Geomorphic Changes Caused by the 2011 Flood at Selected Sites Along the Lower Missouri River and Comparison to Historical Floods

Chapter H of
2011 Floods of the Central United States

Professional Paper 1798–H

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

Front cover. Top photograph: View of flooding from Nebraska City, Nebraska, looking east across the Missouri River, August 2, 2011. Photograph by Robert Swanson, U.S. Geological Survey.

Right photograph: Measurement of Missouri River stage at Omaha, Nebraska, July 1, 2011. Photograph by Carlos Lazo, U.S. Army Corps of Engineers.

Back cover. A partially submerged statue at Omaha, Nebraska, July 1, 2011. Photograph by Carlos Lazo, U.S. Army Corps of Engineers.

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Measurement of road overflow on highway 2 near Nebraska City, Nebraska, July 2011. Photograph by Roger Haschemeyer, U.S. Geological Survey.

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Conversion Factors

Inch/pound to SI

Multiply	By	To obtain
	Length	
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)	2.59	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot (ft^3)	0.00002296	acre-foot (acre-ft)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Geomorphic Changes Caused by the 2011 Flood at Selected Sites Along the Lower Missouri River and Comparison to Historical Floods

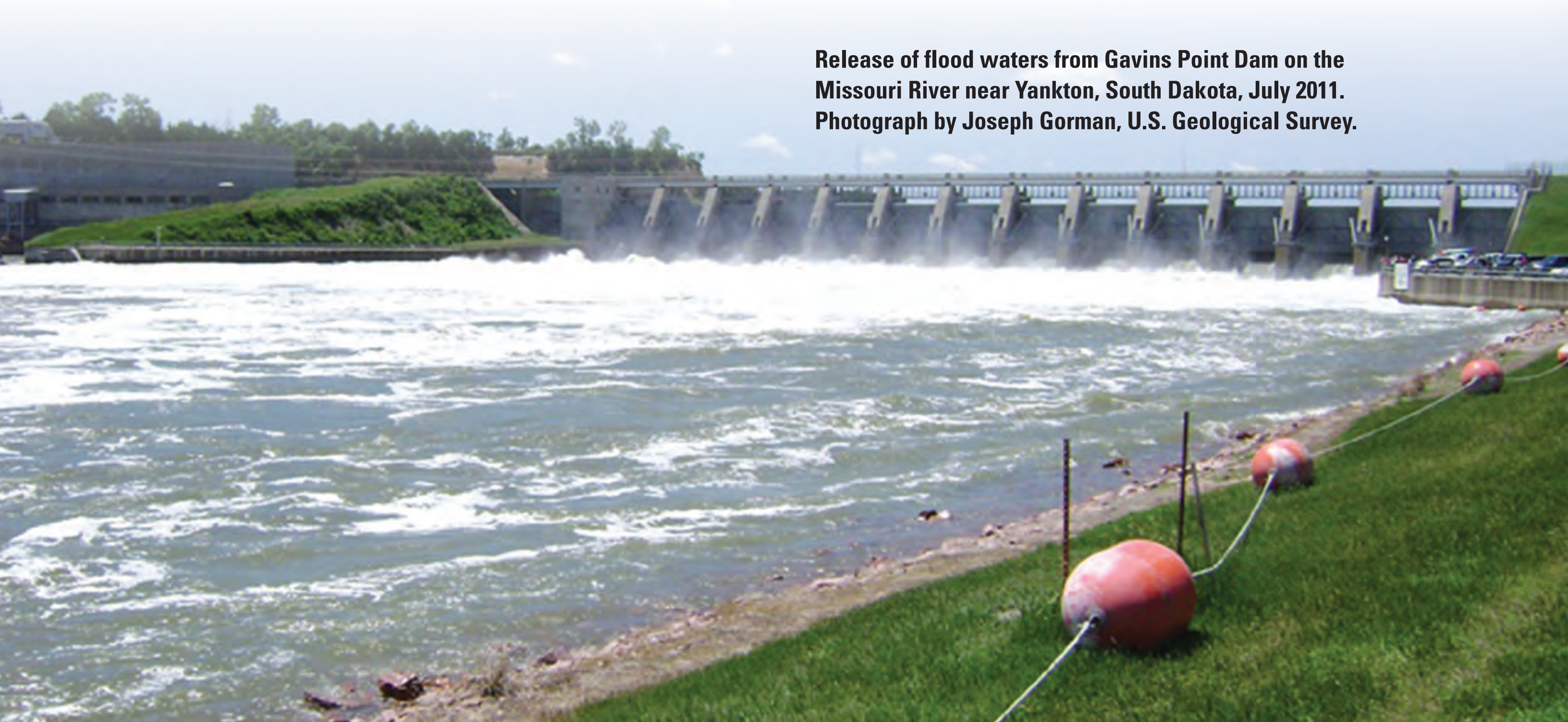
By Kyle E. Juracek

Abstract

An analysis of recent and historical U.S. Geological Survey streamgage information was used to assess geomorphic changes caused by the 2011 flood, in comparison to selected historical floods, at three streamgage sites along the lower Missouri River—Sioux City, Iowa; Omaha, Nebraska; and Kansas City, Missouri. Channel-width change was not evident at the three streamgage sites following the 2011 flood and likely was inhibited by bank stabilization. Pronounced changes in channel-bed elevation were indicated.

At Sioux City and Omaha, the geomorphic effects of the 2011 flood were similar in terms of the magnitude of channel-bed scour and recovery. At both sites, the 2011 flood caused pronounced scour (about 3 feet) of the channel bed; however, at Omaha, most of the channel-bed scour occurred after the flood had receded. More than 1 year after the flood, the channel bed had only partially recovered (about 1 foot) at both sites. Pronounced scour (about 3 feet at Sioux City and about 1.5 feet at Omaha) also was caused by the 1952 flood, which had a substantially larger peak discharge but was much shorter in duration at both sites. Again, at Omaha, most of the channel-bed scour occurred after the flood had receded. At Sioux City, substantial recovery of the channel bed (about 2.5 feet) was documented 1 year after the 1952 flood. Recovery to the pre-flood elevation was complete by April 1954. The greater recovery following the 1952 flood, compared to the 2011 flood, likely was related to a more abundant sediment supply because the flood predated the completion of most of the main-stem dam, channelization, and bank stabilization projects. At Omaha, following the 1952 flood, the channel bed never fully recovered to its pre-flood elevation.

The geomorphic effect of the 2011 flood at Kansas City was fill (about 1 foot) on the channel bed followed by relative stability. The 1952 flood, which had a substantially larger peak discharge but was much shorter in duration, caused modest fill (about 0.5 foot) on the channel bed. The 1993 flood, which also had a substantially larger peak discharge but was much shorter in duration, caused pronounced scour of the channel bed (possibly as much as 4 feet). Similar to the floods at Omaha, much of the channel-bed scour at Kansas City occurred after the 1993 flood had receded. More than 1 year after the 1993 flood, following partial recovery (about 1 foot),



Release of flood waters from Gavins Point Dam on the Missouri River near Yankton, South Dakota, July 2011. Photograph by Joseph Gorman, U.S. Geological Survey.

the channel bed had stabilized, at least temporarily. Following the 1993 flood, the channel bed never fully recovered to its pre-flood elevation.

For each flood in the post-dam era that resulted in substantial channel-bed scour (Sioux City in 2011, Omaha in 2011, Kansas City in 1993), recovery of the channel bed to its pre-flood elevation had not occurred more than 1 year after the flood (20 years after the 1993 flood at Kansas City). Thus, the possibility exists that channel-bed scour caused by large floods may have a cumulative effect along the lower Missouri River. The persistence of the flood-related decreases in channel-bed elevation may be indicative of the constrained ability of the channel to recover given a limited sediment supply caused by one or more of the following factors: upstream storage of sediment in reservoirs, bank stabilization, commercial sand dredging, depletion of readily available sediment by the flood, and a lack of post-flood sediment contributions from tributaries.

