LETTER REPORT
INTERIM LEVEL OF PROTECTION FOR THE
BIRDS POINT-NEW MADRID FLOODWAY

1. Purpose. The purpose of this letter report is to transmit information related to an assessment and evaluation of an interim level of protection for the Birds Point-New Madrid Floodway with a recommended approach.

2. Description and Pre-Operation Conditions.

A. Description. The Floodway is about 33 miles long and 10 miles wide. Its area comprises about 205 square miles of alluvial valley land and is enclosed by Mississippi River project levees, except for a 1,500-foot authorized but not constructed closure at the lower end. This opening provides a drainage outlet and allows flood backwaters to enter. The Mississippi River project levees enclosing the Floodway are the lower portion of the Upper St. Francis Levee (hereinafter called the Floodway Frontline Levee) which forms the eastern boundary, and the Birds Point-New Madrid Floodway Levee (hereinafter called the Floodway Setback Levee) which forms the western boundary. The Frontline Levee consists of three parts: the upper fuseplug section, 11 miles in length; the lower fuseplug section, 5 miles in length; and the section between the two fuseplugs. The fuseplug sections are about 2 feet lower in grade than the remainder of the Frontline Levee except for 12,500 feet in the upper fuseplug for the Inflow Crevasse and 7,500 feet in the lower fuseplug for Inflow/Outflow No. 2. The setback levee extends from its junction with the Frontline Levee at Birds Point, directly across the Mississippi River from Cairo, Illinois, southwesterly for a distance of about 36 miles and ties in with the St. Johns Bayou Levee near New Madrid, Missouri.

B. Pre-Operation Conditions. Presently the 1965 Flood Control Act controls the features of the Floodway. The Frontline Levee provides protection to a grade equivalent to 62.5 feet on the Cairo gage, except for the fuseplug sections which provide protection equivalent to 60.5 feet on the Cairo gage. The 1,500-foot opening which has been authorized for closure remains open allowing backwater to enter the lower end of the Floodway. Additional improvements for flood damage reduction in the Floodway have been recommended by the Corps in the St. Johns Bayou-New Madrid, Missouri Flood Control Project design documents. Recommended improvements in the Floodway consist of channel improvements and a 1,500 cfs pumping plant for interior drainage. The pumping plant would be located at the authorized, but as yet unconstructed, closure and gravity outlet at the southern end of the Floodway. Before the closure is constructed, additional flowage easements will have to be obtained over the lands below elevation 300. Operation of the Floodway (estimated at once in 80 years) will not alter the need or economic justification for the pumping plant.

3. Objectives of the Analyses. The Epic Flood of 2011 required the Memphis District to implement extraordinary flood fight activities across its entire area of responsibility, especially in Missouri, Illinois, and Kentucky. Melting runoff from mountains of snow combined with rainfall ten times greater than average spread out over a 200,000 square-mile area within the Mississippi River's watershed produced the Epic Flood of 2011. This year's event saw historic levels on our nation's mightiest river.

The Corps of Engineers' response required using every flood risk reduction resource within the Mississippi River watershed, the 3rd largest in the world, to shave height from historic crest levels during the flood's most dangerous hours. In Missouri, for the first time since 1937 operation of the Birds Point-New Madrid (BPNM) Floodway was required to relieve pressure on the MR&T system features adjacent to and upstream of the Floodway. It has been estimated that this one action lowered stages 3.5 feet or more at Cairo, Illinois. In Illinois and Kentucky, uncontrolled underseepage became the main focus in preventing failures that would have flooded thousands of acres, hundreds of structures, and placed numerous lives at risk.

Following the operation of the Floodway in May 2011, the Commander, Mississippi Valley Division, issued a memorandum directing the Memphis District to implement make safe and stability operations based on a target elevation (stage) of 51 feet on the Cairo gage to provide a stable base for flood fight operations and subsequent reset operations by 30 November 2011. Based on previous physical model studies and the design of the operation plan, a stage of 51 feet is required to safely pass 550,000 cfs of the total Mississippi River Project Design Flood (PDF) discharge of 2,360,000 cfs. However, at that stage the level of protection for the Floodway is minimal as compared to the pre-operation level of protection. Evaluation of the risk to system performance associated with an interim or higher level of protection is herein based on geotechnical and hydraulic analyses.

4. Geotechnical Assessment of Key Areas in MO/IL/KY. Although no "safe" condition exists when sand boils are present, the risk to failure of project levees due to sand boils is significantly lower at Cairo gage readings below 55 feet. Detailed geotechnical investigations, observations, and analysis related to sand boils adjacent to project levees in Missouri, Illinois, and Kentucky have been conducted; pertinent information related to the relative safety of the project levees due to sand boils is presented below.

The Epic Flood of 2011 crested at 61.72 feet at the Cairo gage. Although significant sand boil activity threatened the integrity of the levee systems, there were no breaches in the Cairo, Illinois or Fulton County, Kentucky systems. This fact may suggest that the levee systems can withstand future river levels similar to these experienced during the spring 2011 event. However, significant flood fighting efforts were required in these systems prior to and during the crest. Additionally, future sand boil activity may be greater as a result of the damage to the clay blanket from the 2011 event. Because the flood duration and floodwater rate of rise are different for every event, prediction of performance during future events is difficult and should be considered estimations.

Experienced geotechnical engineers have evaluated the flood fight records to estimate the maximum gage reading at Cairo that can be maintained by flood fighting without putting significant stress on the Cairo, Illinois and Fulton County, Kentucky levee systems. These geotechnical engineers have calculated gradients at both Cairo and Fulton County in the past. However, gradient calculations are only an indication of when a sand boil will start. After a sand boil starts, it is difficult to predict if the levee will fail or not as a result of the internal erosion of the foundation. Since we have records of multiple flood events and performance data related to sand boil activity, flood fight records are the best method of predicting future sand boil activity.

In general, sand boils have been observed in three general areas in the Cairo, Illinois system. These areas include the Klondike area, the Future City area, and the northern part of the City of Cairo. In general, hundreds of boils small to medium sized with throat diameters less than 6 inches developed in the Klondike and Future City areas at relativity low heads (approximate 52-53 feet on the Cairo gage). These boils are generally managed by flooding areas within the pumping station sump areas, highway ditches, or other low lying areas. Because of the number and size of the boils noted in these areas, we anticipate that similar flood fighting activities will be successful in future events similar to the 2011 event.

Larger high energy boils have been noted in the northern area of the City of Cairo for many years, but have been documented recently during the 1975, 1995, 1997, 2002 and 2011 events. In most cases, the boils developed prior to the crest. For example, a large high energy boil developed on May 23, 2002 approximately 100 feet from the floodwall near the water plant at an approximate 53.8 feet on the Cairo gage (see attached photograph). Sand boils in the northern area of Cairo have not always developed in the same location, but were similar in size and energy level. In each of these events, field personnel had a difficult time ringing the boil and controlling the quantity of sand transported. Each boil and the related internal erosion of the foundation materials posed a significant risk to system integrity.

On April 28, 2011, a large sand boil developed at a Cairo gage reading of 58.7 feet. In 1975 and 1995, boils developed at elevations greater than 55.5 feet. In 2002, the boil developed at 53.8 feet. During 2005, 2008, and early spring 2011, the gage was no higher than 53.9 and no large boils developed. The flood fight records shown in Table 1 suggest that large boils are likely to form at an elevation greater than approximately 54 feet at the Cairo gage.

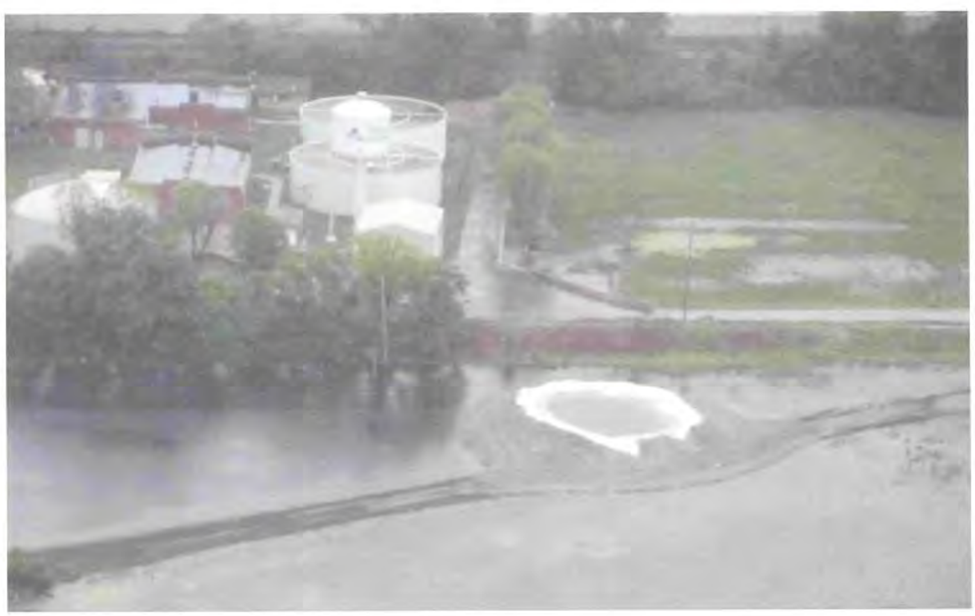
Based on flood records reviewed for the Fulton County, Kentucky levees, small sand boils and pin boils start when the Cairo gage reaches approximately 53 feet. During the 2002, 2005, 2008 and early spring 2011 events (less than 55 feet on the Cairo gage), sand boil activity was manageable and required only minor ringing to control sand boil activity. However, more significant ringing was required in 1997 (56.2 feet on the Cairo gage) and the 2011 event to control sand boil activity. Records suggest that sand boils begin in the worst areas of Fulton County (mile 7) at a Cairo gage reading of approximately 56 feet or greater.

