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Comparison of Two Major Floods, 1993 and 2019, on the Missouri River at Hermann, Missouri

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1. Introduction

The flooding on the Missouri River in 1993 and 2019 was monumental. The following analysis will go into some detail about both events and point out some possible long-term trends, possible reasons for these trends, and suggest some possible future outcomes. Hermann, on the lower end of the Missouri River, near the confluence with the Mississippi, is an excellent location for an overall view of these floods because nearly all the runoff from the Missouri Basin flows by Hermann and is measured by the U.S. Geological Survey (USGS) both in terms of stage and discharge. Drainage area above Hermann is 522,500 square miles, about 99% of the total basin. Section 2 provides general background information, sections 3 and 4 are brief reviews about the flooding of 1993 and 2019. Section 5 compares the two flood years, while section 6 discusses rating curve issues. Section 7 has comments and conclusions.

2. Background

Congress agreed in 1944 to a combined plan by the U.S. Army Corps of Engineers (USACE) and the U.S. Bureau of Reclamation (USBR) to dam the Missouri River at five places in the Dakotas, the last of them being Gavin's Point Dam on the South Dakota-Nebraska state line. While Fort Peck Reservoir was built before 1944, it is generally included as part of the Pick-Sloan Reservoirs. These dams created the country's largest reservoir system, with 72.4 million acre-feet of storage, and from the beginning, were to be multipurpose reservoirs, operated to provide primarily flood control and navigation. In 1945, the USACE also began building hundreds of miles of levees from Sioux City, Iowa, to St. Louis, Missouri, and to deepen the river channel to at least nine feet the entire distance for navigation purposes (see Figure 1).

Figure 1. Map of the Pick – Sloan Reservoirs on the Missouri River (Source: U.S. Army Corps of Engineers)

3. Brief Review of 1993 Missouri Basin Flooding

From May through September of 1993, major and or record flooding occurred across much of the Midwest. Many record crests were set while some locations experienced multiple records. Fifty flood deaths occurred and damages approached $15 billion (NOAA 1994) or $27 billion in 2019 dollars. Hundreds of levees failed along the Missouri and Mississippi Rivers. The magnitude and severity of this flood ranks as one of the greatest natural disasters ever to hit the United States. It is certainly one of the most significant and damaging flood events. Over 600 river forecast points were above flood stage in the Midwest at the same time and 150 major rivers and tributaries were affected (NOAA 1994). Tens of thousands of people were evacuated and over 10,000 homes were totally destroyed (NOAA 1994). Seventy-five towns and over 15 million acres of farmland were inundated (NOAA 1994). Transportation was severally impacted. Barge traffic was stopped for over two months, and many bridges were damaged, lost, or not accessible. Bridges from Kansas City downstream to St. Louis were impacted. Three interstate highways were closed, ten commercial airports were shut down, all railroad traffic was halted through the area and numerous water and sewage treatment plants were impacted (NWS 1993).

The Missouri River is 2,315 miles long. Hermann is at river mile 97.9, the distance upstream from confluence with the Mississippi River near St. Louis. After months of record summer rainfall (some states received 300 to 400% of normal amounts) the Missouri River finally crested at Hermann, at a stage of 36.97 feet on July 31, 1993. This was an all-time record with recorded discharge of 750,000 cubic feet per second (CFS), and 61 record high crests were set at other locations within the Missouri Basin (NOAA 1994) during this time. Kansas City, Missouri, which at the time had a long-term average annual precipitation (1889-1990) of 36.56 inches had 51.46 inches of precipitation in 1993. Above-average rainfall was widespread throughout the Midwest in 1993.

4. Brief Review of 2019 Missouri Basin Flooding

During the 2019 flood event, 53 record high crests occurred within the Missouri River Basin (NOAA 2019). Extreme cold temperatures during the winter months caused the wet soils from previous fall rains to freeze solid. Heading into the mid-March event, the Missouri Basin saw multiple rounds of snow that deepened the plains snow pack on top of the “block of ice” i.e., the hard and deeply frozen ground. A worst-case scenario for the Central Plains then occurred: an upper-level low that tapped into an abundance of Gulf moisture. In addition, this system brought the much-below normal temperatures quickly to slightly above normal and ample rain during its onset followed by an Arctic blast with snow and blizzard conditions on the backside. A side note, this low pressure system dropped to 969 mb, one of the lowest pressures ever recorded for this portion of the United States (NOAA 2020). Some regions of Nebraska had over 10 inches of snow on the ground leading up to the storm; melting took less than 24 hours, and additional rainfall led to an extreme amount of runoff. Rivers, some of which had 1-to-2-feet thick ice cover, rose rapidly and catastrophically, carrying chunks of ice the size of automobiles downstream breaking levees, dams, roads and everything in their path. Tragically, twelve lives (NOAA 2020) were lost during the floods in Nebraska, Kansas, South Dakota and Iowa. Countless others became homeless and millions of dollars in damage occurred during a short period of time. Flood damages were estimated at $20 billion (NOAA 2020).