Introduction

Floods can cause substantial geomorphic changes in rivers including channel-bank erosion, channel widening, avulsions, channel-bed erosion or deposition, change in channel width-depth ratio, and change in channel cross-sectional area. Likewise, the adjoining flood plain may be substantially changed by erosion and deposition. The geomorphic effectiveness of a flood can be defined as the amount of channel morphological change caused by the flood and the subsequent time required for the channel to recover (Wolman and Gerson, 1978). Various factors determine geomorphic effectiveness including channel-bed and channel-bank composition, channel morphology, channel slope, valley confinement, sediment load, flood magnitude and duration, stream power, the temporal ordering of floods, climate, and vegetation (Baker, 1988; Kochel, 1988; Costa and O’Connor, 1995; Osterkamp and Friedman, 2000; Emmett and Wolman, 2001; Fuller, 2007).

Flood-related geomorphic changes can adversely affect property and structures in or near the channel. For example, such changes can damage or threaten critical infrastructure including levees, bridges, underground pipelines or cables, and water-supply intakes. Moreover, flood-related changes affect navigation and may alter channel and flood plain habitats important to federally protected species. For the Missouri River, federally protected species include the Interior least tern (*Sternula antillarum*), the pallid sturgeon (*Scaphirhynchus albus*), and the piping plover (*Charadrius melodus*) (U.S. Fish and Wildlife Service, 2003). An understanding of the geomorphic effects of floods is necessary for the protection of existing property and infrastructure, improved design of future structures, and river management to meet navigation and habitat objectives.

The large flood that affected the Missouri River in the summer of 2011 originated in the upper Missouri River Basin as a result of snowmelt from an above average snowpack combined with unusually heavy spring rains (Vining and others, 2013). The resultant flood wave, which could not be fully contained by the six large main-stem reservoirs on the Missouri River, proceeded downstream. Along the lower Missouri River, defined as the segment from Gavins Point Dam (fig. 1), near Yankton, South Dakota, to the confluence with the Mississippi River, the flood was atypical. First and foremost, the flood was unusually long in duration, lasting for about 3 months (Holmes and others, 2013). Additionally, because most of the sediment load had been deposited in the upstream reservoirs, the flood water emerging from Gavins Point Dam contained minimal sediment (Alexander and others, 2013). The combination of long duration and minimal sediment load created the potential for the 2011 flood to cause substantial geomorphic change along the lower Missouri River.

Purpose and Scope

The purpose of this report is to present the results of a U.S. Geological Survey (USGS) study to assess the geomorphic changes caused by the 2011 flood and other historical floods at selected streamgage sites along the lower Missouri River. Study objectives were accomplished by an analysis of recent and historical USGS streamgage information including stage-discharge ratings and individual discharge measurements. From a national perspective, the methods and results presented in this report will provide guidance and perspective that will benefit scientists and managers in the ongoing pursuit to understand, predict, prepare for, and respond to the geomorphic processes and changes associated with future floods.

Description of Study Area

Three streamgage sites located along the lower Missouri River, downstream from Gavins Point Dam (Lewis and Clark Lake), were selected for the purpose of determining the geomorphic effects of the 2011 and other historical floods. In downstream order, the Missouri River streamgage sites investigated were at Sioux City, Iowa (station 06486000, hereafter Sioux City); Omaha, Nebraska (station 06610000, hereafter Omaha); and Kansas City, Missouri (station 06893000, hereafter Kansas City) (fig. 1, table 1). Respectively, Sioux City and Omaha are located about 88 and 204 river miles downstream from Gavins Point Dam. Despite the intervening distance, the drainage basin size for these two sites is similar (table 1). Kansas City is located about 454 river miles downstream from Gavins Point Dam. Between Omaha and Kansas City, the size of the Missouri River Basin increases by 50 percent (table 1) mostly in response to the contributions of two major tributaries—the Platte (of Nebraska) and Kansas Rivers (fig. 1).

Figure 1. Location of the Missouri River Basin, the Missouri River, and selected U.S. Geological Survey streamgages.

Table 1. U.S. Geological Survey streamgages used in this study.

[USGS, U.S. Geological Survey; mi^2, square miles; %, percent; --, not applicable]

USGS streamgage number (fig. 1)	USGS streamgage name	Drainage basin area (mi^2)	Increase in drainage basin area (%)	Period of record
06486000	Missouri River at Sioux City, Iowa	314,600	--	1928–2012
06610000	Missouri River at Omaha, Nebraska	322,800	3	1928–2012
06893000	Missouri River at Kansas City, Missouri	484,100	50	1928–2012

Methods

Typically, streamgages provide the only long-term (often multidecadal), continuous source of channel-geometry information for the sites being monitored. Streamgage information can be used for a variety of geomorphic purposes including documentation of channel changes (for example, channel-bed erosion or deposition, or channel-width change), reconstruction of historical channel conditions, estimation of geomorphic process rates, and the estimation of future channel changes (Juracek and Fitzpatrick, 2009).

In this study, an analysis of geomorphic change caused by the 2011 flood, in comparison to selected historical floods, was completed for three USGS streamgage sites located along the lower Missouri River at Sioux City, Iowa; Omaha, Nebr.; and Kansas City, Mo. (fig. 1, table 1). For Sioux City and Omaha, the 2011 flood was compared to the 1952 flood. The 1952 flood was selected because, in terms of peak discharge, it was the largest flood measured during the period of continuous record for both sites (U.S. Geological Survey, 2013). For Kansas City, the 2011 flood was compared to the 1952 and 1993 floods. The 1993 flood was selected because it had the second largest peak discharge (nearly as large as the 1951 flood) measured during the period of continuous record and provided a more contemporary comparison. Unlike the 2011 and 1952 floods, the 1993 flood at Kansas City mostly resulted from flows contributed to the Missouri River downstream from Omaha (U.S. Geological Survey, 2013).

The analysis consisted of an assessment of flood-related geomorphic change at each streamgage site as evidenced by changes in channel-bed elevation and channel width. The reader is referred to Juracek and Fitzpatrick (2009) for a discussion of potential limitations of using streamgage data for geomorphic investigations.

Determination of Channel-Bed Elevation Changes

The relation between stage and discharge at streamgages is quantified on rating curves and updated as necessary to accommodate changes in channel shape, slope, and other factors that affect the relation. Each rating represents a best-fit line through the measurement data (that is, paired measurements of stage and discharge). Discharge measurements at, and stage-discharge ratings for, USGS streamgages are made using standard USGS techniques (Kennedy, 1984; Turnipseed and Sauer, 2010) with a typical accuracy of about ±5 percent (Kennedy, 1983; Sauer and Meyer, 1992; Turnipseed and Sauer, 2010).

By computing the stage that relates to a reference discharge for each rating curve developed during the entire period of record of a gage (and correcting to a common datum, if necessary), changes in channel-bed elevation can be inferred by examining the resulting time-series data. This method was called specific gage analysis by Blench (1969). Ideally, the reference discharge selected is a relatively low flow that is sensitive to change in channel-bed elevation. For the study described in this report, the mean annual discharge for the period of record was used as the reference discharge (Juracek, 2004; Bowen and Juracek, 2011) to investigate long-term trends and possible flood-related changes in channel-bed elevation. The mean annual discharge was selected because it is a relatively low discharge that typically covers the entire channel bed. For each streamgage site, the mean annual discharge was rounded to the nearest 10,000 cubic feet per second (ft^3/s) for convenience. For Sioux City and Omaha, a mean annual discharge of 30,000 ft^3/s was used. A mean annual discharge of 60,000 ft^3/s was used for Kansas City.