Table 1. City of Cairo near Water Treatment Plant

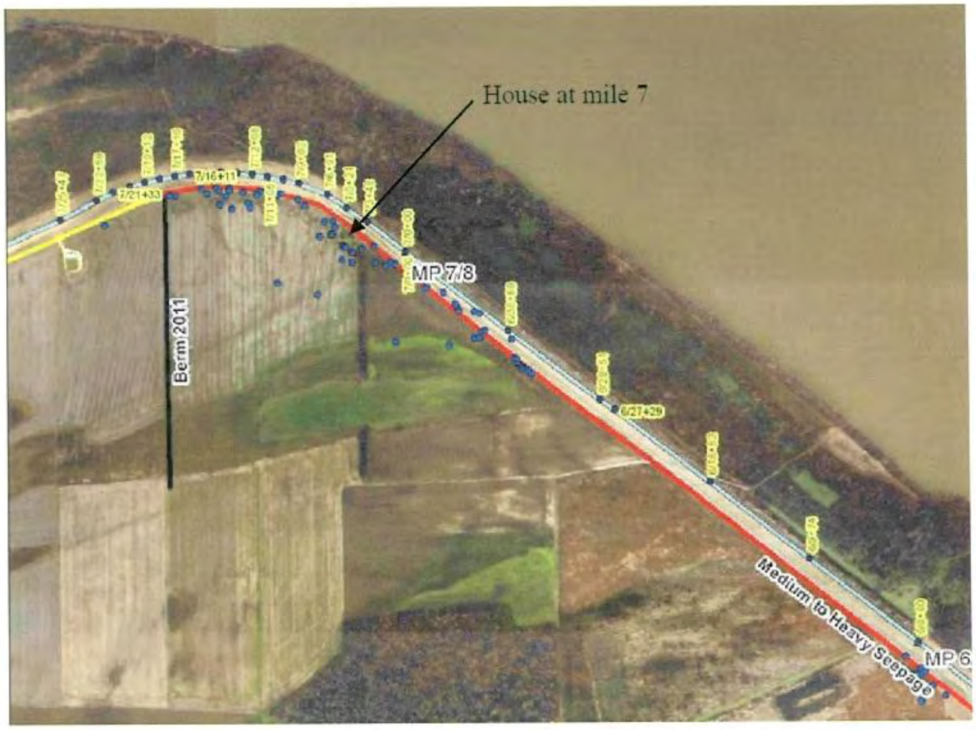
Date – Gage Reading	Description
4/1/1975 – 55.8 feet	2 sand boils developed pumping 20 tons of material
5/27/1995 – 55.6 feet	Large sand boil behind the Creative Insurance building near Union and Sycamore (See attached photo)
1997 – Crest 56.2 feet	1 sand boil 4" in size located approx. 1000' from the flood wall.
5/23/2002 – 53.8 feet	Large, high energy sand boil located 100' from floodwall in vicinity of water treatment plant (see attached photo).
2005 – Crest 53.2 feet	No significant sand boil activity in area of water plant
2008 – Crest 53.9 feet	No significant sand boil activity in area of water plant
03/2011 – Crest 53.4 feet	No significant sand boil activity in area of water plant
4/28/2011 – 58.7 feet	Large, high energy sand boil pumping large amount of coarse material

May 27, 1995 - Cairo gage 55.6 feet

May 23, 2002 - Large, high Energy Boil located 100 feet from floodwall - Cairo gage 53.8 feet



April 28, 2011 – Large, high energy sand boil located 500 feet from floodwall – Cairo gage 58.7 feet



2011 - Fulton Co., KY

May 2, 2011 – Multiple large sand boils at toe of levee

1997 – Fulton County, KY at Crest – Cairo gage 56.2 feet

5. Hydraulic Assessment of the Ability to Pass the Project Design Flood (PDF). During the Epic Flood of 2011, approximately 9,000 feet of the available 11,099 feet of the Floodway Inflow Crevasse followed by the Inflow/Outflow crevasses were activated by explosive assist. As the flood waters flowed into the Floodway, the crevasses eroded to natural ground elevation, leaving the land in the Floodway with minimal protection against another Mississippi River flood. Currently, the crevasse areas are being partially restored by placement of compacted earth fill to flowline elevations corresponding to a stage of 51.0 feet on the Cairo gage. Stakeholders with property interests in the Floodway have requested that the crevasses be raised even higher to obtain greater flood protection, and this raises the question of what the PDF capacity of the Inflow Crevasse would then be.

The term Inflow Crevasse used in the previous paragraph refers to the location where flow from the main stem Mississippi River will enter the northern end of the Floodway by overtopping. In its inactivated state, the Inflow Crevasse is simply a fuseplug whose capacity is determined by the length and elevation of its crest. This initial capacity can be increased through explosive assist and/or erosion. In this letter report the term Inflow Crevasse refers to the structure in its inactivated state.

This portion of the letter report describes how the PDF capacity of the existing 9,000 foot long Inflow Crevasse would vary with the crest elevation selected for repair, and describes how this relationship was analyzed. The results of the analysis are presented as rating curves (stage vs. discharge) for the Inflow Crevasse. The rating curves were based on flowlines obtained from physical model studies conducted on the Mississippi Basin Model (MBM) and from a flowline numerical model of the Inflow Crevasse as a broad crested weir. Analysis was first performed for the 11,099 foot crevasse of the 1986 Plan of Operation and was then adapted to the current 9,000 foot crevasse. The remainder of this section is divided into three parts. The first part is a description of the hydraulic aspects of the crevasse under the 1986 Plan of Operation. The second part presents the results of this analysis. The third part presents the methods used.

A. Hydraulic Aspects. A map of the Floodway is given in Figure 1 and depicts the 1986 Plan of Operation with an 11,099 foot long Inflow Crevasse site, labeled as Inflow. For the 1986 Plan of Operation, the elevations along the crevasse correspond to a flowline attaining a stage of 51.0 feet on the Cairo gage. The definition of the reference to the Cairo gage is shown in Figure 2, such that elevations along the crevasse conform to a flowline that would attain a stage of 51.0 feet at the Cairo gage. The gage zero of the Cairo gage is 270.47 feet NGVD 1929, and a stage of 51.0 feet equals an elevation of 321.47 at the gage. Since the flowline falls in the downstream direction, the flowline elevation at the upstream end of the crevasse corresponding to a Cairo stage of 51.0 feet is approximately 320.0 feet, according to the MBM. In contrast, an elevation of 320.0 feet equates to a stage of 49.53 feet on the Cairo gage as a strictly level equivalent. All discussion in this analysis is based on flowline relationships between the Cairo gage and the Inflow Crevasse, rather than on a strictly level equivalent between the gage and crevasse.

