MISSOURI RIVER 2011 FLOOD – CHANNEL RESPONSE AND OBSERVATIONS

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ABSTRACT

The Missouri River 2011 flood event within Omaha District resulted in a sustained high peak flow with unprecedented duration. The Missouri River and entire floodplain experienced large areas of sediment erosion and deposition. Normal Corps activities include the monitoring of degradation and aggradation reaches on the Missouri River associated with Missouri River dam construction and also conditions within the navigation channel. Post-flood observations indicated sediment deposition, scour, and significant damage. Survey data was collected and hydraulic modeling performed in support of numerous programs for post-flood repairs. A review of the post flood status of several specific projects and observed channel response during and after the flood are presented.

INTRODUCTION

Introduction

The purpose of this report is to present gage stage trends on the Missouri River within the Omaha District from Ft Peck, MT, to Rulo, NE with a focus on 2011 flood impacts. Gages provide data with which to monitor changes in the river due to hydrologic events and construction of main stem dams and river structures. Record releases occurred from all Missouri River dams in 2011. This report addresses the stage to discharge relationship at each gage, the effects of the 2011 high flows, and how the stages have responded Additional response to or recovery from the 2011 event is expected to continue in many areas in the future.

The views expressed in this paper are those of the authors and do not necessarily reflect the official policy or position of the United States Army Corps of Engineers, the Department of the Army, Department of Defense, or the United States Government.

Description of Missouri River System

The Missouri River Mainstem system of dams is composed of six large earth embankments, which impound a series of lakes that extend for 1,257 miles from Gavins Point Dam near Yankton, SD to the head waters of Fort Peck Lake southeast of Glasgow, MT. These dams were constructed by the Corps of Engineers on the mainstem of the Missouri River for flood control, navigation, power production, irrigation, water supply, water quality, recreation and fish and wildlife enhancement. Fort Peck Dam, the oldest of the six, was closed in 1937. Fort Randall Dam was closed in 1952, followed by Garrison Dam in 1953, Gavins Point Dam in 1955, Oahe Dam in 1958 and Big Bend Dam in 1963. The dams provide nearly 988,000 acres of water surface area and extend a total length of 750 miles. There are 325 miles of open river between the lakes. The reservoirs contain an aggregate storage volume of approximately 73 million acre-feet, three times the average annual flow of the Missouri River at Sioux City, IA. There are 811 miles of open river downstream from Gavins Point Dam to the mouth of the Missouri River where it enters the Mississippi River at St. Louis, Missouri. The Omaha District Boundary ends at mile 498.

