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The 1973 Flood and Man's Constriction of the Mississippi River

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Naturam expelles furca, tamen usque recurret.—Horace, 20–30 B.C. (*1*).

The news media reported the 1973 Mississippi deluge as a 200-year flood, yet the flow was only a 30-year event (*2*). I analyzed the hydrographic history to find out the reasons for record-breaking stages.

The 1973 flood broke the stage (river level) records between Burlington, Iowa, and Cape Girardeau, Missouri, a distance of 562 km (349 miles). At Saint Louis, Missouri, the flood, which began 10 March, continued for 77 consecutive days, exceeding the record set in 1844 when the river was in flood for 58 days during the entire year. The river crested at Saint Louis on 28 April 1973 at a gage height of 13.18 m (4.03 m above flood stage) and a peak discharge of 24,100 m^3/sec. The stage topped the 189-year record by 0.3 m. The flood peak was 0.61 m higher in 1973 than in 1844 but the discharge was about 35 percent less than the estimated flow for 1844. The 1908 flood had the same flow as the 1973 flood but the peak was 2.51 m lower.

Maher (*3*), Leopold (*2*), and Kazmann (*4*) attribute rise in stage to man-made levees, which confine the water to the channel and prevent it from spreading over the floodplain. Belt (*5*) and Simons *et al.* (*6*) attribute higher stages to a combination of levee confinement and navigation works such as wing dikes, side channel dikes, and revetments, which reduce channel cross section by causing net bank deposition. Increased flooding on the Missouri River has been attributed to navigation works (*7*).

Maximum and minimum annual stages were studied for two rated and six unrated gages on the Mississippi using polynomial time trend analyses. At rated gages both discharge and river stage records are taken, at unrated gages only stage records are. These gages extend over a distance of 129.5 km from Chain of Rocks, Missouri, to Chester, Illinois (Fig. 1). Polynomial time trend analysis of maximum annual discharge was done for Saint Louis and Chester gages. Estimates of the rise in stage from the early 20th century were obtained using plots of stage versus discharge (rating curves), routing the 1927 flood, and differential stage analysis. Changes in average riverbed elevation in relation to flood peaks were studied. Average bottom elevations of a series of sections taken at low water when the discharge was about the same were studied to determine a baseline before and after the peak. Average bottom elevations for higher flows were calculated from records of the U.S. Geological Survey using the same location as the standard low-water section. Finally, the history of man-made modifications of the river was studied to see if they correlated with changes in the river's hydrology.

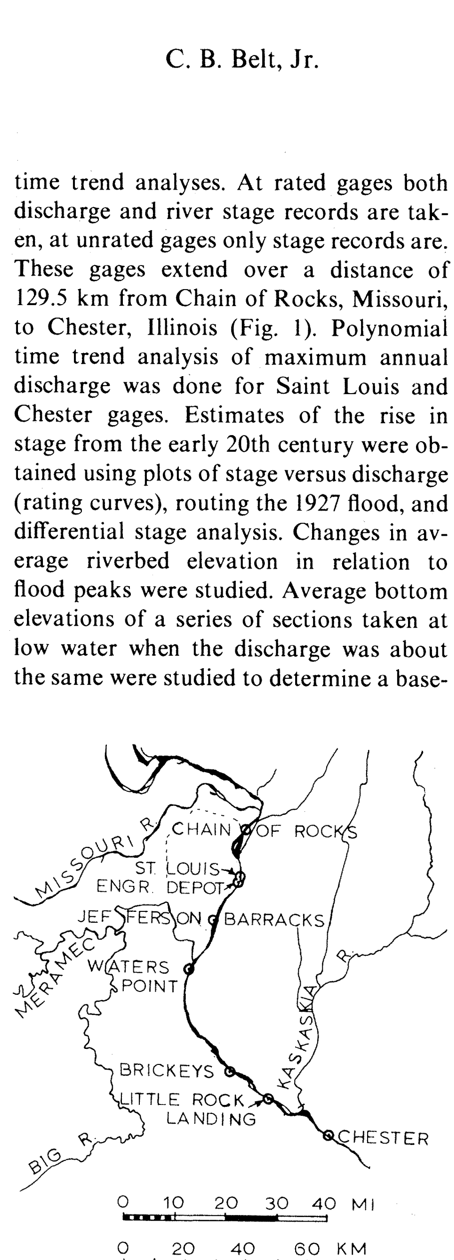

Fig. 1. The Mississippi River and tributaries, showing gage stations from Chain of Rocks to Chester.