If the stage for the reference discharge (hereafter referred to as the reference stage) has a downward trend, it may be inferred that the channel-bed elevation has decreased with time because of erosion. Conversely, if the reference stage has an upward trend, it may be inferred that the channel-bed elevation has increased with time as a result of deposition. An abrupt increase or decrease in reference stage may be indicative of a relatively rapid change in channel-bed elevation. The absence of a pronounced change or trend in reference stage indicates channel-bed stability.

Flood-related changes in channel-bed elevation also were assessed using a comparison of pre- and post-flood shifts from a base (pre-flood) rating curve for a range of in-channel discharges. A shift is a temporary departure from an established rating curve caused by a change in channel conditions (Rantz and others, 1982). A negative shift (that is, a shift to the left of the curve) indicates an increase in channel-bed elevation caused by deposition, whereas a positive shift (that is, a shift to the right of the curve) indicates a decrease in channel-bed elevation caused by erosion. To account for possible stage changes caused by migrating sand dunes on the channel bed, a typical occurrence in the Missouri River (Galloway and others, 2013), the pre- and post-flood shifts were selected for time periods that were similar temperature-wise. This decision was made in recognition of the fact that the dune effects vary seasonally. Specifically, such effects lessen during the cold part of the year when lower water temperatures cause the dunes to flatten (U.S. Army Corps of Engineers, 1977). For consistency, the pre- and post-flood shifts for each flood at each streamgage site were determined using the same range of in-channel discharges to the extent possible.

Determination of Channel-Width Changes

Changes in channel width were assessed by an analysis of discharge-width relations. In this report, width refers to water-surface width data available for individual discharge measurements. For each streamgage site, discharge-width relations were grouped into the same pre- and post-flood time periods for the 2011 flood as were used in the analysis of channel-bed elevation change. For each time period, the channel widths for a range of in-channel flows were used in the assessment. Plotting of the pre- and post-flood data was used to determine if channel width changed in response to a flood.

The 2011 Missouri River Flood in Context

The recorded flood history at Sioux City and Omaha is similar and reflects the fact that the drainage basin size for the two sites is similar (table 1). For Sioux City and Omaha, the largest flood was measured in 1952 with respective instantaneous peak discharges of 441,000 and 396,000 ft^3/s (figs. 2*A* and 2*B*). The 2011 flood was the largest measured for both sites since the closure of Gavins Point Dam in 1955, with respective instantaneous peaks of 192,000 and 217,000 ft^3/s (figs. 2*A* and 2*B*). Between 1952 and 2011, annual instantaneous peaks at the two sites were in the range of 33,000 to 120,000 ft^3/s. During the post-dam era (1956 to 2012), the respective mean annual discharges at Sioux City and Omaha were about 30,000 and 34,000 ft^3/s and were exceeded about 65 percent of the time (U.S. Geological Survey, 2013).

At Kansas City, the recorded flood history includes two large floods that predate the period of continuous streamflow monitoring. In 1844 and 1903, floods with respective estimated instantaneous peak discharges of 625,000 and 548,000 ft^3/s occurred (U.S. Geological Survey, 2013). The flood history during the period of continuous monitoring (1928 to 2012) differs considerably from the two upstream sites. The divergence is not surprising given the intervening contribution of two major tributaries—the Platte (of Nebraska) and Kansas Rivers (fig. 1). Compared to Omaha, the drainage basin at Kansas City is 50 percent larger (table 1). The largest flood measured during this period was in 1951 with an instantaneous peak of 573,000 ft^3/s. The 1993 flood was nearly as large with an instantaneous peak of 541,000 ft^3/s. Other floods of note included 1943 and 1952 with respective instantaneous peaks of 366,000 and 400,000 ft^3/s. The instantaneous peak during the 2011 flood was comparatively small at 245,000 ft^3/s (fig. 2*C*). The mean annual discharge during the post-dam era at Kansas City (1958 to 2012) was about 56,000 ft^3/s, which was exceeded about 52 percent of the time (U.S. Geological Survey, 2013).

The Missouri River flood at Omaha, Nebraska, July 2011. Photograph by Matthew Noon, U.S. Geological Survey.

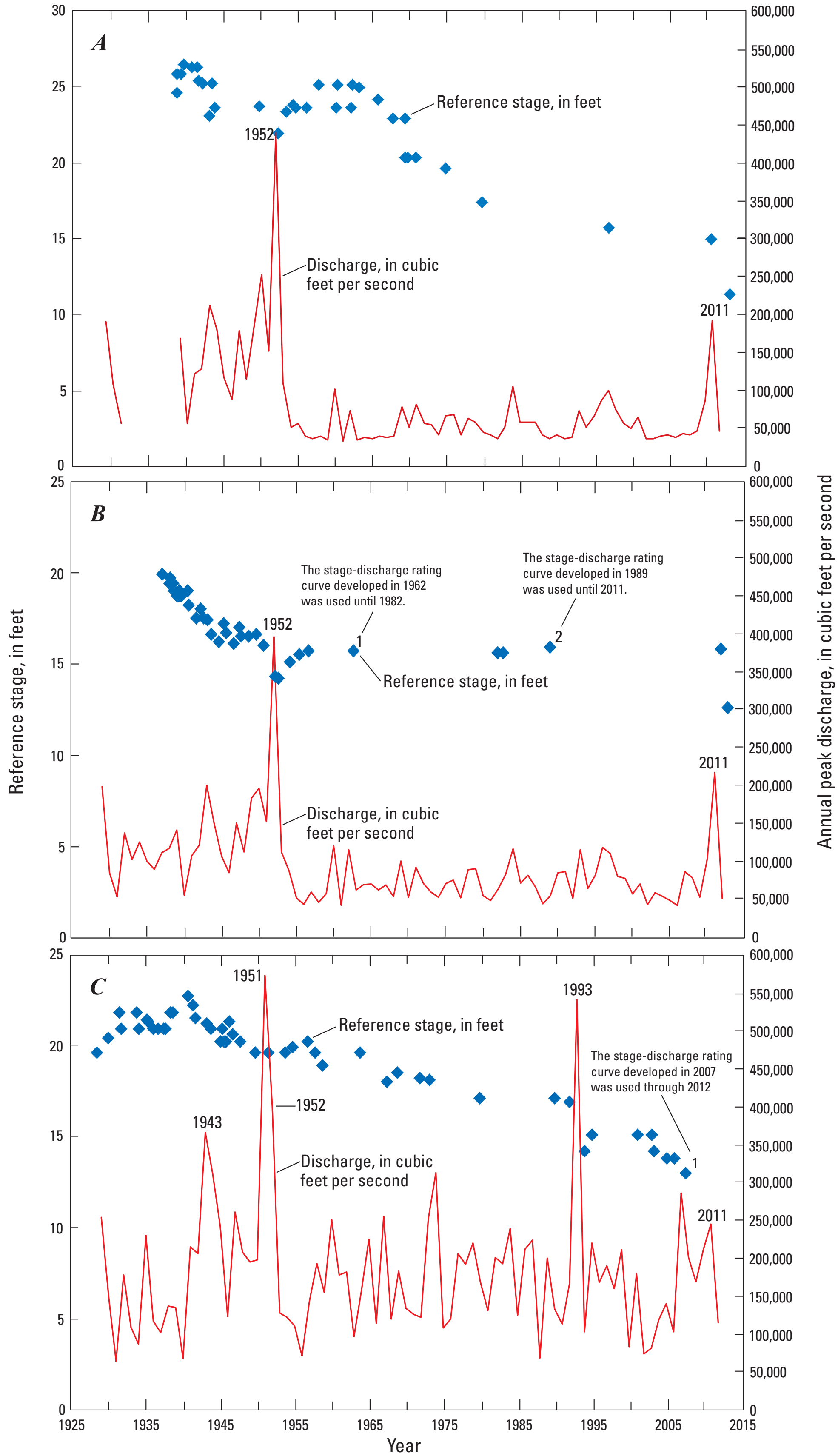


Figure 2. Variation in annual peak discharge and stream stage for mean annual discharge (reference stage) for the Missouri River streamgages at *A*, Sioux City, Iowa (station 06486000); *B*, Omaha, Nebraska (station 06610000); and *C*, Kansas City, Missouri (station 06893000), 1929–2012.

