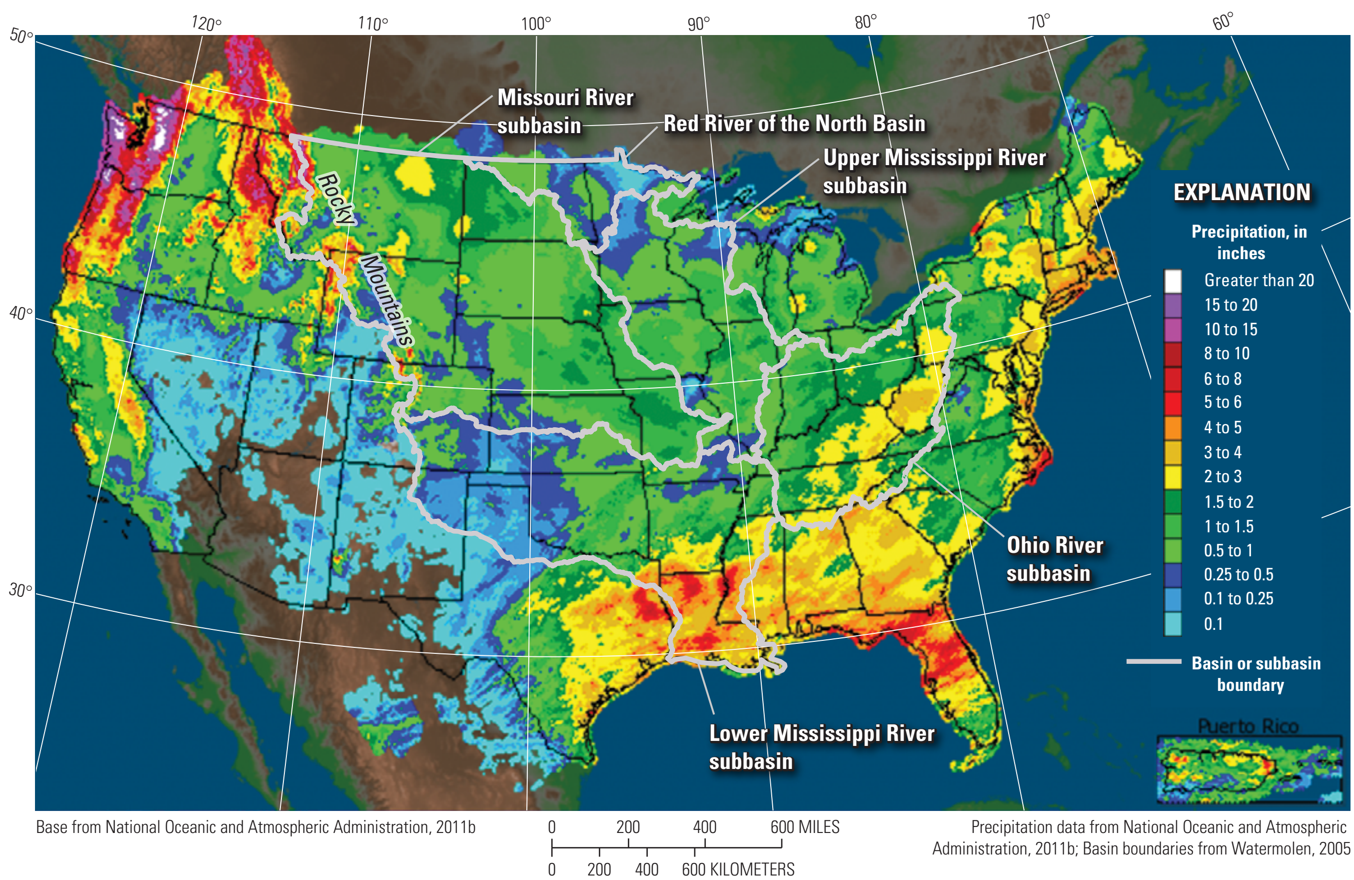
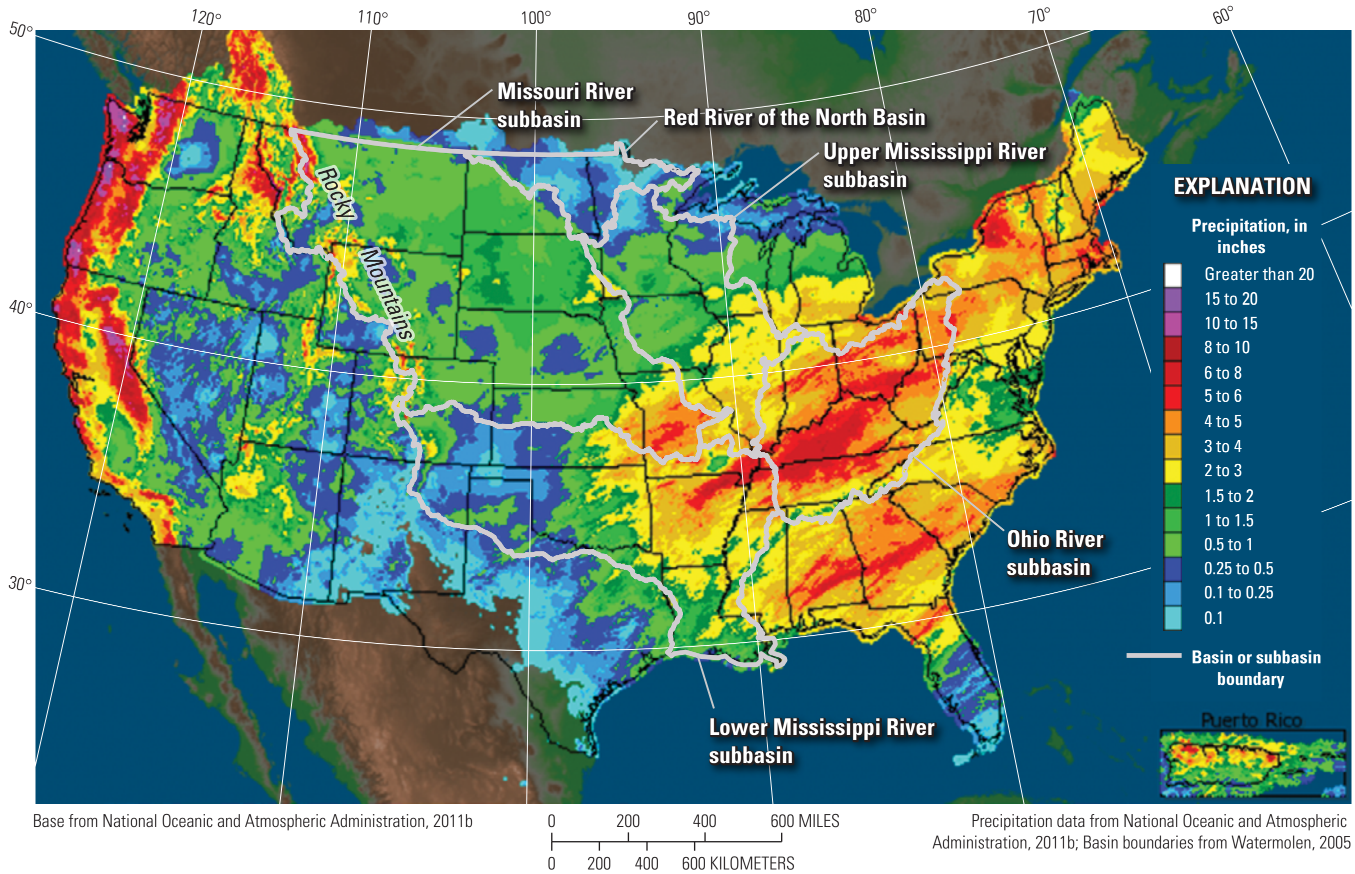


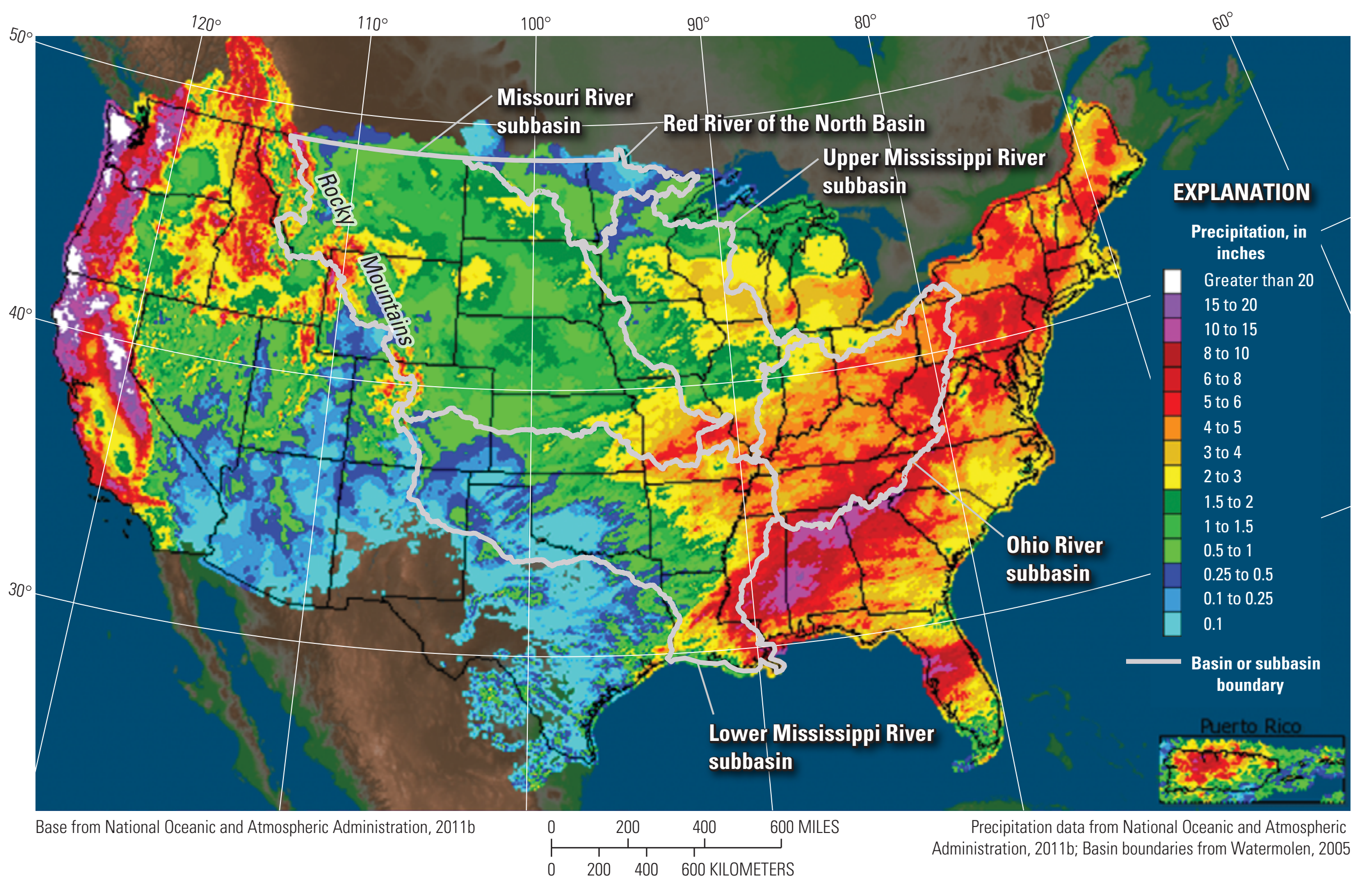
Figure 5. January 2011 observed precipitation.



