EFFECTS OF NAVIGATION-DAM OPERATING PROCEDURES ON MISSISSIPPI RIVER FLOOD LEVELS

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ABSTRACT

The effects of navigation-dam operating procedures on flood levels in the reach of the Mississippi River between Dams 13 and 15, upstream from the Quad Cities, is described. The results of a computational investigation show that the procedure established by the Corps of Engineers for operating the gates at the navigation dams causes no increase in the crest levels of large floods over that which would occur if the gates were completely opened well in advance of the flood.

FOREWORD

The study described in this report was conducted by a group of Research Engineers at the Iowa Institute of Hydraulic Research, The University of Iowa. The computations were performed by Drs. S. T. Hsu and F. A. Locher and several graduate students under the supervision of Prof. W. W. Sayre, who wrote the report. The whole project was under the general supervision of Prof. J. F. Kennedy, Director of the Institute.

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Background

The upper Mississippi River nine-foot navigation project has converted the Mississippi River above St. Louis into essentially a series of pools during periods of low and normal flows. Navigation dams, each consisting of a row of gates mounted between piers over a low sill, are used to maintain depths sufficient for navigation all along the river. During periods of low river flow the gates are lowered to hold water levels at the elevations required for navigation. During periods of high flow, the gates are completely opened because they are no longer needed to maintain the required navigation depth.

Many people have suggested that flood crests could be significantly lowered by completely opening the gates well before the arrival of the floods to let as much water as possible out of the pools. According to the U.S. Army Corps of Engineers, the agency charged with the responsibility for operating the navigation dams, this would not lower the flood crests. Because this question comes up again each time a flood threatens, the North Central Division of the Corps of Engineers requested the Iowa Institute of Hydraulic Research to undertake an independent investigation of the effects of gate-operating procedures on flood levels in the upper Mississippi River. The results of this investigation are presented herein.

The Study Reach

The section of river selected for the investigation extends from Dam 15, in the Quad Cities, upstream to Dam 13, which is about five miles upstream from Clinton, Iowa. The entire study reach is 40 miles long and is divided into two pools. The water level in the downstream pool, Pool 15, is controlled by the gates of Dam 15. The gates of Dam 14, which is located 10 miles upstream from Dam 15, regulate the water level in Pool 14. A map of the study reach is shown in Figure 1.

Method of Investigation

The specific objective of the investigation was to compare water levels that occur along the study reach during flood flow conditions for two different gate-operating procedures at Dams 15 and 14. These operating procedures are:

Case 1 — Throughout the normal range of flow discharges the gates at each dam are operated so as to maintain the pool level necessary to provide the depth, specified by law, required for navigation and wildlife conservation. At higher discharges, when the water level just downstream from the dam rises nearly to the water level at the upstream side of the dam, the gates are completely opened. This is the Corps of Engineers' normal operating procedure.

Case 2 — The gates are fully opened, so that they are entirely out of the water, before, during and after the passage of a flood.

In both cases the rate of flow in the river was based on U.S. Geological Survey records of the flow discharge at Clinton for the period of the April-May, 1965, flood.

Computational rather than experimental methods were adopted in the investigation. It was recognized early in the study that the slow rate of movement of the flood wave and the relatively short length of the study reach make the rate of change of storage in the reach very small in comparison to the volume of flow passing through the study sections. Therefore quasi-steady flow conditions could be assumed without any significant sacrifice of accuracy. This assumption effected a considerable simplification because use could then be made of standard techniques for analyzing gradually-varied flow in non-uniform channels. The computational methods together with extensive data describing the physical characteristics of the study reach were used to calculate water surface levels along the reach for several flow discharges covering the range of flows that occurred during the 1965 flood.

This was done for each of the two gate-operating procedures described above. Examples of these water-surface profiles are shown in Figure 2. From the information depicted in these water-surface profiles, graphs showing the variation of stage, or water level, with flow discharge were plotted for selected locations along the study reach. These stage-discharge curves were used together with the April-May, 1965, daily flow discharge records for the Clinton gaging station to plot graphs which show the variation of river stage with time at each of the selected locations. Examples of these graphs are shown in Figure 3.