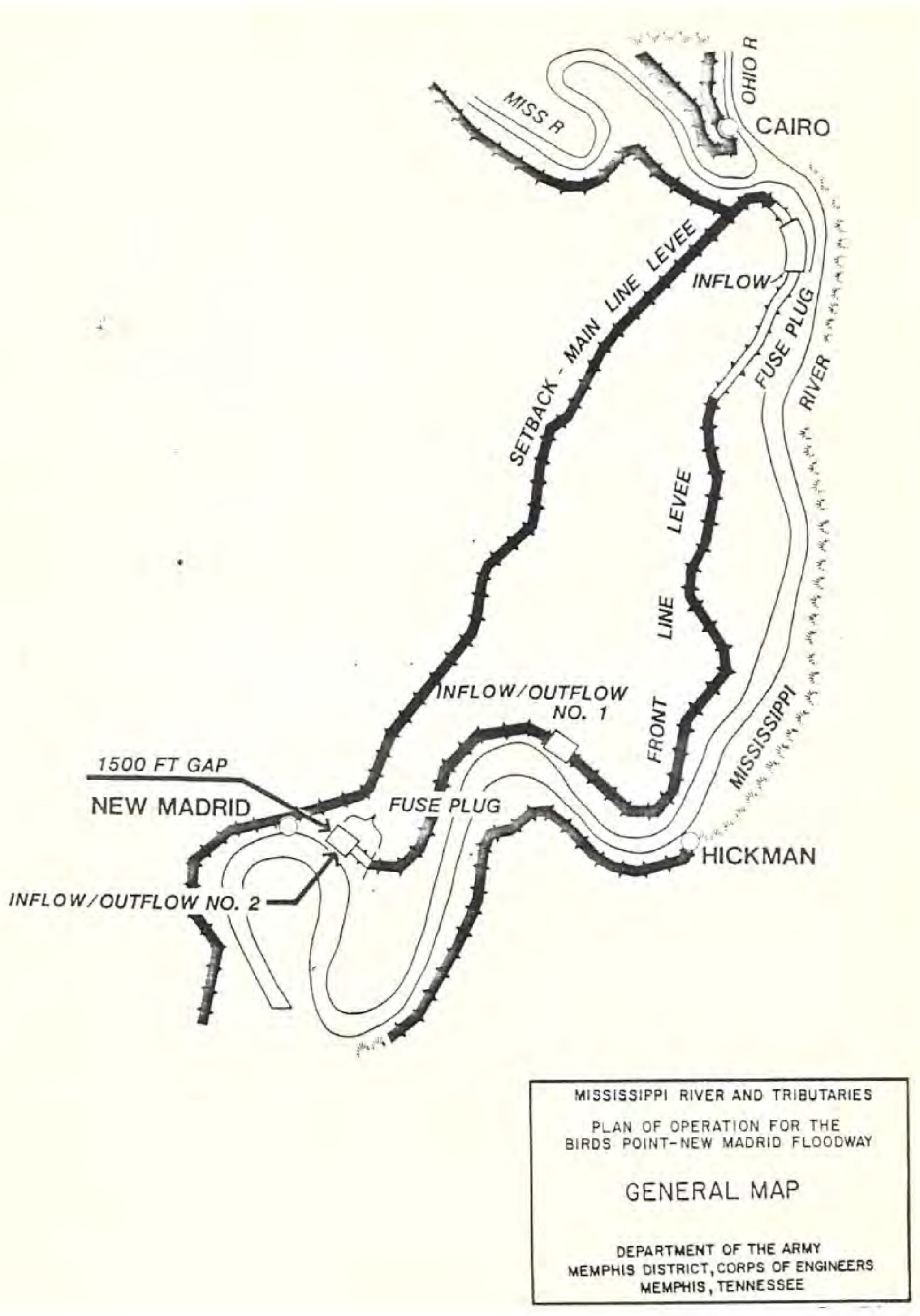


Figure 1. Map of Birds Point-New Madrid Floodway

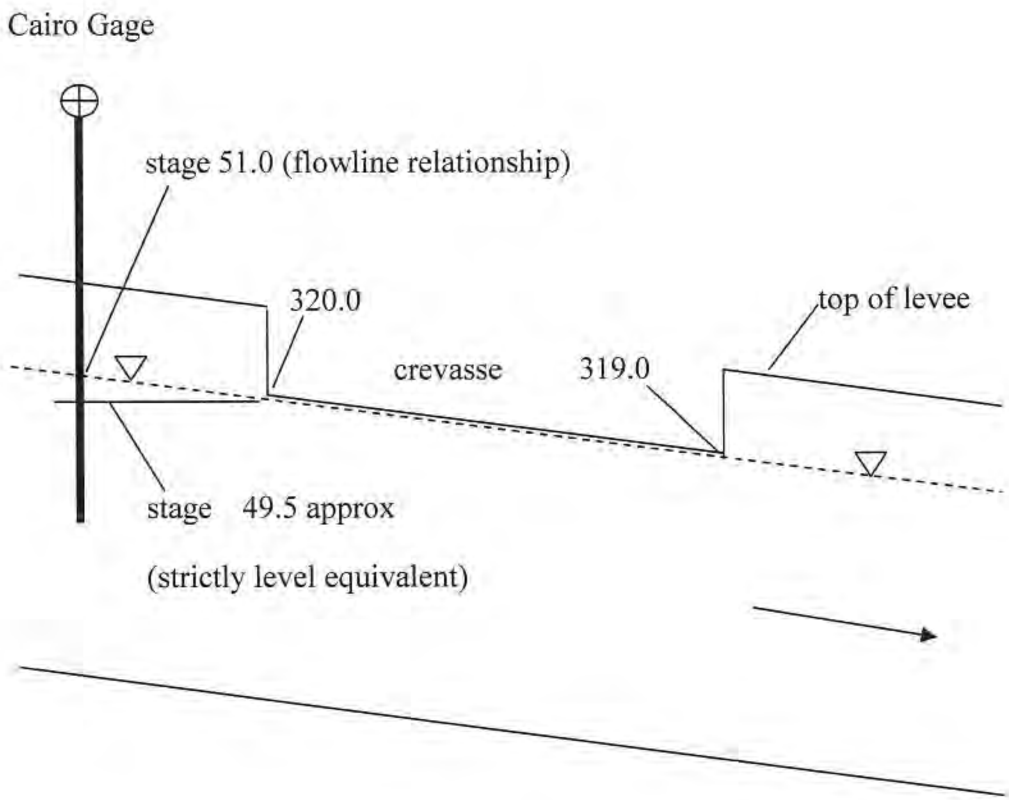


Figure 2. Definition of the Reference to Cairo Stage Used in the Analysis

Data for the ends of the crevasse are listed in Table 1. As shown in Table 1, the downstream end of the crevasse is lower than the upstream end, to match the flowline for the 51.0 foot reading at Cairo. The PDF elevations were obtained from the MBM. A profile of the Inflow Crevasse design is shown in Figure 3, and the PDF flowline shown in the figure differs slightly from the MBM values because it was obtained from a HEC-2 numerical model.

Table 1. Data at Ends of Inflow Crevasse

Location	Levee Station Ft	Crevasse Design Elev. Ft	MBM Project Flowline Ft
Upstream End	33/30+49	320.0	328.37
Downstream End	35/24+46	319.0	327.12

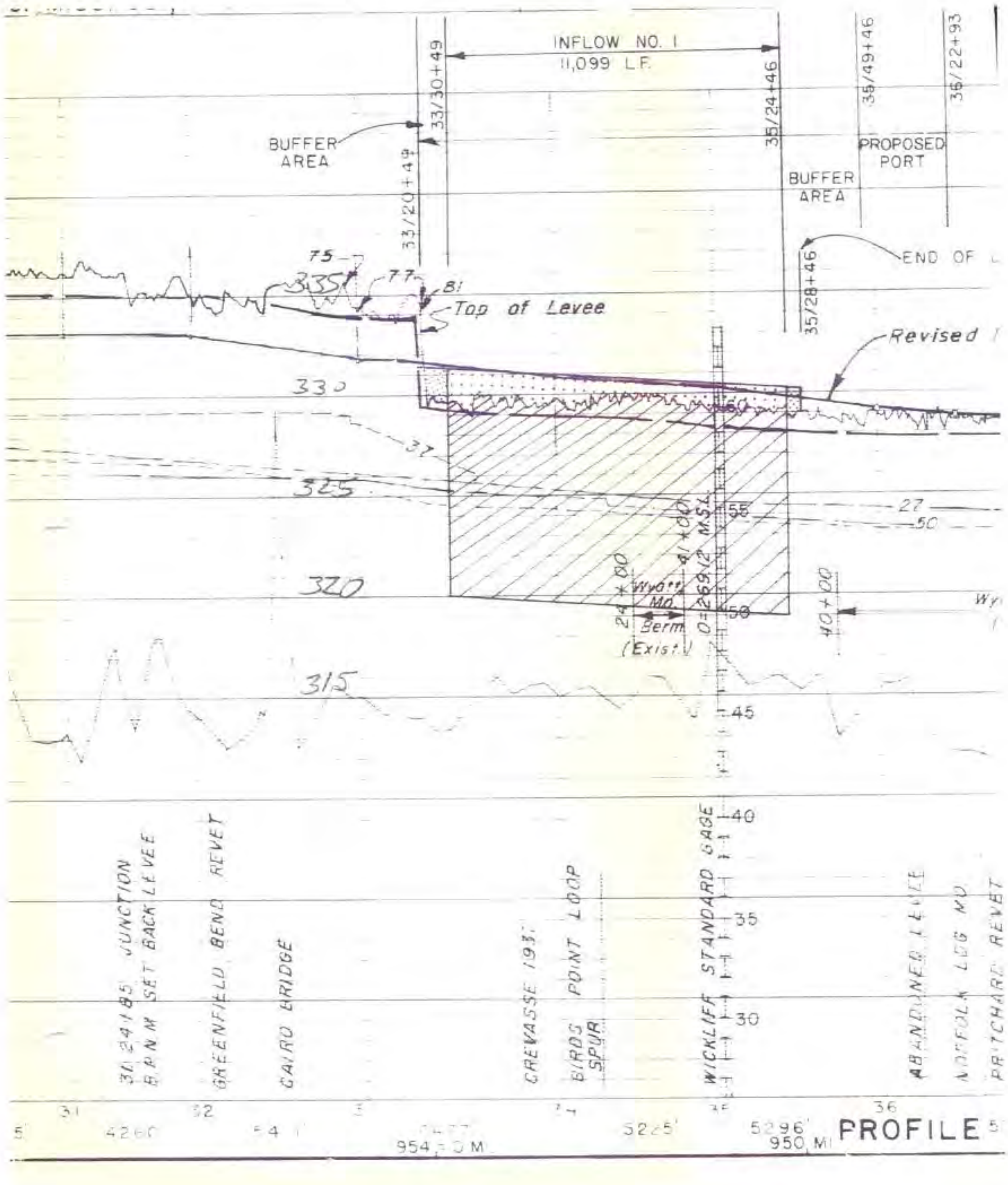


Figure 3. Profile of the Inflow Crevasse Design

A schematic map of the Mississippi River and Floodway under PDF conditions is shown in Figure 4. A diversion of approximately 550,000 cfs through the Floodway results in a flow of approximately 1,810,000 cfs in the Mississippi River between the Inflow Crevasse and the point where the flow in the Floodway rejoins the river. For simplicity, the details of the 1,500 foot gap and Inflow/Outflow Crevasses 1 and 2 are omitted in this figure. The significance of Figure 4 is that the magnitude of flow diverted through the Inflow Crevasse controls the elevation of the Mississippi River flowline at the downstream end of the Inflow Crevasse, which controls the head available to drive flow through the Inflow Crevasse. A curve relating the elevation of the Mississippi River flowline at the downstream end of the crevasse to the amount of flow diverted through the crevasse is presented in the part of this section describing the analysis method.

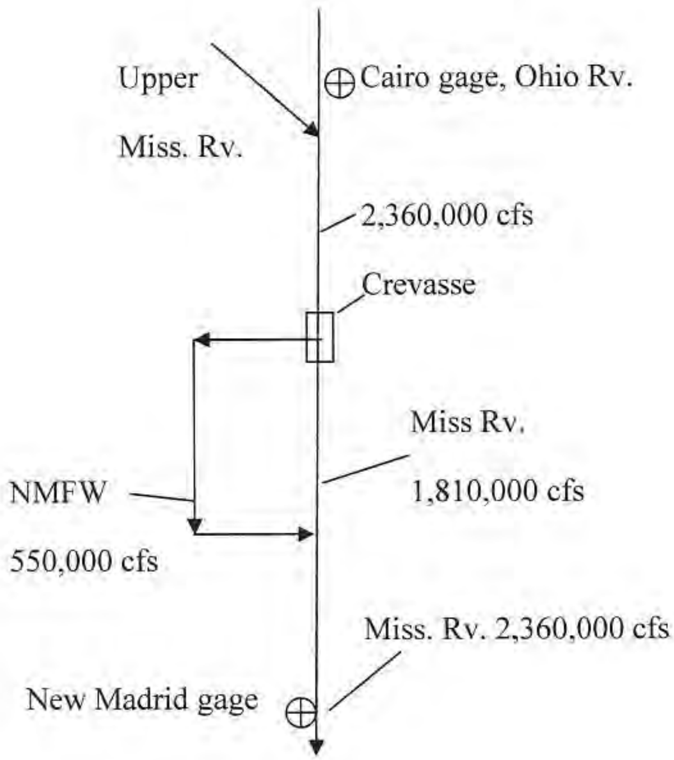


Figure 4. PDF Schematic of Mississippi River and Floodway Under the 1986 Plan of Operation

B. Results of Hydraulic Analysis. The results of the analysis are shown in Figures 5, 6, and 7. Figure 5 shows five rating curves for the 11,099 foot long Inflow Crevasse. The rating curves are based on crevasse elevations matching Cairo stages of 51, 52, 53, 54, and 55 feet. The rating curves show flow through the Inflow Crevasse on the horizontal axis and the stage at Cairo on the vertical axis. For a given rating curve, the stage at Cairo is the flowline stage that will occur at Cairo if a given amount of flow is diverted through the Inflow Crevasse, based on the crevasse elevation for that curve. For example, the rating curve for an Inflow Crevasse elevation matching a Cairo stage of 51 feet shows the performance determined for the 1986 Plan of Operation. If the calculated flow of 550,000 cfs is diverted through the crevasse, the flowline stage at Cairo will be 62.5 feet. The minimum design capacity of the Floodway under the 1986 Plan of Operation is 550,000 cfs. Continuing the example, the flow through the Inflow Crevasse is zero at a Cairo stage of 51.0 feet, since the bottom of the crevasse matches that flowline. The remaining four rating curves for higher Cairo stages represent the performance of the Inflow Crevasse at higher elevations, which permit less flow to be diverted for a given Cairo flowline stage.