Base from National Oceanic and Atmospheric Administration, 2011b

Precipitation data from National Oceanic and Atmospheric Administration, 2011b; Basin boundaries from Watermolen, 2005

Figure 6. February 2011 observed precipitation.



Base from National Oceanic and Atmospheric Administration, 2011b

Precipitation data from National Oceanic and Atmospheric Administration, 2011b; Basin boundaries from Watermolen, 2005

Figure 7. March 2011 observed precipitation.

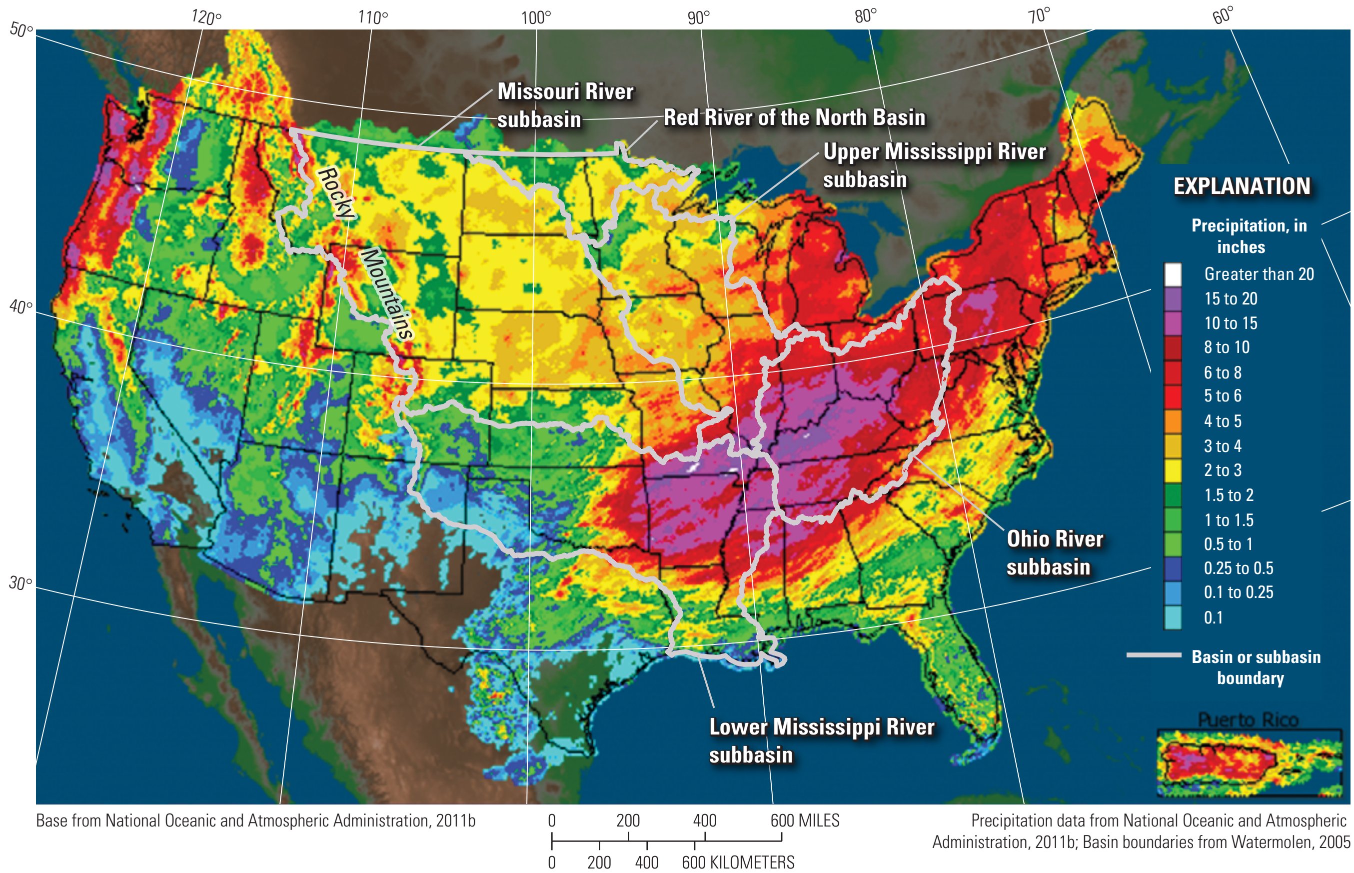


Figure 8. April 2011 observed precipitation.

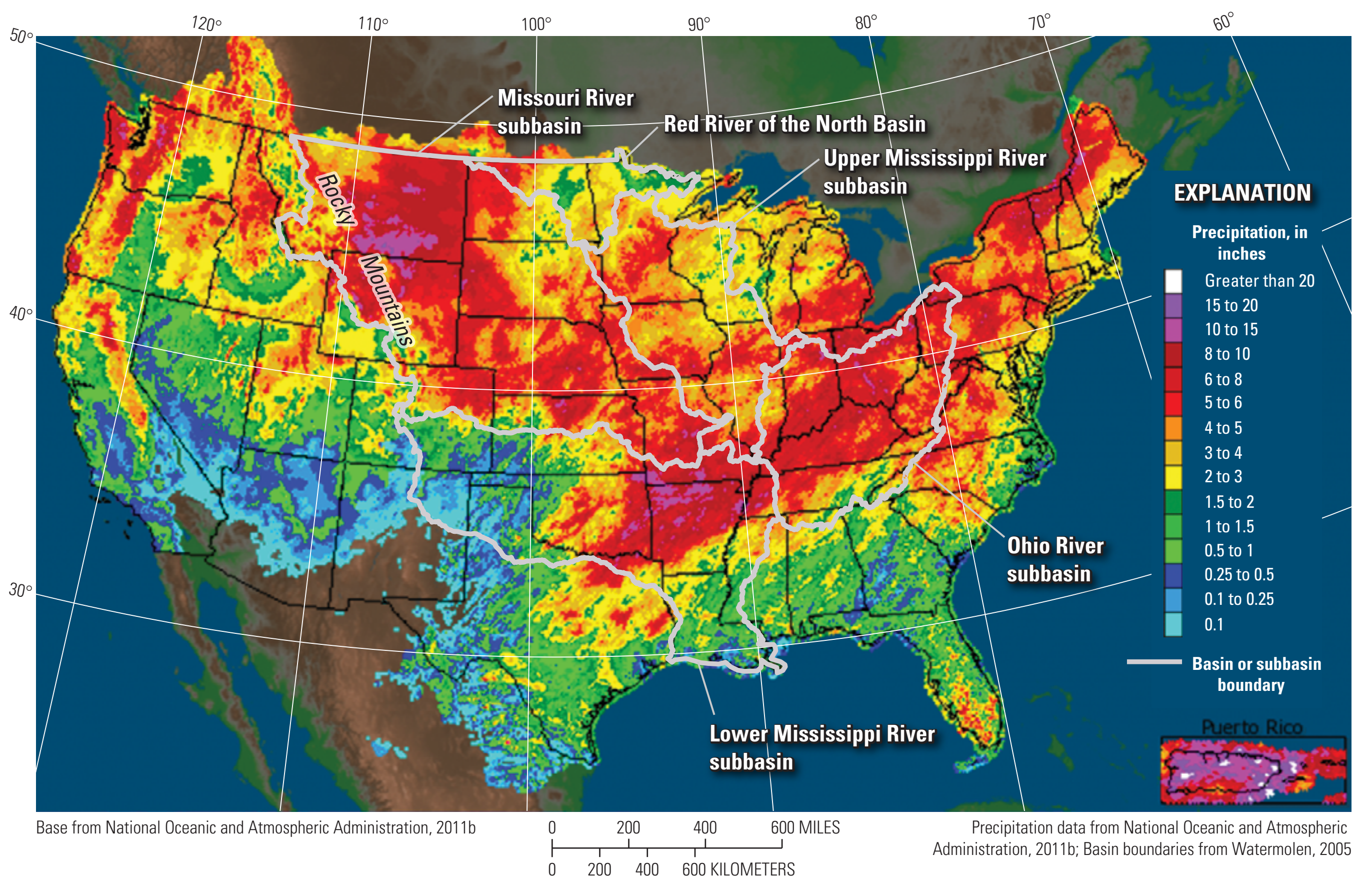


Figure 9. May 2011 observed precipitation.