Results

Consider first the water-surface profiles in Figure 2. The water-surface elevation above sea level is plotted in the vertical direction. River mile (distance in miles upstream from the junction of the Ohio and Mississippi Rivers) is plotted in the horizontal direction. Because the vertical scale is in feet whereas the horizontal scale is in miles, the slopes of the lines representing the water surface are greatly exaggerated. The water-surface profiles shown in Figure 2 are for flow discharges of 125,000 cfs (cubic feet per second) and 270,000 cfs. For reference, the flood stage elevations at several locations along the study reach are shown as crosses. The discharge of 125,000 cfs, although fairly large for the study reach, is less than a flood flow discharge. The discharge of 270,000 cfs definitely represents a flood flow, but is well under the 307,000 cfs peak discharge experienced in the 1965 flood. For comparison, the onset of flood-flow conditions occurs at discharges ranging from approximately 150,000 cfs to 200,000 cfs, depending mainly on location along the study reach. When the Corps of Engineers follows their normal gate-operating procedure (Case 1), the gates at Dames 14 and 15 are opened completely when the discharge reaches about 200,000 cfs. For the discharge of 125,000 cfs, water-surface profiles are shown for the two gate-operating proceudres; the solid line for Case 1 and the dotted line for Case 2, described above. Comparison of the two profiles shows clearly that the amount by which the water surface is raised by the gates decreases with increasing distance upstream from the dams. For example, at Clinton, Dam 14 has almost no effect. For the discharge of 270,000 cfs, there is no difference between the profiles for Case 1 and Case 2, because the gates have been opened fully when the flow discharge reached about 200,000 cfs. Comparison of the 125,000 cfs profile for Case 2 and the profile for 270,000 cfs shows how the water-surface level rises as the flow discharge increases, even when the gates are fully opened.

Consider now the stage versus time graphs in Figure 3. River stage, in feet above the zero point on the river gage for each location, is plotted in the vertical direction. Time, in days of the month for the 1965 flood period, is plotted in the horizontal direction. The solid lines represent the stage for Case 1, in which the Corps of Engineers follows their normal procedure of operating the gates until the flow reaches about 200,000 cfs. The dashed lines represent the river stage for Case 2, in which the gates have been completely opened for two weeks or more before the arrival of the flood. The three graphs show the pool levels just upstream from Dam 15; at 48th Street in Moline, which is about 5 miles upstream from Dam 15; and at Clinton, which is about 25 miles upstream from Dam 14. All three graphs share the characteristic that the solid line and the dashed line join together on the rising limb of the curve, and that they stay together over the peak and do not separate again until the stage has decreased to well below its peak value. This means that the river stage, during the period that the two curves are together, is the same for both Case 1 and Case 2. The curves always join together at or before the time the gates are completely opened, and separate only at or after the time the gates are lowered back into the flow. In the 1965 flood, according to the procedure outlined for Case 1, the gates at Dams 15 and 14 should have been fully opened on April 20 and 21 respectively, and the gates at both dams should have gone back into operation on May 10. During this flood, the gates were actually opened several days earlier. This accomplished nothing more than a shift from the upper curve down to the lower curve. The graphs in Figure 3 show conclusively that the flood levels that occur after the gates have been completely opened are in no way affected by the time at which the gates were opened, regardless of whether this was a day, a week, a month, or even longer, before the arrival of the flood.

Comparing the three graphs in Figure 3, it is seen that the difference between the elevation of the two curves for the periods that the gates are in operation tends to decrease as the distance from the nearest downstream dam increases. Thus at Clinton, which is about 25 miles upstream from Dam 14, the stage is scarcely affected by the manner of gate operation, even at low flows.

A line indicating flood stage is shown for reference on the graphs for Moline and Clinton. Flood stage is defined as that stage, on a fixed river gage, at which overflow of the natural banks of the stream begins to cause damage in any portion of the reach for which the gage is used as an index. The regions between the flood-stage lines and the points where the two curves join together are significant because they represent conditions at which the river level, although at or above flood stage, is still controlled to a slight extent by the gates. Considering the case of a relatively minor flood that crests at a stage within this region, it would be possible, by opening the gates shortly before the river reaches flood stage, to reduce the flood crest by an amount equal to the vertical distance between the two curves. At Moline, for example, the crest of a flood having a peak discharge of about 160,000 cfs could be reduced by about 0.3 ft. by fully opening the gates at Dam 15 when the flow discharge reaches about 150,000 cfs. If the Corps of Engineers followed their prescribed operating procedure, the gates would not be completely opened until the river discharge reached about 190,000 cfs. However, for floods that have peak discharges in excess of that corresponding to the point where the two curves join together (about 180,000 cfs at Moline), no reduction in flood crest would be achieved by opening the gates earlier. The best that could be accomplished would be a short delay, say of a day or so, in reaching flood stage. The estimated maximum reduction in flood crest and the range of discharges within which the crest could be reduced are listed in Table 1 for various locations along the study reach. It should be emphasized once more that where large floods are concerned, opening the gates before the arrival of the flood is no more than a futile gesture.