Geomorphic Changes Caused by Floods

In the following sections, the geomorphic changes caused by the 2011 and other selected historical Missouri River floods are described and compared. Pronounced flood-related changes in channel width were not evident at the selected streamgage sites for the 2011 flood. For example, a comparison of pre- and post-flood widths for a range of in-channel flows at Omaha is presented in figure 3.

Several possible explanations may account for the absence of pronounced channel-width change at the three Missouri River streamgage sites. One possibility is that channel width essentially was stable before, during, and after the flood at each streamgage site. A second possibility is that, for a given site, channel width may have changed but the amount of change was less than what the analyses were able to detect. Finally, it is possible that the locations where substantial channel-width change occurred (if any) were different from where the discharge-width data were collected. For example, discharge measurements for large rivers typically are made at a bridge, whereas the locations of channel-width change may be upstream or downstream from the bridge. A related complication is the fact that channel banks at and near bridges often are armored with riprap or otherwise stabilized. This is the case at Sioux City, Omaha, and Kansas City. The channelization and stabilization of the lower Missouri River for navigation has resulted in an artificial channel that is resistant to bank erosion and channel widening (Pinter and Heine, 2005; Jacobson and Galat, 2006); however, bank erosion is still possible. For example, according to Galloway and others (2013), substantial bank erosion was observed in November 2011 at some locations along the lower Missouri River where bank protection that existed before the flood had been eliminated.

Discussion in the following sections is focused on channel-bed elevation change. In addition to floods, channel-bed elevation at a given time and place also may have been affected to an uncertain extent by dredging for navigation, commercial purposes, or both, and by other factors that may have affected changes in sediment supply, including dam closures on tributaries and substantial land-cover changes such as conversion of erodible cropland to grassland or vice versa (Hellerstein and Malcolm, 2011).

Geomorphic terms used in the following sections are defined here. “Scour” and “fill” refer to short-term (less than 1 year) erosion and deposition, respectively. “Degradation” and “aggradation” refer to long-term (multiple years) erosion and deposition, respectively.

Missouri River at Sioux City, Iowa

At Sioux City, the change in reference stage indicated a progressive decrease in channel-bed elevation during the period of record (fig. 2*A*). From 1938 to 2012, the net degradation was about 14 feet (ft). Most of the post-1955 decrease in channel-bed elevation likely was related to the closure of Gavins Point Dam, which is located about 88 river miles upstream (fig. 1). Because large reservoirs typically trap and permanently store more than 90 percent of the inflow sediment

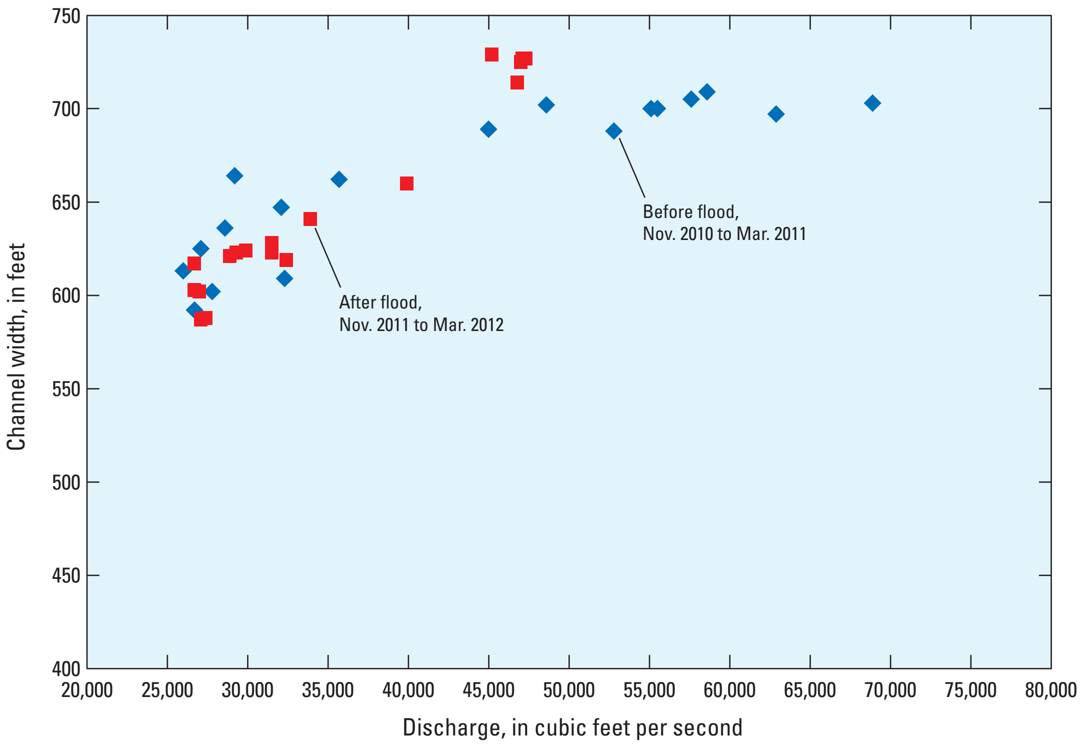


Figure 3. Relation between discharge and channel width at the Missouri River at Omaha, Nebraska, streamgage (station 06610000).

load (Brune, 1953; Williams and Wolman, 1984; Shotbolt and others, 2005), the outflow is sediment depleted. For alluvial rivers such as the Missouri, channel-bed degradation is a common downstream geomorphic response to an upstream reservoir as the sediment-depleted water emerging from the dam attempts to replenish its sediment load (Leopold and others, 1964; Petts, 1984; Williams and Wolman, 1984; Brandt, 2000). Embedded within the overall degradational trend are multiple short-term fluctuations in channel-bed elevation that may be indicative of a response to scour and fill processes associated with individual flow events.

The 2011 flood at Sioux City caused a pronounced scour of the channel bed. A comparison of the pre-flood shifts (November 2010 to March 2011) with the first set of post-flood shifts (November 2011 to March 2012) indicated a decrease in channel-bed elevation of about 3 ft (fig. 4). Generally consistent shifts from November 2011 through mid-February 2012 indicated a period of relative stability in channel-bed elevation. Subsequently, decreasing shifts in late February and March 2012 indicated partial recovery of the channel bed (about 0.7 ft) as a result of fill. More than 1 year after the flood, the limited range for the second set of post-flood shifts (November 2012 to March 2013) indicated that, following a total post-flood recovery (fill) of about 1 foot, the channel bed had stabilized (fig. 4). Thus, as of March 2013, channel-bed elevation at this site had not recovered to the pre-flood condition.