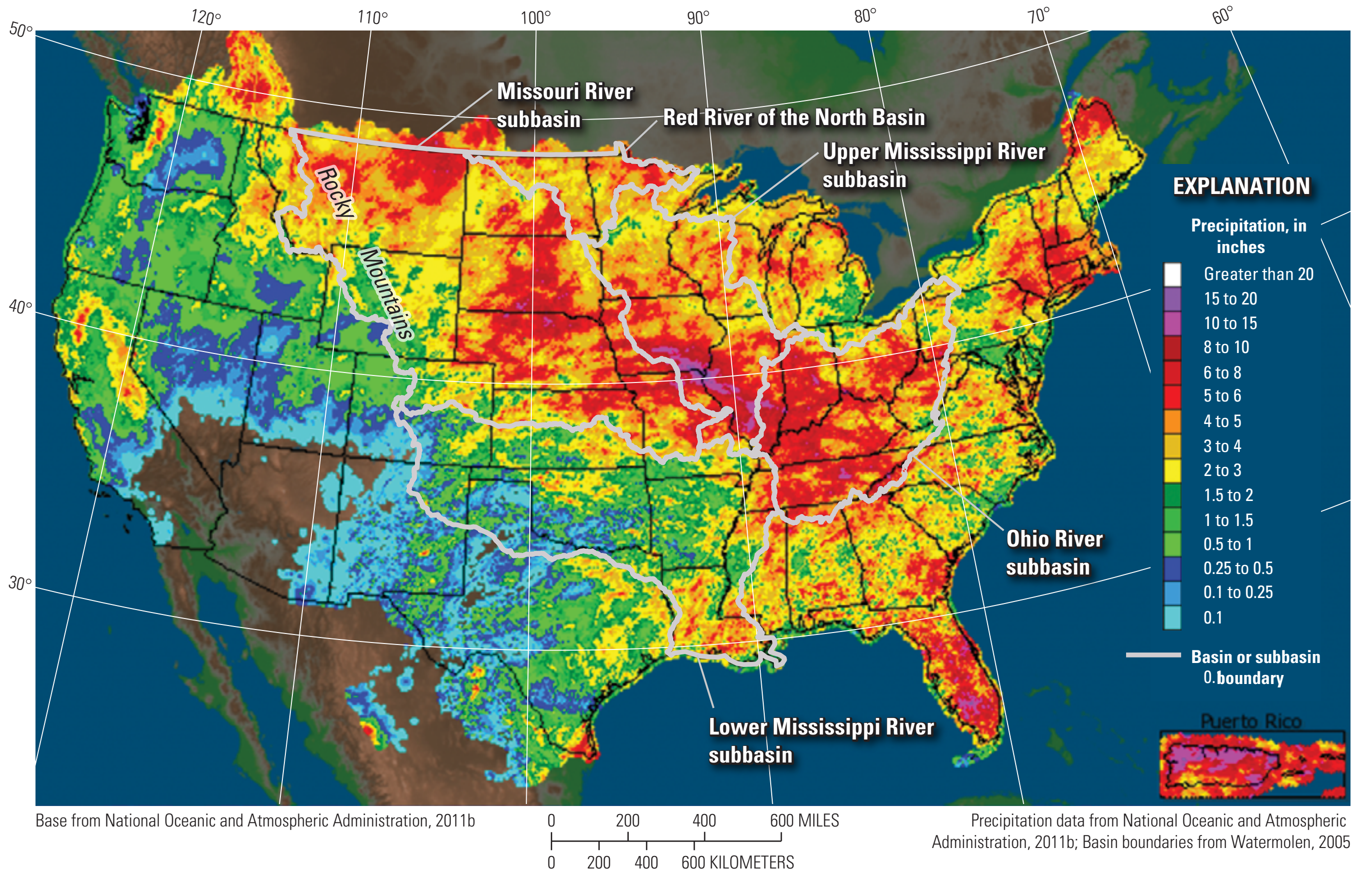


Figure 10. June 2011 observed precipitation.

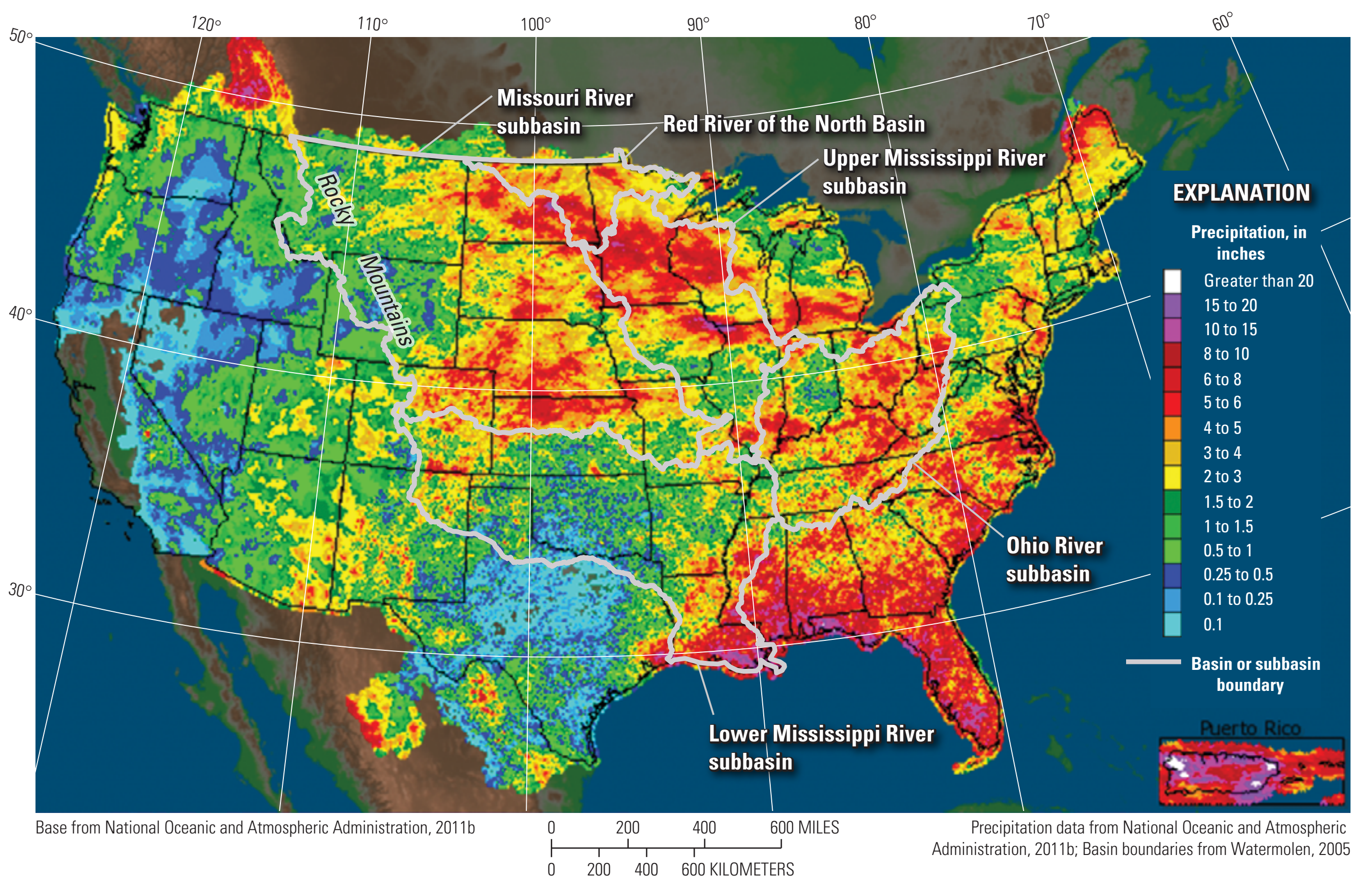


Figure 11. July 2011 observed precipitation.

Table 1. Summary of monthly precipitation totals for December 2010 through July 2011[1] and normals for 1971–2000[2] for selected States in the Mississippi and Red River of the North Basins.

State		Total monthly precipitation, in inches							
		December	January	February	March	April	May	June	July
Arkansas	December 2010—July 2011	1.48	1.55	4.17	2.74	10.41	8.45	1.62	2.10
	1971—2010 Normals	4.68	3.65	3.61	4.93	4.82	5.20	4.31	3.52
Colorado	December 2010—July 2011	1.11	0.52	0.85	0.84	1.66	2.14	0.87	2.61
	1971—2010 Normals	0.76	0.79	0.75	1.29	1.47	1.92	1.44	2.01
Illinois	December 2010—July 2011	1.82	1.19	3.17	2.67	7.40	5.18	6.46	3.77
	1971—2010 Normals	2.73	1.97	1.99	3.22	3.83	4.31	4.12	3.94
Indiana	December 2010—July 2011	1.52	1.55	4.17	3.46	9.42	6.47	5.12	2.91
	1971—2010 Normals	3.07	2.44	2.31	3.40	3.96	4.47	4.25	4.19
Iowa	December 2010—July 2011	1.29	0.92	1.42	1.52	3.78	4.87	6.30	3.44
	1971—2010 Normals	1.23	0.95	0.98	2.20	3.33	4.23	4.62	4.26
Kansas	December 2010—July 2011	0.20	0.44	1.13	1.13	1.83	3.42	2.80	2.62
	1971—2010 Normals	0.96	0.77	0.91	2.25	2.58	4.18	3.88	3.61
Kentucky	December 2010—July 2011	3.08	2.04	4.72	5.24	11.74	6.70	5.26	3.96
	1971—2010 Normals	4.38	3.77	3.76	4.60	4.19	5.05	4.34	4.47
Louisiana	December 2010—July 2011	1.94	4.66	2.08	3.73	2.62	1.51	3.25	6.39
	1971—2010 Normals	5.42	5.91	4.66	5.32	4.89	5.46	5.20	5.15
Minnesota	December 2010—July 2011	1.88	1.05	0.67	1.32	2.69	4.10	4.39	4.93
	1971—2010 Normals	0.77	0.86	0.64	1.45	2.06	3.06	4.05	3.95
Mississippi	December 2010—July 2011	1.55	4.39	2.50	6.60	6.20	1.94	3.21	5.75
	1971—2010 Normals	5.50	5.92	4.96	6.30	5.61	5.40	4.47	4.80
Missouri	December 2010—July 2011	0.89	1.08	3.48	3.51	7.45	6.14	4.23	2.43
	1971—2010 Normals	2.79	1.95	2.15	3.51	4.04	4.82	4.26	3.95
Montana	December 2010—July 2011	1.11	1.10	0.94	1.07	1.82	5.24	3.03	1.27
	1971—2010 Normals	0.78	0.80	0.60	0.90	1.30	2.34	2.40	1.65
Nebraska	December 2010—July 2011	0.39	0.91	0.62	0.89	2.78	5.31	3.97	3.67
	1971—2010 Normals	0.56	0.51	0.60	1.66	2.38	3.75	3.45	3.27
North Dakota	December 2010—July 2011	1.23	0.90	0.34	1.05	1.75	3.89	3.83	3.93
	1971—2010 Normals	0.43	0.50	0.45	0.80	1.40	2.31	3.19	2.75
Ohio	December 2010—July 2011	2.07	1.55	4.50	4.24	7.70	6.40	3.71	3.72
	1971—2010 Normals	2.91	2.51	2.27	3.06	3.47	4.06	4.10	4.09
Oklahoma	December 2010—July 2011	0.87	0.35	1.46	0.71	3.33	4.07	1.13	0.71
	1971—2010 Normals	2.04	1.48	1.78	3.07	3.32	5.13	4.24	2.73
Pennsylvania	December 2010—July 2011	3.50	1.86	3.60	5.65	7.80	5.68	3.00	2.81
	1971—2010 Normals	3.11	3.04	2.58	3.41	3.55	4.07	4.45	4.15
South Dakota	December 2010—July 2011	0.98	0.90	1.10	1.00	2.24	4.50	4.67	3.37
	1971—2010 Normals	0.43	0.45	0.53	1.30	2.11	3.10	3.23	2.75
Tennessee	December 2010—July 2011	2.91	3.16	4.11	6.86	9.62	5.09	5.71	3.32
	1971—2010 Normals	5.17	4.66	4.31	5.60	4.51	5.33	4.48	4.67
Texas	December 2010—July 2011	0.74	1.63	0.74	0.29	0.77	1.60	1.03	0.73
	1971—2010 Normals	1.85	1.59	1.67	1.85	2.14	3.52	3.35	2.22
West Virginia	December 2010—July 2011	3.44	2.13	2.88	5.69	7.51	5.08	3.99	3.71
	1971—2010 Normals	3.38	3.46	3.11	3.97	3.63	4.57	4.23	4.75
Wisconson	December 2010—July 2011	1.87	0.91	1.13	2.39	3.69	2.95	4.27	4.45
	1971—2010 Normals	1.34	1.22	1.00	1.96	2.86	3.37	4.02	4.07
Wyoming	December 2010—July 2011	1.09	0.60	0.69	0.86	1.72	4.11	1.38	1.00
	1971—2010 Normals	0.59	0.63	0.57	0.86	1.36	2.06	1.58	1.33

[1]National Oceanic and Atmospheric Administration, 2012c.