The onset of summer brought much warmer temperatures, but little relief from rainfall. Very heavy rainfall occurred all across the Missouri Basin. Some extreme events occurred during the first week of July, in which on different days, areas recorded 12-hour precipitation totals of 5-6 inches in central Kansas, 7-8 inches in west-central Missouri, and over 11 inches in central Nebraska (NOAA 2019; NOAA 2020).

Along with many record stages throughout the basin, there were three dam failures. The most notable failure was Spencer Dam in Nebraska on the Niobrara River.

The failure of Spencer Dam on March 14 was attributed to the high water, rapid snow melt and large ice chunks. Enough water and ice to wash out the dam caused mass flooding and an 11-foot "wall of water" to flow down river. Several roads were washed out, including U.S. Hwy 281 located directly downstream of the dam. Nebraska Highway 12 was so badly damaged at the river crossing, that the bridge was swept downstream and washed up on higher ground. Figure 2 shows the hydrograph at the downstream river gage before it was destroyed by the dam failure. Within a matter of minutes, the stage at Verdel, Nebraska, rose some 12-plus feet before the gage was destroyed, eclipsing the previous flood of record by nearly 9 feet. Gavin's Point Dam, the last dam on the Missouri River, had to immediately increase its releases to accommodate the flow from the dam failure. This increase amplified flooding downstream on the Missouri River. Omaha, Nebraska on the Missouri River crested at 34.10 feet on March 17, 2019 feet – the 3rd-highest stage of record.

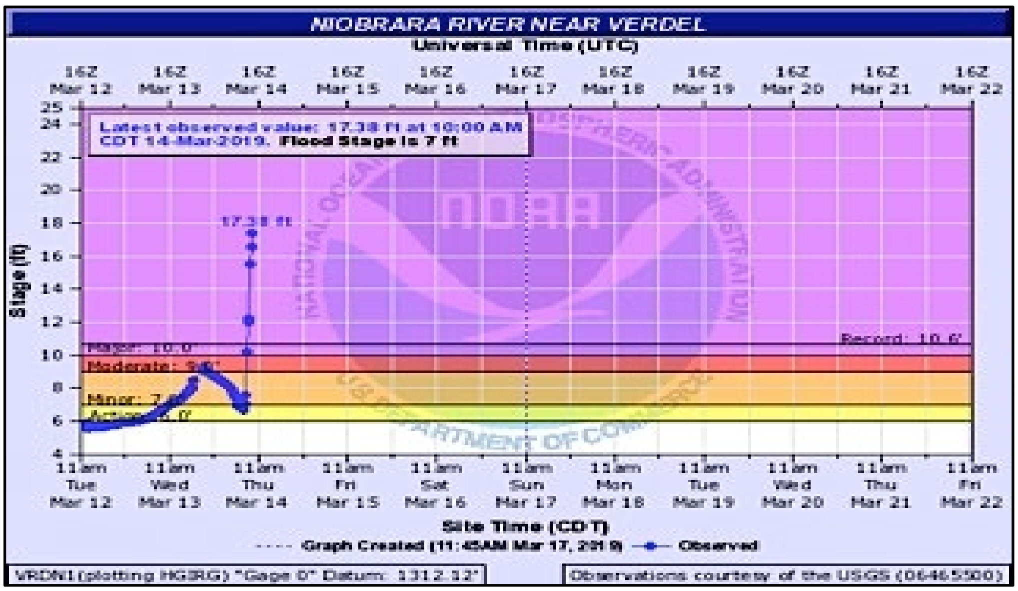


Figure 2. Downstream gage, Niobrara River near Verdel, NE hydrograph showing the Spencer Dam failure (Source: NOAA NWS AHPS webpage on March 14, 2019)

5. Comparison of Crests and Discharges for 1993 and 2019 at Hermann, Missouri

Typical Midwest flooding is generally caused by snowmelt in the higher mountains and by snowmelt and rainfall in the plains. Later in the spring and summer, heavy rainfall also cause flooding. Figure 3 overlays the hydrographs at Hermann for 1993 and 2019.