The 1952 flood at Sioux City had an instantaneous peak discharge that was more than double the 2011 flood peak; however, the 1952 flood was of much shorter duration (table 2). The first set of post-flood shifts (May and June 1952) indicated a decrease in channel-bed elevation of about 3 ft relative to the pre-flood shifts (September and October 1951) (fig. 5). Note that shifts for November 1951 through March 1952 (not shown) generally were similar to the pre-flood shifts. Thus, despite substantial differences in the

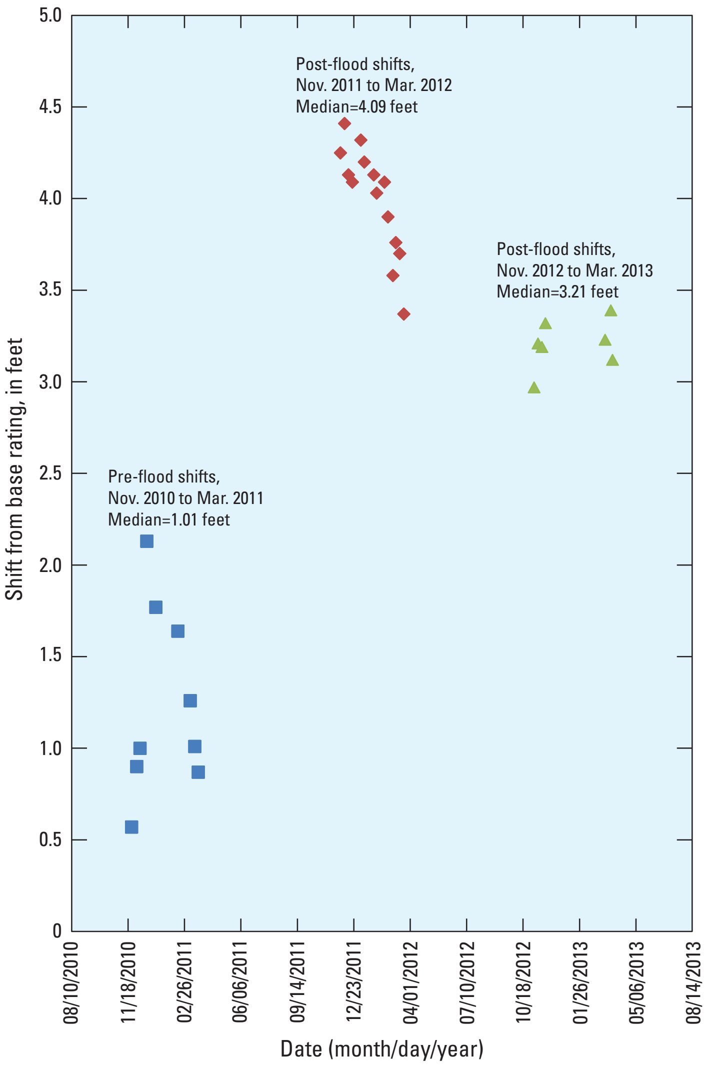


Figure 4. Shifts from the base rating curve before and after the 2011 flood for the Missouri River at Sioux City, Iowa, streamgage (station 06486000).

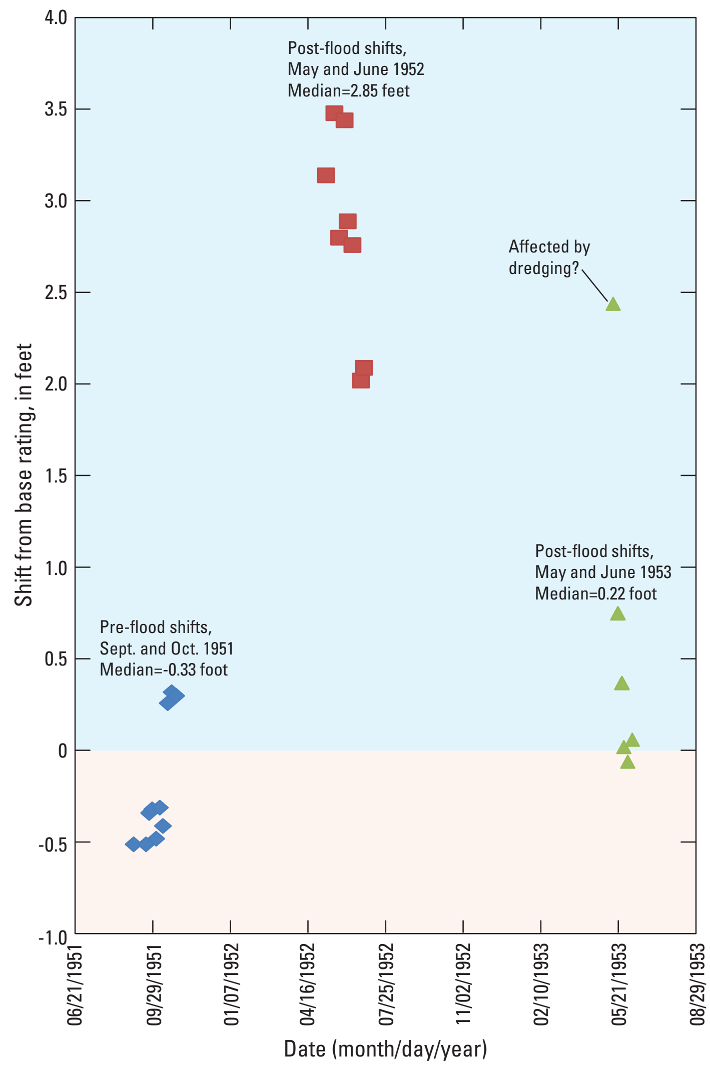


Figure 5. Shifts from the base rating curve before and after the 1952 flood for the Missouri River at Sioux City, Iowa, streamgage (station 06486000).

Table 2. Comparison of 2011 with historical Missouri River floods at Sioux City, Iowa (station 06486000), Omaha, Nebraska (station 06610000), and Kansas City, Missouri (station 06893000).

[ft^3/s, cubic feet per second; --, not applicable. Data from U.S. Geological Survey (2013)]

2011 flood		1952 flood		1993 flood	
Instantaneous peak discharge (ft^3/s)	Total days at or above 2011 flood-stage discharge[1]	Instantaneous peak discharge (ft^3/s)	Total days at or above 2011 flood-stage discharge[1]	Instantaneous peak discharge (ft^3/s)	Total days at or above 2011 flood-stage discharge[1]
Missouri River at Sioux City, Iowa (station 06486000)					
192,000	80	441,000	16	--	--
Missouri River at Omaha, Nebraska (station 06610000)					
217,000	104	396,000	26	--	--
Missouri River at Kansas City, Missouri (station 06893000)					
245,000	8 (99)	400,000	9 (24)	541,000	22 (38)

[1]In 2011, the flood stage used by the National Weather Service (NWS) for Sioux City, Iowa, was 30 feet with a discharge equivalent of 127,000 ft^3/s. The 2011 NWS flood stage for Omaha, Nebraska, was 29 feet with a discharge equivalent of 103,000 ft^3/s. The 2011 NWS flood stage for Kansas City, Missouri, was 32 feet with a discharge equivalent of 238,000 ft^3/s. For Kansas City, the total number of days the flood equaled or exceeded 150,000 ft^3/s is listed parenthetically. According to the U.S. Army Corps of Engineers (2006), a streamflow of 150,000 ft^3/s will cause flooding downstream from St. Joseph, Missouri, to the mouth of the Missouri River.

magnitude and duration of the 2011 and 1952 floods, the initial geomorphic effect on channel-bed elevation was similar. One year after the 1952 flood, the second set of post-flood shifts (May and June 1953) indicated about 2.5 ft of recovery in the channel-bed elevation (fig. 5). By April 1954, the recovery to the pre-flood channel-bed elevation was complete (fig. 2*A*). A possible explanation to account, at least in part, for the greater recovery in channel-bed elevation in the year following the 1952 flood (compared to the more limited recovery following the 2011 flood) is a more abundant supply of sediment before the completion of most of the Missouri River main-stem dam, channelization, and bank stabilization projects (Meade, 1995; Meade and Moody, 2010). Also, the disturbance associated with the construction of Gavins Point Dam, which began in May 1952, may have provided an additional temporary source of sediment.

Missouri River at Omaha, Nebraska

At Omaha, the change in reference stage indicated a decrease in channel-bed elevation of about 3.5 ft from 1937 to 1944. Subsequently, channel-bed elevation was relatively stable for about 8 years. The 1952 flood caused nearly 2 ft of channel-bed scour. Following partial recovery in the mid 1950s, minimal change in channel-bed elevation was indicated for about 55 years until the bed was scoured about 3 ft by the 2011 flood (fig. 2*B*). Apparently, during the 55-year period before the 2011 flood, the Missouri River channel bed at this location essentially was in an equilibrium state.