[2]National Oceanic and Atmospheric Administration, 2002.

Table 2. Summary of monthly precipitation totals for December 2010 through July 2011[1] and normals for 1971—2000[2] for selected weather stations in the Mississippi River Basin.

Station		Total monthly precipitation, in inches							
		December	January	February	March	April	May	June	July
Lower Mississippi River subbasin									
Baton Rouge, Louisiana	December 2010—July 2011	4.59	5.28	1.90	6.93	0.99	0.59	4.74	6.22
	1971—2000 Normals	5.26	6.19	5.10	5.07	5.56	5.34	5.33	5.96
Memphis, Tennessee	December 2010—July 2011	2.91	2.13	3.53	4.65	12.58	7.86	3.53	3.09
	1971—2000 Normals	5.48	3.92	4.39	5.18	5.36	4.97	4.36	4.64
Oklahoma City, Oklahoma	December 2010—July 2011	0.13	0.10	2.09	0.03	0.99	9.21	1.24	3.04
	1971—2000 Normals	1.89	1.28	1.56	2.90	3.00	5.44	4.63	2.94
Ohio River subbasin									
Cincinnati, Ohio/Covington Airport, Kentucky	December 2010—July 2011	1.77	1.58	5.79	4.55	13.52	6.71	8.89	2.22
	1971—2000 Normals	3.28	2.92	2.75	3.90	3.96	4.59	4.42	3.75
Louisville, Kentucky	December 2010—July 2011	1.66	1.48	5.69	5.17	13.97	7.81	7.14	2.35
	1971—2000 Normals	3.69	3.28	3.25	4.41	3.91	4.88	3.76	4.30
Terre Haute, Indiana	December 2010—July 2011	1.74	0.61	3.88	2.94	11.01	5.33	4.62	2.62
	1971—2000 Normals	3.01	2.13	2.58	3.68	4.12	4.46	4.09	4.45
Missouri River subbasin									
Great Falls, Montana	December 2010—July 2011	1.56	0.46	1.77	0.42	2.83	4.12	2.58	0.87
	1971—2000 Normals	0.67	0.68	0.51	1.01	1.40	2.53	2.24	1.45
Rapid City, South Dakota	December 2010—July 2011	0.57	0.36	1.16	0.85	2.13	8.24	4.70	1.16
	1971—2000 Normals	0.40	0.37	0.46	1.03	1.86	2.96	2.83	2.03
Williston, North Dakota	December 2010—July 2011	1.95	1.30	0.55	0.98	2.99	5.28	1.86	2.34
	1971—2000 Normals	0.57	0.54	0.39	0.74	1.05	1.88	2.36	2.28
Upper Mississippi River subbasin									
Chanhassen, Minnesota	December 2010—July 2011	2.90	0.98	1.14	2.32	3.02	4.78	3.98	5.38
	1971—2000 Normals	0.84	0.93	0.62	1.77	2.40	3.65	4.21	4.43
Madison, Wisconsin	December 2010—July 2011	1.49	1.28	1.59	2.96	3.61	2.40	3.55	1.85
	1971—2000 Normals	1.66	1.25	1.28	2.28	3.35	3.25	4.05	3.93
Springfield, Illinois	December 2010—July 2011	1.67	0.95	2.81	1.67	5.46	3.35	6.31	1.08
	1971—2000 Normals	2.54	1.62	1.80	3.15	3.36	4.06	3.77	3.53
Red River of the North subbasin									
Fargo, North Dakota	December 2010—July 2011	1.75	0.90	0.08	1.84	2.02	4.30	4.41	4.35
	1971—2000 Normals	0.57	0.76	0.59	1.17	1.37	2.61	3.51	2.88
Grand Forks, North Dakota	December 2010—July 2011	0.72	0.85	0.04	0.76	2.40	2.45	3.34	2.69
	1971—2000 Normals	0.55	0.68	0.58	0.89	1.23	2.21	3.03	3.06
Minot, North Dakota	December 2010—July 2011	0.73	0.42	0.06	0.79	1.34	6.22	2.97	5.58
	1971—2000 Normals	0.63	0.65	0.53	1.05	1.55	2.31	3.15	2.70

[1]National Oceanic and Atmospheric Administration (2011d).

[2]National Oceanic and Atmospheric Administration (2012d).

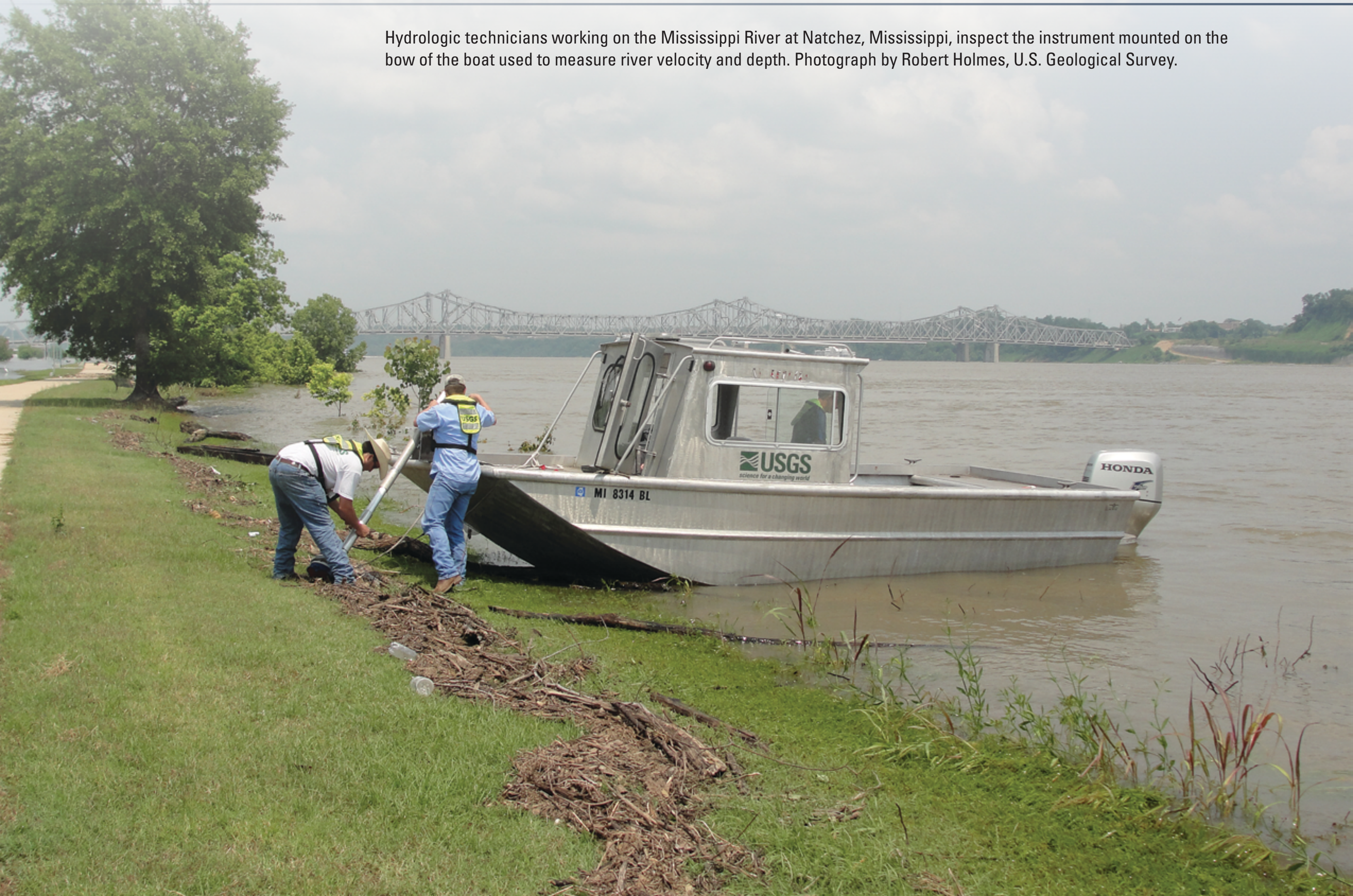
Lower Mississippi River Subbasin

As most weather systems were being steered across the northern portion of the United States during the climatological winter of 2010–11, the lower Mississippi River subbasin had mostly dry conditions (fig. 2). Climatological spring brought a slight shift in the weather pattern with passing low pressure systems tapping into subtropical moisture. This shift created some significant rainfall over portions of the subbasin that exacerbated flooding (National Oceanic and Atmospheric Administration, 2012b) (figs. 3, 7, 8, and 9).

Much of the lower Mississippi River subbasin received less than one-half of the December normal precipitation. For December 2010, Louisiana reported a statewide average monthly total of only 1.94 inches (table 1), resulting in the third driest December since 1895; however, Baton Rouge received 4.59 inches, or about 80 percent of normal December precipitation (table 2). Mississippi also had its third driest December on record with a monthly precipitation total of only 1.55 inches (table 1). Areas in the western part of the subbasin, including Oklahoma City, reported only a small fraction of their normal December precipitation (National Oceanic and Atmospheric Administration, 2012c; table 2).

January and February were mostly dry in the subbasin. In central Louisiana and southern Mississippi, most of the weather stations reported precipitation totals that ranged between one-quarter and one-half of normal. Baton Rouge had less than one-half of normal February precipitation. However, Oklahoma City had above normal February precipitation. The wettest area of the subbasin included much of north-central Arkansas, which had precipitation totals of 50 to 300 percent above normal in February (National Oceanic and Atmospheric Administration, 2012c). Several low pressure systems tracked across and to the north of this area interacting with warm, moist air from the Gulf of Mexico. Showers and thunderstorms that developed along the frontal boundaries resulted in areas of heavy rain.

