

STAGE TRANSMISSION
IN THE LOWER MISSISSIPPI RIVER

by

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The popular belief that a flood crest advances with great and destructive speed in excess of ordinary stream velocity, and that its rate of advance accelerates the higher the stage, does not appear to be true for large rivers. This belief is correct, however, as applied to precipitous mountain streams of the closely confined canyon type and generally to small streams flowing in narrow valleys where valley storage is either greatly restricted or amounts to little more than channel storage. These conditions bear no analogy to flood-wave movement in large rivers flowing in wide valleys, reference being made here more especially to those of the alluvial type whose overbank flow and valley storage assume importance. The study here presented was confined to observations made in the Lower Mississippi River, a stream of the alluvial type.

The rate of speed with which changes in stage are transmitted down the Mississippi River below Cairo appears to be controlled principally by the rate at which water is either abstracted through channel and valley storage during an advancing flood wave or returned to the channel by inflow from such storage during falling stages. Mean velocity of flow appeared to have no direct relation to stage transmission. A change of stage at low water was usually found to be transmitted with a speed appreciably in excess of the mean velocity of flow. This speed may even exceed that of the thread of maximum surface velocity. Furthermore, a change in low-water stage, whether rising or falling, nearly always was found to travel more rapidly than the crest of a great flood. A high stage, on the other hand, is transmitted at a speed much less than the mean velocity of flow. Conditions quite analogous obtain on rivers like the Po in Italy and the Rio Grande in North America.

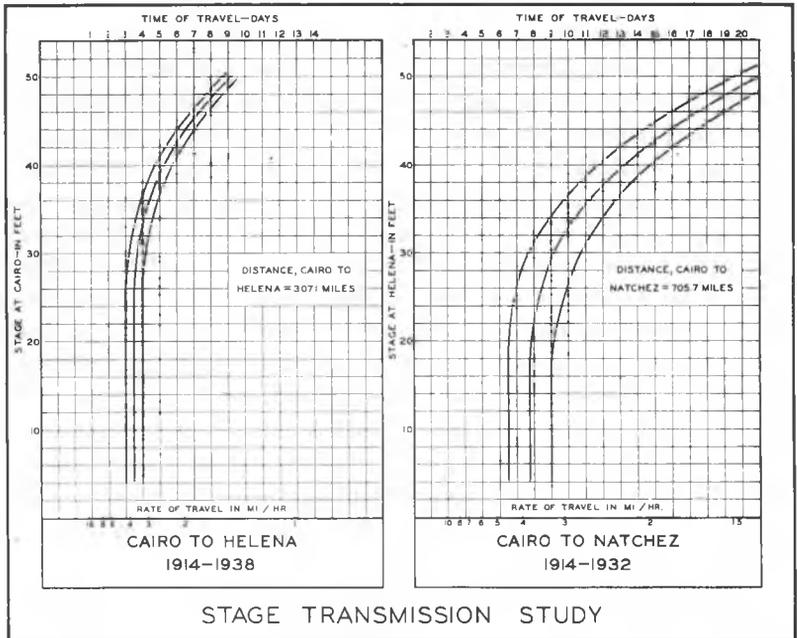
The first reach that will be discussed extends from Cairo to Helena, the second from Cairo to Natchez. The study was not carried below Natchez as the river there tends to assume tidal characteristics. A third study will be shown indicating the difference in time of travel between Arkansas City and Natchez before, and also after, the river became shortened by means of cut-offs. The eleven cut-offs made in this reach have shortened it about one-third of its length which in 1929 was 299 miles and today is 191 miles.

It was found advisable to consider long reaches rather than short ones as the latter showed too much time-distortion when affected by strong winds, local rains or local inflows. Long reaches minimize the effects of these disturbing factors and were found to give more consistent time-of-travel values for all stages. Both crests and troughs were used because they are the only pronounced features in stage hydrographs that could readily be traced through from station to station. At first, a distinction was made in plotting between crests and troughs; however, no difference could be found in their respective times of travel. Crest and trough data therefore were used indiscriminately in fixing the location of the curves. Only in a few instances were hourly readings available, as for instance at the crest of a great flood like that of 1937. Aside from these rare cases the study was made throughout on the basis of 8 a.m. gage readings. The errors so introduced affect time rather than stage, and this was a further reason for dealing with long reaches.