TABLE 1. Estimated maximum reduction in crest height and range of discharges within which the crest could be reduced.

Location	Maximum obtainable crest stage reduction	Range of discharges in which crest could be reduced
Moline	0.3 ft.	150,000 - 180,000 cfs
LeClaire	0.3 ft.	180,000 - 202,000 cfs
Princeton	0.5 ft.	140,000 - 202,000 cfs
Camanche	0.2 ft.	140,000 - 180,000 cfs
Clinton	0.1 ft.	140,000 - 180,000 cfs

Interpretation of Results

Let us now turn to an explanation of why the navigation dams of the upper Mississippi River are of no use in controlling large floods, and why lowering the water level in the river before the flood arrives is of no help in lowering the crests of large floods. To understand these points, one should appreciate: first, the difference between flood control dams and navigation dams; second, the way in which navigation dams are operated; and finally, the tremendous amount of water which flows down the Mississippi during a large flood in comparison to the limited volume of water that the pools can hold.

A flood control dam, to be completely effective, must be able to impound an amount of water nearly equal to the amount of water that flows down the river during the flood. This requires a high dam and a large reservoir. Navigation dams on the other hand are low structures that impound just enough water at low flows to float the barges and tow boats.

The manner in which navigation dams are operated is illustrated in Figure 4, which shows, going from the bottom illustration toward the top one, successive stages in the gate-operating procedure as the flow discharge increases. The gates are operated so as to keep the pool depths above a certain minimum regardless of flow rate. For the upper Mississippi River this minimum depth is nine feet. As the flow discharge increases, the gates are raised enough to let the additional flow pass under them, and the pool levels remain the same at the dam, but there is an increase in depth toward the upper end of the pool that is required to convey the increased flow through the pool. This process continues until the water levels at the upper end of the pools rise nearly to the water levels in the lower end of the adjacent upstream pool. At this time the gates are removed from the water and the river stages are then no longer controlled. As the discharge increases still further, the water levels continue to rise just as they would if the gates had never been present.

The line at the lower edge of the shaded areas in the illustrations represents the water level that would exist if the gates were removed from the water, and the shaded area represents the amount of water that is stored in the pools by the gates. As the flow discharge increases and the gates are raised, the amount of stored water decreases, so that by the time the gates are removed from the water, no water is being stored by the gates. This explains why completely opening the gates before the arrival of a large flood would not lower the flood crest. Taking the 1965 flood as an example, even if all the pools from Guttenberg to Davenport could have been completely emptied before the arrival of the flood, they would have been filled again during the first 18 hours of the flood. But the flood lasted for some 30 days!

A good way to explain how the dams work is by analogy. Let us compare the river with a bathtub. Open river or natural flow conditions in the river, with the gates fully opened and the pools initially drained, correspond to the situation in which the faucet in the bathtub is turned on and the drain is open. The water level in the bathtub will rise to some height, perhaps as much as two or three inches above the bathtub bottom, depending on the flow rate, where it will remain. The flow rate from the faucet is then equal to that into the drain. Now let us represent the action of the navigation dam gates by a partial blockage of the bathtub drain. Provided that the blockage is not too great, the water level in the bathtub will rise until the tub is perhaps one-half or two-thirds full, at which time the depth of water is such that the flow rate out of the tub again equals that into the tub through the faucet. If nothing is done to disturb this balance, the water will remain at this level and the tub will not overflow. Now to simulate a large flood, imagine that a fire hydrant is brought into the bathroom and uncapped so that all the flow from the fire hydrant goes into the bathtub, and suppose that the flow from the hydrant continues for several hours. Suppose also that the partial blockage of the drain is removed after a short time when the water level in the tub reaches the three-quarters-full mark. This corresponds to the Corps of Engineers' gate-operating procedure. Under these conditions it is obvious that the bathtub will very rapidly become filled and begin to overflow. It stands to reason that the amount of overflow in the bathroom and the rest of the house after, say, one hour will not depend on the level of the water in the bathtub at the time the drain was unblocked. Just as bathtub drains are not designed to cope with fire-hydrant flows, nature has not formed river channels to cope with large flood flows.