March and April precipitation was variable throughout the subbasin. March precipitation was below normal in Arkansas, Louisiana, and Oklahoma and above normal in Mississippi and Tennessee. April precipitation was below normal in Louisiana and above normal in Arkansas, Mississippi, Oklahoma, and Tennessee (National Oceanic and Atmospheric Administration, 2012c; table 1). Texas had its second driest March on record (National Oceanic and Atmospheric Administration, 2012b), with a statewide average of 0.29 inches (table 1).



Hydrologic technicians working on the Mississippi River at Natchez, Mississippi, inspect the instrument mounted on the bow of the boat used to measure river velocity and depth. Photograph by Robert Holmes, U.S. Geological Survey.

In April, Memphis had 12.58 inches of rainfall, or more than 100 percent above normal (table 2). The April rain in Memphis was part of a larger precipitation event that also included most of the Ohio River subbasin. The last half of April brought a slow moving weather pattern coupled with a quasi-stationary front over the Ohio River subbasin. As deep tropical moisture pushed northward, it interacted with this quasi-stationary frontal boundary over western Tennessee as well as with additional low pressure systems and their associated fronts moving through the Southern States. Numerous large thunderstorm complexes developed and propagated across the Central to Southern Plains, eventually moving into western Tennessee and northeast along the Ohio River subbasin. Rainfall totals were substantial; just less than 5 inches of rain fell in a 24-hour period in Memphis, and several locations reported amounts of 15 to 20 inches for the storm total precipitation. Areas in southeastern Missouri recorded more than 20 inches of rain. Conversely, Texas had the fifth driest April on record (National Oceanic and Atmospheric Administration, 2012b).

May was a mostly dry month in the lower Mississippi River subbasin (National Oceanic and Atmospheric Administration, 2012b). Much of the subbasin averaged less than one-half of normal precipitation for the month; however, in northern and central Arkansas, some locations reported nearly twice the normal values. Precipitation also was above normal for the areas around Memphis and in northeastern Oklahoma, including Oklahoma City (table 2).

Most areas of the subbasin recorded below-normal precipitation during June; however, during July, southern Louisiana and much of Mississippi had normal to above-normal precipitation. This occurrence was in part the result of cold fronts dropping southward and colliding with the warm, moist air from the Gulf of Mexico, which created thunderstorms with areas of rain along the frontal boundary (National Oceanic and Atmospheric Administration, 2012b). July precipitation totals in the subbasin ranged from normal to twice the normal amounts. Louisiana averaged 6.39 inches of precipitation for July, while Mississippi averaged 5.75 inches (table 1). During July, Baton Rouge had slightly above-normal precipitation, but farther north, Memphis had only about three-quarters of the normal precipitation (table 2).

Ohio River Subbasin

In the Ohio River subbasin mostly dry conditions during December and January were followed by very wet conditions for February through April. The heavy February through April precipitation caused flooding along the Ohio River and contributed to some of the earliest flooding on the lower Mississippi River in April 2011 (National Oceanic and Atmospheric Administration, 2011a, National Oceanic and Atmospheric Administration, 2012e).

Precipitation during December and January was mostly below normal across the Ohio River subbasin (table 2). Precipitation increased during February and March, with above-normal amounts recorded at several locations, including Louisville and Cincinnati/Covington Airport (table 2). Six states that are partially within the Ohio River subbasin (Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia) reported the wettest April on record.

During April 18–28, 2011, a series of storm systems produced large amounts of precipitation across much of the Ohio River subbasin and the northern portion of the lower Mississippi River subbasin along the border between Illinois and Missouri (National Oceanic and Atmospheric Administration, 2011d). Two primary weather features (fig. 12) contributed to the April 18–28, 2011, precipitation event. First, a high pressure region was strengthening across the far Southeastern States that pushed warm, moist air from the Gulf of Mexico northward across the lower Mississippi River subbasin. Second, a jet stream progressed from the northern Rocky Mountains southward into the Central Plains and then across the Ohio River subbasin through the Northeastern States. The position of the jet stream led to the development of low-pressure areas near the Texas and Oklahoma Panhandles. These low-pressure areas then moved slowly towards the northeast into the eastern Great Lakes. The clash of colder air in the Northern States with the warm, moist air from the south occurred in addition to these low-pressure areas, which generated large amounts of precipitation and severe weather, especially in the Midwestern United States. At several weather stations in this region, some precipitation was recorded almost every day during April 18–28, 2011 (National Oceanic and Atmospheric Administration, 2011d).

Precipitation totals during April 18–28, 2011, generally were very large across the Ohio River subbasin except for the extreme eastern and northeastern parts of the subbasin (figs. 1 and 13). During the 11-day period, precipitation totals over 8 inches were recorded at Terre Haute and Evansville, Indiana, Louisville, Kentucky, and Cincinnati, Ohio/Covington Airport, Ky. (table 3). At Cape Girardeau, Missouri, in the lower Mississippi River subbasin about 30 miles northwest of the Mississippi River and Ohio River confluence, an impressive 11-day total of 16.15 inches was recorded. Monthly precipitation totals for April at some weather stations in the Ohio River subbasin (fig. 13) were more than 10 inches, or nearly one-quarter to one-half the average annual totals. April totals of 13.52 inches at Cincinnati/Covington Airport, 13.97 inches at Louisville, and 20.52 inches at Cape Girardeau were all records for the month (National Oceanic and Atmospheric Administration, 2011d). May and June total precipitation was near or above normal for most selected locations in the subbasin. In July, all selected locations reported near to below-normal precipitation (National Oceanic and Atmospheric Administration, 2011d).

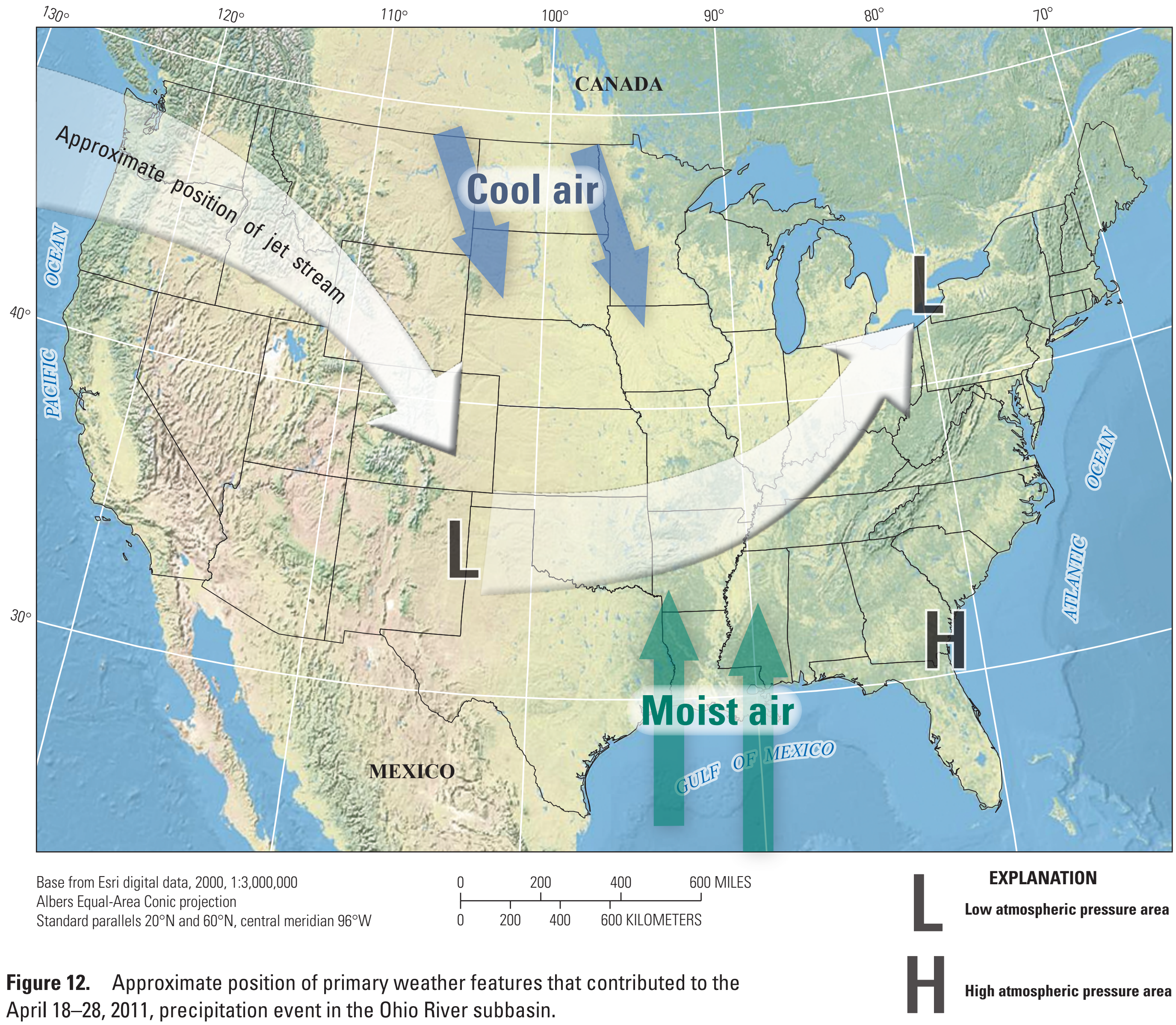


Figure 12. Approximate position of primary weather features that contributed to the April 18–28, 2011, precipitation event in the Ohio River subbasin.

Table 3. Summary of precipitation totals during the April 18–28, 2011, precipitation event[1], total precipitation for April 2011[1], the 1971–2000 normal April precipitation[2], and the 30-year average annual precipitation (1971–2000)[2] for selected weather stations in and near the Ohio River subbasin.

Station	Precipitation, in inches			
	April 18–28, 2011	April 2011	April normal 1971–2000	Average annual 1971–2000
Cape Girardeau, Missouri	16.15	20.52	4.34	46.54
Cincinnati, Ohio/Covington Airport, Kentucky	8.03	13.52	3.96	42.60
Evansville, Indiana	8.23	11.77	4.48	44.27
Louisville, Kentucky	8.37	13.97	3.91	44.54
Memphis, Tennessee	9.74	12.58	5.36	53.63
Terre Haute, Indiana	8.05	11.01	4.12	42.47

[1]National Oceanic and Atmospheric Administration (2011d).

[2]National Oceanic and Atmospheric Administration (2012d).