The performance of the current 9,000 foot long Inflow Crevasse as a function of crevasse elevation is shown in Figure 6. For a crevasse elevation matching a Cairo flowline stage of 51.0 feet, the calculated capacity of the crevasse is 445,000 cfs at a Cairo stage of 62.5 feet. Similarly, the calculated capacity of the Inflow Crevasse for an elevation matching a Cairo flowline stage of 54.0 feet is 220,000 cfs at a Cairo stage of 62.5 feet. Figure 7 presents the performance of the 9,000 foot Inflow Crevasse as a percentage of required flow of 550,000 cfs versus the Inflow Crevasse elevation. For example, at Inflow Crevasse elevations corresponding to Cairo flowline stages of 51.0 and 54.0 feet, the attainable flows through the crevasse are 81 percent and 40 percent of the required flow, respectively.

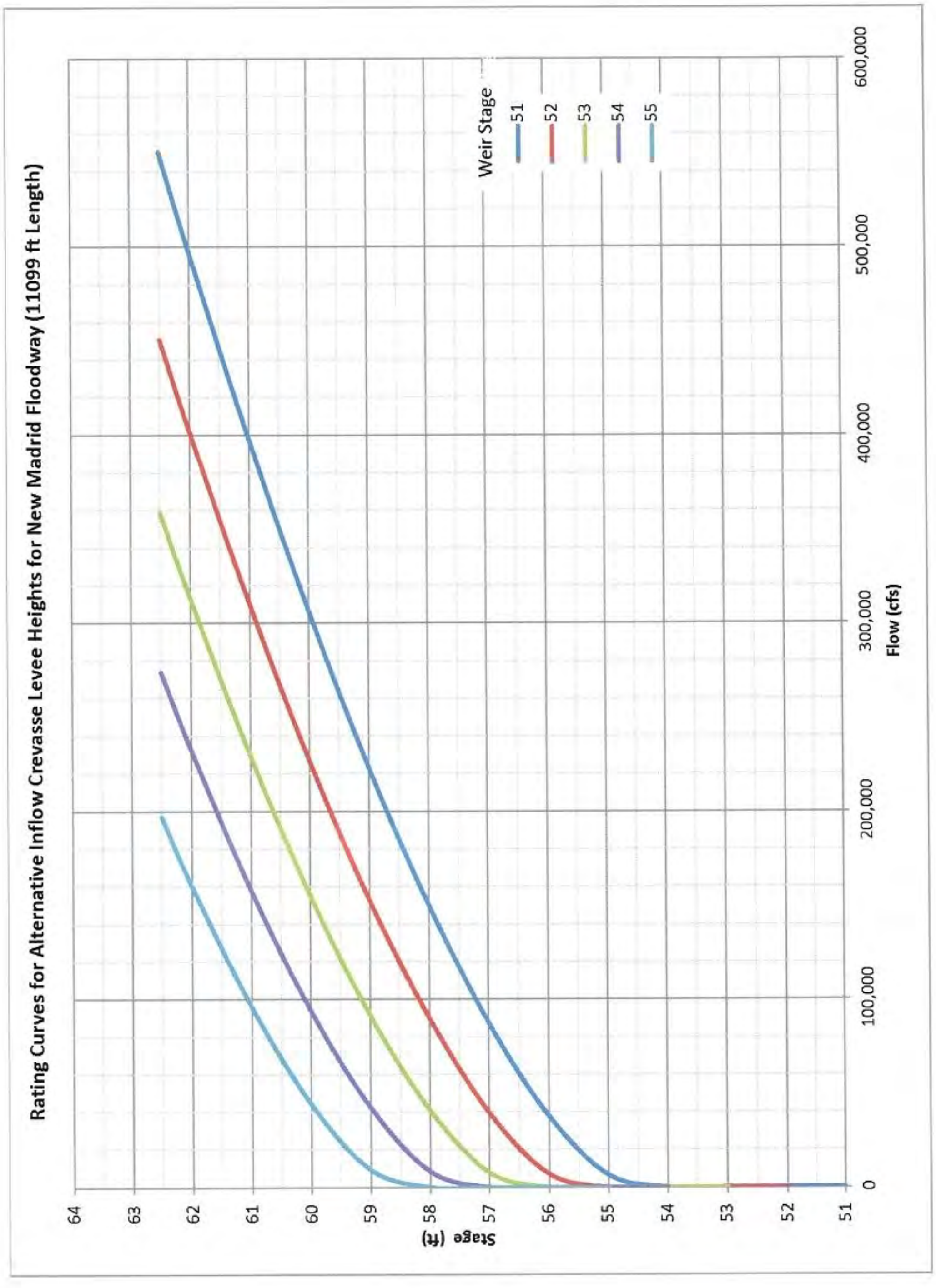


Figure 5. Rating Curves for 11,099 Foot Long Crevasse

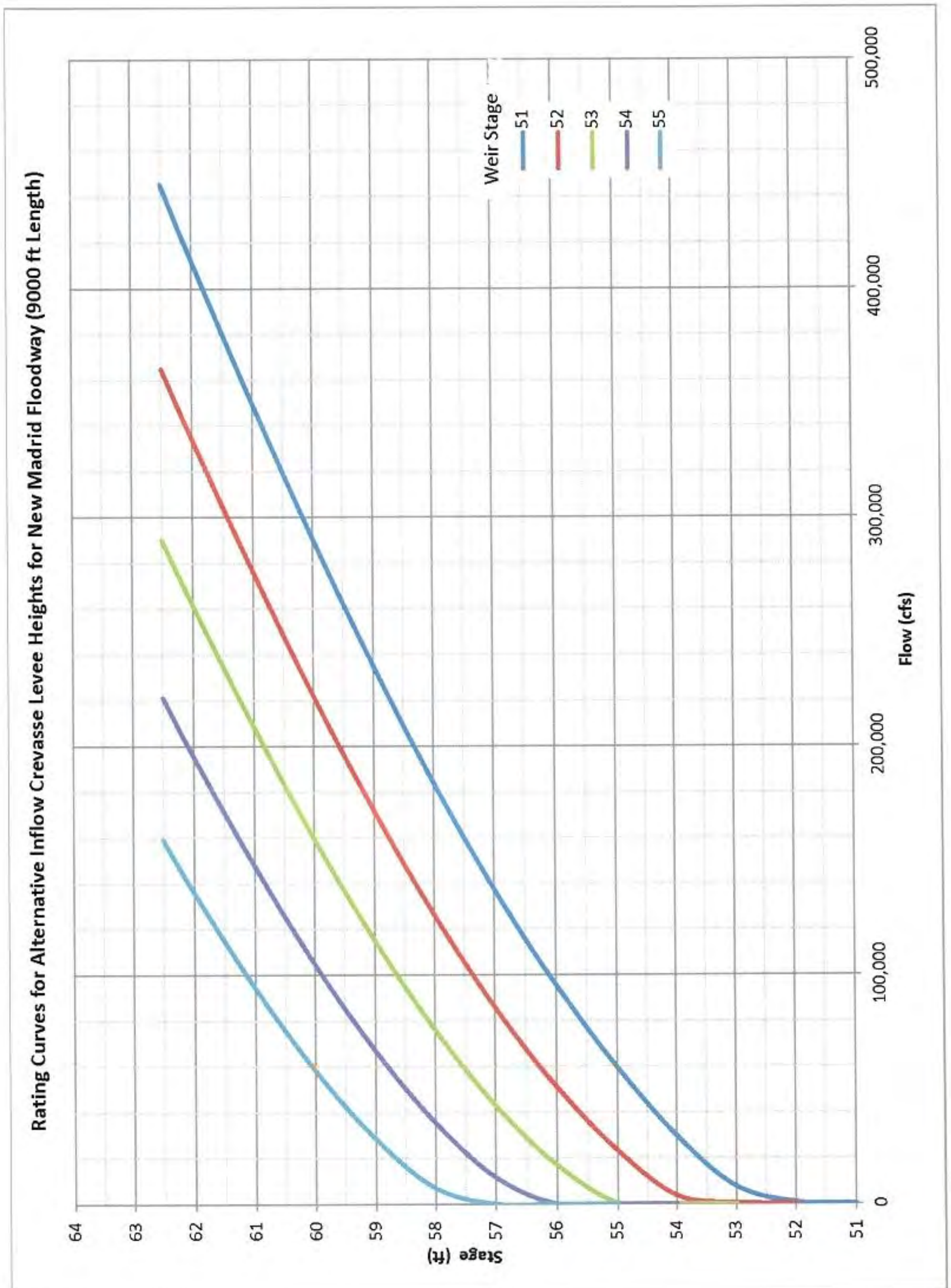


Figure 6. Rating Curves for 9,000 Foot Long Crevasse

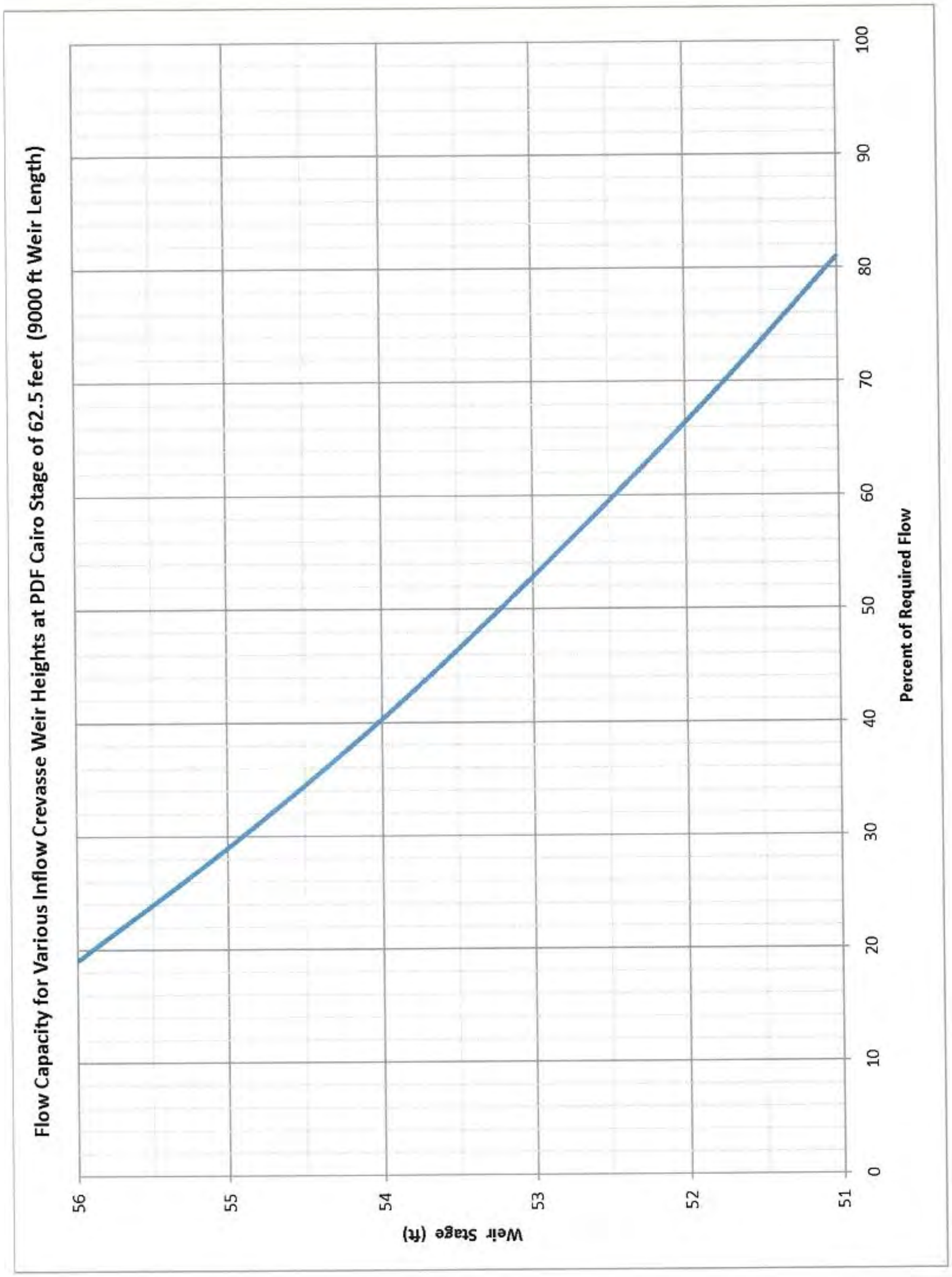


Figure 7. Percent Capacity Curve for 9,000 Foot Long Crevasse

C. <u>Hydraulic Methods.</u> The description of hydraulic methods begins with analysis of the Inflow Crevasse as a broad crested weir and concludes with the application of an appropriate broad crested weir coefficient to the case of the crevasse as a side weir.

The Inflow Crevasse is a broad crested side weir that removes water from the Mississippi River and directs it into the Floodway. The section view in Figure 8 shows why the Inflow Crevasse is considered broad crested. The length "W" of the crevasse from its riverside edge to its landside edge is somewhat greater than the head "H" on the weir. For example, under PDF conditions described in the 1986 Plan of Operation, the Inflow Crevasse length should be approximately 160 feet long, while the head should be approximately 11 feet, for an H/W ratio of approximately 0.07. As the H/W ratio decreases, the water surface profile resembles an open channel more than an abrupt overfall and friction losses increase, causing the weir coefficient to be less than that for a sharp crested weir. The flow passes through critical depth, Dc, at the downstream edge of the crevasse. At the time of the design discharge through the crevasse, the weir is