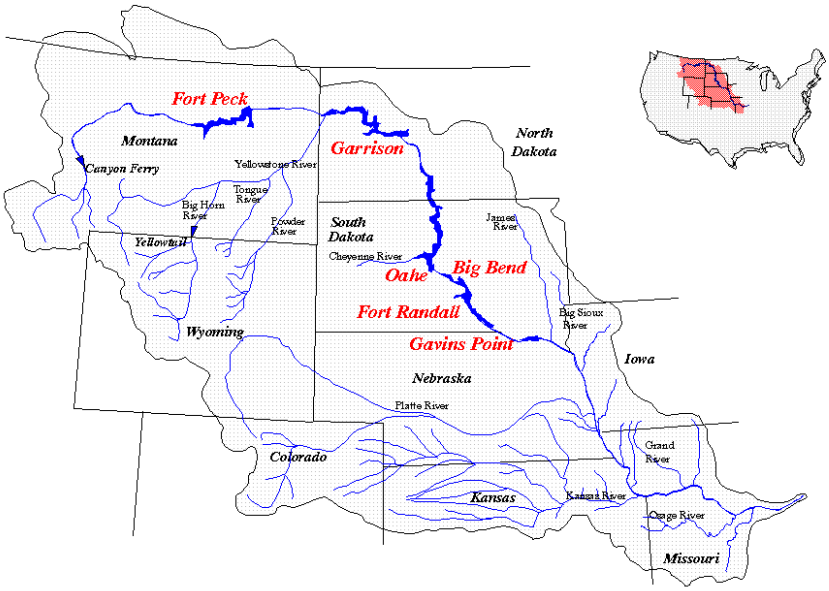

Figure 1 Missouri River Basin

Significance of 2011 Event

Flow Measurements and Observations

The 2011 runoff year was the highest runoff year of record in the upper Missouri River basin since records were initiated in 1898. Upstream of Sioux City, IA, annual runoff volume was estimated at 61 million acre-feet (MAF). In comparison, the previous greatest annual runoff volumes were 49 MAF in 1997 and a roughly estimated 50 MAF in 1881. For the period from March – July, the 1881 runoff volume was more than 40 MAF compared to 48.4 MAF for 2011 (USACE, 2013b).

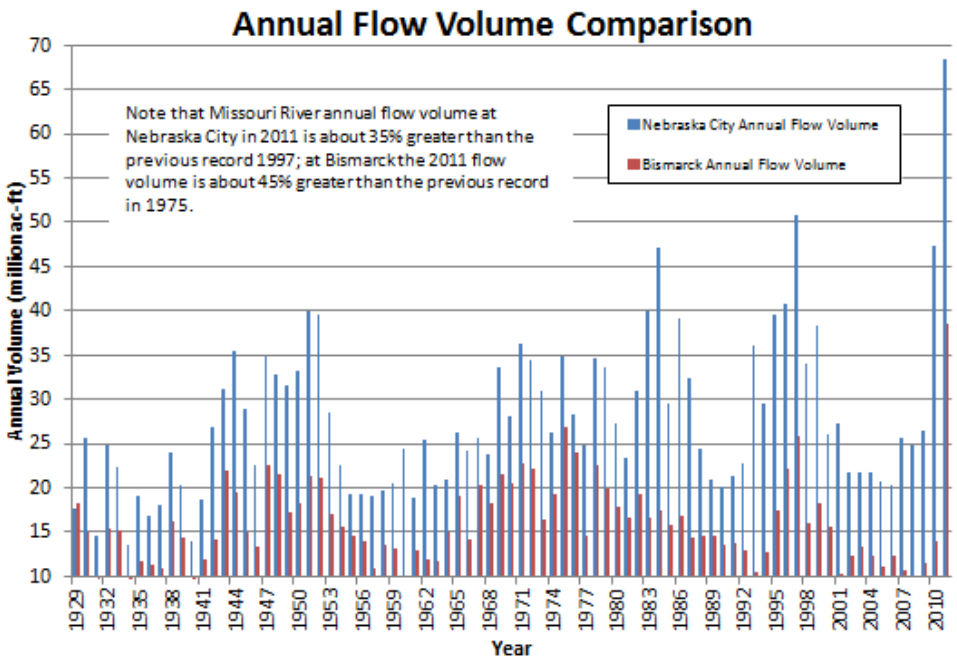

Figure 2 Nebraska City and Bismarck Annual Flow Volume Comparison

When compared to historic events, it should be recognized that historic river flows were affected by main stem dam construction and reservoir filling, primarily in the period 1953 to 1967. All flow frequency values reported in the comparison are post dam construction (USACE, 2003). As a result, compared to historic events is somewhat misleading since the reservoir system has significantly altered peak flows. Data from the USGS gage at Nebraska City is shown in Figure 3.