Summary and Conclusions

This study was undertaken to investigate the effects of navigation-dam operating procedures on flood levels in the reach of the Mississippi River between Dam 15 in the Quad Cities and Dam 13 a few miles upstream from Clinton, Iowa. Computational methods that are based on well-established principles of engineering hydraulics were employed in the study. The results of the study show that:

(1) When large floods, say those that peak at a discharge of greater than 200,000 cfs, occur in this reach of river, the procedure established by the Corps of Engineers for operating the navigation dam gates causes absolutely no increase in the flood crest level over that which would occur if the gates were completely opened well in advance of the flood.

(2) In the case of smaller floods (those that peak at less than about 200,000 cfs), a reduction in flood crest of between 0.1 and 0.5 ft. depending on location in the reach and the flow rate, could be achieved by opening the gates at Dam 14 when the flow reaches 140,000 cfs, and the gates at Dam 15 when the flow reaches 150,000 cfs.

(3) At all flow conditions the effect of gate-operating procedures on water levels in the river decreases markedly with increasing distance from the nearest downstream dam.

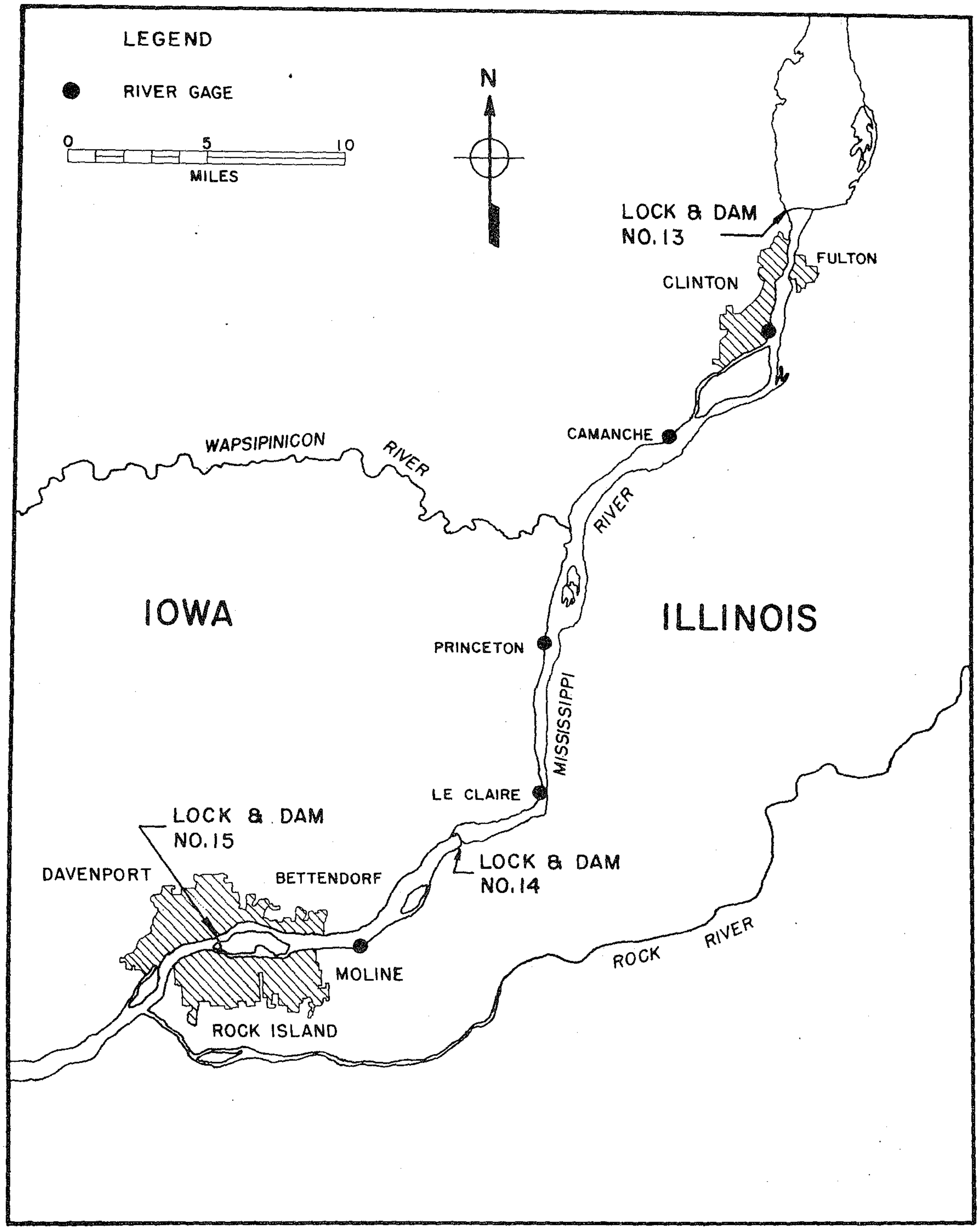

Figure 1. Location map for study reach.

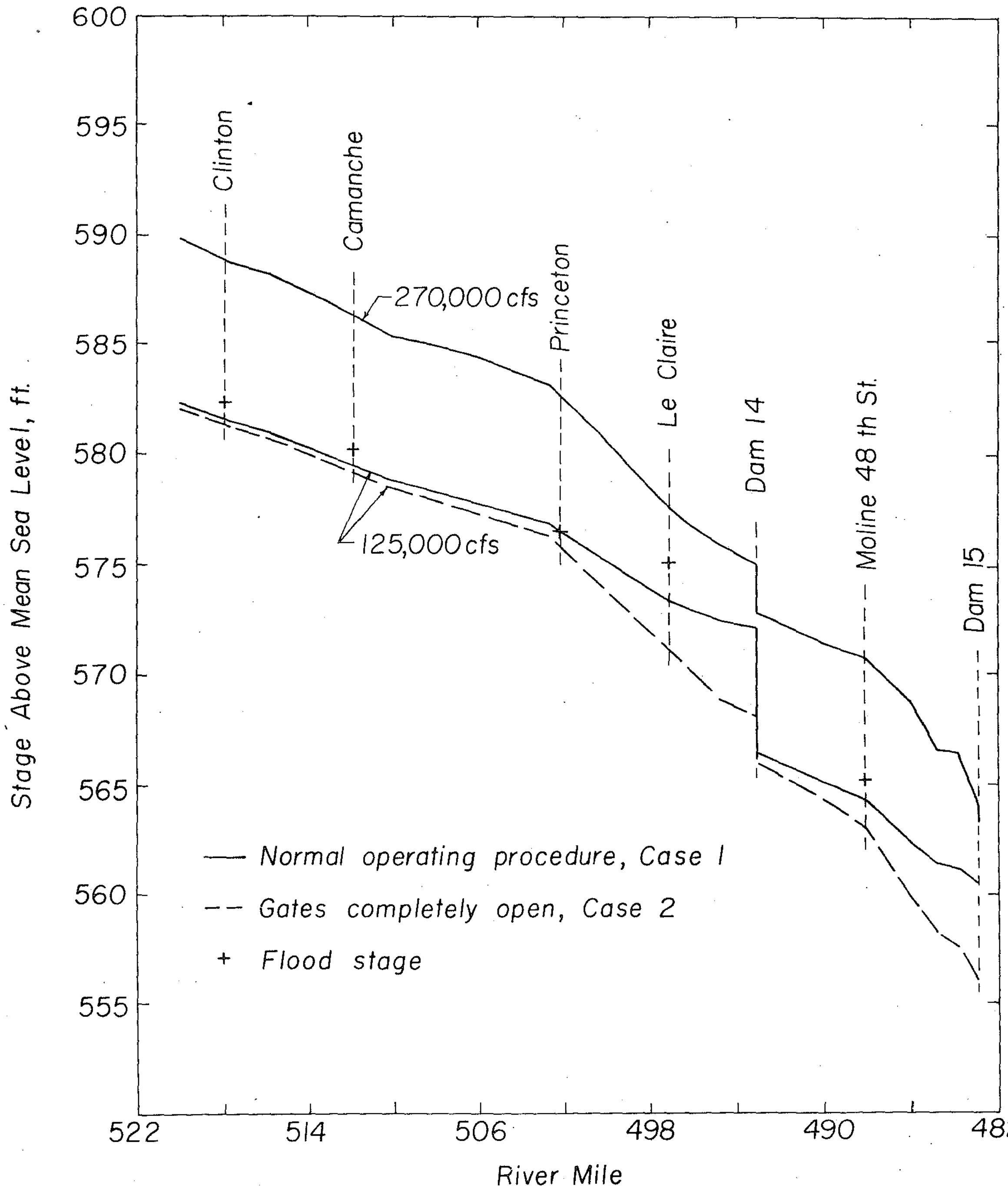

Figure 2. Water surface profiles for different discharges and operating procedures.