Inflow from tributaries was studied to determine if it affected the time of arrival of a crest or trough, and all cases obviously distorted by heavy tributary inflows were eliminated from consideration. The data were plotted showing time interval in days against stage, the latter being either the gage reading at the upper end of the reach or that of a gage intermediate between the two ends of the reach.

Two curves were drawn for each reach enveloping the great majority of the plotted points. The time-spread between these enveloping curves is somewhat less at the lower stages than at the higher stages. The curves usually were drawn a uniform distance apart horizontally above a stage of about 30 feet, and were tapered off to a smaller time-spread at the lower stages. An average curve was then sketched midway between the enveloping curves for use in correlating the several studies with each other.

Fig. 1 shows the number of days required for stages, ranging from the lowest to the highest, to travel down the Mississippi River from Cairo to Helena, a river distance of 307 miles. In this stretch no large tributaries enter. However, there are contributions from the St. Francis, Obion, and Forked Deer rivers and from several smaller streams. For stages between 8 and 22 feet on the Cairo gage,



FIGS. 1 AND 2.

fluctuations in stage are transmitted downstream to Helena with much uniformity, varying from 3 to 4 days. This is at an average speed of 3.7 miles per hour (5.4 ft./sec.), although the mean velocity of flow at low water is only from 2 to $3\frac{1}{2}$ ft./sec. At stages over 30 feet on the Cairo gage valley storage begins to take a heavy toll of the river's discharge due to the water spreading out over large bars and islands, and also to a portion of the flow then filling up abandoned channels. At 40 feet on the Cairo gage the Mississippi flows bankful and stage transmission requires 5 to 6 days to reach Helena, the movement being at an average rate of $2\frac{1}{2}$ miles per hour (3.7

ft./sec.), although the mean velocity of flow is well in excess of this, usually ranging between 4 and 5 ft./sec. During extreme flood stages, say around 50 feet on Cairo gage, the volume of water that leaves the river channel overbank to pass into valley storage becomes very large. This causes the crest stage, or for that matter any material fluctuation in stage, whether up or down, to take 9 days to reach Helena. This is more than $2\frac{1}{2}$ times as long as for a 10-foot stage, namely at the very slow rate of travel of 1.4 miles per hour (a little over 2.0 ft./sec.), and in marked contrast with the 6 to 7 ft./sec. mean velocity of flow and the 9 to 13 ft./sec. maximum surface velocities which prevail in the river at a 50-foot stage. The data utilized were taken from the 25-year period, 1914 to date.

Fig. 2 shows the time of stage transmission between Cairo and Natchez platted against Helena gage readings, Helena being about halfway in this 706-mile stretch of river. Below Helena the White and Arkansas rivers have their mouths. Their joint discharge at times reaches high figures and required careful study in order to eliminate distortion in the rate of stage transmission. Discarding all excessive distortions, the diagram was plotted in the same manner as in the preceding case and enveloping curves were drawn as before. However, the spread between the curves had to be increased to $2\frac{1}{2}$ days for less than bankful stages and to 3 days for overbank stages in order to take care of the irregularities introduced by the inflow of the Arkansas and White rivers. At Vicksburg the Yazoo River enters, but its flow is seldom so appreciable as to cause serious distortion in the time of transmission.

This study shows a nearly uniform average speed of $3\frac{3}{4}$ miles per hour (5.5 ft./sec.) up to a 20-foot stage on the Helena gage, which is nearly the same rate as for the Cairo to Helena reach. For higher stages the time required increases rapidly. The values are seen to range from $7\frac{3}{4}$ days for low stages to 11 days for a 35-foot stage, and to 21 days for a 50-foot flood crest. The latter's movement, therefore, is 2.84 times slower than for a low-water stage. These rates are in close agreement with those for the Cairo to Helena reach. In the preparation of this diagram the period 1933 to date was omitted as the effect of the cut-offs below the mouth of the Arkansas River has changed the rate of transmission quite appreciably.