Historical Changes in Hydrology

The minimum yearly stages at Saint Louis have been falling since 1865 (Fig. 2A). According to Simons *et al.* (*6*) and Maher (*3, 8*) this results from the downward erosion of the river bottom due to man-induced channel confinement. Man's tampering with the river started in 1837 when Lieutenant Robert E. Lee built the first confinement dikes to remove sandbars threatening the Saint Louis harbor. The river was narrowed by man from 1300 m in 1849 to 610 m in 1907, and finally to 580 m in 1969 (*6, 8*). Channel confinement has taken place over the middle Mississippi from Saint Louis to Cairo, Illinois (*6*). Although the width of the river at one place at Saint Louis was stabilized at about 610 m in 1907 and about 85 percent of the navigation works were constructed before 1909 (*3*), bottom erosion and other hydrologic effects continued until 1930. There were no dams upstream of Saint Louis in 1930, only wing dikes and other navigation works. There appears to have been at least a 20-year lag between the construction of wing dikes and the effects of bank-full widths and bottom erosion.

A plot of average bottom elevations of sections measured when the discharge was about 4930 m^3/sec (the mean flow of the river) was made over time for five stations in the Saint Louis reach. All stations were within a distance of 3.7 km. It is remarkably similar to the time trend of minimum annual stages, showing that at Saint Louis this trend reflects bottom elevation. The time trend of maximum annual stages is flat except for the four large floods in the middle 19th century (and is not statistically significant) (Fig. 2B). After about 1900, there is increased dispersion in the maxi-

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mum yearly stages, with the highest being higher and the lowest stages lower. The time trend for yearly maximum discharge (Fig. 2C) has a similar shape (and is also not statistically significant), but the scatter from the polynomial trend is uniform, showing that changes in stage do not result from changes in discharge.

If the stages below discharges of 11,300 m^3/sec in Fig. 2B are eliminated, there is a significant rise in trend. This discharge is below bankfull for the entire time interval. The higher the cutoff the more the stage rise (Fig. 2D). A flow of 14,200 m^3/sec is close to bank-full discharge for 1973, and 17,000 m^3/sec was close to bank-full discharge for 1881. Thus, the increased dispersion of the time series diagram for maximum annual stage is due to rising high stages accompanied by falling low stages during the period 1870–1973.

The maximum annual stage and associated discharge values for 1861–1927 were plotted in chronological order on log-log paper. The whole sequence was found to lie remarkably close to a gentle curve (Fig. 3), which defines a good baseline. There is a possibility that this may be due in part to the variety of different methods of measuring discharge that were used during this period. Studies of rating curves from this period by Maher (*3*) and Belt indicate that fluctuations between adjacent curves were at most 0.6 m above 9910 m^3/sec. The trend seems to be significant. The estimates are based on the best available information (*9*). Maher's paper (*3*) includes two diagrams that show progressive changes in rating curves from 1861–1927 below 8490 m^3/sec, but very slight changes in rating curves above a discharge of 8490 m^3/sec. This discharge is approximately the point at which the family of rating curves cross. The 1973 preliminary rating curve was plotted for the Saint Louis gage to indicate the net change between the two periods. At bank-full discharge—the flow at flood stage—for 1973 (13,500 m^3/sec) the baseline is 0.9 m below the 1973 curve. This is due to the loss in cross-sectional area of the channel and its discharge-carrying capacity. The bottom erosion caused by the confinement and increased velocity due to a more efficient channel shape did not compensate for the channel narrowing. Instead, the channel's cross-sectional area was reduced by one-third (*6*) and its discharge-carrying capacity by about one-fourth. At a discharge of 24,100 m^3/sec the baseline is 2.4 m lower than the 1973 rating curve (Fig. 3). This was caused by levee confinement, channel narrowing for navigation, and perhaps slight sedimentation. The 1881 rating curve is 3.0 m lower than the 1973 curve at 24,300 m^3/sec. Missouri River dams cut the peak 0.1 m on 28 April 1973. Under 19th-century conditions, the 1973 flood would have been about 2.9 m lower.