In 2019, significant rains started the night of March 12 in eastern Nebraska, southern South Dakota and western Iowa, in addition to heavy snowmelt runoff from the Rockies and plains resulted in major flows into the Pick-Sloan reservoirs requiring significant releases downstream. Rain fell on snow pack that was on top of frozen ground. This impervious condition resulted in the rain and snowmelt to almost entirely flow directly into creeks and waterways that eventually empty into the Missouri River. Flows from Nebraska's Platte River (the largest contributor), peaked at an estimated 250,000 CFS, twenty-two times the river's March average. This amount was almost equal to the Missouri River's flow where the Platte meets it just south of Omaha. The early snowmelt flooding, as seen on the hydrograph in Figure 3, shows the flood peak in late March/early April due primarily to snowmelt. Later in the spring in early May, tremendous rainfall occurred, culminating with the 8th-highest crest for Hermann on June 7, 2019 at 33.52 feet and a peak streamflow of 403,000 CFS.

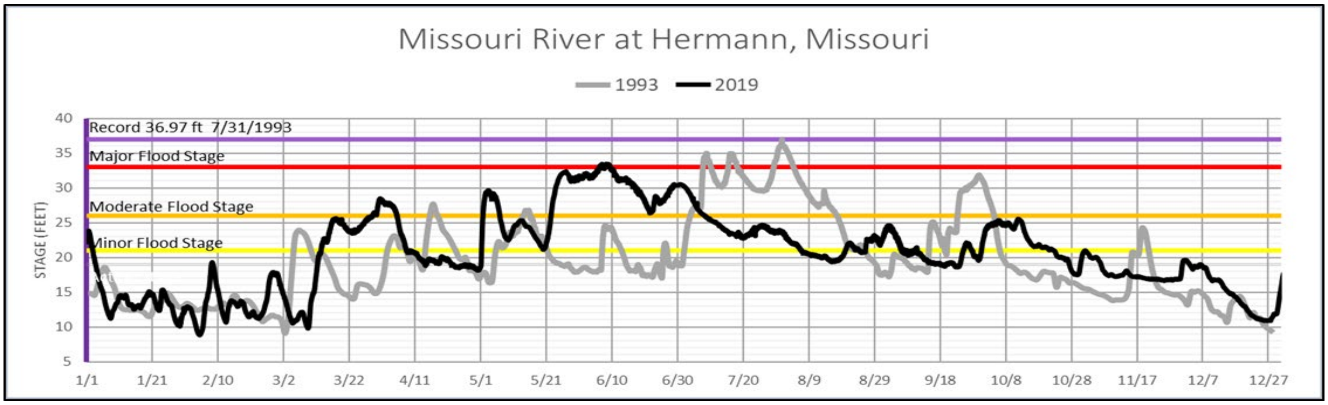


Figure 3. Hydrographs of the Missouri River at Hermann for 1993 and 2019 (data source: USGS)

The 1993 floods were caused primarily by prolonged epic summer rainfall in the Midwest, with little snowmelt from the plains or the Rockies. The worst damage was on the lower Missouri River downstream of the major Missouri mainstem dams. The heavy and continuous summer rains caused delayed crests in late July and early August with several additional significant crests on into late summer and even early fall. The record crest at Hermann, Missouri occurred on July 31st at 36.97 feet and a discharge of 750,000 CFS. About 1500 levees were over-topped (NOAA 1994), damaged or destroyed with 15 million acres of farmland being inundated. This could have had a lowering effect on the eventual crest that occurred on the 31st of July.

The 1993 flood is both a record in peak streamflow and stage as shown in Tables 1 and 2. These tables show the variability of streamflow and stage. The top 20 stages vary by 10%, while the top-20 peak streamflows vary by a staggering 86%. It is somewhat surprising that the flood of 2019 ranks only eighth in the list of highest observed crests at Hermann (see Table 1). If one ranks by the peak streamflow, 2019 falls to 20th on the list (see Table 2). This shows how stage-discharge ratings can change at high flows. Table 3 compares 2019 to several past events and shows the wide variability of streamflow and stage at Hermann. Note that the 1973 flood had a discharge of 500,000 CFS with a stage of 33.70 feet, just about 0.18 feet higher stage than 2019. The 1951 flood with a discharge of 618,000 CFS and a stage of 33.33 feet had much more flow, but was 0.19 feet lower than 2019. While the 1961 flood had nearly the same discharge (405,000 CFS), it had a lower stage by 2.92 feet of 30.60 feet when compared to 2019.

