COMPARING FLOOD STAGE-DISCHARGE DATA---BE CAREFUL!

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The chronic complaint of the hydrologic engineer is the lack of sufficient data, particularly gaged discharge data. Consequently, when measured long-term discharge data are available, one relies on it heavily. Statistics are developed and analyzed, trends in stage or discharge relationships are studied, and specific changes in high or low stages are identified. When records are very long, and if the adjacent floodplain or upstream watershed has changed significantly, different flood events having similar peak discharges but different flood crest elevations or stages are often compared. Inferences are then made about what man has or has not done to the river's flood regime. Such has been the case for the Mississippi River at the St. Louis, Missouri, gage.

Discharge data have been taken since 1866 at the gage, located 179.6 mi (289.0 km) above the mouth of the Ohio River and 15 mi (24 km) downstream of the Missouri River. Highwater marks from floods dating to 1785 are also available. With 200 yrs of flood stage information and 120 yrs of discharge data, one might think that little additional information is needed to analyze flood potential and how man has affected flood stages. In fact, several private analyses of these data have been made since the record flood of 1973, attempting to show how man has severely increased flood stages by his floodplain occupation and particularly with his levee construction. About 156 mi (251 km) of the Mississippi River Valley now receive a high level of flood protection by levees, stretching from Alton, Illinois on the north, river mile 202.7 (326.1 km) to Thebes, Illinois on the south, river mile 46 (74 km). The gage is in the narrowest reach of the river, with the leveed floodway averaging about 2200 ft (671 m) in width.

The levees throughout this reach have borne the brunt of criticism regarding the so-called "man-made flood" of 1973, when the twelfth largest flood in terms of discharge passed the St. Louis gage at the highest stage on record (Table 1). No one can argue that levees don't increase flood levels upstream of their location, or that part of the record increase was not due to the levees. However, the 4-8 ft (1.2-2.4 m) increase in stage found by comparing the 1973 discharge to flood flows occurring 30-100 yrs ago is an exaggeration of the levee's effects. Many other items play a significant part in the stage increases. These items can be broken into three distinct categories---the validity of historical data used for comparisons, homogeneity of stream data throughout the period of comparison, and the natural variation in modern discharge measurements.

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Historical Data. The first measured discharge at St. Louis was taken in Aug 1866 by the City Engineer. The Corps of Engineers began flow measurements in May 1872, and continued until this function was transferred to the U.S.Geological Survey in 1933. The most accurate method of obtaining velocity measurements, the Price current meter, was not used exclusively at St. Louis until 1930. This method is still the preferred technique for measuring velocities today. Thus, 1930 can be considered the breakpoint between modern and historic methods of discharge measurement.

TABLE 1

Twelve Highest Discharges at the St. Louis Gage

Rank	Discharge (cfs)	Date	Stage (ft)	How Measured*
1	1,300,000	1844	41.3	E
2	---	1785	40.7	HWM
3	1,146,000	1892	36.0	M,F
4	1,055,000	1858	37.2	E
5	1,054,000	1855	37	E
6	1,022,000	1851	36.7	E
7	1,019,000 +	1903	38	F +
8	896,000	1881	33.2	F
9	889,000	1927	36.1	F
10	863,000	1883	34.8	F
11	861,000	1909	35.3	F
12	852,000	1973	43.3	PCM

* M-meter, unknown type; F-float; E-estimated from 1903 flood and stage-discharge relationship; PCM-Price current meter; HWM-highwater mark

\+ Estimated from Chester and Thebes gage measurements and adjusted to St. Louis

To compare stages from modern discharge records to those from historical floods, one should first know if earlier measurements are compatible with modern data. Historic measurements of velocity at St. Louis were taken by timing various floats moving on the surface or at different depths. The Corps commissioned the University of Missouri-Rolla to evaluate historical methods of discharge measurement (1), investigating the accuracy of the techniques and the need for any adjustments to historical discharge data. The UMR study was conducted over two years and examined discharge measurements at low, medium and high flows using the historic gaging techniques and comparing the results to a base measurement using today's methods. UMR's findings concluded that skilled streamgagers could take acceptable discharge measurements using any of the different historical methods. Acceptable measurements were taken by the UMR study to be within 10% of the base value. Since the majority of measurements were within 10% of the base value, the study recommended that no adjustments to the historic data be made. However, analysis of only the high in-bank and flood flow measurements found that historical techniques consistently over-estimated flood flows compared to the base method, using the Price current meter. Comparison of high flow measurements taken during the tests resulted in 42% of the measurements with historic techniques being more than 10% over-estimated and in 83% being more than 5% over-estimated. From these findings, one could conclude that historical measurements of flood flows are too high.