not submerged if it is assumed that the crevasse does not erode. A weir exponent of 3/2 was adopted as suitable for a broad crested side weir. King's Handbook and Henderson are examples of references that list the 3/2 power as applicable for broad crested weirs and side weirs, respectively. Therefore, it is only necessary to determine an appropriate weir coefficient and head to calculate unit flow through the crevasse using the equation:

$$q_u = CH^{3/2}.$$

where,

q_u is the unit discharge in cfs/ft

C is the weir coefficient

and H is the head, ft.

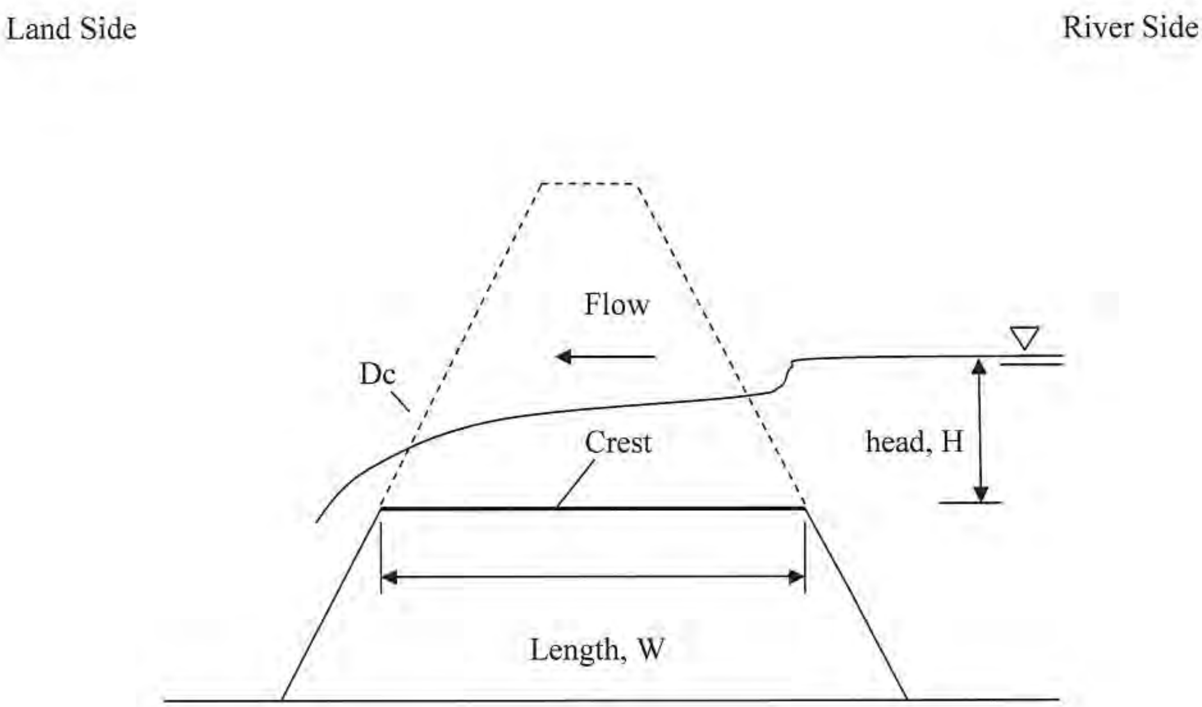


Figure 8. Section of Inflow Crevasse as a Broad Crested Weir

It was necessary to evaluate what effect, if any, the side weir configuration might have on the weir coefficient. Some references state that the coefficient for a side weir may need to be less than that for an in-line weir. For example, in *Open Channel Hydraulics* (page 346), Chow states that: "For practical purposes, the formula for the regular weir of similar crest shape may be used if the corresponding discharge coefficient is reduced by 5%." Much of the physical modeling used to study side weirs has been based on prismatic channels feeding flow over side weirs that would be precisely built steel or concrete structures in the prototype. The applicability of such models tests to the Inflow Crevasse is uncertain. In the MBM, momentum of flow entering the crevasse was accurately accounted for by the realistic structural geometry and currents. In this analysis, momentum of the flow toward the side weir was not readily quantifiable. The approach taken was to treat the Inflow Crevasse as if it were the spillway of a deep reservoir, such that the approach velocity was negligible. Therefore, the weir head was based only on the water surface elevation, rather than on the energy grade line for the Mississippi River flow, and this approach corresponded well with the assumption of no momentum toward the crevasse. In contrast, the head for an in-line weir on a channel should include the velocity head of the flow approaching the weir, as is pointed out in USDA-NRCS National Engineering Handbook-11, Drop Spillways (page 3.1). No reduction was applied to the broad crested weir coefficient for the Inflow Crevasse's function as a side weir.