Table 1. Historical Crests Ranked by Stage for Hermann, MO

Rank	Peak Stage feet	Peak Discharge CFS	Date
1	36.97	750,000	31-Jul-1993
2	36.22	579,000	19-May-1995
3	35.79	549,000	05-Oct-1986
4	35.62	515,000	04-May-2017
5	35.50	700,000	June 1844
6	34.82	468,000	29-Dec-2015
7	33.70	500,000	25-Apr-1973
8	33.52	403,000	07-Jun-2019
9	33.33	618,000	19-Jul-1951
10	33.14	457,000	01-Jun-2013

(Source: USGS)

Table 2. Historical Crests ranked by Discharge for Hermann, MO

Rank	Discharge CFS	Stage feet	Date	Rank	Discharge CFS	Stage feet	Date
1	750,000	36.97	31-Jul-1993	11	487,000	31.20	29-Jun-1947
2	700,000	35.50	June 1844	12	473,000	29.15	07-Jun-1935
3	676,000	29.50	07-Jun-1903	13	468,000	34.82	29-Dec-2015
4	618,000	33.33	19-Jul-1951	14	457,000	33.14	01-Jun-2013
5	579,000	36.22	19-May-1995	15	445,000	31.42	13-Apr-1994
6	577,000	30.90	28-Apr-1944	16	435,000	29.62	28-Jun-1942
7	550,000	31.20	21-May-1943	17	415,000	32.85	25-Feb-1985
8	549,000	35.79	05-Oct-1986	18	407,000	24.60	08-Jun-1929
9	515,000	35.62	05-May-2017	19	405,000	30.60	10-May-1961
10	500,000	33.70	25-Apr-1973	20	403,000	33.52	07-Jun-2019

(Source: USGS)

Table 3. 2019 Flood comparisons for Stage and Discharge at Hermann

Water Year	Discharge CFS	Stage feet	Difference feet	Difference CFS
2019	403,000	33.52	-----	-----
1993	750,000	36.97	3.45	347,000
1973	500,000	33.70	0.18	97,000
1961	405,000	30.60	-2.92	2,000
1951	618,000	33.33	-0.19	215,000

(Source: USGS)

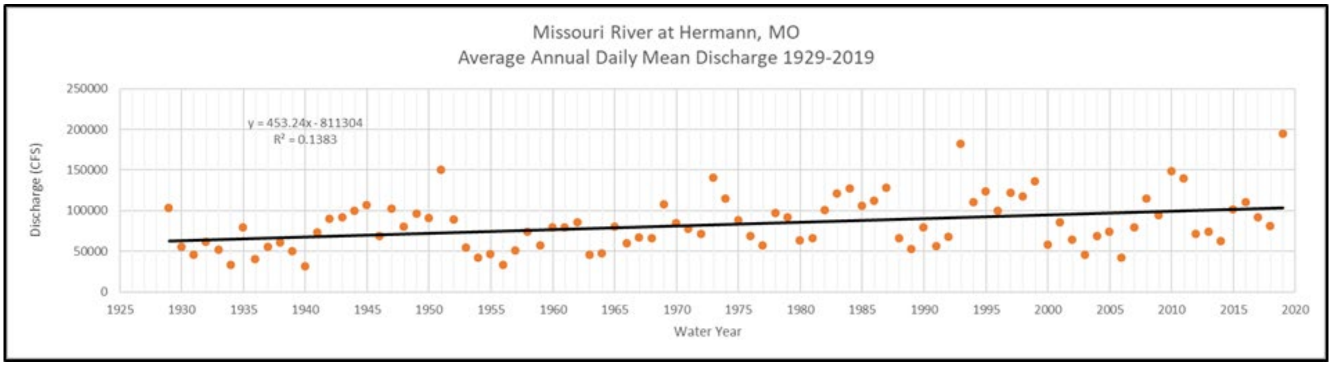


Figure 4. Average Annual Daily Mean Discharge 1929-2019 (data source: USGS)

As shown above in Figure 4, the trend line for average daily mean discharge at Hermann for the last 90 years shows a slight positive upward trend. This shows an annual daily mean discharge increase of about 453 CFS per year or 0.6% of the long-term average. This is the same long-term increase in flow as found by Larson and Schwein (2004). They also showed an annual basin increase in average precipitation of about 0.7% per year. So, average annual flow at Hermann is apparently increasing at a rate nearly equal to the average increase in basin precipitation. There are other possible causes of increased annual discharge at Hermann and these are discussed in Section 7.