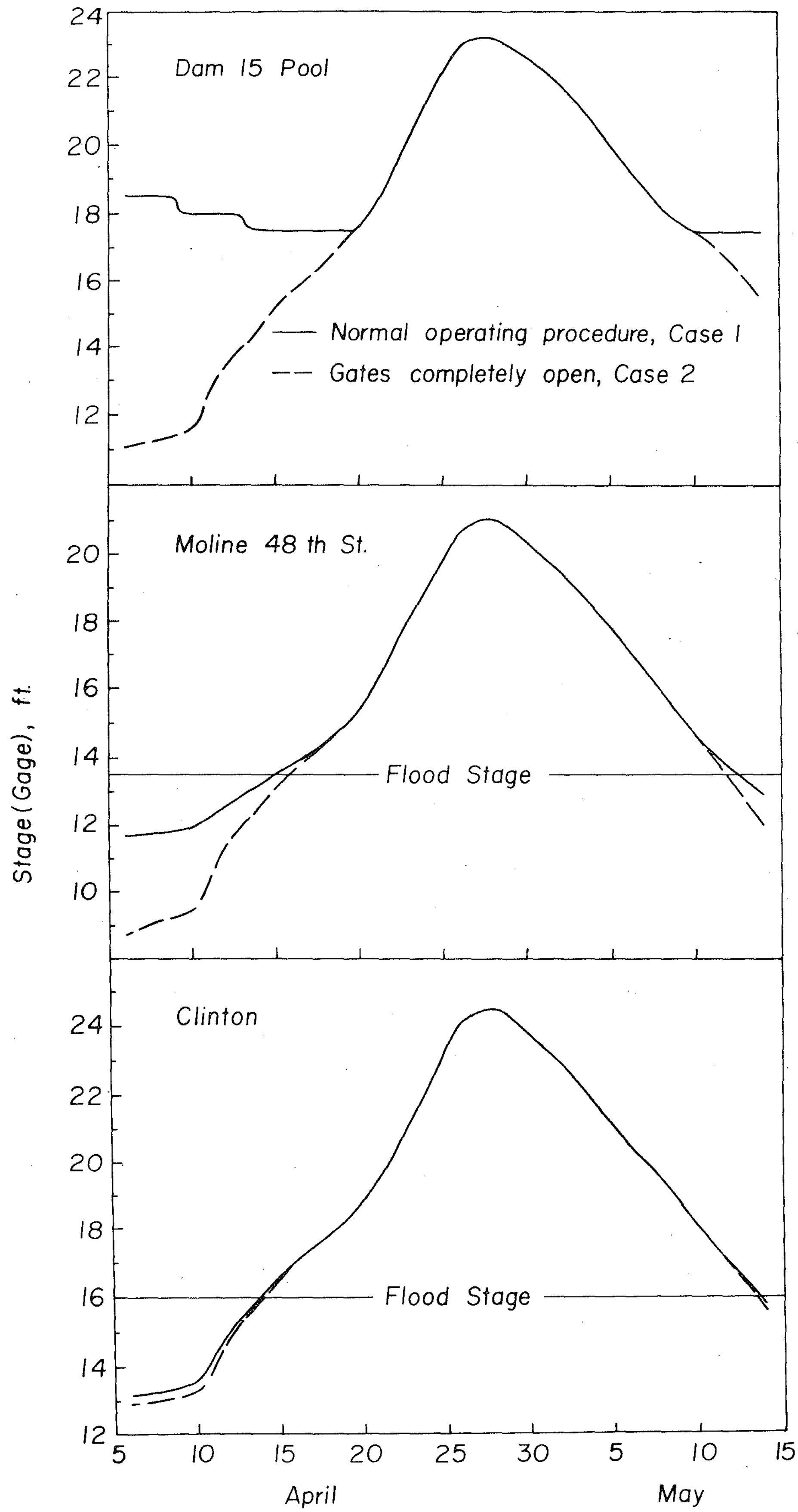

Figure 3. Water levels during period of 1965 flood for different gate-operating procedures.