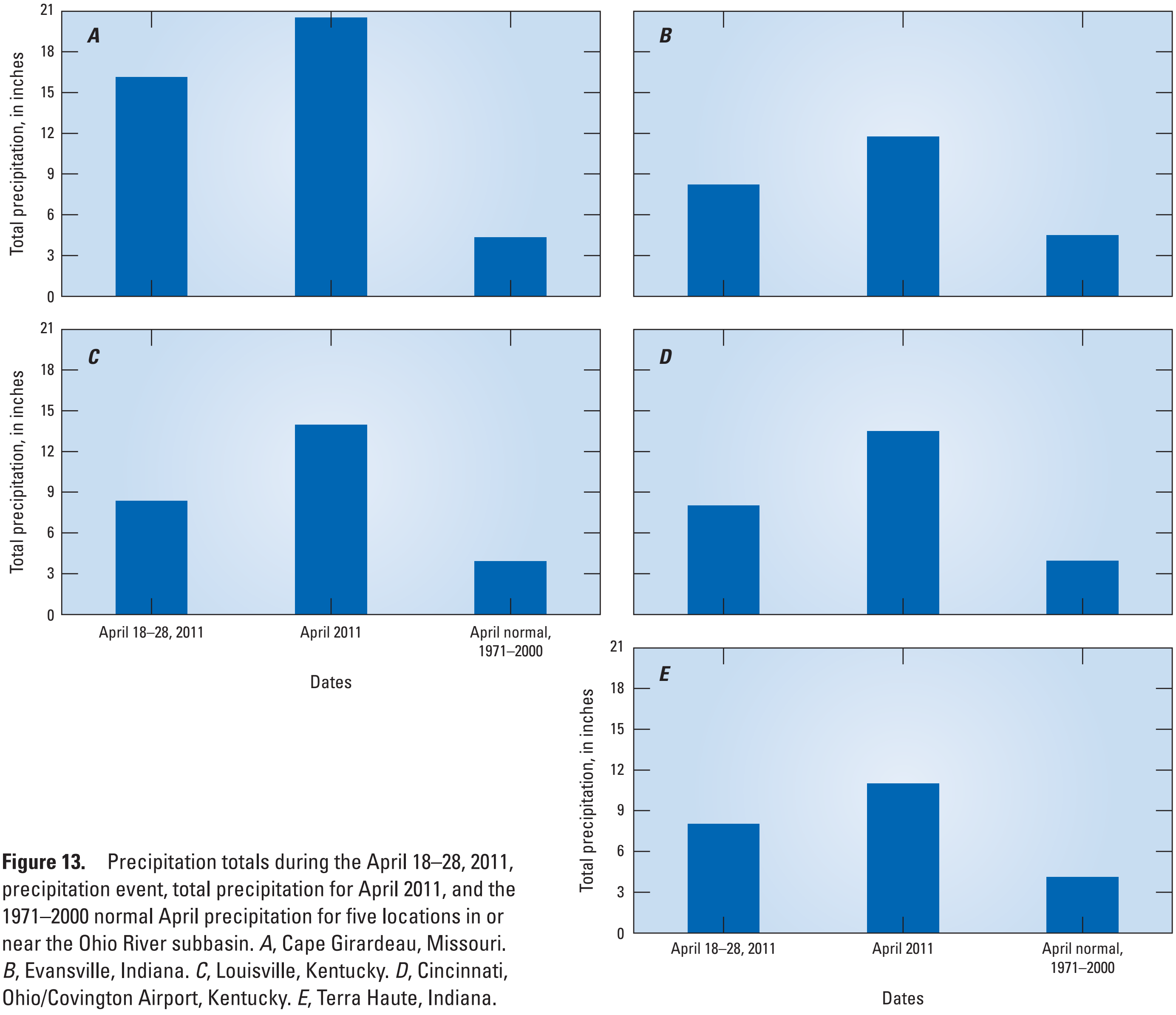


Figure 13. Precipitation totals during the April 18–28, 2011, precipitation event, total precipitation for April 2011, and the 1971–2000 normal April precipitation for five locations in or near the Ohio River subbasin. *A*, Cape Girardeau, Missouri. *B*, Evansville, Indiana. *C*, Louisville, Kentucky. *D*, Cincinnati, Ohio/Covington Airport, Kentucky. *E*, Terra Haute, Indiana.

Photograph at left: Levee stoplogs in place on Illinois Route 34 at Harrisburg, Illinois. The levee system protects Harrisburg from backwater flooding from the Ohio River, more than 20 miles away. Photograph by Robert Holmes, U.S. Geological Survey.

Missouri River Subbasin

Extensive flooding occurred in the Missouri River subbasin during the spring and summer of 2011 (National Oceanic and Atmospheric Administration, 2011a; National Oceanic and Atmospheric Administration, 2012e). The flooding was caused by an exceptional snowpack produced by plentiful precipitation that fell December through April in the Rocky Mountain headwater areas and the plains of South Dakota, North Dakota, and Montana (figs. 4–8), and exceptional rainfall that fell throughout most of the subbasin during May through July (figs. 9–11).

Several locations within the Missouri River subbasin had record snowfalls during the 2010–11 winter season (National Oceanic and Atmospheric Administration, 2011a). These record snowfalls were caused by moisture and low pressure troughs overriding cold continental polar air that blanketed the Northern Plains. At Glasgow, Montana, the seasonal snowfall record was established with 108.6 inches. The previous snowfall record was 70.7 inches set during the 2006–07 season. Williston, N. Dak., received a record 107.2 inches of snow in 2010–11. The previous record was 94.7 inches set during the 1895–96 season. In Aberdeen, South Dakota, a new December snowfall record was established with 24.6 inches of snow compared to 24.1 inches in 1927. January and February snowfall amounts at Aberdeen were also higher than normal, resulting in a winter snowfall record of 61.2 inches, as compared to the previous record of 57.0 inches set in 1915. Winter precipitation was above or much above normal for most of the Missouri River subbasin (fig. 2). Some locations along the Missouri River in Montana and North Dakota had winter 2010–11 precipitation totals that ranged from more than 135 percent to almost 280 percent above normal (National Oceanic and Atmospheric Administration, 2011d).

With little change in the overall weather pattern that dominated the winter months, snowfall continued into the spring months in the Rocky Mountains of Montana and Wyoming.

Snow bank in Wyoming, June 2011. Photograph by Paul Thatch, Wyoming Department of Transportation.

Snow-water equivalents (SWE), determined on May 1, 2011, from SNOTEL (snowpack telemetry) sites operated by the U.S. Department of Agriculture Natural Resources Conservation Service, ranged from about 4 to 58 inches in subbasins of the Missouri River subbasin in Montana and Wyoming (Natural Resources Conservation Service, 2011a). Also on May 1, 2011, almost one-half of the SNOTEL sites in Montana and Wyoming recorded SWE greater than 20 inches. SWE values were 111 to over 150 percent of average in most of the SNOTEL sites in the Missouri River subbasin (Natural Resources Conservation Service, 2011a). The Wyoming State Climate Office reported that statewide SWE topped 150 percent of normal at the end of April 2011 (Wyoming State Climate Office, 2011a). By the end of May, Wyoming statewide SWE topped 327 percent of normal (Wyoming State Climate Office, 2011b). The large snowpack in the Rocky Mountains of Montana and Wyoming, combined with the large amounts of snow throughout the Northern Plains, made excessive amounts of runoff possible during spring and summer 2011.

Precipitation at the Missouri River subbasin locations in Rapid City, S. Dak., Williston, North Dakota, and Great Falls, Mont., was near to above normal for the months of December, January, February, April, and May (table 2). Most of Nebraska had normal precipitation during December through February and above-normal precipitation during March–May (figs. 2 and 3).

During May 16–31, a large high-pressure area strengthened over the southeastern third of the country that resulted in hot, dry weather in the Southern United States (Hydrometeorological Prediction Center, 2012). Meantime, a large low pressure trough moved into the west. This trough was cool, moist, slow-moving, and strong. Furthermore, the significant moisture already associated with the system was increased as the trough tapped into moist air from the Southern Plains and the Gulf of Mexico. As the low passed to the south and east of Montana, isentropic processes—warm, moist air overriding the cooler air—produced substantial, and even record breaking, precipitation amounts to parts of the Northern Plains (fig. 14). As the rainfall was occurring in the northern portion of the system, the cold front was tracking further south across the Central and Northern Plains with widespread thunderstorms along the frontal boundary. With the excessive atmospheric moisture available, this front produced widespread areas of heavy rain, which were further enhanced by the slow moving nature of the system.

May 2011 precipitation amounts at some locations in the Missouri River subbasin were almost as large as normal annual totals (National Oceanic and Atmospheric Administration, 2011d). Mildred, Mont., about 50 miles northeast of Miles City, Mont. (fig. 1), reported 10.14 inches of rain for May, relative to the normal annual precipitation of 12.63 inches. Rock Springs, Mont., located about 35 miles northwest of Miles City, reported 10.46 inches of rain, relative to the normal annual precipitation of 11.67 inches. Farther west at Great Falls, Mont., the May 2011 precipitation