The 2011 flood at Omaha caused a pronounced scour of the channel bed. Compared to the pre-flood shifts (November 2010 to March 2011), the first set of post-flood shifts (November 2011 to March 2012) indicated a progressive scour of the channel bed from November 2011 to mid-February 2012 at which time a maximum decrease in channel-bed elevation of about 3 ft was indicated (fig. 6). Thus, at this site, channel-bed scour that presumably initiated during the flood continued for several months after the flood had receded. The continued post-flood scour of the channel bed indicated that bed-material (sand) transport capacity exceeded supplies delivered from upstream. A combination of factors possibly accounted for the limited supply of bed material including sediment storage upstream from Gavins Point Dam, a depletion of readily available sediment by the flood, and a lack of post-flood sediment contributions from tributaries. From mid-February to the end of March 2012, decreasing shifts indicated partial recovery of the channel bed (about 0.7 ft) as a result of fill. More than 1 year after the flood, the second set of post-flood shifts (November 2012 to March 2013) indicated that, with a total fill of about 1 foot, channel-bed elevation was recovering slowly (fig. 6). As of March 2013, the channel-bed elevation had not fully recovered to the pre-flood condition.

Overall, the net geomorphic effects of the 2011 Missouri River flood at Sioux City and Omaha were similar. In both cases, maximum channel-bed scour of about 3 ft was followed by partial recovery of about 1 foot as of March 2013. Thus, for these two sites, it was documented that much of the channel-bed scour associated with the 2011 flood persisted for more than a year post flood.

Similar to the situation at Sioux City, the 1952 flood at Omaha, compared to the 2011 flood, had a much larger instantaneous peak discharge (nearly double) but was much shorter in duration (table 2). At a glance, a comparison of the pre-flood shifts (September and October 1951) with the first set of post-flood shifts (May and June 1952) indicated minimal geomorphic change, especially if the median shifts are compared (fig. 7); however, further examination revealed that the flood-related change in channel-bed elevation was just

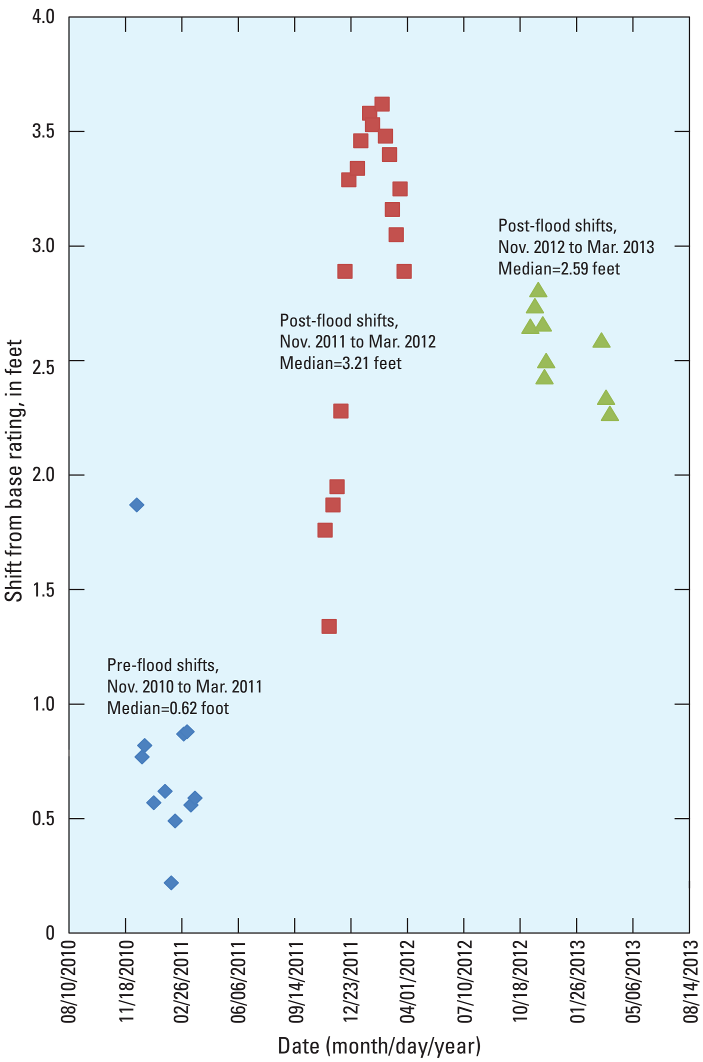


Figure 6. Shifts from the base rating curve before and after the 2011 flood for the Missouri River at Omaha, Nebraska, streamgage (station 06610000).

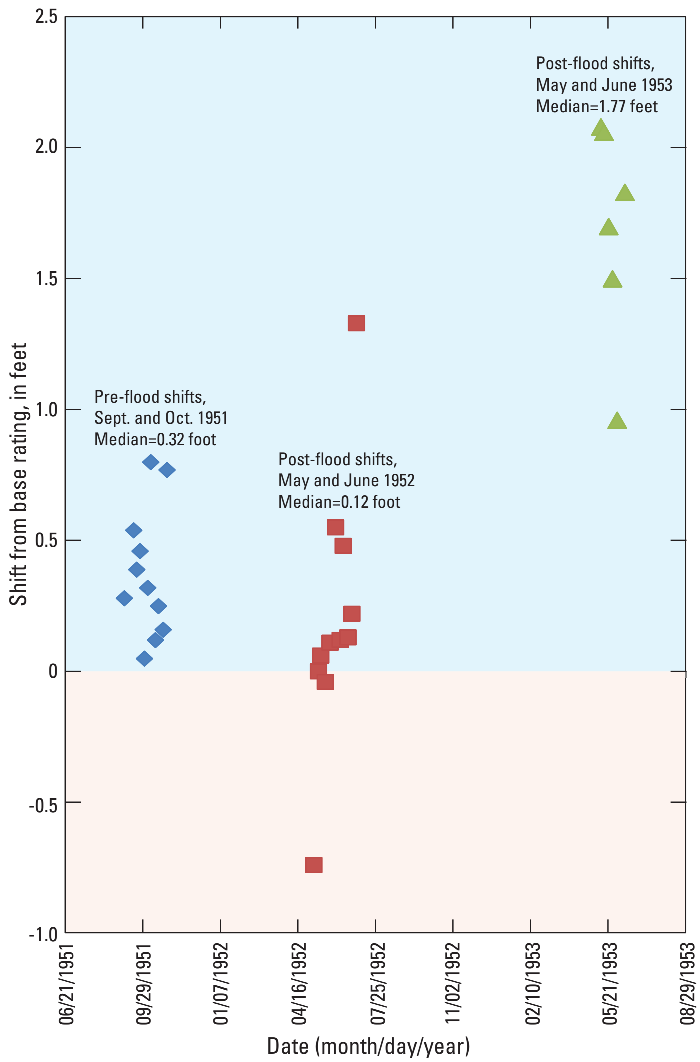


Figure 7. Shifts from the base rating curve before and after the 1952 flood for the Missouri River at Omaha, Nebraska, streamgage (station 06610000).

beginning at the end of the first selected post-flood evaluation period. During this evaluation period, the largest shift (1.33 ft) occurred on June 30, 1952 (fig. 7). Thus, analogous to the pattern determined for the 2011 flood, substantial channel-bed scour occurred after the 1952 flood had receded. Shifts computed for the time interval between the two post-flood evaluation periods (that is, July 1952 through April 1953) documented a scoured channel condition with a bed elevation that generally was about 1.5 ft lower than the pre-flood bed elevation. Unlike at Sioux City, the scoured channel condition persisted into the second post-flood evaluation period (May and June 1953) with no pronounced indication of recovery (fig. 7). In fact, the channel bed never fully recovered to its pre-flood elevation (fig. 2*B*). The lack of full recovery following the 1952 flood indicated the possibility of a cumulative effect of large floods on channel-bed elevation with time.

