RISING FLOOD STAGES ON THE LOWER MISSOURI RIVER

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Abstract. Dramatic increases in flood stages on the lower Missouri River are indisputable given the historical record, as is evident at Hermann (Fig. 1). Flood stages at constant discharge have risen approximately 4 to 9 feet over the last ~70 years at seven of the nine long-term gauging stations on the lower Missouri River. Stage increases are seen for all flows above flood stage, and tend to be greatest for the greatest discharges. Wing dams and levees constrict the river channel and have forced flood stages to rise to accommodate given flows. Flood stages continue to rise because of new river engineering projects and considerable inertia in the system.

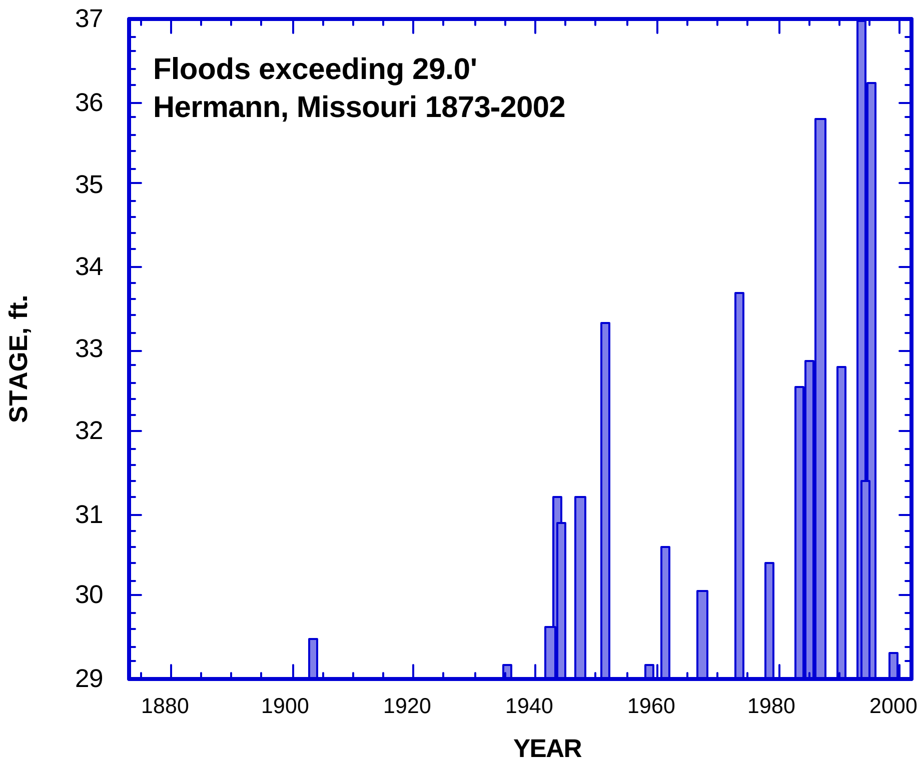

Figure 1: Flood stages of the Missouri River at Hermann have risen markedly over the last 130 years. The flood of 1903 had the highest stage (29.5 ft.) recorded within an interval exceeding 60 years, but stages over 30 feet are now commonplace and occur every 3 years or so. Data from Jarvis et al. (1936) and USGS (2002).

INTRODUCTION

In the last ten years, the St. Louis region has experienced floods of such severity and frequency that they would not, according to government estimates, have been expected to have all occurred in a period less than two centuries. This phenomenon is popularly recognized and is widely attributed to global warming or climate change. However, beginning with the important study by Belt (1975), a series of independent studies have demonstrated that stages on the Mississippi River at St. Louis have risen considerably over the last 160 years for given discharge magnitudes (Stevens, 1975; Pinter et al., 2000; Criss and Shock, 2001). This effect cannot be related to climate change and instead is due to reduced channel conveyance, particularly the construction of wing dams and levees which restrict the river channel, reduce water velocities, and generally impede flow (Stevens, 1975; Pinter et al., 2000).