The weir coefficient was adopted as a function of the ratio of head to the length of the broad crested weir in the direction parallel to flow, based on a HEC-RAS numerical model. For a given crevasse elevation, the length of the broad crested weir was calculated based on the top elevation, topwidth, and sideslopes of the levee. For example, the length of the broad crested weir at the crevasse elevation to be produced by explosives, according to the 1986 Plan of Operation, was approximately 160 feet from its river side edge to its land side edge. The RAS model featured combinations of weir lengths, roughness values, and flows, so that best fit curves for weir coefficient could be estimated. HEC-RAS weir lengths were 50, 100, 200, and 300 feet. HEC-RAS Manning's N-values were 0.01, 0.02, and 0.04. Flows were selected to obtain heads throughout a range applicable to the Inflow Crevasse. It was found that the Manning N-value had little effect on the weir coefficient for the heads applicable to the Inflow Crevasse, and the best fit curve for the roughness of 0.04 was selected, as shown in Figure 9. Within the applicable range of H/W, the curve approaches an asymptote of 2.72 as H/W increases past a value of 0.2. The greatest curvature occurs in the H/W range of 0.03 to 0.2 At H/W ratios less than 0.03 the value of the coefficient is extremely sensitive to H/W, due to the frictional effects across the broad crested weir. For example, at a value of H/W of 0.01 the value of C is approximately 1.3. The coefficient values for H/W ratios greater than 0.2 compare well with broad crested weir coefficients listed in King's Handbook. For example, the weir coefficients for a weir breadth of 15 feet and a head of 3 feet is 2.63 and 2.59 in King's Handbook and in the best fit curve, respectively. The best fit equation for the weir coefficient was used to calculate unit discharges at points along the crevasse under different scenarios.

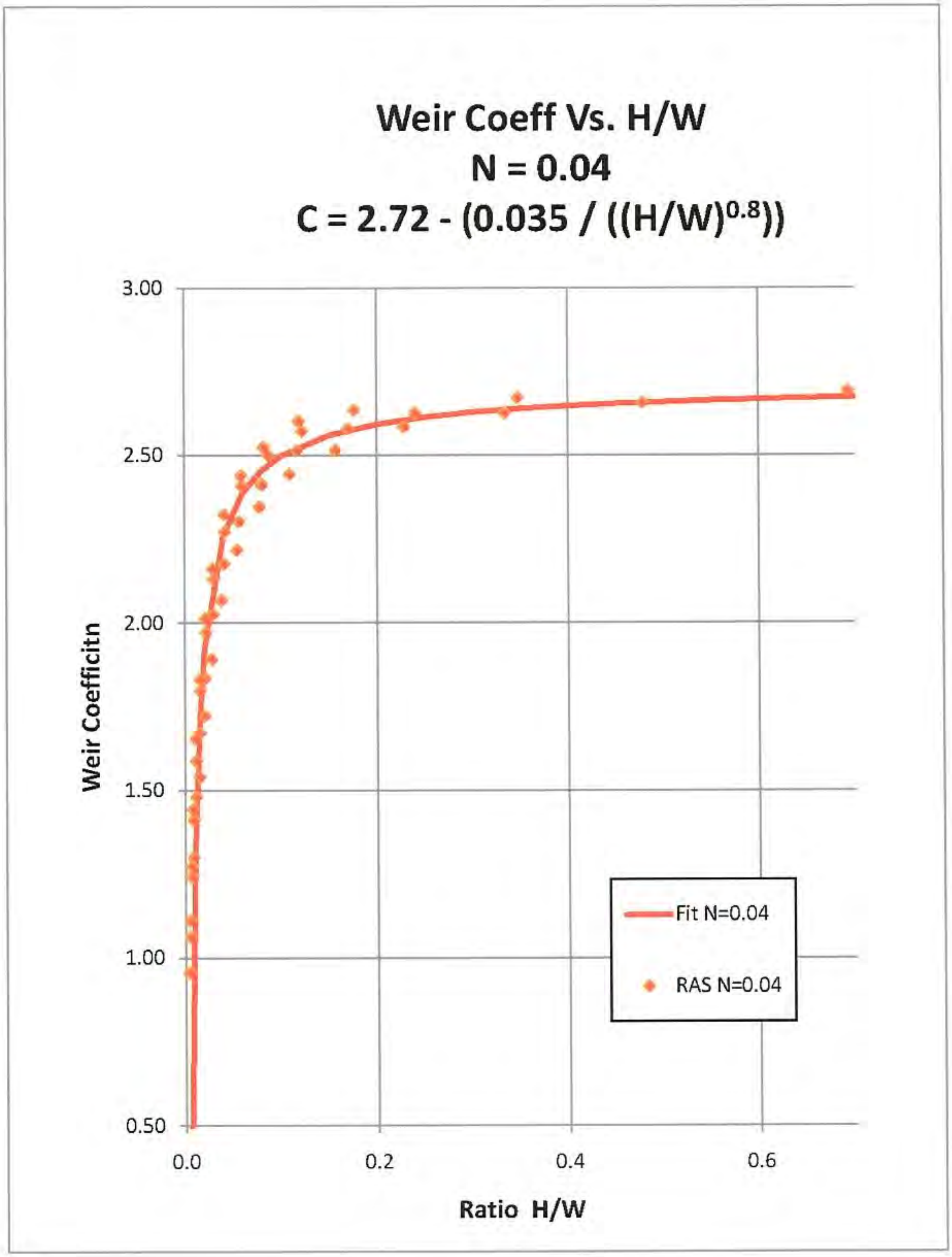


Figure 9. Best Fit Curve for Broad Crested Weir Coefficient

Because the Inflow Crevasse is a side weir of relatively high capacity, it strongly affects the flowline in the Mississippi River, which, of course, is the intent of the structure. As shown in Figure 10, the path of the main current of the Mississippi River is only approximately perpendicular to the path of water flowing through the Inflow Crevasse. Due to the current in the river, the flowlines are not entirely symmetrical at the upstream and downstream ends of the Inflow Crevasse. However, the end effects of the crevasse should be small under the 1986 Plan of Operation, since the crevasse is 11,099 feet long from its upstream to downstream ends, which is longer than the river is wide, and also roughly 1,000 times greater than the weir head.

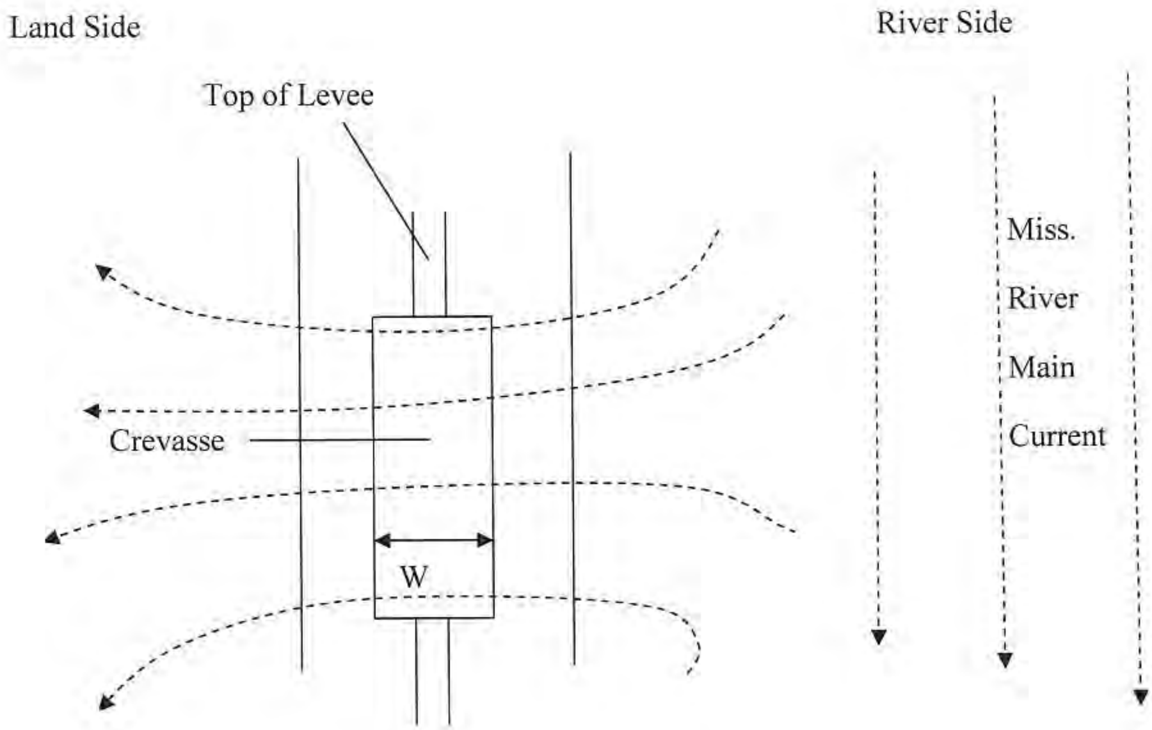


Figure 10. Plan view of Levee Crevasse

For subcritical flow, a profile for a prismatic channel and side weir may resemble that shown in Figure 11. For comparison, the MBM measured flowline alongside the Inflow Crevasse is shown in Figure 12. The water surface elevations obtained from the MBM were representative of the main current in the Mississippi River and were not obtained over the crevasse itself. Estimation of the Mississippi River water surface profile along the Inflow Crevasse for different scenarios was the most difficult part of this analysis and has the most effect on the reliability of the crevasse capacity estimates, since the values of head used in computations are raised to the 3/2 power. The MBM did not generate water surface profile data to match the scenarios evaluated other than the recommended plan. The MBM water surface profile for the 1986 Plan of Operation was adapted for use in the other scenarios evaluated.