Figure 4 also seems to suggest a fairly obvious sinusoidal curve with a period of about 10 years for mean annual daily discharge. It would appear that on average, there is about 5 years of rising mean annual daily discharge followed by about 5 years of descending mean annual daily discharge. Further examination of these data in this regard would be interesting.

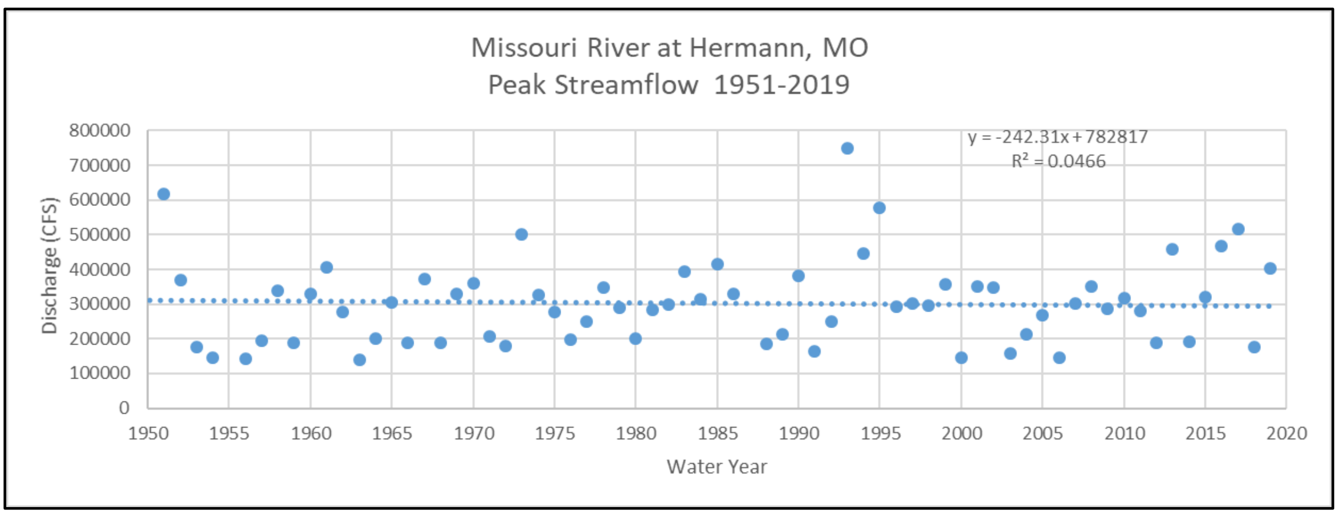


Figure 5. Annual Peak Streamflow at Herman, MO 1951-2019 (data source: USGS)

As shown in Figure 5, the trend line for peak streamflow is nearly horizontal, but it does shows a very slight increase in average peak discharges. The peak discharge for 1993 can easily be seen, while the 2019 peak discharge is not as noteworthy. As expected, the higher the annual streamflow, the higher the peak discharge.

Figure 6 below shows monthly mean discharge at Hermann for 1993 and 2019. In both 1993 and 2019, the average mean discharge for May through September are well above the long-term average (1957-2019). In addition, it can be seen that the trend for Missouri River flooding begins in early spring (March) and continues on through early fall (September) with the peak season being June and July. As was discussed earlier, these are the months when spring high-level elevation and rainstorms begin. The highest flows usually occur in June and July when there is some snowmelt runoff but the annual thunderstorm peak is underway across the Missouri Basin.