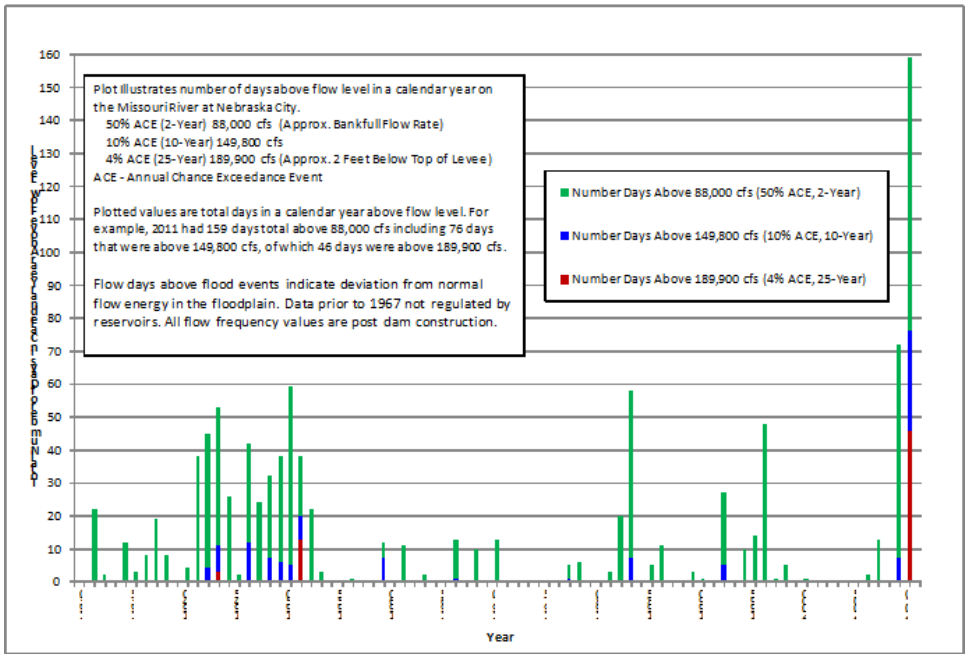

Figure 3 Nebraska City Days above Flow Value by Year

The above figure illustrates the severity of the 2011 event. Using the 189,900 cfs benchmark for comparison, the 2011 event dwarfs all other flood events on the Missouri River. This event was unique in the historic record with the floodplain inundated at a very high level for a prolonged duration. Table 1 presents additional information at both Nebraska City, NE, and Bismarck, ND.

Table 1 Nebraska City and Bismarck, Number of Days above Flow Value by Year

Nebraska City

Event	2011	1993	1984	1952	1944	Total (All Years)	2011 % of Total
189,900 cfs 4% ACE (25-Year)	46	0	0	13	3	62	74
149,800 cfs 10% ACE (10-Year)	76	5	7	20	11	169	45
88,000 cfs 50% ACE (2-Year)	159	27	58	38	53	1029	15

Bismarck

Event	2011	1997	1975	1952	1944	Total (All Years)	2011 % of Total
81,000 cfs 2% ACE (50-Year)	90	0	0	8	14	192	47
57,000 cfs 10% ACE (10-Year)	105	19	46	20	38	545	19

40,000 cfs 50% ACE (2-Year)	134	186	93	58	61	1716	8

Total refers to the number of days above given flow target since gage record began in 1929. Includes the period prior to dam construction. Historic large events tabulated to provide comparison to 2011.

Sediment Measurements and Observations

Sediment measurements were conducted at a number of locations by the USGS during the 2011 event. These sediment measurements during the 2011 event were compared to historic measurements from both the pre- and post-dam era. Measurements indicate a dramatic difference in the suspended sediment vs. flow relationship for the 2011 event. Suspended sediment plots from 2011 and other periods for comparison are illustrated for Nebraska City, NE in Figure 4 and for Bismarck, ND, in Figure 5 .