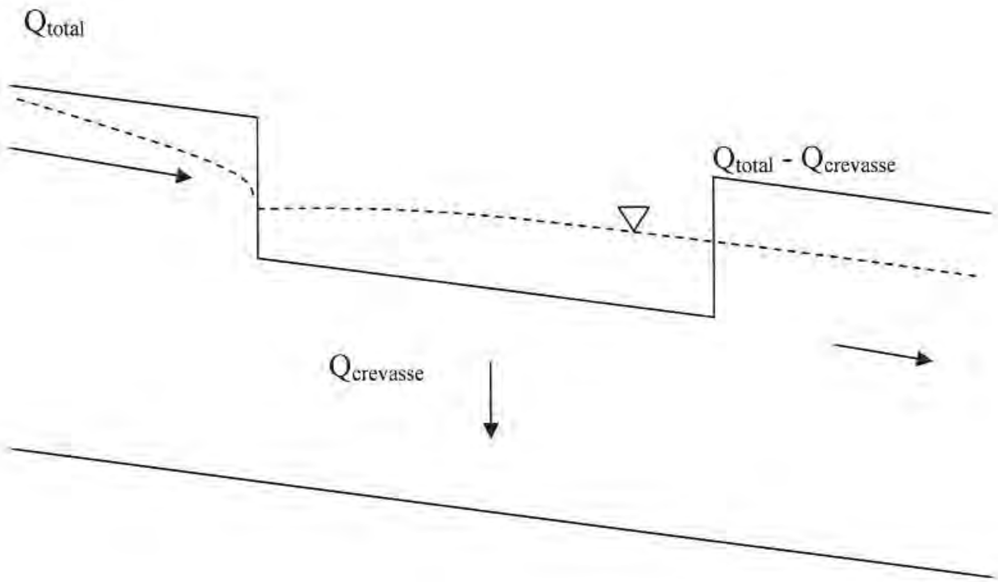


Figure 11. Idealized Side Weir Flowline for a
Prismatic Channel and Subcritical Flow

As stated above, the magnitude of flow diverted through the crevasse controls the elevation of the Mississippi River flowline at the downstream end of the crevasse, which controls the head available to drive flow through the crevasse, as shown in Figure 13. Without a crevasse, the combined flow of the Ohio and Upper Mississippi passes undiminished to New Madrid and the flowline has a uniform slope. A crevasse formed at a comparatively high elevation diverts a comparatively smaller flow through the crevasse, and the Mississippi River flowline between the crevasse and New Madrid is only slightly depressed, which limits the desired drop attainable between the crevasse and Cairo. A comparatively lower crevasse diverts a comparatively greater flow through the crevasse and obtains a greater depression in the Mississippi River flowline between the crevasse and New Madrid. To compute the capacity of the crevasse at a given elevation it is desirable to estimate the Mississippi River flowline elevation at the downstream end of the crevasse, and this is generally a trial and error solution.

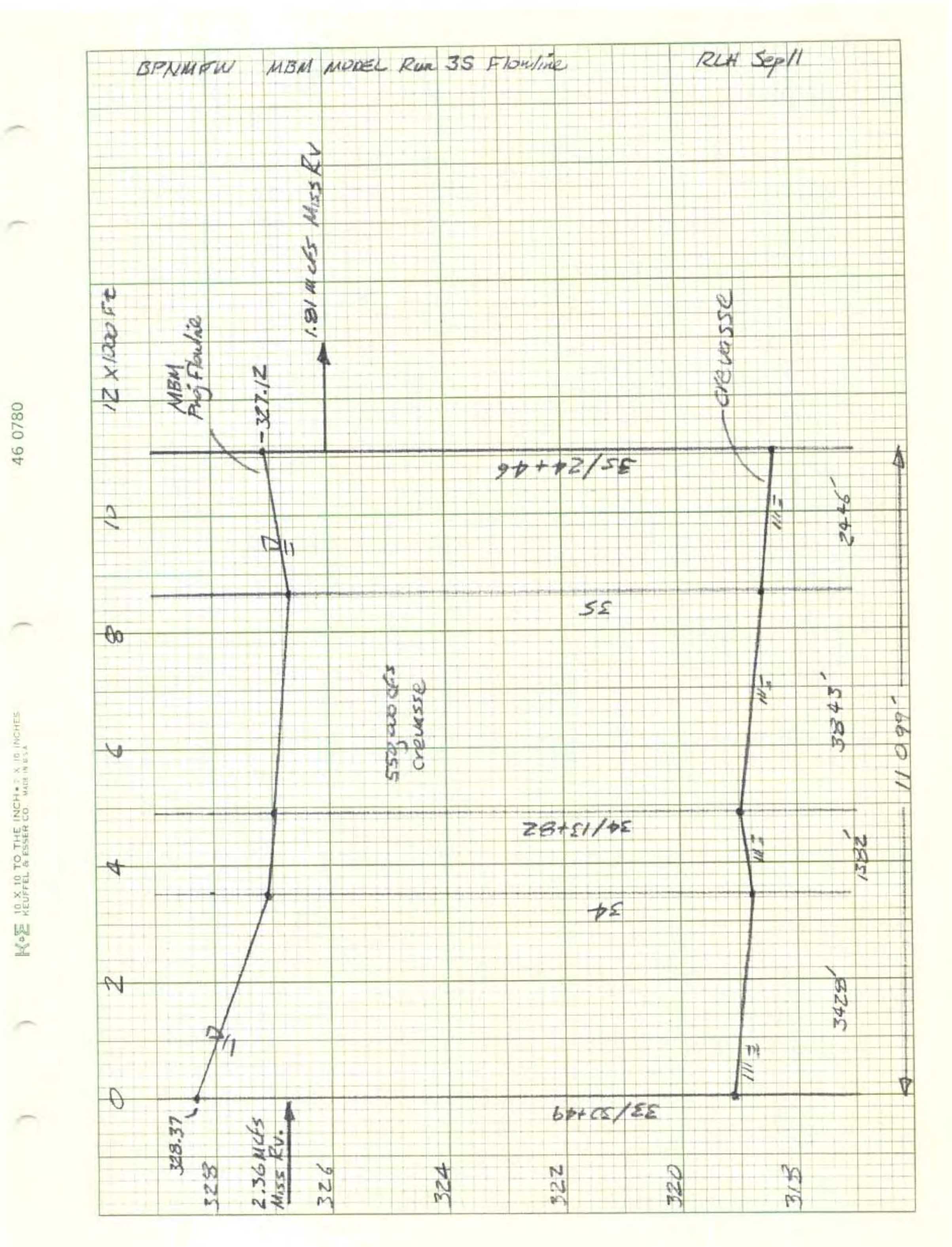


Figure 12. MBM Flowline at Inflow Crevasse

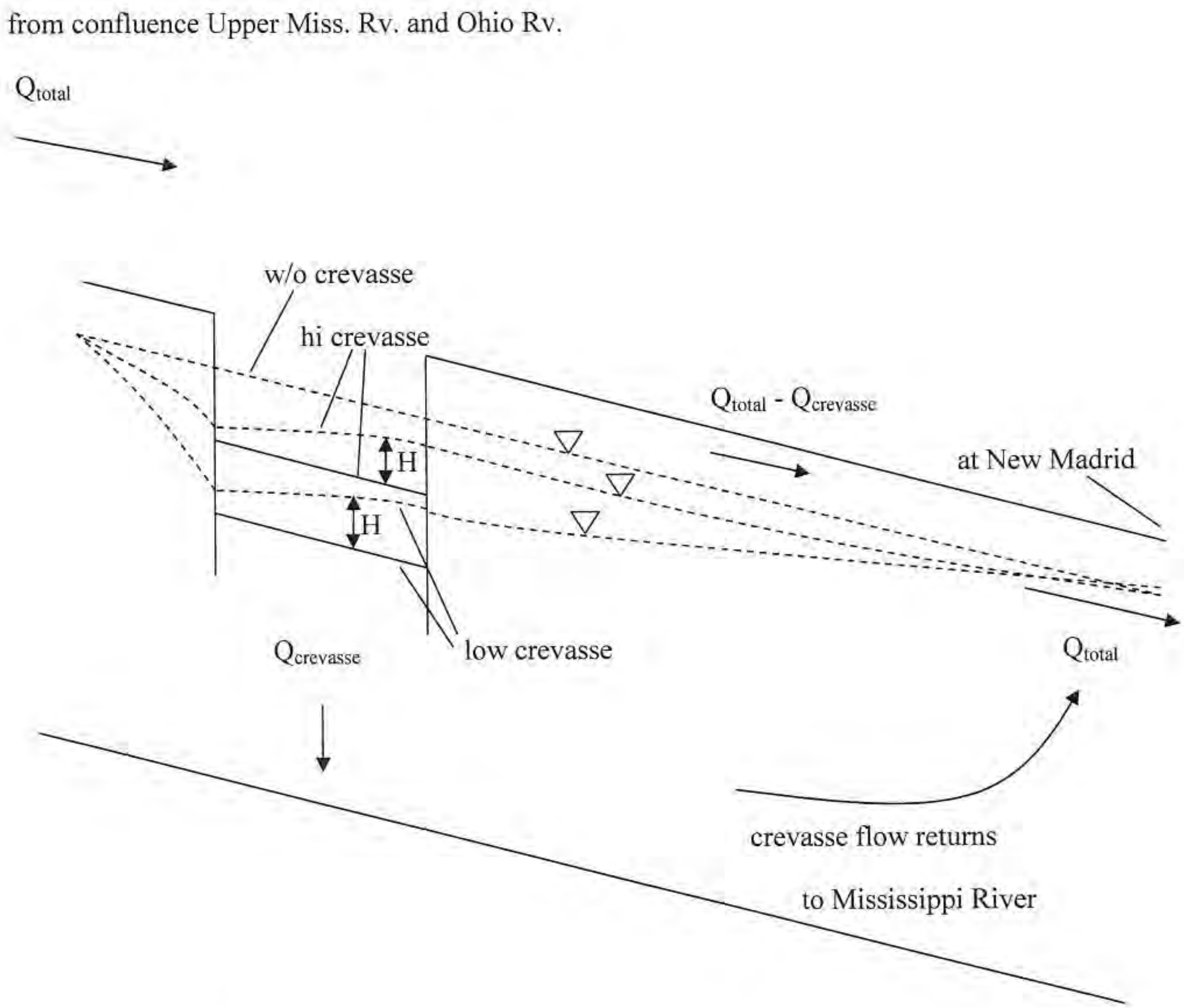


Figure 13. Relationship Between Flow Diverted Through Inflow Crevasse and the Mississippi River Flowline Elevation at the Downstream End of the Inflow Crevasse

To estimate the relationship between the Mississippi River flowline elevation at the downstream end of the crevasse and the magnitude of flow diverted through the crevasse, a Mississippi River HEC-2 model dating from the 1970's was modified and used without inclusion of the effects of Inflow/Outflow Crevasses 1 and 2. The MBM PDF flowline elevation at New Madrid was used as the downstream boundary condition for all runs. Manning's N-values in the HEC-2 model were adjusted until the elevation at the downstream end of the crevasse matched that obtained from the MBM for the PDF and the 1986 Plan of Operation. The model was then used to calculate flowline elevations at the downstream end of the crevasse for other magnitudes of diverted flow, and the results are shown in Figure 14.