A plot of difference in stage of all yearly maxima from the baseline was constructed (Fig. 4). After 1930 there are significant in-

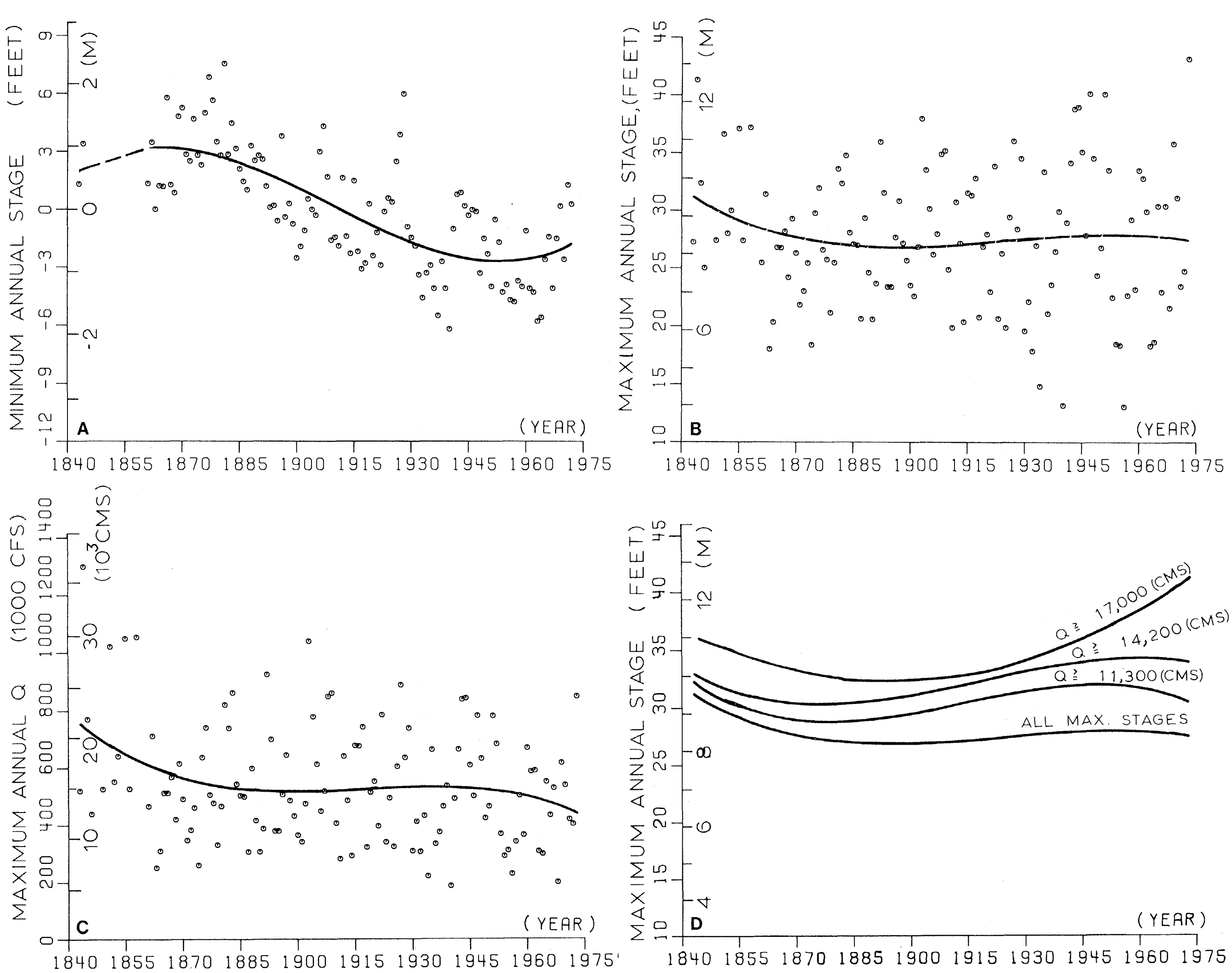


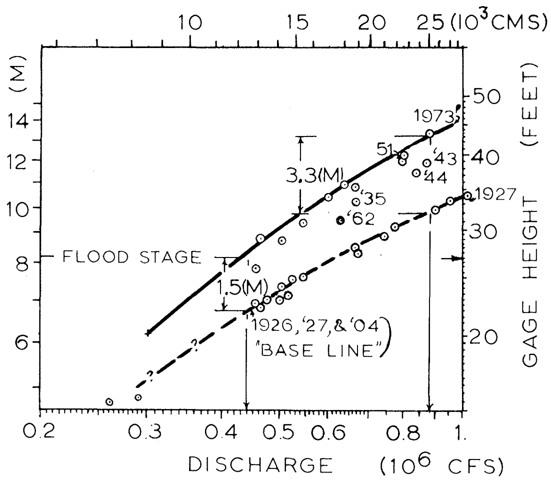
Fig. 2. Time trends at Saint Louis: (A) minimum yearly stages, (B) maximum yearly stages, (C) maximum yearly discharges (Q), and (D) maximum yearly stages with different cutoff values of discharge. Abbreviations: CFS, cubic feet per second; CMS, cubic meters per second.

creases in fluctuations of stage-discharge relations, which can be explained by the large bottom fluctuations and other changes in hydrologic regimen to which the channel is not adjusted. The year 1930 may have been the end of a 90-year erosional phase at Saint Louis and the beginning of a phase marked by large fluctuations in bottom elevation.

A natural alluvial river generally widens its channel in response to large floods (*10*), depending on the relative erodibility of its bed and banks. The width of an alluvial river channel over a long period of time is a function of average discharge, when different rivers are compared, all other hydrological and geomorphologic factors being equal (*10–12*). The Mississippi widened itself between 1803 and 1860 in response mostly to four large floods (*6*). After 1881, it became more difficult for the river to widen itself because of the number of navigation dikes and the bank protection installed for navigation. Total channel widening in response to floods is now insignificant because of navigation works. This man-modified channel is not in equilibrium according to the natural relationships found by Schumm (*10*) between channel shape and sediment load. Man has forced the Mississippi out of the natural dynamic regimen it established since the ending of the Ice Age.

At Saint Louis three different trends in erosion and deposition can be seen. First, there was bottom erosion between 1865 and 1930 (with superimposed bottom fluctuations). Second came a period of bottom fluctuations with about 10-year cycles. Third were the shortest cycles, related to flooding. During the rise in stages in a 4-month period before the 1951 flood at MacArthur Bridge (288.1 km from the Ohio River) 1.8 m of bed was eroded. A 0.3-m rise in bottom occurred just after the peak because of transport of coarse material at or on the river bottom (bedload). A comparable situation was observed by Jordan (*13*).

Erosion occurred on the falling stages 1 week or more after the discharge. Deposition during the next 6 months raised the channel bottom to nearly the same elevation as before the flood. A similar situation was observed at Poplar Street Bridge in 1973 (0.3 km downstream). Maher (*3*) reported on hydrographic surveys of three stretches of river totaling 8.8 km in length between bridges from 3 months before the peak of 21 July 1951 to 9 months later. He concluded that "the river bed fills during and scours after a flood." The bridges confine the river. Bank-full widths are about 560 m under bridges and about 610 m elsewhere. During floods the river scours under the bridges but may deposit in areas of broader channel between. During the winter of 1951–1952 the Missouri River dumped a 6.1-m-high mound of bedload