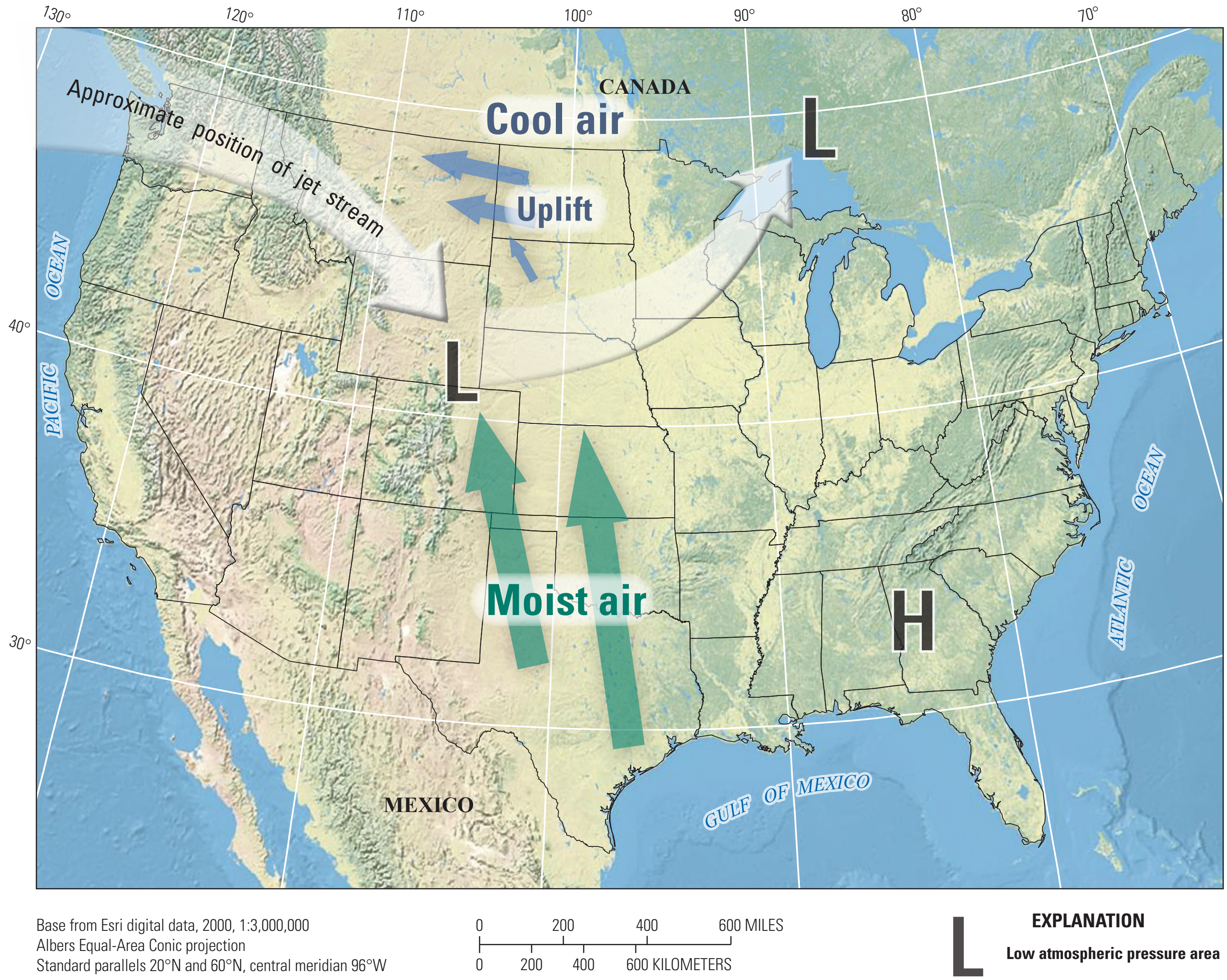


Figure 14. Approximate position of primary weather features that contributed to the May 16–31, 2011, rainfall event in the Missouri River subbasin.

total was also greater than normal, but by a smaller amount (National Oceanic and Atmospheric Administration, 2011d). In the mountains of Montana, snow fell during the May 16–31 storm, particularly in the headwaters of the Yellowstone River. Throughout the month of May, there was some snow accumulation in the mountains of Montana into late May. Total May 2011 precipitation values at Rapid City, S. Dak., and Williston, N. Dak., were more than double of May normal precipitation values (table 4).

Precipitation totals recorded during May 16–31, 2011, included over 6 inches at Billings and Baker, Mont., and Rapid City, S. Dak., during the 16-day event (National Oceanic and Atmospheric Administration, 2011d) (fig. 15, table 4). Most of the weather stations in Montana, North Dakota, South Dakota, and Wyoming recorded precipitation on at least 14 of the 16 days (National Oceanic and Atmospheric Administration, 2011d). Billings, Miles City, Baker, and Glasgow, Mont., and Rapid City, S. Dak., had precipitation totals during the May 16–31 event that were at least twice the normal precipitation for May. All five locations had precipitation totals during May 16–31 that were about one-third to one-half of their 1971–2000 normal annual amounts.

The areally-averaged May 2011 precipitation in the Missouri River subbasin, upstream from Garrison Dam, N. Dak., was determined to be 6 inches using radar estimates coupled with rain gage precipitation amounts by the National Weather Service River Forecast Centers (National Oceanic and Atmospheric Administration, 2011b). This precipitation fell mostly as rain over the plains with some rain and snow over the mountains. If this depth of precipitation was assumed to

Table 4. Summary of precipitation totals during the May 16–31, 2011, precipitation event[1], total precipitation for May 2011[1], the 1971–2000 normal May precipitation[2], and the 30-year average annual precipitation (1971–2000)[2] for selected weather stations in the Missouri River subbasin.

Station	Precipitation, in inches			
	May 16–31, 2011	May 2011	May normal 1971–2000	Average annual 1971–2000
Baker, Montana	6.09	7.34	2.09	14.38
Billings, Montana	6.63	9.54	2.48	14.77
Glasgow, Montana	5.21	6.97	1.72	11.23
Miles City, Montana	5.79	9.36	2.19	13.49
Rapid City, South Dakota	7.61	8.24	2.96	16.64
Williston, North Dakota	2.91	5.28	1.88	14.16

[1]National Oceanic and Atmospheric Administration (2011d).

[2]National Oceanic and Atmospheric Administration (2012d).

have fallen across the 181,400-square mile portion of the Missouri River subbasin upstream from Garrison Dam, then the estimated volume of water that fell on that part of the subbasin was about 58,000,000 acre-feet. For comparison purposes, the combined volume of conservation pool capacities for the two Missouri River main stem reservoirs upstream from Garrison Dam, Fort Peck Reservoir in Montana, and Lake Sakakawea in North Dakota is about 42,300,000 acre-feet (U.S. Army Corps of Engineers, 2012a). The May 2011 precipitation plus the runoff that was occurring as a result of a record snowpack in the subbasin produced enormous volumes of flow in the subbasin.

Precipitation amounts in June and July 2011 were relatively large in much of South Dakota, North Dakota, and Montana (figs. 10 and 11). Similar to May 2011, some areas of northeastern Montana received about twice the normal precipitation in June and July. Glasgow, Mont., reported 9.70 inches of precipitation or about 5.5 inches above normal during June and July 2011 (National Oceanic and Atmospheric Administration, 2011d). These occasional large amounts of precipitation during early summer on the Missouri River subbasin contributed to flooding conditions along the Missouri River.

Upper Mississippi River Subbasin

December and January precipitation was variable across the upper Mississippi River subbasin. Springfield, Ill., and Madison, Wis., had below to near normal precipitation while Chanhassen, Minn., had above-normal precipitation (table 2). The above-normal precipitation was due in large part to a mid-December storm, the seventh in a series of snowstorms to hit Minnesota in less than 2 months. The storm was initiated by a low pressure system working its way across Southern Canada. As the associated cold front was moving through the Upper Midwest, a secondary low developed along the cold front near the Minnesota/Iowa border, intensifying as it moved to the east. The intensification strengthened the inflow, feeding moisture into the storm system from the south. Snowfall with the storm was significant enough that snowplows were called off the roadways, and many roads were closed. This was the greatest snowfall for the area in nearly 20 years, and the fifth largest snowfall at the Minneapolis-St. Paul International Airport. Two more storms hit the area in December, and at the end of the month, Minnesota had recorded the third wettest December on record (National Oceanic and Atmospheric Administration, 2012b). Some weather stations in Wisconsin and Minnesota reported snowfalls of 36 inches to 48 inches in December while other stations in Iowa and Minnesota reported a maximum snow depth on the ground of at least 24 inches during the month. January snowfall was more than 100 percent above normal from northwestern Minnesota through northern Iowa (National Oceanic and Atmospheric Administration, 2011a).

Through the remainder of winter and into spring, cold continental polar air continued to filter into the Northern Plains from Canada, and moisture worked its way into the area from low pressure systems pushing through from the west or from a tap into subtropical moisture from the Gulf of Mexico. January snowfall was more than 100 percent above normal from northwestern Minnesota through northern Iowa (National Oceanic and Atmospheric Administration, 2011a). February, March, and April precipitation was normal to above normal for Madison, Wisconsin, and Chanhassen, Minnesota, and February and April precipitation was above normal for Springfield, Illinois. March snowfall exceeded 24 inches from southern Minnesota to across much of Wisconsin. Some of the earliest major flooding in 2011 occurred in Minnesota along the upper Mississippi River in March 2011 as the result of rapid snowmelt and spring rains (National Oceanic and Atmospheric Administration, 2011a; National Oceanic and Atmospheric Administration, 2012e).

As the seasons shifted to late spring and summer, the tap into moist, unstable subtropical air increased. These systems

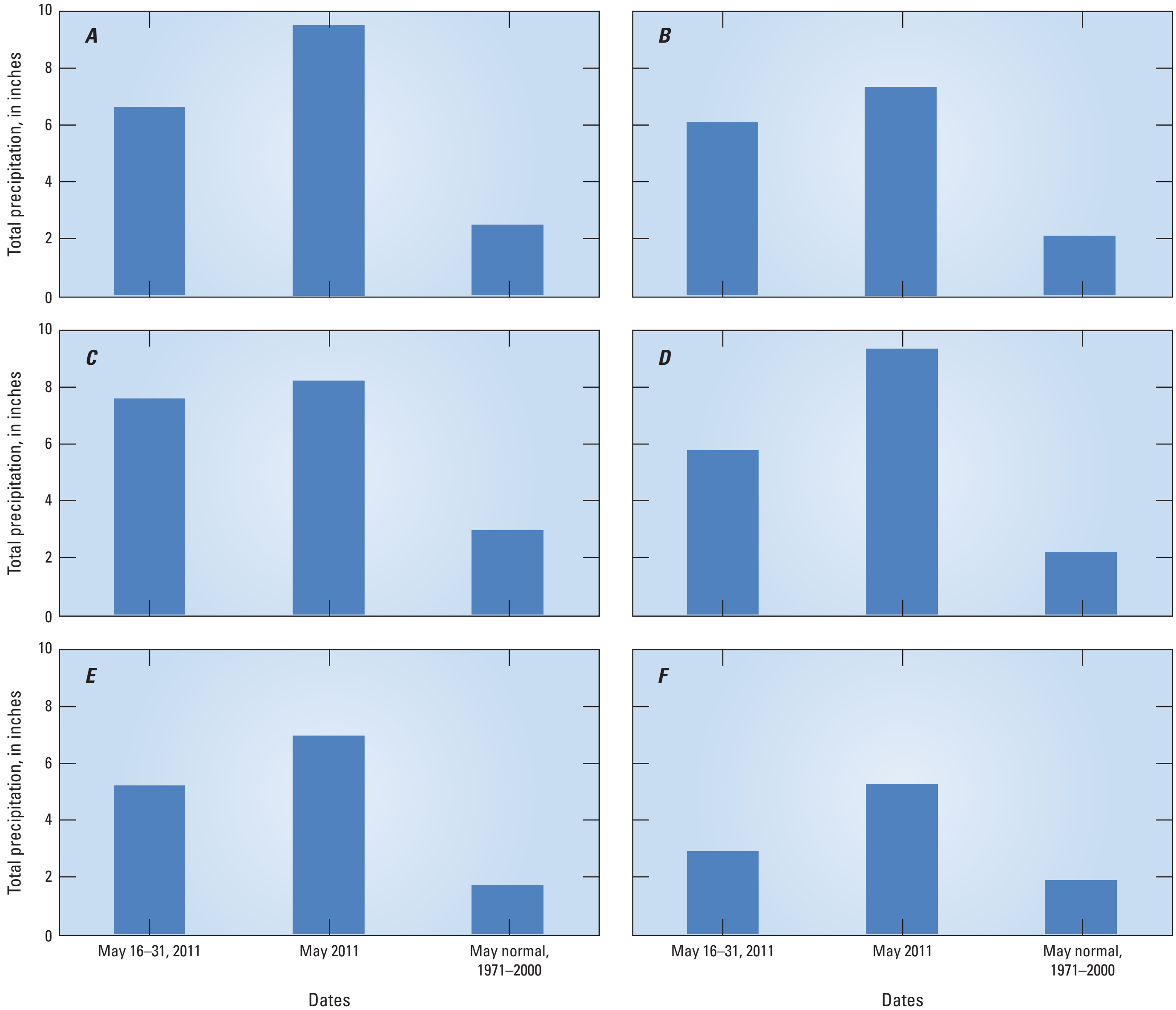


Figure 15. Precipitation totals during the May 16–31, 2011, precipitation event, precipitation totals for May 2011, and the 1971–2000 normal May precipitation for six locations in the Missouri River subbasin. *A*, Billings, Montana. *B*, Baker, Montana. *C*, Rapid City, South Dakota. *D*, Miles City, Montana. *E*, Glasgow, Montana. *F*, Williston, North Dakota.