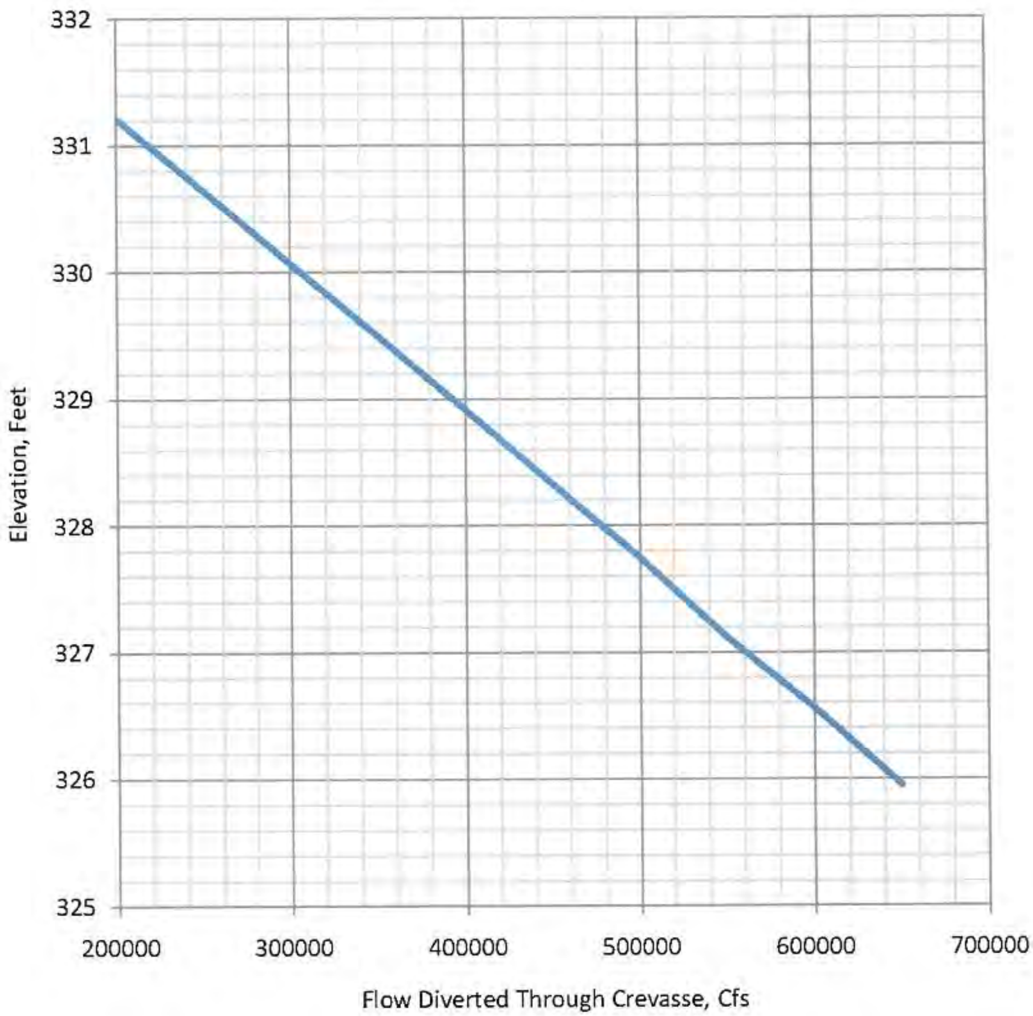


Figure 14. Mississippi River Flowline Elevation at Downstream End of Inflow Crevasse as a Function of Flow Diverted Through the Inflow Crevasse

Flows through the crevasse and flowline elevations at Cairo were calculated using a spreadsheet. The MBM PDF flowline along the crevasse was translated vertically to calculate heads on the crevasse, and the weir coefficients applicable to the H/W ratios were used to calculate unit flows at points along the crevasse. Flows were calculated for segments of length along the crevasse and summed to obtain total crevasse flow. For the existing 9,000 foot crevasse, the MBM flowline along the 11,099 foot crevasse was truncated and then translated vertically. The values calculated in the spreadsheet are represented by the rating curves in Figures 5 and 6.

D. References.

Brater and King, *Handbook of Hydraulics*, 6th Ed.

Chow, V.T., *Open Channel Hydraulics.*

Henderson, *Open Channel Flow*, 1966.

USACE, *Analysis of Potential Modification to the Plan of Operation for the Birds Point- New Madrid Floodway*, May, 1985.

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USACE, *Mississippi Basin Model Letter Report 89-1*, 1989.

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6. Evaluation of Information. An evaluation of the information presented in the geotechnical and hydraulic sections of this report is presented in this section.

The description of sand boils in the geotechnical section relates levee safety to the elevation of the Mississippi River flowline. Although no exact relationship can be devised between flowline elevation and the likelihood of levee failure due to sand boils, experience indicates that flowlines higher than that corresponding to a stage of 55.0 feet on the Cairo gage cause sand boils of sufficient number and severity to threaten the levee. The significance of this is that any interim levee repair that would raise the PDF upstream of the Inflow Crevasse above that for the 1986 Plan of Operation flowline would reduce the safety of the levees. Of course, the same threat would apply to floods less than the PDF that also involve flowlines raised above the 55.0 foot stage.

The description of the hydraulic performance of the Inflow Crevasse presented in the hydraulics section relates the amount of flow diverted through the Inflow Crevasse to the resultant flowline elevation upstream of the Inflow Crevasse. The Inflow Crevasse functions as a weir. The longer the Crevasse is from upstream to downstream and the lower the elevation of the crest of the Crevasse, the greater the flow diverted through the Crevasse, and the lower the flowline elevation of the Mississippi River is between the Crevasse and Cairo. To lower the crest is to increase the head on the weir. Due to the mathematical form of the equation for weir flow, doubling the length of a weir perpendicular to its flow, while holding head constant, doubles the flow through the weir. On the other hand, doubling the head on a weir, while holding length constant, almost triples the flow through the weir. The significance of this weir behavior is that losses in Inflow Crevasse capacity due to raising the crest of the Crevasse could become difficult to compensate for by lengthening the Crevasse from upstream to downstream. At a very high crest elevation the Inflow Crevasse would need to be many miles long, which would require a reevaluation of the hydraulics of the Floodway. A very high crest elevation is probably a technically feasible alternative for a permanent solution, but difficult to implement for the interim. The desirability of keeping flowlines low, and especially lower than a stage of 55.0 feet at the Cairo gage, is pointed out in the geotechnical section. From the point of view that the safety of the levee is the main consideration, the most conservative approach to estimating the amount of flow diverted through the Inflow Crevasse is to assume that no erosion of the Crevasse occurs after overtopping, which is the approach presented in the hydraulics section.

The recommendation to adopt a particular crest elevation for the interim repair of the existing 9000 foot long Inflow Crevasse involves weighing at least three considerations:

(1) The service life of the interim repair until a permanent structure is installed;

(2) The risk of the Mississippi River flowline attaining elevations high enough to threaten the levee;

(3) The risk to property in the Floodway.

Due to the short schedule for this work, very little new analysis could be performed, and the recommendation is based mostly on available data and analysis and on flood fighting experience. A cursory analysis of stages at the Cairo gage indicates that the 0.5, 0.2, and 0.1/year frequency stages are approximately 49.2, 54.1, and 55.5 feet, respectively. Although the normal procedure to estimate frequency is by analyzing flows, the analysis of stages should be approximately correct for these frequent events. The service life of the interim repair is unknown, and will be influenced by funding and by future flooding. Without flood fighting, the risk of flow through the Inflow Crevasse during a 5 year service life would be approximately 91 percent for a crest elevation corresponding to a Cairo stage of 51.0 feet. Without flood fighting, the risk of flow through the Inflow Crevasse during a 5 year service life would be approximately 46 percent for a crest elevation corresponding to a Cairo stage of 55.0 feet. Taking all the important considerations into account it is believed that an interim Inflow Crevasse elevation corresponding to a Cairo stage of 55.0 feet provides an appropriate balance of risk to the levee and the property in the Floodway.

7. <u>Operational Assessment of the Ability to Activate from an Interim Level.</u> As discussed in previous sections, at a Crevasse crest elevation corresponding to a stage of 51.0 feet on the Cairo gage, without erosion, the current 9,000 foot Inflow Crevasse would divert approximately 80% of the flow required to pass through the Crevasse under PDF conditions and the 1986 Plan of Operations. However, some erosion of the Crevasse is likely, since the earthen section for the make safe and stability operations of 51.0 feet provides only a 15 foot top width and comparatively steep side slopes of 1 vertical to 4 horizontal. Such a section has much less erodible bulk than a standard project levee section having the same crest elevation, and it is likely that any significant overtopping for a sustained period of time would eventually cause the entire 9,000 foot crevasse to erode to natural ground, which would assure sufficient open area to convey 80% of the required flow.

If an Inflow Crevasse crest elevation corresponding to a Cairo stage of 55.0 feet is adopted, the Crevasse will pass about 30% of the required Crevasse flow under PDF conditions, assuming no erosion of the overtopped section. However, it is expected that under these conditions the Crevasse would eventually degrade to natural ground as a result of sustained overtopping.

9. Recommendation. In accordance with the information and evaluation presented in this Letter Report, it is recommended to adopt a Crevasse crest elevation corresponding to a stage of 55.0 feet on the Cairo gage as the interim level of protection, based on the expectation the Crevasse will erode to natural ground after activation.

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