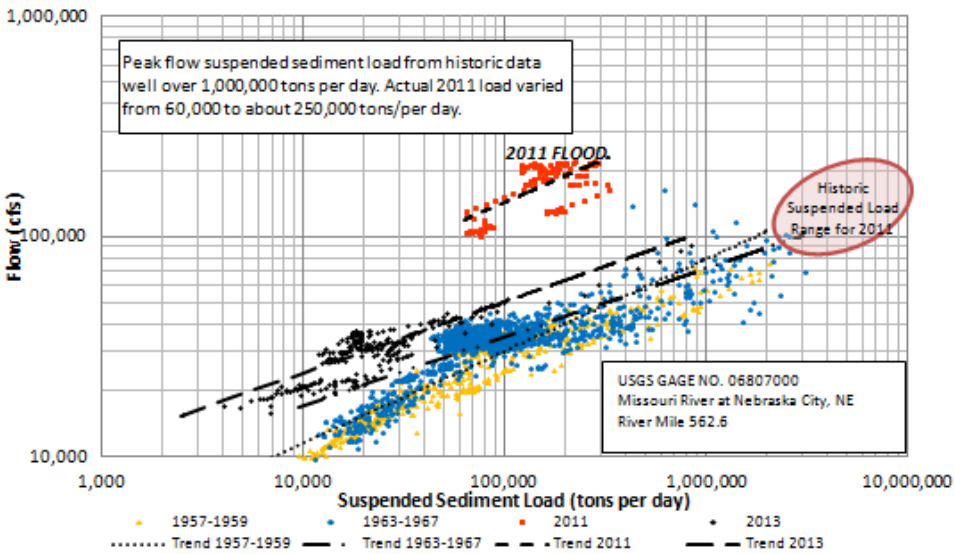

Figure 4 Nebraska City Suspended Sediment Load Comparison from Various Time Periods

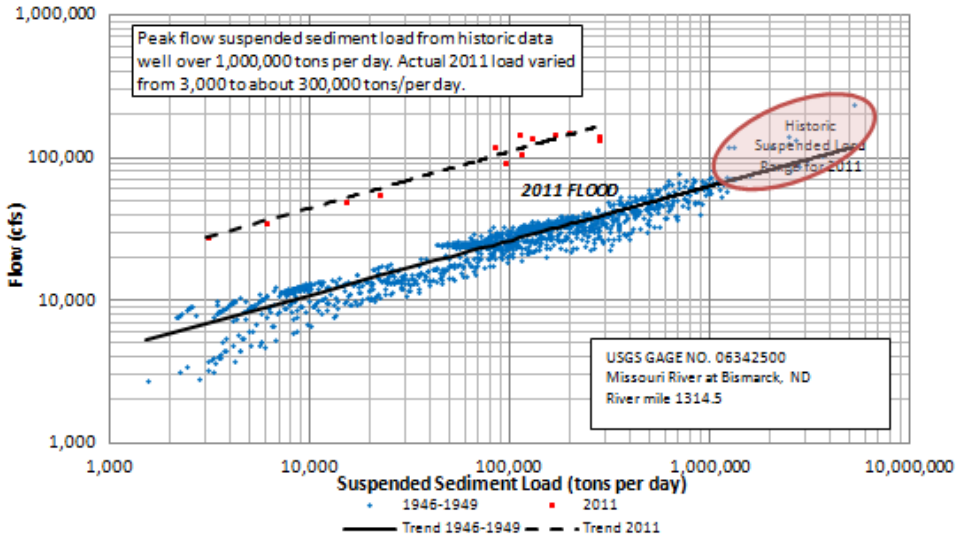

Figure 5 Bismarck Suspended Sediment Load from Various Time Periods

Gage Analyses and Methods

Stage trend plots presented in this report contain data points taken off rating curves or recorded historic data. Two methods are used to develop the rating curves. The first is to plot USGS field measurements (stage/discharge) for a certain water year and fit a rating curve through the points. The second method is to obtain average daily stage data from recorders at the gages and combine that information with average daily discharge measurements from dams and stage/discharge gages on tributaries or from a stage/discharge gage immediately upstream of the subject gage.

Major rivers such as the Missouri River often exhibit the characteristics of a looped rating curve as illustrated by individual gage data; one for the rising limb of the flood hydrograph when flows are increasing up to the occurrence of the flood peak and a second curve for the receding side of the flood hydrograph with decreasing flows from the peak.

Fort Peck Dam to Lake Sakakawea

Geographic Description

Fort Peck Dam is located on the Missouri River at RM 1771.5 in northeastern MT. The project was placed in operation for navigation and flood control in 1938. The Fort Peck degradation reach is considered to extend from the dam nearly 173 miles downstream to RM 1598. The Milk River is the major tributary in this reach entering the Missouri River about 10 miles downstream of the dam. The aggradation reach extends downstream from RM 1598 to the Williston, ND area. The Yellowstone River is the major tributary entering this reach near RM 1578.