Missouri River at Kansas City, Missouri

At Kansas City, change in the reference stage indicated an increase in channel-bed elevation of about 3 ft from 1928 to 1940. Since 1940, a net decrease in channel-bed elevation of about 10 ft was evident (fig. 2*C*). Throughout the period of record, multiple short-term fluctuations in channel-bed elevation may be indicative of a response to scour and fill processes associated with individual flow events. For example, the 1993 flood resulted in a nearly 2-foot decrease in channel-bed elevation (fig. 2*C*). In the Kansas City area, commercial sand dredging was a contributing factor for decreases in channel-bed elevation (Jacobson and others, 2009; National Research Council, 2011).

In contrast to Sioux City and Omaha, shift changes indicated that the 2011 flood at Kansas City caused fill on the channel bed. Possible sources for the deposited bed material include the upstream Missouri River and tributaries. For example, the Platte River (of Nebraska) likely was a substantial contributor of bedload to the Missouri River in 2011 (Galloway and others, 2013). Compared to the pre-flood shifts (November 2010 to March 2011), the first set of post-flood shifts (November 2011 to March 2012) indicated an increase in median channel-bed elevation of about 1 ft (fig. 8); however, given the variability in the pre-flood shifts, the stated increase of about 1 ft may over or under represent the actual change in channel-bed elevation caused by the 2011 flood. More than 1 year after the flood, the second set of post-flood shifts (November 2012 to March 2013) were similar thus providing evidence for relative stability in channel-bed elevation at this site following the fill.

As at Sioux City and Omaha, the 1952 flood at Kansas City, compared to the 2011 flood, had an instantaneous peak discharge that was much larger and a duration (using a streamflow of 150,000 ft^3/s as the basis for comparison) that was substantially shorter (table 2). The first set of post-flood shifts (May and June 1952), in comparison to the pre-flood shifts (September and October 1951), indicated an increase in channel-bed elevation of about 2 ft (fig. 9); however, because the shifts from November 1951 through March 1952 (not shown) declined to near zero, the fill attributable to the 1952 flood may only be about 0.5 ft. At Kansas City, the 1952 flood was preceded by the larger 1951 flood, which occurred less than 9 months prior. An analysis of shifts immediately before and after the 1951 flood indicated that the 1951 flood scoured a foot or more of bed material at the streamgage site. Thus, the declining shifts from November 1951 through March 1952 may indicate a progressive recovery from the 1951 flood in the months leading up to the 1952 flood. One year after the 1952 flood, the second set of post-flood shifts (May and June 1953) indicated minimal change. Thus, as of June 1953, the modest fill associated with the 1952 flood persisted.

For the 2011 and 1952 floods, a consistent geomorphic response was indicated for the three streamgage sites. That is,

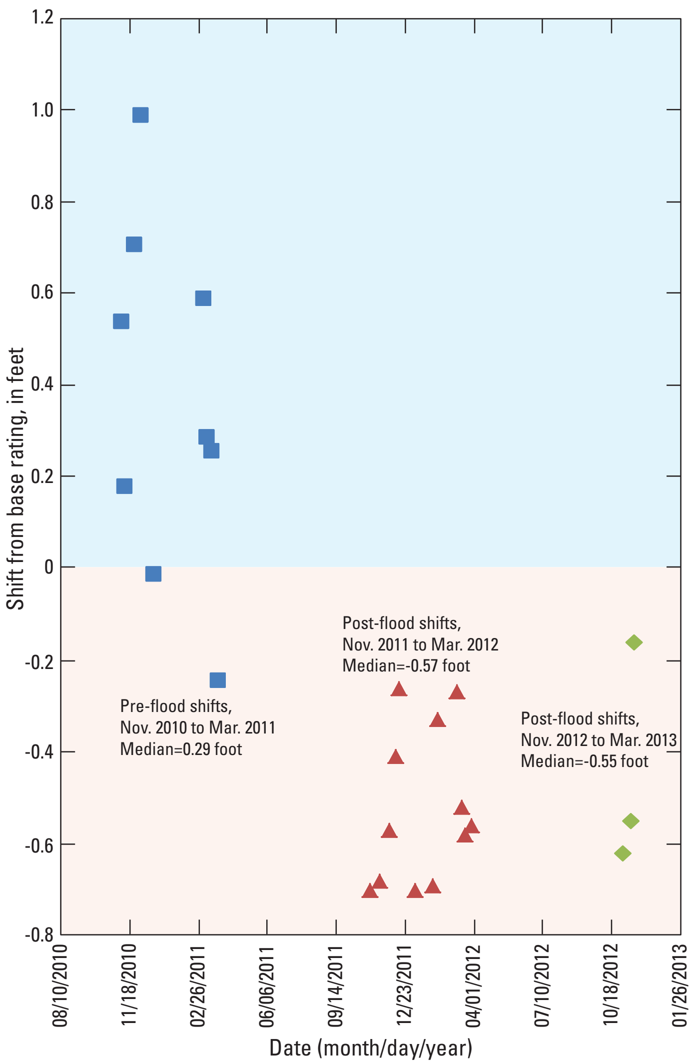


Figure 8. Shifts from the base rating curve before and after the 2011 flood for the Missouri River at Kansas City, Missouri, streamgage (station 06893000).

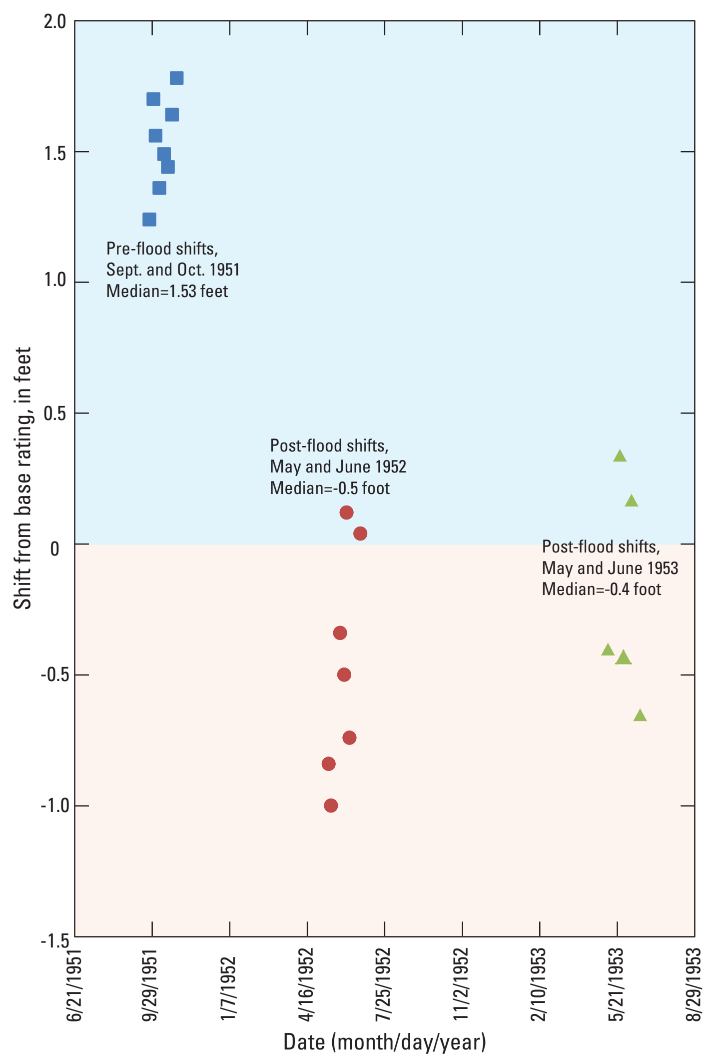


Figure 9. Shifts from the base rating curve before and after the 1952 flood for the Missouri River at Kansas City, Missouri, streamgage (station 06893000).