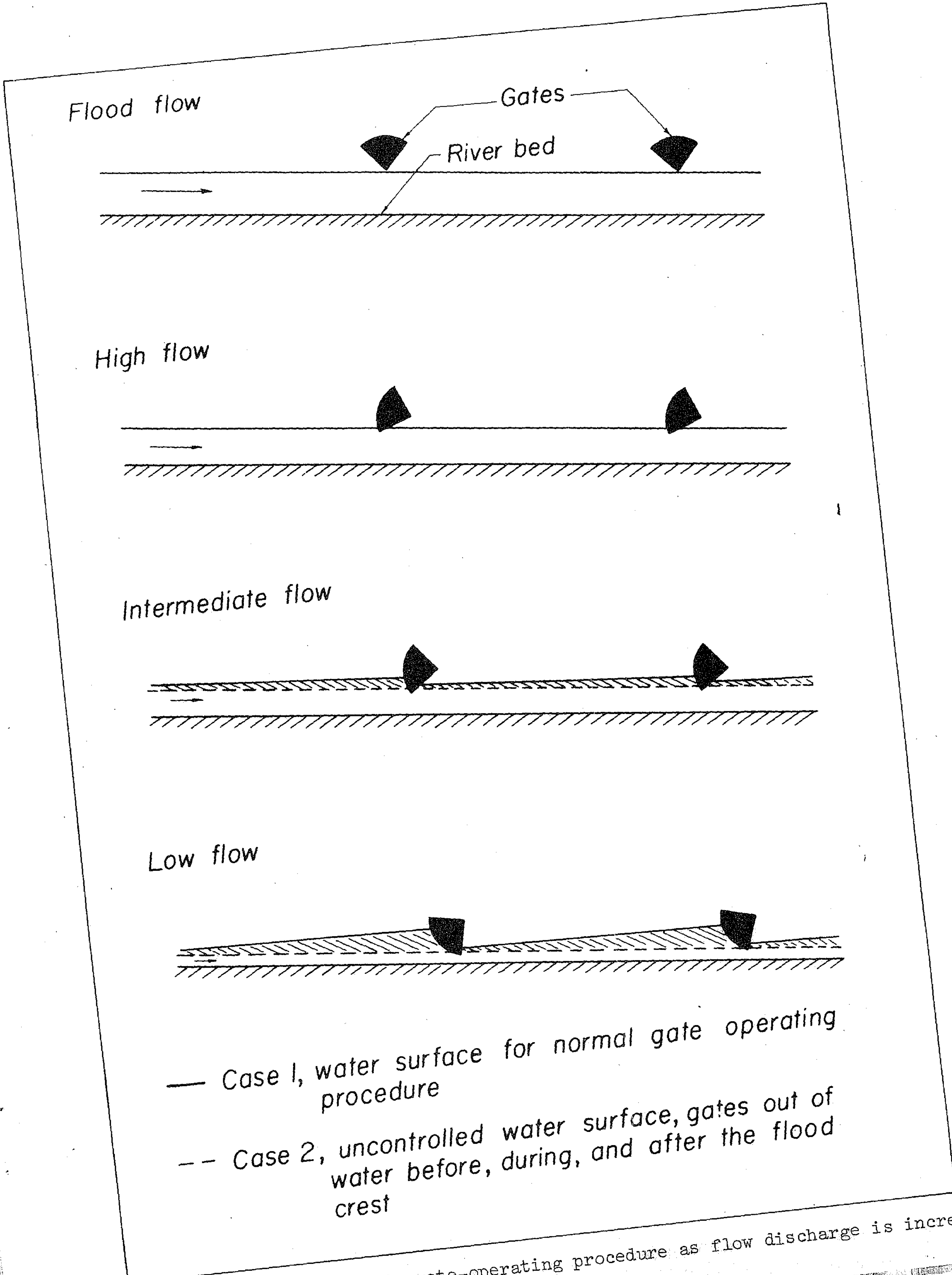

Figure 4. Successive steps in gate-operating procedure as flow discharge is increased.

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13. ABSTRACT

The effects of navigation-dam operating procedures on flood levels in the reach of the Mississippi River between Dams 13 and 15, upstream from the Quad Cities, is described. The results of a computational investigation show that the procedure established by the Corps of Engineers for operating the gates at the navigation dams causes no increase in the crest levels of large floods over that which would occur if the gates were completely opened well in advance of the flood.

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