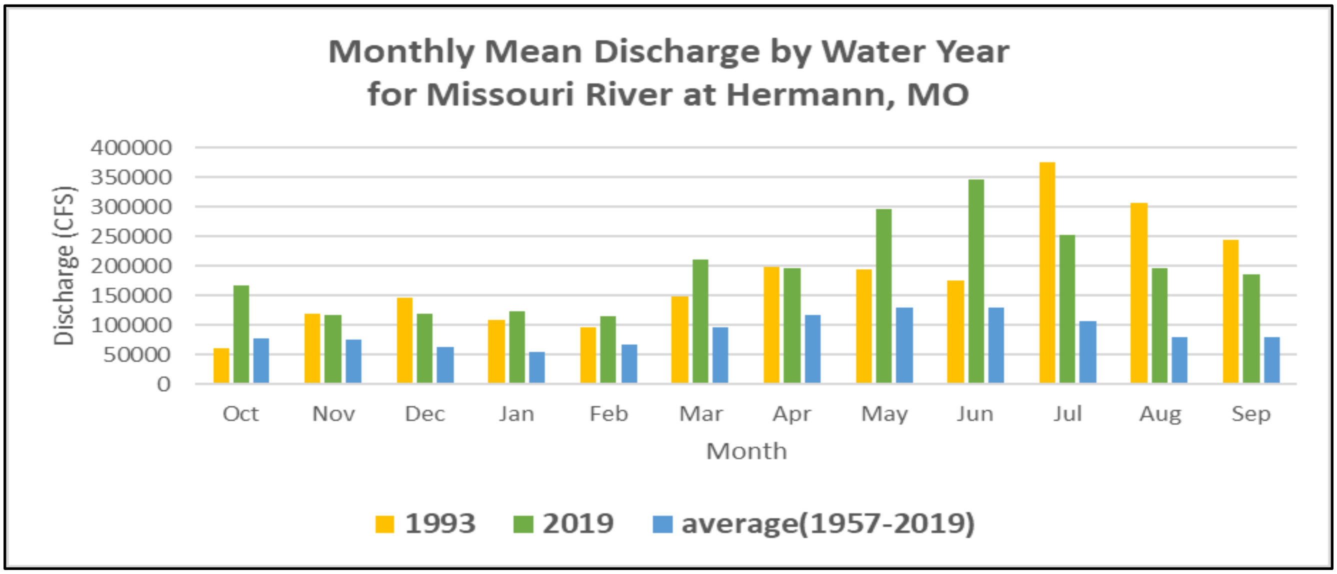


Figure. 6. Monthly Mean Discharge by Water Year for 1993 and 2019 compared with long-term average (data source: USGS)