While historical flood data will not be adjusted, these discharges are almost certainly higher than actual flows. The flood flows examined during the UMR studies only ranged from 400,000-650,000 cfs (11,300-18,400 cms), respectively, about one-third and one-half of the 1844 estimated discharge. These flood flows were over-estimated by 5% in 83% of all measurements and by 10% in 42% of all measurements. Discharges of 2-3 times this magnitude could be even further over-estimated. It would seem prudent to treat all flood discharges taken prior to the start of modern gaging methods as simply historic data, with published values being at least 5-10% higher than the actual discharge. One need only look at Table 1, using the date for the start of modern gaging practices, and compare the number of large floods occurring before and after that date. There are 10 events in the previous 86 yrs with discharges exceeding the 852,000 cfs (24,100 cms) measured at the crest of the 1973 flood. Only the 1973 flood has reached this discharge in the 55 yrs since 1930. The probability of this sequence is remote.

Record Homogeneity. Even if one were to arbitrarily reduce the historic flood discharges for comparison with more recent events, could the differences be pinpointed to one or two causes? The problem of non-homogeneous records becomes important. Man's effects have greatly influenced both the stages and discharges measured throughout the recording period, and differences in stage are seldom the result of any one change. Table 2 provides a list of items affecting stage and discharge records during the recording period.

TABLE 2

Some Causes of Stage Variations

Natural	Man Induced
Time of Year	Land Use Changes
Vegetation	Reservoirs
Water Temperature	Bridges
Riverbed Configuration	Levees
Multiple Peak Floods	Channel Stabilization
Sediment Load	Water Transport Facilities
Flow Measurement Error	Industrial Encroachments
Measurement Techniques	Flood Plain Clearing
Rising/Falling River	

Land use changes in the 697,000 sq mi (1,805,000 sq km) watershed upstream of St. Louis have undoubtedly changed the runoff pattern and volume. For instance, the Missouri River Basin has changed from 5% agricultural, 5% pasture and 90% forest and other land use in 1860 to 36% agricultural, 34% pasture, 8% forest and 22% other land use in the late 1960's (2). The conversion of land for agricultural purposes has likely increased the amount of runoff for given rainfall events compared to earlier time periods. The first bridge across the Mississippi was built in 1874 at St. Louis and there have been 10 more added through 1985. All affect flood stages by some finite amount.

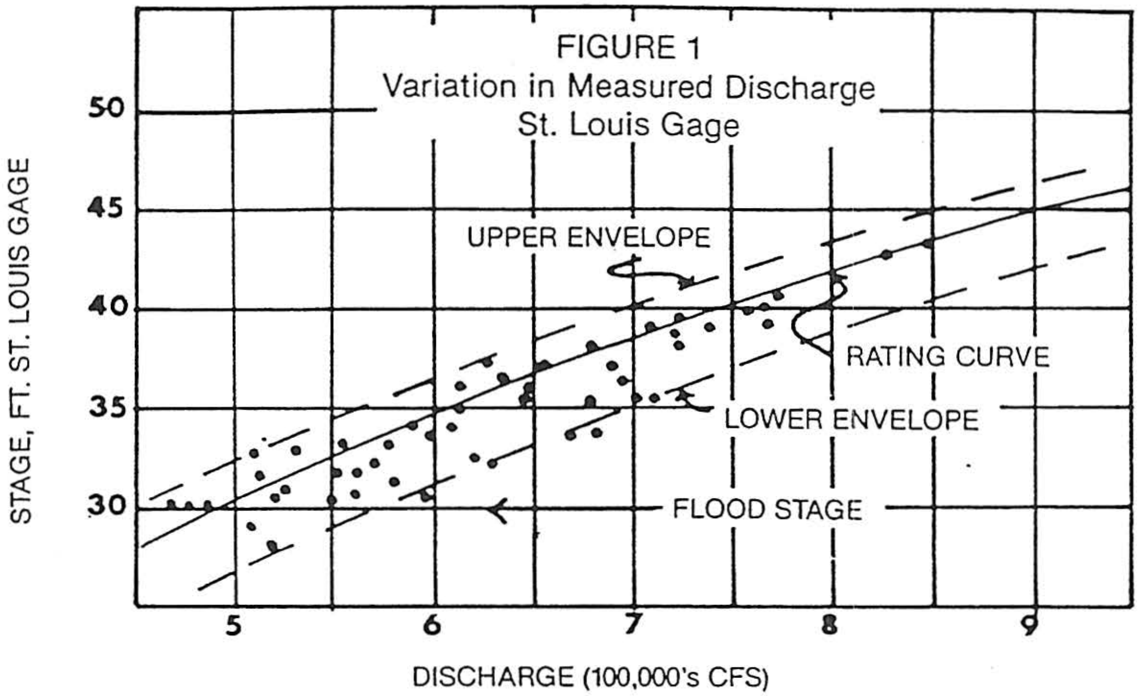
The channel geometry of the Mississippi between the Ohio and Missouri Rivers has changed drastically, from a relatively narrow and deep channel in the 1820's to a wide and shallow river in the 1880's back to a narrow, deep channel today. The widening was due to the extensive bank clearing and floodplain deforestation during the early to mid-1800's, with the return to a narrower configuration the result of the channel training and navigational improvement program begun in the late 1800's. The overbank vegetative cover has been greatly reduced by converting the timbered and swampy floodplain to agricultural usage. The first levee in the St. Louis area was built by local interests in the 1890's, and continued intermittently through the 1940's until the Corps of Engineers provided a uniform system during the early 1950's. Upstream flood control reservoirs have reduced the flood discharges past St. Louis since the 1950's. There are now 45-50 Corps reservoirs on tributaries of the Mississippi River upstream of St. Louis. Peak flood stages today are reduced an average of 3-4 ft (0.9-1.2m) by these structures, compared to the stages that would have been experienced before the 1950's. Landfills, wharves, and industrial development have also served to somewhat obstruct flood flows past St. Louis. It becomes obvious that a homogeneous record has not existed for most of the 120+ yrs of gage record. Thus, it has been the practice of the St. Louis District to use only the time since the 1950's to approximate a homogeneous record. The last three decades reflect a fairly stable stage-discharge relationship at the gage, with the Federal levee system in place and most of the flood control reservoirs on line. The comparison of a flood stage-discharge relationship in 1980 to one in 1940 or 1900 indicates a trend, but does not show that the entire difference in the stages for different floods are due only to levees.