Criss and Shock (2001) demonstrated that stage increases at constant discharge are not restricted to the middle Mississippi River, but have occurred over the last century on several major rivers in the Midwest. The sites studied by Criss and Shock include the Missouri River at Boonville, Missouri, where flood stages have risen approximately 8 feet over 75 years. Criss and Shock (2001) found the largest stage increases on rivers controlled by a combination of wing dams and levees, while smaller increases occurred on reaches with locks and dams, and no stage increases were found on rivers where no engineering projects have been undertaken.

This paper will use the methods of Criss and Shock (2001) to show that flood stage increases are practically universal along the lower Missouri River. Historical stage increases for constant discharge will be demonstrated for seven of the nine gauging stations on the lower Missouri where long-term records are available, notably Omaha, Nebraska City, Rulo, St. Joseph, Waverly, Boonville, and Hermann. Kansas City and Sioux City are exceptional in that historical stage increases are negative to small.

STAGE-DISCHARGE PLOT

In the discussion to follow, the distinction between stage and discharge is very important. "Stage" is the elevation or level of water in the river at any time, and is commonly reported in feet. Flood stages are the high water levels associated with flooding, and are the most obvious cause of destructive losses. Stages must rise to accommodate high "discharge", which is the rate of flow of water in the river channel. "Discharge" in the USA is normally reported in cubic feet per second (cfs) or less commonly in gallons per minute. Stages are directly, easily and accurately measured by staff gauges, whereas discharge is difficult to measure because it requires data on the channel configuration and water velocity. Nevertheless, huge data sets are available for stage and discharge at thousands of gauging stations in the United States (Wahl et al., 1995).

Criss and Shock (2001) developed a simple graphical method to evaluate systematic historical changes in river stage for peak annual flood events. These peak annual floods include the most destructive events, and data sets for these floods at numerous gauging stations are readily available over the internet (USGS, 2002). The graph of interest is nothing more than a plot of stage for these peak annual floods versus the year of occurrence, so that a single point representing the maximum flood for that location is plotted for each year over the period of record. Little can be learned from the resulting stage-year scatter plot until different symbols are used to distinguish the discharges (flow rate, in cfs) associated with each data point. The least squares method is then applied to define linear trends for the points comprising each of several discharge ranges.

As emphasized by Criss and Shock (2001), any trends revealed by the linear regressions on such a plot are independent of climate change. Climate change can cause peak river discharges to fluctuate over time, and this will obviously affect stages. However, for floods having a constant discharge magnitude, climate change cannot significantly change the stage. The question addressed below is, for a fixed discharge, how deep must the river become to accommodate the flow, and has this level changed over time?

HISTORICAL CHANGES TO THE LOWER MISSOURI RIVER

The lower Missouri River historically had a braided channel with many small islands, snags and bars (e.g., Thwaites, 1904), though this character has been dramatically modified for navigation as described by Funk and Robinson (1974). Subsequently the river was engineered to a single channel by dredging and by construction of levees and thousands of wing dams (Fig. 2). Across the State of Missouri, the transformation of the natural river to its nearly invariant channel with a 9 foot minimum depth was effected by an 8% reduction in total length, a 50% reduction in the water surface area, a 98% reduction in island area, and the removal of nearly 20,000 snags (Funk and Robinson, 1974; Fig. 2).

Figure 2: Photograph of the Missouri River north of St. Louis, looking northwest from a position near Mile 6.5 at an altitude of 1500 feet, during the low flow conditions of July 31, 2002. Lewis Bridge on US 67 is in the middle background (Mile 8.2). Note the prominent wing dams located every 600 to 1200 feet along both sides of the river; the tree line on the north side marks the approximate position of a levee. The site of Fort Bellefontaine is located in the left foreground and is proximal to the first and last campsites of the Lewis and Clark expedition (May 14, 1804 and Sept. 22, 1806). Photo by author.

In addition, six huge reservoirs were constructed between 1933 and 1964 in Montana and the Dakotas to provide water supply, hydroelectricity, and navigational and flood control benefits. These reservoirs have greatly attenuated pulses in streamflow and reduced the sediment load. Management strategies to control the flow from the dams to maintain the navigational channel while improving habitat for endangered species, providing water supply and minimizing flood risk are being actively debated (Criss and Wilson, 2003).