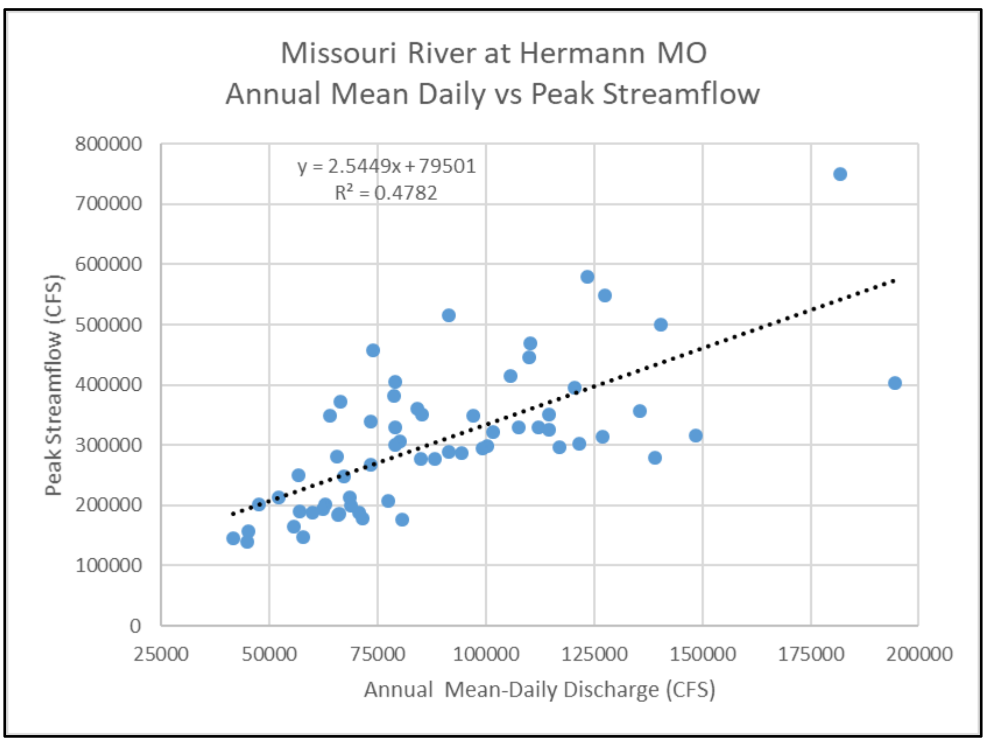


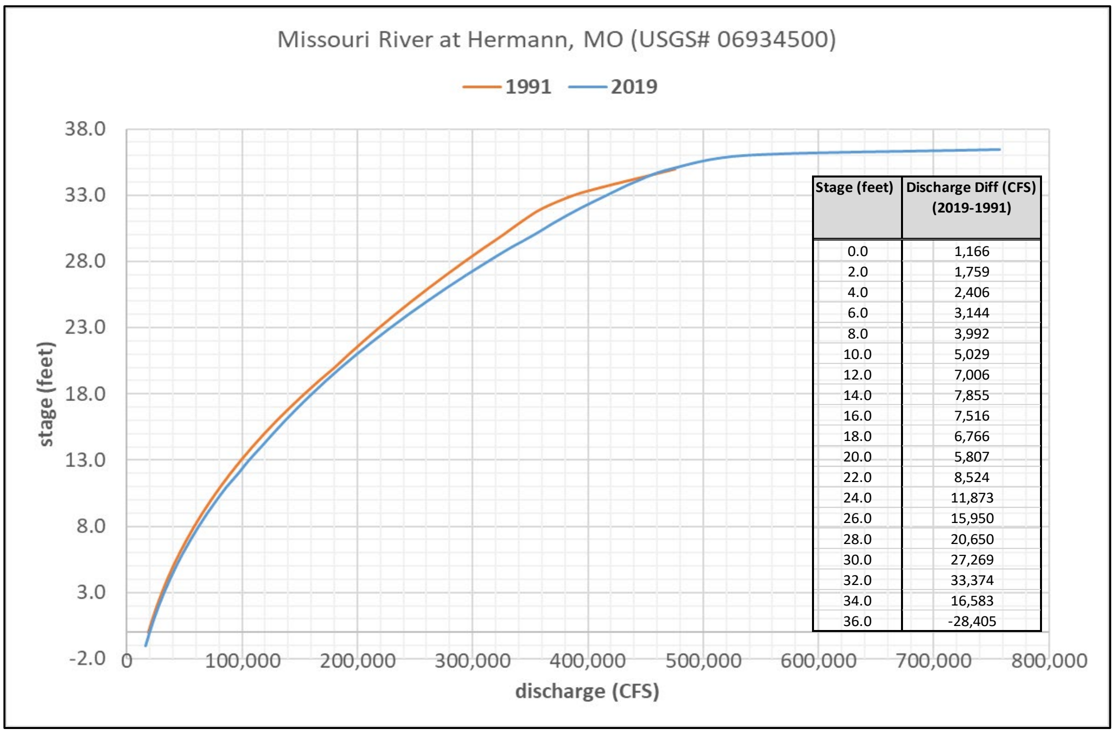
Figure 7. Annual Mean Daily Discharge vs Peak Streamflow at Hermann, MO (data source: USGS)

Figure 7 shows peak annual streamflow versus annual mean discharge at Hermann. It is logical that the higher the peak flow, one would expect the higher the mean annual discharge. This is shown in this plot and a relatively high correlation coefficient (0.51). There is wide variability in the relationship between peak streamflow and annual mean discharge. For example, at a peak stream flow of 400,000 CFS, the annual mean daily discharge ranges from 80,000 CFS up to 160,000 CFS. It is interesting to note that peak flows are, on average, about 2.8 times the mean daily discharge. This could perhaps be used to forecast what the ultimate maximum discharge may be later in the year.

6. Rating Curve Issues

River Forecast Centers (RFCs) forecast river floods with hydrologic models. These models simulate the flows in the rivers, at the forecast points, in cubic feet per second (CFS). In order to convert the CFS flows into stages, a stage-discharge relationship is necessary at each forecast location. The stage-discharge relationships can change with time and need to be updated continuously. It is especially difficult to convert a discharge at record flows to record stages because the stage-discharge relationship must be extended into gage heights not previously seen.

The base stage-discharge relationship, i.e., rating curve, as mentioned earlier, changes over time. The Missouri River is known for its sandy bottom channel, where the channel scours and fills as the streamflow increases and decreases. Changes to the flood plain, such as levees, often affect the high streamflow portion of a rating. Figure 8 shows two ratings, the base rating from 1991, and the base rating from early March 2019 for the Missouri River at Hermann, Missouri. These are just two examples of relationships used in converting flow (CFS), which the RFC's hydrologic models produce, to stages (feet).



Stage (feet)	Discharge Diff (CFS) (2019-1991)
0.0	1,166
2.0	1,759
4.0	2,406
6.0	3,144
8.0	3,992
10.0	5,029
12.0	7,006
14.0	7,855
16.0	7,516
18.0	6,766
20.0	5,807
22.0	8,524
24.0	11,873
26.0	15,950
28.0	20,650
30.0	27,269
32.0	33,374
34.0	16,583
36.0	-28,405

Figure 8. Rating curve for Missouri River at Hermann, MO- USGS# 06934500
(Source: USGS data from MBRFC files)