Degradation Reach

This reach appears to be more stable than other reaches in the system. West Frazier Pumphouse and Wolf Point have behaved similarly. Trend plots show that the stages for a 10,000 cfs flow had dropped about three feet from 1950 to the mid-1980s, then changed little overall until 2011. Since 2011 the West Frazier gage showed slight degradation whereas the Wolf Point gage showed about 1.5 feet of degradation in 2012, followed by a slight rebound in 2013. Stages for the 20,000 and 30,000 cfs discharge have changed little since the mid-1980s at West Frazier, but dropped another 1 to 2 feet at Wolf Point by 2011, with a rebound occurring in 2013 at 20,000 cfs. At Culbertson, about 150 miles below the dam, the stages dropped about 1 to 3 feet depending on discharge from 1950 to 2011, and then slightly rebounded by 2013.

Table 2 Fort Peck Degradation Reach Elevation Changes at 10,000cfs

Gage	River Mile	1950	1984	2011	Total change
West Frazier	1751.3	2011.9	2008.8	2009.5	-2.4
Wolf Point	1701.2	1964.6	1961.5	1961.6	-3
Culbertson	1620.8	1888.5	1889.5	1887.4	-1.1

Aggradation Reach

Lake Sakakawea had high pool elevations through the mid-1990s that were followed by record low pools from 2005 through 2007 and then a high pool again in 2011. The extended time of high pool elevations in the mid 1990s probably caused an increase in deposited material from Williston, ND to the confluence with the Yellowstone River. However, much of this deposited sediment was probably re-suspended and then transported farther into the lake with low pool elevations during the first decade of the 21st century.

Table 3 Garrison Aggradation Reach elevation changes at 20,000 cfs

Gage	River Mile	1970	1985	2011	Total change
At Buford #5A	1577.5	1857.0	1859.3	1858.4	+1.4
Near Buford #6	1573.1	1854.0	1856.4	1857.3	+3.3
Williston	1552.7	1842.9	1845.6	1847.5	+4.6

Garrison Dam to Lake Oahe

Geographic Description

Garrison Dam is located in central ND on the Missouri River at RM 1390, about 75 river miles northwest of Bismarck and 11 river miles south of Garrison. Closure was made in April 1953. Since 1956, outflows from Garrison Dam have generally been through the power facilities, having a maximum capacity of about 38,000 cfs. Exceptions occurred in 1975, 1997, and 2011 when outflows of approximately 65,000, 50,000 and 150,000, respectively, were needed to pass high upstream runoffs.

The reach of the Missouri River between Garrison Dam and the headwaters of Lake Oahe covers a distance of about 80 miles of which the first 53 miles below the dam is considered the degradation reach. The Knife River enters the Missouri River approximately 14 miles downstream of the dam at RM 1376. The Heart River enters the aggradation reach just downstream of Mandan, ND at RM 1311.

Degradation Reach

The stage at the Garrison Dam tailwater gage has decreased slightly more than 11 feet at a discharge of 20,000 cfs in the period from 1953 and 2013. Most of this decrease occurred by 1980. The high flows from 1996 and 1997 caused another 1 foot of degradation. The 2011 event cause another 1 foot of degradation. All five gages located in this reach behave similarly.

Four gages in this reach show that the stage decreased in 2011. Records from the other two gages were inconclusive due to limited observations on the falling limbs of the hydrograph.