LONG TERM GAUGING STATIONS

Daily discharge data on the lower Missouri River have been collected for >70 years at eight gauging stations in Missouri, Iowa, and Nebraska and since 1950 at Rulo (Table 1). All but Rulo have essentially continuous records since or before 1930, and substantial records on peak flood stages are available for Kansas City and Hermann since 1873 (Jarvis et al., 1936). Annual peak flows and stages for the period of record at all of these stations are available in annual USGS Water Supply Papers, and records for all but Kansas City are readily accessible over the internet (USGS, 2002). All historical stage data used in this report have been corrected to the modern datum indicated for the site in Table 1; significant corrections due to changes in the reporting datum were required for Sioux City, Omaha and Kansas City.

TABLE 1: LONG TERM GAUGING STATION CHARACTERISTICS[#]

STATION	USGS ID No.	RIVER MILE	DRAINAGE AREA mi^2	ELEVATION (feet MSL)	MEAN* DISCHARGE	DISCHARGE RECORDS
Sioux City	06486000	732.2	314,000	1056.98	36830	1929 to 2002
Omaha	06610000	615.9	322,800	948.24	39110	1929 “
Nebr. City	06818000	562.6	410,000	905.36	42710	1930 “
Rulo	06813500	498.0	414,900	837.23	43850	1950 “
St. Joseph	06818000	448.2	420,300	788.19	47070	1929 “
Kansas City	06893000	366.1	485,200	706.40	56950	1929 “
Waverly	06895500	293.5	487,200	646.00	58720	1929 “
Boonville	06909000	196.6	501,700	565.42	69220	1926 “
Hermann	06934500	97.9	524,200	481.56	87950	1929 “

After Hauck and Nagel (2002) and Hitch et al. (2002)

*1953-2001 average for Sioux City, Omaha and Nebraska City; otherwise 1958-2001

HISTORICAL STAGE CHANGES

Historical changes in flood stages have been evaluated for the nine, long term gauging stations on the lower Missouri River using the method of Criss and Shock (2001). Representative graphs are shown below (Figs. 3-5) for Nebraska City, Kansas City and Hermann, and a graph for Boonville is presented in Criss and Shock (2001). Table 2 gives summary data for the historical changes at these and the other stations.

TABLE 2. Approximate Stage Increase in Feet for Indicated Discharge Range, 1930-2000*

Station	50 to 100,000	100 to 150,000	150 to 200,000	200 to 250,000	250 to 300,000	300 to 400,000	400 to 500,000	500 to 600,000
Sioux City	-6.0							
Omaha	+2.0	+3.5						
Nebr. City	+7.0	+7.5	+10.0					
Rulo	+3.5*	+5.5*	+2.0*					
St. Joseph	+4.5	+7.0	+8.0					
Kansas City	-5.0	-3.5	-1.5	-2.0	+1.0			+4 est
Waverly	+2.0	+6.0	+7.0	+7.0	+9.0			
Boonville	+6.0	+2.5	+6.5	+6.5	+7.0	+9.0		
Hermann		+4.0	+4.0	+5.5	+5.5	+3.0	+ 5.5	+7.5

*1950-2000 change for Rulo

Nebraska City. Stages of annual floods on the Missouri River at Nebraska City have increased significantly since 1930 (Fig. 3). The trend lines for all three discharge ranges (labeled curves, in 1000's of cfs) for the annual floods slope upward at this site, and indicate that the stages have increased by 7 to 10 feet over the last 70 years (Fig. 3; Table 2).

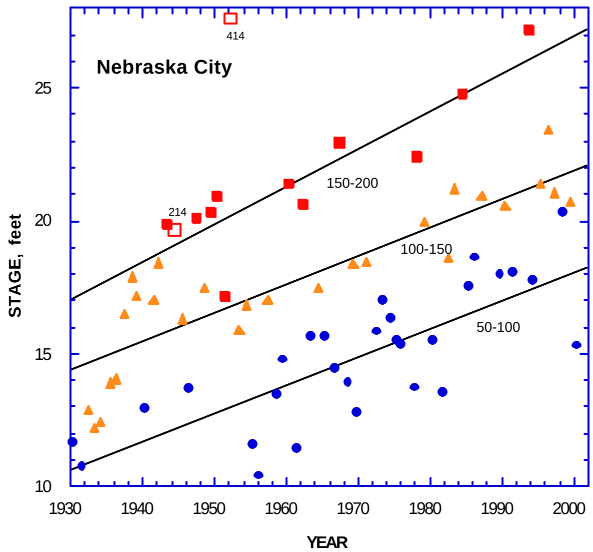

Figure 3. Graph of river stages vs. year for annual floods on the Missouri River at Nebraska City. Linear regressions are shown for data in three discharge ranges, 150 to 200,000 cfs (solid squares), 100-150,000 cfs (triangles), and 50-100,000 cfs (dots); the floods of 1944 and 1952 were larger at 214,000 and 414,000 cfs (open squares). Stages for a given discharge have increased 7 to 10 feet since 1930. Data from USGS (2002).