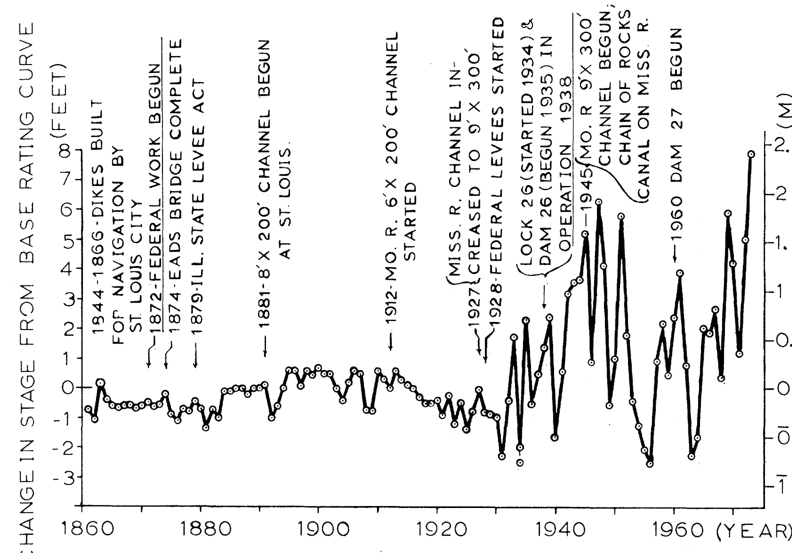
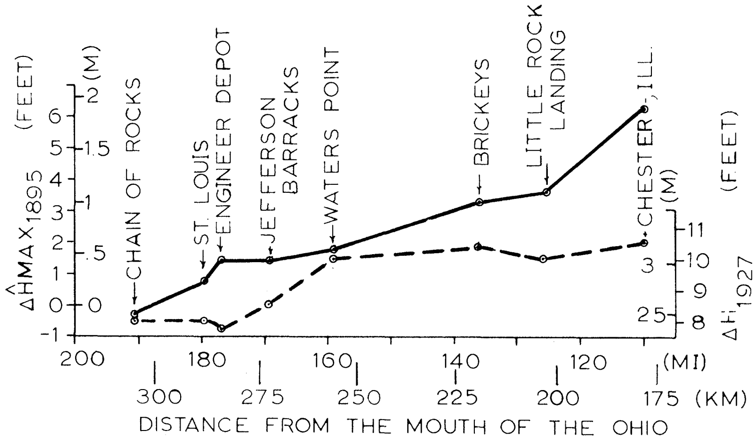


Fig. 3 (left). Maximum annual stage and discharge relations, including base (1861–1927) and 1973 preliminary rating curves, Saint Louis. Fig. 4 (right). Relation of change in stage from base rating curve to time at Saint Louis.



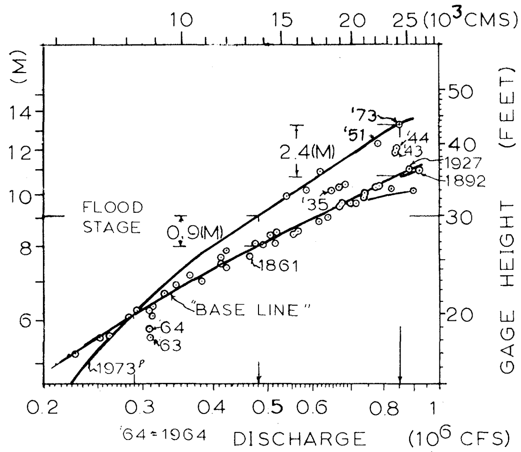


Fig. 5 (left). Relation of difference in stage of 1927 and 1973 flood (ΔH_{1927}) (dashed line) and difference in regression annual maximum stage from 1895 to 1973 ($\Delta \hat{H}\max_{1895}$) to river distance of each gage from the Ohio River. Fig. 6 (right). Maximum annual stage and discharge relations, including base and preliminary 1973 rating curves at Chester.

into the Mississippi; the slug moved downstream (*3*). The Missouri often dumps more material into the Mississippi after floods.