Variation of Modern Data. It is well known that man affects flood stages with his works---levees, reservoirs, channels, diversions, bridges, and urban development. Less well known is the fact that stages can vary without any help from man. Figure 1 shows measured flood discharges for all significant flood events occurring at the St. Louis gage since the 1950's, a relatively homogeneous period. A comparison of the rating curve, derived by the USGS, with the plotted discharge values shows the variation that routinely exists. The upper and lower envelope curves show about 5 ft (1.5 m) of variation, based on actual floods. Using the envelope values at selected points gives the data in Table 3.

TABLE 3

Ranges of Stages for Measured Flood Discharges
Flood Stage is 30 ft.

For Measured Discharges of	Recorded Stages Have Varied from	to
510,000	26.9 in 1965	32.5 in 1947
630,000	32.1 in 1960	37.3 in 1983
710,000	35.4 in 1983	38.9 in 1973



From the extension of the envelope curves, it is apparent that the 852,000 cfs (24,100 cms) measured at 43.3 ft on the St. Louis gage in 1973 could have passed at stages 2 ft (0.6 m) higher or lower. Do the variations in stages for similar discharges represent acceptable accuracy? For all USGS stream gages, an accuracy rating is assigned to the discharges. This rating is: "excellent"--±5%, "good"--±10%, "fair"--±15%, or "poor"--greater than 15% variation. St. Louis gage records are currently rated "excellent", which indicates that 95% of the daily discharges are within 5% of the actual discharge. Even with "excellent" accuracy, Fig 1 shows that significant variations in stage exist when compared to earlier measurements using the same gaging methods. While these differences may reflect only accuracy limits, the water temperature, time of year, and vegetation also affect the stage of a flood. Colder water carries more sediment than warm water, often causing scour and some smoothing of bed geometry. Floods in late winter or early spring may experience considerably different channel geometry than similar flood discharges occurring in summer. No accurate accounting for these differences now exists, therefore it must be an unknown when floods from different years are compared.

An outstanding example of flood crest variation under homogeneous conditions occurred during the December 1982 to May 1983 period, as shown in Table 4.

Table 4
Flood Crest Comparison

Date	Stage (ft)	Measured Discharge (cfs)
4 May 1983	39.3	707,000
7 Dec 1982	38.0	739,000
8 Apr 1983	36.6	714,000

Three different floods passed the St. Louis gage at distinctly different elevations, although discharges were very similar. Of particular note is the April-May comparison. Although the floods were only 4 weeks apart, the May crest was 3 ft (0.9 m) higher than the April crest. Over the past 10 yrs, different individuals have compared the flood of record in 1973 with slightly lower discharges that occurred 30 yrs earlier and found that the 1973 flood was 4 ft (1.2 m) higher. Their conclusions were that Corps levees raised flood heights by 4 ft (1.2 m). As seen, if there can be a 3 ft (0.9 m) variation between similar flood discharges only 4 weeks apart, how much of the 4 ft (1.2 m) difference 30 yrs apart is due to man's levees and other works, and how much is due to the natural variation in the river, the limits of gaging accuracy, and natural effects of temperature, vegetation, etc? Such questions are difficult or impossible to answer.

Summary. A long term stage-discharge record is extremely valuable data. However, simplified applications of long term records to draw sweeping conclusions about man's effects should be avoided, particularly for a major alluvial river like the Mississippi. Upward shifts of flood ratings are caused by man's works, yet many other factors affect the stages at which a given discharge passes. Comparisons of modern to historic data are frought with uncertainties. Different measurement techniques, man's modifications over the period of record, and the natural dynamics of the river all must be included in analyzing stage and discharge variations for different floods. Even with modern techniques, the river's dynamic nature will cause natural stage variations for a given discharge, and may largely mask the effects of specific flood control works. This paper reflects the findings and opinions of the author and not necessarily those of the Corps of Engineers.

References

1. SLD Potamology Study (S-3), Institute of River Studies, University of Missouri at Rolla, March 15, 1979

2. Potamology Program (P-1), Characterization of the Suspended Sediment Regime and Bed Material Gradation of the Mississippi River Basin, Report 1, Volume 1, Waterways Experiment Station, August 1981.