Table 4 Garrison Degradation Reach elevation changes at 20,000 cfs

Gage	River Mile	Original	1984	2011	Total change
Garrison Tailwater (1953)	1390.0	1680.3	1671.47	1669.5	-10.8
Stanton (1950)	1379.0	1676.5	1666.9	1665.2	-11.3
Fort Clark (1960)	1372.6	1668.5	1662.95	1659.5	-9
Hensler (1959)	1362.0	1660.7	1657.2	1655.8	-4.9
Washburn (1955)	1354.7	1656.1	1652.6	1650.2	-5.9
Price (1960)	1338.0	1642.4	1640.3	1638.2	-4.2

Aggradation Reach

Two gages are located in this reach. The 2011 event caused stages for both flows to lower significantly such that the stage for the 30,000 cfs flow in 2013 is about the same as in 1927. The stages for the 10,000 cfs flow fluctuated slightly until the 2011 event dropped the stage about 2 feet. The stages at Schmidt gage are affected by high Lake Oahe pool elevations. Current stages at the various discharges are lower than they were in the mid-1970s.

Table 5 Oahe Aggradation Reach elevation changes at 20,000 cfs

Gage	River Mile	Original	1985	2011	Total change
Bismarck (1927)	1314.5	1623.9	1624.3	1623.3	-0.6
Schmidt (1974)	1298.0	1611.2	1613.95	1616.2	+5

<u>Fort Randall Dam to Lewis and Clark Lake</u>

Geographic Description

Fort Randall Dam is located on the Missouri River at RM 880. The reservoir, Lake Francis Case, extends to the Big Bend Dam tailwater. Closure was made in July 1952. The Niobrara River is a major tributary located at RM 843.8.

Degradation Reach

The Fort Randall tailwater gage has decreased between 7 and 8 feet since 1952, most of which occurred by 1985. The 2011 event had little effect at this location. At the Greenwood gage the stages had decreased about one foot in 27 years (1960-1987). High flows in 2011 lowered the stages 1 to 1.5 feet. Some rebounding has occurred in 2012 and 2013.

Table 6 Fort Randall Degradation Reach elevation changes at 30,000 cfs

Gage	River Mile	Original	1984	2011	Total change
Fort Randall Tailwater (1952)	880.0	1239.8	1233.58	1232.7	-7.1
Greenwood (1960)	862.9	1228.8	1228.05	1225.9	-2.9

Aggradation Reach

The Verdel and Niobrara gages show the same pattern on the stage trend plots. Both show increasing trends from the mid 1970s until the high flows in 1995 when the stages decreased. By 1999 the stages were increasing again through 2008. Stages at both gages decreased between 3 and 4 feet in 2011. The stage at the Verdel gage was close to 3 feet higher for a 40,000 cfs flow on the increasing flow to peak curve than on the post flood curve and about 1 foot high at the Niobrara gage.

Table 7 Gavins Point Aggradation Reach elevation changes at 30,000 cfs

Gage	River Mile	Original	1985	2011	Total change
Verdel (1968)	846.5	1217.95	1220.2	1220	+2.05
Niobrara (1956)	842.9	1212.4	1218.3	1218.9	+6.5

Gavins Point Dam to Ponca, NE

Geographic Description

Gavins Point Dam is located at RM 811.1 on the Missouri River, 4 miles west of Yankton, SD and is the most downstream dam on the river. Therefore, there is no aggradation reach due to a reservoir is located downstream of this degradation reach. Closure was made July 1955.

Degradation Reach

The Gavins Point degradation reach extends from Gavins Point Dam downstream 58 miles to RM 753.18. The major tributaries in this reach include the James River at RM 797.5 and the Vermillion River at RM 772.0. The degradation trend is not limited to this reach and extends downstream to near Omaha, NE (approximately another 135 river miles).

Gavins Point tailwater gage over its period of record (1955 to 2013) shows a stage decrease of 13 feet for a flow of 20,000 cfs, most of which occurred by 1980. A decrease of about 1 foot occurred due to the 2011 flood event. Stages at the Yankton gage have decreased in a similar pattern to the tailwater gage.

The two most downstream gages in this reach (Maskell and Ponca) showed very little change in stages through the 1980's and early 1990's. Higher flows in 2010 and the record high flows of 2011 dropped stages between 2 and 4 feet. Since 2011, stages at the Maskell gage appear to be leveling off. Stages at Ponca have rebounded about 1 to 1.5 feet from the 2011 degradation level at the 20,000 cfs and above.