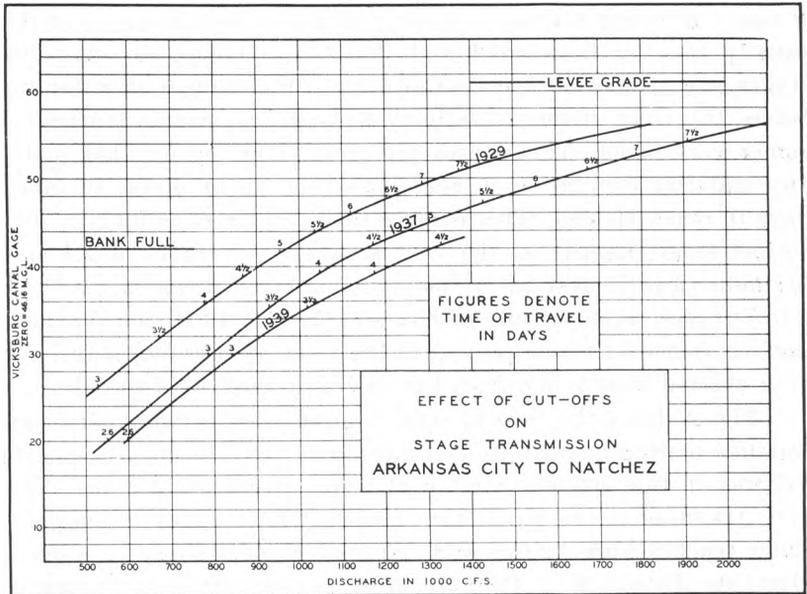


FIG. 3.

Fig. 3 compares the time of travel between Arkansas City and Natchez before and since the cut-offs were made. It shows the average rating curve for Vicksburg gage (stage discharge relation) for 1929, before cut-off operations were begun, and also the average rating curves for 1937 and 1939 when most of the cut-offs had become sizable channels. The stage-lowering at Vicksburg is represented by the vertical intercept between rating curves and amounts to as much as 8 feet for discharges in the neighborhood of 1,200,000 c.f.s. For this discharge the time of travel is seen to have decreased from $6\frac{1}{2}$ days in 1929 to $4\frac{1}{2}$ days in 1937 and to 4 days in 1939, a total saving in time of 2 $\frac{1}{2}$ days. For the smaller discharges the diagram shows a reduction of only 1 day. The diagram was not extended below 500,000 c.f.s. for the reason that at low water no appreciable diminution in time of travel was found to take place. How much of the shortening in time of stage transmission has resulted from channel shortening and how much from decreased valley storage cannot be readily ascertained. The situation is complicated by the fact that the lowering in flood stages has not been uniform throughout the reach under consideration. The lowering

amounts to 15 feet at Arkansas City and tapers off to 8 feet at Vicksburg, and to 2 feet at Natchez.

One reason why stage transmission of flood crests has not been speeded up more by the river shortening than here shown is attributable to the fact that during high stages an appreciable flow still follows around the old bends at the cut-offs. The cut-off channels themselves have not yet developed to the extent of carrying the entire flood flow, except in two instances. Until all the cut-offs become large enough to carry the entire flood flow, no clear-cut picture can be obtained of the true shortening in time of stage transmission effected by the cut-offs.

An attempt was made to determine how much the time of travel of flood crests on the Mississippi River has changed since the advent of high levees. A study was made of the flood of 1858, at which time daily gage readings were taken at a number of gages which have been maintained unto the present time. In 1858 the levees, generally, were low and not continuous. Through the gaps floodwaters could escape into the low valley lands. The valley storage in 1858 was so great that it caused the crest to flatten completely by the time it reached the mouth of the Arkansas River, below which point the flood hydrograph during high stages showed a nearly horizontal line over a period of nearly 3 months at all stations down the river. The enormous overbank losses of water caused the crest of the 1858 flood at first to become greatly retarded and finally to disappear entirely. Stages of from 35 to 40 feet on the Cairo gage took from 2 to 6 days longer to reach Helena than under present conditions. On the other hand, the time of travel for stages below 15 feet on Cairo gage, that is, well below banks, did not differ appreciably from present-day conditions, showing that the river channel in those days was much the same as it is today.