Kansas City. In contrast to Nebraska City, flood stages at constant discharge for the Missouri River at Kansas City show little or no increase over the period or record (Fig. 4). The trend lines for all but the greatest annual floods slope downward at this site, indicating that stages for floods below 250,000 cfs have decreased by a 1 to 5 feet over time for a given discharge, with the amount of decrease being greatest for the smallest discharges. Such decreases in stage are not observed for annual floods of any size at any of the other long term gauging stations except Sioux City (Table 2). Apparently, the conveyance of the central river channel at Kansas City has increased with time for most discharge ranges, possibly because of dredging.

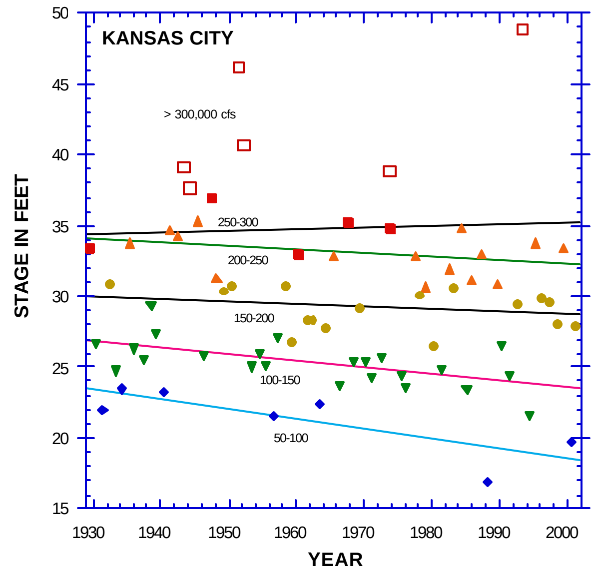

Figure 4: Graph of river stages vs. year for annual floods on the Missouri River at Kansas City. Linear regressions are shown for five discharge ranges, labeled in 1000's of cfs. Stages for most discharge ranges have decreased since 1929, but increased slightly for the greatest floods (>250,000 cfs). Data compiled from annual USGS Water Supply Papers, with stages corrected to the current datum.

In contrast, stages for floods with discharges of >250,000 have increased historically, by 1 to 3 feet over the last 73 years. A 1 foot increase in stage is suggested in Figure 4 by the uppermost trend line representing the 250,000 to 300,000 discharge range. Greater stage increases may apply for floods having even higher discharges. For example, the discharge during the 1903 flood at Kansas City was higher than that during the great 1993 flood, yet the 1993 stage was nearly 4 feet higher (Table 3).

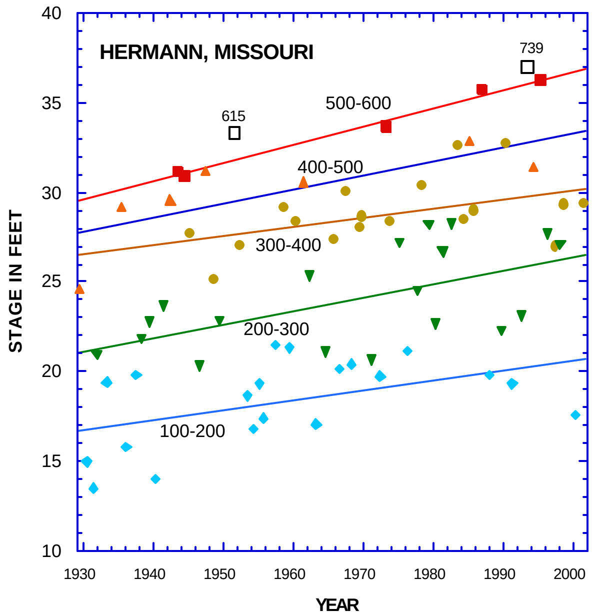

Figure 5: Graph of river stages vs. year for annual floods on the Missouri River at Hermann. Linear regressions are shown for five discharge ranges, labeled in 1000's of cfs; the great floods of 1952 and 1993 had higher discharges of 615,000 and 739,000 cfs (open squares). Stages for a given discharge have steadily increased 3 to 7.5 feet since 1929. Data from USGS (2002).