Table 8 Gavins Point Degradation Reach elevation changes at 30,000 cfs

Gage	River Mile	1955	1985	2011	Total change
Gavins Point Tailwater	811.0	1169.1	1159.8	1156.5	-12.6
Yankton	805.8	1163.4	1156.4	1153.8	-9.6
Maskell	775.4	1129.5	1124.8	1120.0	-9.5
Ponca	751.0	1096.5	1095.8	1089.0	-7.5

Missouri River Navigation Reach – Sioux City to Rulo, NE

Geographic Description

The Kensler Bend and the Bank Stabilization and Navigation Program (BSNP) Projects from Ponca (RM 753) to Rulo (RM 498), along with the construction of upstream dams, have drastically changed the characteristic of the Missouri River in this reach. Prior to construction, the river was a wide, sandy, sinuous channel containing numerous islands and sandbars and acting like any natural river system, by aggrading, degrading, or eroding its banks at any location dependent on the year. Today this reach is

narrower in cross-section, shorter in distance, with increased velocity, and is contained in rock-protected banks with constructed levees in many locations on the floodplain. A major influence in this reach is the Platte River at RM 594.

Generally, the stage (especially at the lower flows) has decreased in elevation to varying degrees upstream of Omaha. Downstream of the Platte River the stages have shown little change at the lower flows and an aggrading trend at the higher flows.

Navigation Reach

Overall, the stage at both Sioux City and Decatur shows a degradational trend. However, stages at both gages appeared to be leveling in the 1980s through the early 1990's. High flows in the mid 1990's caused a lowering of stages of about 4 feet at Sioux City and about 1 foot at Decatur. With the higher flow in 2010 and record high flows in 2011, both gages showed a decrease in stage elevations. The Sioux City gage, which decreased about 4 feet during the 2011 event, had rebounded about 1 to 2 feet depending on flows through 2013, while stages at the Decatur gage, which only decreased about 1 to 1.5 feet, also show some rebounding of stages. The Blair gage, which did not include any analysis of pre-2011 event stages, shows a slight increase in stages in 2012 and 2013.

Omaha's stage showed some degradation from 1930's through the early 1950's at all flows with a large decrease from the 1952 flood. A period of rebound and perhaps slight aggradation occurred through the mid-1970's. Since then, the stage at 40,000 cfs has shown very little overall change. Lower flows show a slight decreasing trend and higher flows a slight increasing trend. From 2010 to 2012 there had been between 0.5 to 3 feet of degradation at the various flows. All flows showed some rebounding in 2013 from 2011.

Nebraska City stages for flows below 70,000 cfs have been within the same range since 1990. Historic stages showed a mild decrease from years 1930 to 1950 followed by a period of mild increase. Stages for floodplain events above 100,000 cfs do indicate a slight rising trend since 1980. Nebraska City stages, as well as Plattsmouth and Brownille, show very little change since 2011.

At the Rulo gage, stages have fluctuated within about a one foot band for flows below 40,000 cfs since 1960. A slight aggradational trend is visible since the mid 1990's at higher flows. Since 2011, the stages have lowered between 0.5 and 1.5 feet at and below 40,000 cfs. The stage at a 70,000 cfs flow at Rulo increased about 0.5 feet between 2012 and 2013.

Table 9 Missouri River Sioux City to Rulo

Gage	River Mile	Original	1984	2011	Total change
Sioux City (1930)	732.2	1084.5	1077.4	1070.3	-14.2
Decatur (1957)	691.0	1040.3	1033.1	1030.7	-9.6
Omaha (1930)	615.9	967.7	966.9	965.6	-2.1
Nebraska City (1930)	562.6	913.7	914.9	915.5	+1.8
Rulo (1950)	498.0	845.7	847.0	846.5	+0.8