The net rise in stage since 1927 at 24,100 m^3/sec was estimated for six unrated gages in the reach from the Chain of Rocks gage to Chester by routing the 1927 flood. The crest was followed downstream. Two small tributaries, the Meramec River and the Kaskaskia River, did not contribute a significant discharge to the river for the 1927 flood. Subtraction of 1927 from 1973 peak stages gives an estimate of the rise in stages, but the flow of the 1927 flood was 25,200 m^3/sec. Small correction factors were calculated from the slope of the baseline at the nearest rated gage and added to the difference in stage. The 1908 flood was also studied. The average difference between the 1927 and 1908 figures is only 8 percent. The rise in stages increases downstream from Saint Louis (Fig. 5). The difference in maximum annual regression stage between 1895 and 1973 was calculated using a polynomial fit for each station and plotted against river distance from the mouth of the Ohio River (Fig. 5). The difference increases from −0.049 m for Chain of Rocks to +1.9 m for Chester in the same direction as the rise in stages between 1927 and 1973.

A base rating curve (baseline) was constructed for Chester using hydrologic data from 1903, 1906, and 1926–1927 (Fig. 6). All yearly maximums after 1928 lie 0.3 m or more above the baseline. At bank-full discharge for 1973, 12,500 m^3/sec, the baseline is 1.5 m below the preliminary 1973 rating curve. Navigation works have caused a decrease in channel capacity of 5100 m^3/sec. At the peak discharge of the 1973 flood, 24,100 m^3/sec, the two curves are 3.3 m apart, indicating a net rise in stage since 1927. This is due to levee confinement and navigation works. The time trends of minimum yearly stage and bottom elevation are flat and undulating (not statistically significant). The river was apparently not confined enough to significantly lower bed elevations as at Saint Louis. Unlike the trend at Saint Louis, this time trend has a significant and marked upward slope and a calculated increase in maximum annual stage of almost 2 m since 1892. This trend is mainly affected by channel changes, as is the case for Saint Louis.

The errors in rise in stage calculations probably range from 10 to 25 percent and are largely due to errors and uncertainties in the published discharge figures.

Hypothesis of Historical River Response

There are several possible causes for the dramatic changes in hydrology of the Mississippi. Channel confinement caused downward erosion until about 1930 at Saint Louis. After that date there were severe bottom fluctuations. According to Leopold and Maddock (*12*) and Schumm (*10*), natural alluvial streams transporting a high percentage of bedload have wide, shallow channels. Channel confinement makes the channel unnaturally narrow and deep in relation to sediment load. Upstream dams (*6*) and navigation works (*14*) apparently reduce suspended sediment load. Dams tend to stop bedload almost entirely, but the streams erode downstream and pick up bedload again. There has been a reduction in suspended load at Saint Louis since 1948; most of the suspended load comes from the Missouri River (*6, 13, 14*).

Increased velocity due to change in channel shape and to both levee and channel confinement may make the Missouri, and the Mississippi from Saint Louis to Cairo, Illinois, even more efficient transporters of bedload than they were under early 19th-century conditions. Navigation locks and dams on the upper Mississippi probably cause channel deposition of bedload during periods of low flow. When the gates are open during floods there may be a slight flushing action. The slight deposition of bedload in the middle Mississippi from this area and the much more important contribution of bedload from the Missouri River may explain the deposition during flood peaks found by Maher (*3*).

Under natural conditions, the Mississippi eroded its bottom and banks during flood peaks, making room for some of the floodwaters. The rest spilled out over the natural reservoir, the floodplain. Since 1837, the channel has lost about a third of its volume (*6*) so now, during a flood on the man-modified Mississippi, the stages are higher for a given discharge. In some reaches of the river deposition occurs, causing a further rise in stages. Excess floodwater tries to spill over the floodplain but, hemmed in by levees, flood crests are forced even higher. As flood stages rise, the effect of channel confinement is diluted in the increased flows. Even at the peak flows of the 1973 flood it is probably still significant, although less important in rising stages than levees. The transport of bedload during and shortly after flood peaks causes rises in stage. The system, in disequilibrium, fluctuates wildly. Navigation works and levees make big floods out of moderate ones.

Conclusions

The progressive constriction of the Mississippi for navigation since 1837 has caused bottom erosion in some stretches. In others the bottom oscillates up and down with time. The high stages rise much more rapidly. Constriction of the river channel causes flooding and makes floods higher; thus navigation works degrade the protection afforded by levees. The combination of navigation works and levees causes significant rises in the stages of floods. Additional channel constriction and levee building will cause further problems. The 1973 flood's record was manmade.

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