Prior to the flood of 1993, the highest stage of record occurred on Oct. 5, 1986 at 35.79 feet with a peak discharge of 549,000 CFS. The peak discharge of record prior to the flood of 1993 occurred on June 7, 1903- it was a peak discharge of 676,000 CFS with a peak stage of 29.50 feet. The Great Flood of 1951 (July 19, 1951) was a close 2nd with a peak discharge of 618,000 CFS and peak stage of 33.33 feet. According to Pescatore (1994), the rating curve then in use leading up to the 1993 flood only went to

36.0 feet/566,000 CFS – any observations above that stage meant the rating curve would need to be extended. On the other hand, the 2019 had the advantage of the 1993 peak streamflow data as well as other significant flood events that occurred in the intervening years. In his paper, Pescatore mentions several forecast difficulties. The stage-discharge relationships, i.e., rating curves, were the top challenge followed by backwater, levee failures and/or overtoppings, scouring and deposition of the river channel, and automated gage problems and failures.

Forecast river stages are what the public and emergency managers use to make life- and property-saving decisions. Forecast river stages determine what roads may need to be closed, where evacuations may need to occur, what facilities are in danger, etc. As an example, using Figure 8, it can be seen that at say, a stage of 32 feet, the discharge to produce that stage varied by a flow of 33,374 CFS between 1991 and 2019. As a result stage-discharge relationships at every forecast point must be continuously monitored and updated as necessary.

7. Comments and Conclusions

Forecasting flood crests (timing and height) is critical for emergency managers, public officials, business owners, farmers and the general public in order to prepare for flooding. Levees may need to be raised, equipment moved out of harm's way, cattle and personal belongs may be moved and so on. But, having the ability to forecast an entire hydrograph is also important. The entire hydrograph is important because it gives users a timeline of when to expect the crest, how long they have to prepare and when the flooding may drop below flood levels. The recession side of the hydrograph is just as important as it gives users information as to when they can begin recovery operations.

The Missouri River floods of 1993 and 2019 were two of the most destructive floods of the last 100 years or thereabouts. The 2019 flood was the result of heavy spring rains on frozen soil combined with rapid snowmelt and already heavy flows in the Missouri River mainstem; one might say a typical springtime, early summer flood. The 1993 flood was the result of midsummer heavy rainfall continuing thru the fall with the river remaining above flood stages into late summer and early fall. Both floods caused massive damage to towns, farmland, levees and transportation. Upstream reservoirs lowered record crests in both cases. An examination of long-term trends, both in precipitation and average flows shows slight increases with time. However, peak streamflows from 1958 to 2019 show remarkable consistency with only a very slight increase. Figure 6 showed the tendency of major floods occurring in the spring and again in the fall. Figure 7 showed that when record peak flows do occur, there is a fairly wide variability with corresponding average annual flows. While these two floods standout among all the Missouri River floods of the last 100-plus years, there will be more record floods in the future.

It was shown in this paper that average annual flows and probably basin-wide precipitation, are slowly increasing on the Missouri River at and above Hermann, Missouri. The annual average increase in discharge appears to be about 0.6% per year. As was pointed out previously, this apparent increase seems relatively close to that found by Larson and Schwein (2004). A slow increase in annual flows at Hermann does seem to be occurring for a variety of possible causes.

Possible causes for increasing flows at Hermann could be:

- Actual increase in basin-wide average annual precipitation.
- Increased levee protection for cities and farmland and agricultural practices such as an increase drain tile installation results in more flow reaching Hermann

- Channel change that provide faster flows due to dredging and eliminating some river meandering thus reducing time available for evaporation and groundwater recharge.
- General overall reduction in flood-plain access for high flows.

It should be pointed out that some studies say the flow of significant rivers, in general, have experienced reductions in annual flows. Those reductions are attributed to climate change, reduced precipitation, and an increase in demand for agricultural and municipal needs. However, a study by Nohara, et al. (2006), that included 24 major river basins around the world, found that the projected annual mean discharge of the Mississippi Basin (of which the Missouri Basin is a part of) is increasing by 0.2% per year. This is in line with what is identified in this paper.

The peak stages at Hermann in 1993 and 2019 differed by roughly 3.45 feet and peak flows by 347,000 CFS. An examination of the hydrographs show two distinct types of major Missouri River flooding. The first type is driven by late winter/early spring snowmelt, combined with spring/summer rain (2019). The second type is primarily driven by major summer thunderstorm complexes (1993). The only thing for sure is the Missouri River will see similar, if not larger, floods in the future. To quote Mark Twain, who 137 years ago said, "You cannot bar its path with an obstruction which it will not tear down, dance over and laugh at." Twain was referring to the Mississippi River but it also applies to the Missouri River.

9. Acknowledgements

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