No attempt was made to study the time of stage transmission in the tidal reach of the Mississippi River from Angola to the mouth. It is known that stage transmission there travels at high rates of speed, in fact, the movement is so rapid that it cannot be computed from gage readings taken once a day. Recording gages are being established in this reach as rapidly as bridges are being built, and in time these gages will make it practicable to determine the time element accurately.

As the effect of valley storage has been repeatedly referred to

as constituting a controlling factor in the rate of stage transmission

for overbank stages, Fig. 4 is presented indicating the increment in valley storage in cubic feet per second per day for each foot of stage on the Helena gage. These increments are for the reach extending from Memphis to Helena, in which as yet no cut-offs have been made. It will be seen that up to 20 feet on the Helena gage the increment of storage per foot of stage is quite small, amounting to 20,000 c.f.s./day or less. It increases to about 200,000 c.f.s./day for a change of stage from 46 feet to 47 feet, and to as much as 500,000 c.f.s./day for 1-foot stage increments in the neighborhood of 60

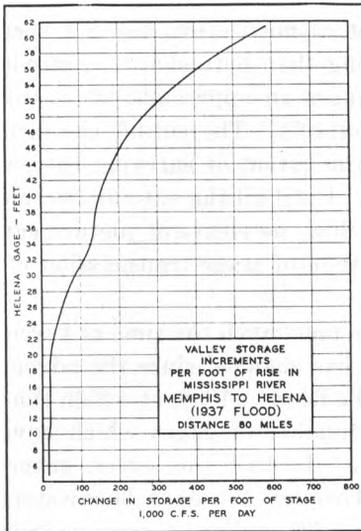


FIG. 4.

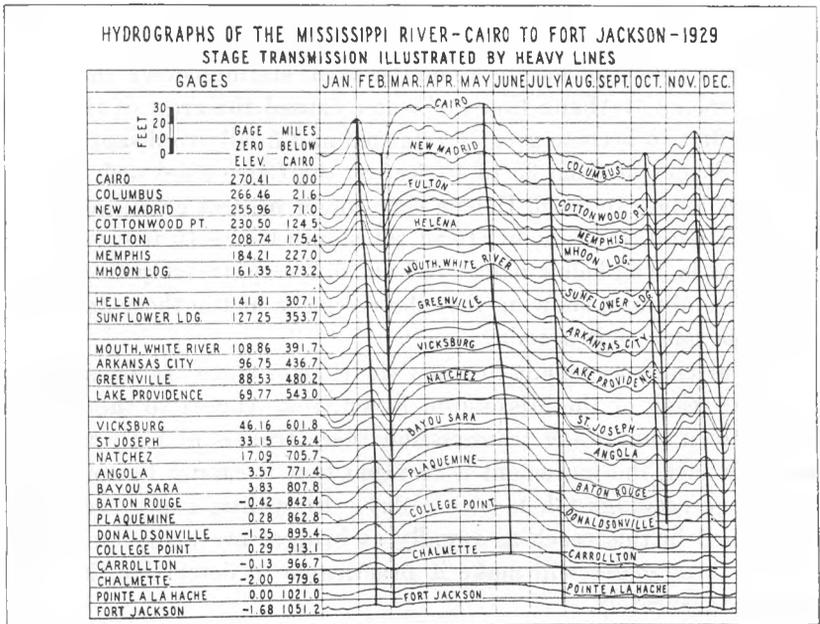


FIG. 5.

feet. These figures, although they do not give total amounts of valley storage, afford some idea of the huge losses of water which the river sustains in its travel from Memphis to Helena, a distance of 80 miles.

For the purpose of visualization, there are shown in Fig. 5 hydrographs of the Mississippi River for stations between Cairo and New Orleans for the year 1929. The hydrographs are arranged in descending order downstream and permit of tracing the movement of a crest as well as of a trough. To facilitate this, heavy lines have been drawn tracing crests and troughs. Some are representative of high stages and some of low stages. The respective inclinations of the heavy lines afford a visual means of comparing the rates of progression, the lines that slant the most indicating a slower rate of travel than do those which descend more nearly vertically. It will be noted that in the bottom portion which covers the tidal reach, the heavy lines descend vertically in nearly all cases. In some instances the time of travel appears to be slightly negative, due probably to tidal action.