<u>Water Surface Profile Evaluation Post 2011 Flood</u>

Four water surface profiles are presented in this report within various reaches. Both the Garrison Dam to Lake Oahe and Fort Randall Dam to Springfield water surface profiles end in a reservoir. Most of the degradation in these reaches occurs in the region near the dam and the amount of degradation decreases as the distance from the dam increases. Within the reach below Garrison, the Oahe pool limits the degradation reach to between 70 and 90 river miles from the dam. In the river reach below Fort Randall the degradation limit is much shorter, primarily due to the location of the Niobrara River, and the degradation extent is only 35 to 40 miles downstream. Of course, the boundary between degradation and aggradation can move upstream or downstream due to pool levels, hydrologic cycles, and other factors.

The river stretch from Gavins Point Dam to Sioux City is interesting with two major processes at work. At the upstream end degradation is caused by the dam trapping all upstream sediment and releasing clear water into the river. In contrast to the other mainstem dam open river reaches, the river below Gavins Point Dam does not end at a reservoir. Near the downstream end of the reach, the construction of navigation channel structures to provide sufficient channel depth for navigation provide a strong influence.

Within the navigation channel reach from Sioux City to Rulo, the Platte River has a major impact on geomorphology. The change in water surface between different time periods is greatest at Sioux City and decreases as the profile approaches the Platte River. Downstream of the Platte River very little change is detected at the 40,000 cfs flow.

Stage Trend Summary

The 2011 flood event presented a challenge when evaluating trends. It was observed that the stages at many locations were different for the rising side of the event (increasing to peak flow) versus the declining side of the event (decreasing from peak flow). The differences in stage range from as little as a few tenths of a foot at some locations to about 6 feet at Ponca for a 40,000 cfs flow. At the degradation locations, the rising side event stages are higher while at aggradation locations the reverse is true. Compared to the degradation observed in 2011, the 2013 stages show varying amounts of rebound at many sites.

References

USACE, (2014a). 2013 Missouri River Mainstem Dams Tailwater Rating Curves and Trends, Omaha District Corps of Engineers, Jan 2014.

USACE, (2014b). Garrison Dam – Lake Sakakawea Headwaters Aggradation Evaluation of the Missouri River and Tributaries, Omaha District Corps of Engineers, January 2014.

USACE, (2013a). MRB Sediment Memorandum 28, Missouri River Fort Peck Project, Downstream Channel and Sediment Trends Study, Updated, Omaha District Corps of Engineers, April 2013.

Galloway, J.M., Rus, D.L., and Alexander, J.S., (2013b). Characteristics of sediment transport at selected sites along the Missouri River during the high-flow conditions of 2011: U.S. Geological Survey Scientific Investigations Report 2013–5006, 31 p.

USACE, (2012). Missouri River Stage Trends, Technical Report, Missouri River Basin Water Management Division, Omaha NE, August 2012.

Grigg, McCarthy, Lawrence, Ockerman, (2012). Review of the Regulation of the Missouri River Mainstem Reservoir System During the Flood of 2011, Independent Technical Review Panel, Missouri River Basin Water Management Division, Omaha, NE.

USACE, (2011). Missouri River Bank Stabilization and Navigation Project – Sioux City, IA to the Mouth, O&M Manual, Omaha District Corps of Engineers, November 2011.

USACE, (2006a). Missouri River Mainstem Reservoir System, Master Water Control Manual, Missouri River Basin. Northwestern Division, Reservoir Control Center, Omaha, NE.

USACE, (2006b). Analysis Outline, Revising Construction Reference Plane, Missouri River, Mil 811 to 498, Omaha District Corps of Engineers, Aug 2006.

USACE, (1994). Aggradation, Degradation, and Water Quality Conditions Missouri River Mainstem Reservoir System, Omaha District Corps of Engineers, January 1994.

USACE, (1990). Lake Sakakawea Headwaters Aggradation Study, 1962 – 1989, Omaha District Corps of Engineers, September 1990.

USACE, (1984). MRD Sediment Series #34, Aggradation and Degradation of the Missouri River Main Stem Dams, Omaha District Corps of Engineers, May 1984.