Photograph at left: Flooding of the Sun River in the town of Sun River, Montana, June 9, 2011. Photograph by Michael Mercer, Meteorologist in Charge, Great Falls Weather Forecast Office, National Weather Service.

were now producing areas of stratiform clouds and rain with areas of heavier convective precipitation as thunderstorms developed along frontal boundaries. Much of the subbasin received normal to above-normal precipitation during May, with the exception of Wisconsin and northeastern Minnesota, where precipitation was slightly below normal (National Oceanic and Atmospheric Administration, 2011a).

June and July precipitation was above normal across a large portion of the subbasin (figs. 10 and 11). June precipitation was two-to-three times normal in parts of Iowa. On more than one occasion, very moist air would overrun a slow moving or stalled cold front resulting in areas of heavy precipitation. Near the end of June, a high pressure ridge became centered over the south-central and southeastern United States. Warm, moist subtropical air was now available to the Northern Plains by means of the Southwest Monsoon and a tap into air off the Gulf of Mexico. As low pressure systems moved through, this moist air fueled the development of areas of heavy rain, primarily as strong thunderstorms developed along the frontal boundaries. July precipitation was nearly twice normal from west-central Minnesota into western Wisconsin. Below normal July precipitation at Springfield, Ill., and Madison, Wis., reflected the northern extent of the strong high pressure system that was in place over the Southern Plains. July precipitation was above normal at Chanhassen, Minn., in response to storms moving around the strong high pressure system (National Oceanic and Atmospheric Administration, 2011a).

Precipitation on the Red River of the North Basin

Portions of the Red River of the North Basin, including the Souris River, often flood during spring when snowmelt that cannot infiltrate frozen or saturated soils runs off into rivers that flow north. Those portions of the rivers that are further north are slower to lose their ice cover, in effect creating a dam to water moving in from the south. During 2011, saturated soils from a wet autumn and abundant snow and the presence of river ice and large amounts of precipitation during spring and summer contributed to high flows and flooding in the Red River of the North and the Souris River (Minnesota Climatology Working Group, 2011). Grand Forks, N. Dak., reported 55.5 inches of snow during November 2010–May 2011, as compared to the 1971–2000 normal of 47.0 inches (National Oceanic and Atmospheric Administration, 2011e). Precipitation totals in parts of North Dakota and northwestern Minnesota were greater than two times normal amounts in April through June (High Plains Regional Climate Center, 2011a, b, c, d).

During the last two weeks of June 2011, there was a noteworthy precipitation event someplace in North Dakota almost daily (High Plains Regional Climate Center, 2011c). This area was hit by a series of low pressure troughs during this period, steered across the Northern Plains by a building high pressure ridge over the Southern States. Thunderstorms that would develop along the frontal boundaries were often slow moving and would train over the same area. With an abundant supply of atmospheric moisture, these storms created areas of very substantial rainfall. June precipitation was higher than normal at Fargo and Grand Forks, N. Dak., but was slightly lower than normal at Minot, N. Dak. (table 2). Regina, near the headwaters of the Souris River in southeastern Saskatchewan, Canada, had a June precipitation total of 5.2 inches, compared to a June normal (1971–2000) total precipitation of 3.0 inches (Environment Canada, 2011). Large amounts of precipitation continued through July at Fargo and Minot, N. Dak., but July precipitation at Grand Forks, N. Dak. was less than normal.

Summary

Excessive precipitation produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011. The flooding resulted from weather conditions during December 2010 through July 2011 that were affected in part by a La Niña climate pattern. This pattern is characterized by cooler-than-average sea surface temperatures in the central and east-central equatorial Pacific Ocean, and a strong high pressure area in the northern Pacific Ocean region. The La Niña pattern tends to produce cooler and wetter than normal weather conditions over the western and north-central regions of the Mississippi River and Red River of the North Basins, and often warmer and drier than normal weather conditions over the southern Mississippi River Basin.

Precipitation patterns across the Red River of the North and Mississippi River Basins from December 2010 through July 2011 followed the mean position of the jet stream. During December, January, and February, a southward push of the jet stream steered several low pressure troughs across the country from the Rocky Mountains into the Ohio River subbasin producing large amounts of precipitation. From March through May, a large low pressure trough dominated the continental States, and a high pressure ridge was centered in the vicinity of the Gulf of Mexico. This weather combination produced storms with copious precipitation along frontal boundaries that were steered across the Central States. During June and July, moisture from the southwestern monsoon and the Gulf of Mexico worked its way into the Plains States. Low pressure troughs moving across the country interacted with this moist unstable air; thunderstorm development along frontal boundaries resulted in areas of heavy rain across the Northern Plains States into the Missouri and upper Mississippi River subbasins. Excessive precipitation that fell on already saturated ground and ran off into already full streams and rivers produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011.

Much of the lower Mississippi River subbasin had below-normal precipitation during December, January, and February. March precipitation was below normal in Arkansas, Louisiana, and Oklahoma, and above normal in Mississippi and Tennessee. April precipitation was below normal in Louisiana and above normal in Arkansas, Mississippi, Oklahoma, and Tennessee. In April, Memphis had 12.58 inches of rainfall that resulted from deep tropical moisture that pushed northward and interacted with this quasi-stationary frontal boundary over western Tennessee. Additional low pressure systems and their associated fronts moved through the region resulting in numerous large thunderstorm complexes. Conversely, Texas had the fifth driest April on record. May and June were mostly dry, but in July, southern Louisiana and much of Mississippi had normal to above-normal precipitation.

Precipitation across the Ohio River subbasin during December and January was mostly below normal, but precipitation increased during February and March, with several locations receiving above-normal amounts. During April, a high pressure region was strengthening across the far Southeastern States that pushed warm, moist air from the Gulf of Mexico northward. A jet stream progressed from the northern Rocky Mountains southward into the Central Plains and then across the Ohio River subbasin through the Northeastern United States. The position of the jet stream led to the development of low-pressure areas near the Texas and Oklahoma Panhandles. These low-pressure areas then moved slowly towards the northeast into the eastern Great Lakes, which generated large amounts of precipitation and severe weather. Rain totals recorded during the April 18–28, 2011, precipitation event were over 8 inches at several locations, while an impressive total of 16.15 inches was recorded at Cape Girardeau, Missouri. Monthly precipitation totals for April at some weather stations in the Ohio River subbasin were more than 10 inches, or nearly one-quarter to one-half the average annual totals. May and June total precipitation was near or above normal for most selected locations in the subbasin. In July, all selected locations reported near to below-normal precipitation.

Several locations within the Missouri River subbasin had record snowfalls during the 2010–11 winter season. The frequent influx of moisture moving in with low pressure troughs then overriding the cold continental polar air that blanketed the Northern Plains during much of the climatological winter resulted in the record snowfall. Some locations in Montana and North Dakota recorded precipitation totals of more than 135 percent to almost 280 percent above normal. During the May 16–31 precipitation event, several locations in the Missouri River subbasin had rainfall totals that were nearly one-third to one-half of their 1971–2000 normal annual amounts. Precipitation amounts in June and July 2011 were relatively large in much of South Dakota, North Dakota, and Montana. Some areas of northeastern Montana received about twice the normal June and July precipitation.

December and January precipitation was variable across the upper Mississippi River subbasin. Springfield, Illinois, and Madison, Wisconsin, had below to near-normal precipitation while Chanhassen, Minnesota, had above normal precipitation. March snowfall exceeded 24 inches from southern Minnesota to across much of Wisconsin. Much of the subbasin received normal to above normal rainfall during May, with the exception of Wisconsin and northeastern Minnesota, where precipitation was slightly below normal. June and July precipitation was above normal across a large portion of the subbasin. Very moist air would overrun a slow moving or stalled cold front resulting in areas of substantial precipitation. Near the end of June, the presence of a high pressure ridge centered over the South-Central and Southeastern United States, and a flow of warm, moist air from the Gulf of Mexico fueled the development of areas of strong thunderstorms and rain along frontal boundaries. July precipitation was nearly twice normal from west-central Minnesota into western Wisconsin. Below-normal July precipitation at Springfield, Ill., and Madison, Wis., reflected the northern extent of the strong high pressure system that was in place over the Southern Plains.

Portions of the Red River of the North Basin, including the Souris River, often flood during spring when snowmelt that cannot infiltrate frozen or saturated soils runs off into rivers that flow north. Grand Forks, North Dakota, reported 55.5 inches of snow during November 2010–May 2011, as compared to the 1971–2000 normal of 47.0 inches. Precipitation totals in parts of North Dakota and northwestern Minnesota were greater than two times normal amounts in April through June. During the last two weeks of June 2011, this area was hit by a series of low pressure troughs. Thunderstorms that would develop along the frontal boundaries were often slow moving and would train over the same area. With an abundant supply of atmospheric moisture, these storms created areas of very substantial rainfall. June precipitation was higher than normal at Fargo and Grand Forks, N. Dak. Regina, near the headwaters of the Souris River in southeastern Saskatchewan, Canada, had a June precipitation total of 5.2 inches, compared to a June normal (1971–2000) total precipitation of 3 inches. Large amounts of precipitation continued through July at Fargo and Minot, N. Dak.

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