Hermann. Flood stages on the Missouri River at Hermann have increased historically (Fig. 5). The trend lines for all five discharge ranges all slope upward, indicating that stages have increased by 3 to 7.5 feet since 1929. The greatest floods tend to exhibit the greatest historical increase in stage.

The historical increase in flood stages at Hermann is confirmed by comparing the 1903, 1951 and 1993 floods (Table 3). For example, the discharge during the 1951 flood at Hermann was less than that estimated by USGS for the 1903 flood, yet the 1951 stage was 3.8 feet higher (Table 3). Similarly, the stage for the modest flood of October 1998 was nearly as high as the peak stage of the great 1903 flood, yet the 1998 discharge was almost a factor of two lower (Table 3).

DISCUSSION

Stages at constant discharge have significantly increased at seven of the nine long-term gauging stations on the lower Missouri River (Table 2). The flood records at these stations are all very complete and the trends they define are generally regular. At most stations, the flood stages have increased by 7 ft. or more since 1930 for the largest annual floods (Table 2).

There are several independent ways to confirm the significant historical increase in flood stages along the lower Missouri River. For example, stages and discharges were measured for many stations during the great flood of 1903, and these can be compared with records for more recent events (Table 3). The last column in Table 3 lists the most recent flood that had a stage comparable to that during the great flood of 1903, which at Kansas City and Hermann had the greatest stages reported since 1873 if not before (Jarvis et al., 1936). Where good comparisons are possible, the stages for many modest floods of the late 1990's compare closely to the peak stages reported at the same sites during 1903! In other words, high flood stages that once were very rare are commonplace now, and this has occurred in spite of the many large reservoirs that have been constructed to reduce the severity of flooding (e.g., Perry, 1994).

Another useful and independent approach is to examine the highest flood stages that have occurred at Hermann since 1873 (Fig. 1). The 1903 flood was the greatest event within an interval exceeding 60 years, yet even higher stages have occurred every three years or so since WWII. Figure 1 is simple, uncontrived, and readily confirmed, and anyone who requires their own opinion on regional flooding would do better to verify it than to adopt any of the opinions promulgated by special interests.

TABLE 3: Comparison of the Great Floods of 1903, 1951, 1993 with Recent* Events

STATION	DISCHARGE, cfs (STAGE, ft) June 1903	DISCHARGE, cfs (STAGE, ft) Apr-July 1951	DISCHARGE, cfs (STAGE, ft) July 1993	DISCHARGE, cfs (STAGE, ft) Recent Date*
Sioux City	NA (32.5)	152,000 (33.0)	72,200 (27.33)	None comparable to 1903
Omaha	NA (24.4)	152,000 (28.2)	115,000 (30.26)	77,200 (24.17) 8/99
St. Joseph	252,000 (20.5)	198,000 (19.9)	335,000 (32.07)	134,000 (20.52) 4/97
Kansas City	548,000 (44.95)	573,000 (48.87)	541,000 (48.87)	None comparable to 1903
Boonville	612,000 (30.5)	550,000 (32.62)	755,000 (37.10)	296,000 (30.12) 5/96
Hermann	676,000 (29.5)	618,000 (33.33)	750,000 (36.97)	357,000 (29.32) 10/98

*Recent flood with stage closest to the June 1903 peak

CONCLUSION

Flood stages at constant discharge have significantly risen at seven of the nine long-term gauging stations on the lower Missouri River. Stage increases have occurred at most stations for annual floods of all sizes, and tend to be greatest for the greatest discharges. Historical stage increases can be independently confirmed by several methods that do not require discharge measurements. Wing dams and levees constrict the channel of the lower Missouri River and have forced flood stages to rise.

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