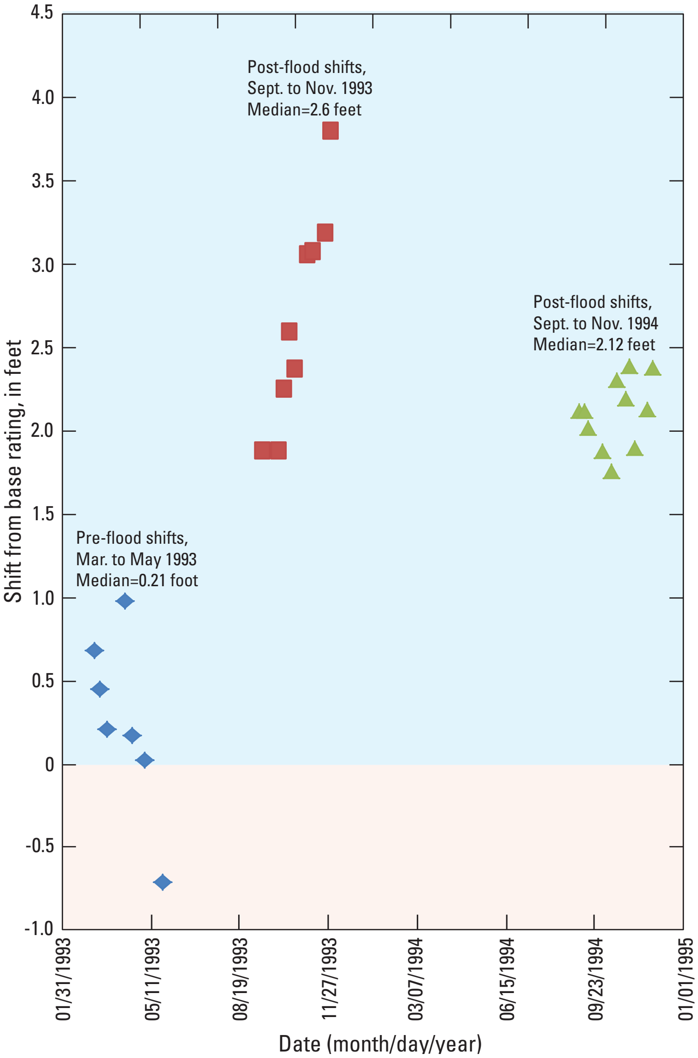


Figure 10. Shifts from the base rating curve before and after the 1993 flood for the Missouri River at Kansas City, Missouri, streamgage (station 06893000).

channel-bed scour at Sioux City and Omaha was accompanied by channel-bed fill at Kansas City.

The 1993 flood at Kansas City, compared to the 2011 flood, had an instantaneous peak discharge that was more than twice as large and a duration (using a streamflow of 150,000 ft^3/s as the basis for comparison) that was considerably shorter (table 2). The pre-flood shifts (March to May 1993) indicated an increase in channel-bed elevation before the flood (fig. 10). A comparison of the medians for the first set of post-flood shifts (September to November 1993) with the pre-flood shifts indicated a decrease in channel-bed elevation of about 2.4 ft; however, because the shifts increased throughout the first post-flood evaluation period, the maximum decrease in channel-bed elevation was about 4 ft. The progressive increase in shifts indicated that channel-bed scour was ongoing during the first post-flood evaluation period. A similar pattern of post-flood channel-bed elevation change was documented at Omaha during the 2011 and 1952 floods. More than 1 year after the 1993 flood, the limited range for the second set of post-flood shifts (September to November 1994) indicated that, following partial recovery (about 1 ft), the channel bed had stabilized, at least temporarily (fig. 10). The channel bed never fully recovered to its pre-flood elevation (fig. 2*C*).

For each flood in the post-dam era that resulted in substantial channel-bed scour (Sioux City in 2011, Omaha in 2011, Kansas City in 1993), the channel bed had not recovered to its pre-flood elevation more than 1 year after the flood (20 years after the 1993 flood at Kansas City) (figs. 4, 6, and 10). Thus, the possibility exists that channel-bed scour caused by large floods may have a cumulative effect along the lower Missouri River. The persistence of the flood-related decreases in channel-bed elevation may be indicative of the constrained ability of the channel to recover because of a limited sediment supply caused by one or more of the following factors: upstream storage of sediment in reservoirs, bank stabilization, commercial sand dredging, depletion of readily available sediment by the flood, and a lack of post-flood sediment contributions from tributaries.

A flooded farm near Rulo, Nebraska, July 2011. Photograph by Jace Cochran, U.S. Geological Survey.

Summary

A study by the U.S. Geological Survey (USGS) was begun in 2012 to determine the geomorphic changes caused by the 2011 flood at three selected streamgage sites along the lower Missouri River—Sioux City, Iowa; Omaha, Nebraska; and Kansas City, Missouri. Also presented is a comparison to geomorphic changes caused by selected historical floods. Study objectives were accomplished by an analysis of recent and historical USGS streamgage information including stage-discharge ratings and individual discharge measurements. Channel-width change was not evident at the three streamgage sites following the 2011 flood and likely was inhibited by bank stabilization. Pronounced changes in channel-bed elevation were indicated.

At Sioux City, the 2011 flood caused pronounced scour [about 3 feet (ft)] of the channel bed. More than 1 year after the flood, the channel bed had only partially recovered (about 1 ft). Pronounced scour (about 3 ft) also was caused by the 1952 flood, which had a substantially larger peak discharge but was much shorter in duration. Despite the differences in peak discharge and duration, both floods caused a similar amount of channel-bed scour at the streamgage site; however, whereas only limited recovery of the channel bed was evident more than 1 year following the 2011 flood, substantial recovery of the channel bed (about 2.5 ft) was documented 1 year after the 1952 flood. The greater recovery following the 1952 flood likely was related to a more abundant sediment supply because the flood predated the completion of most of the main-stem dam, channelization, and bank stabilization projects. Also, the disturbance associated with the construction of Gavins Point Dam may have contributed an additional temporary source of sediment.

At Omaha, scour of the channel bed related to the 2011 flood also was pronounced (about 3 ft). At this streamgage site most of the channel-bed scour occurred after the flood had receded. More than 1 year after the flood, the channel bed had only partially recovered (about 1 ft). In terms of the magnitude of channel-bed scour and recovery, the geomorphic effects of the 2011 flood were similar at Omaha and Sioux City. As at Sioux City, the 1952 flood at Omaha had a substantially larger peak discharge but was much shorter in duration. At Omaha, about 1.5 ft of channel-bed scour was indicated, most of which occurred after the 1952 flood had receded. Following the 1952 flood, the channel bed never fully recovered to its pre-flood elevation.

The geomorphic effect of the 2011 flood at Kansas City was fill (about 1 ft) on the channel bed followed by relative stability. The 1952 flood, which had a substantially larger peak discharge but was much shorter in duration, caused modest fill (about 0.5 ft) on the channel bed. The 1993 flood, which also had a substantially larger peak discharge but was much shorter in duration, caused pronounced scour of the channel bed (possibly as much as 4 ft). Similar to the floods at Omaha, much of the channel-bed scour occurred after the 1993 flood had receded. More than 1 year after the flood, following partial recovery (about 1 ft), the channel bed had stabilized, at least temporarily. Following the 1993 flood, the channel bed never fully recovered to its pre-flood elevation.

For each flood in the post-dam era that resulted in substantial channel-bed scour (Sioux City in 2011, Omaha in 2011, Kansas City in 1993), recovery of the channel bed to its pre-flood elevation had not occurred more than 1 year after the flood (20 years after the 1993 flood at Kansas City). Thus, the possibility exists that channel-bed scour caused by large floods may have a cumulative effect along the lower Missouri River. The persistence of the flood-related decreases in channel-bed elevation may be indicative of the constrained ability of the channel to recover given a limited sediment supply caused by one or more of the following factors: upstream storage of sediment in reservoirs, bank stabilization, commercial sand dredging, depletion of readily available sediment by the flood, and a lack of post-flood sediment contributions from tributaries.

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