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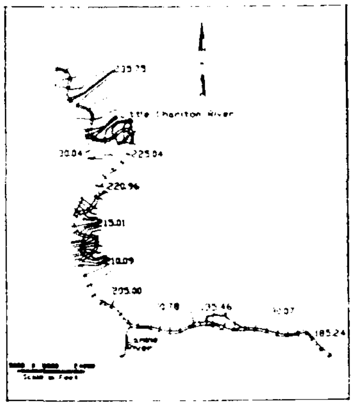

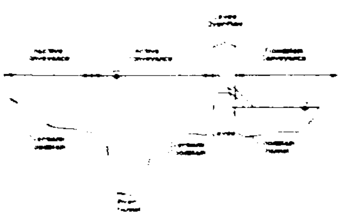

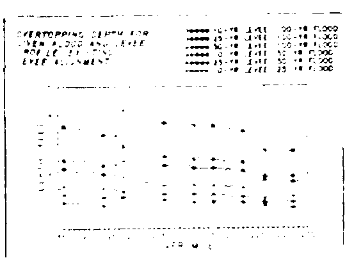

HYDRAULICS LABORATORY

(2)

TECHNICAL REPORT HL-91-21

IMPACT OF AGRICULTURAL LEVEES ON FLOOD HAZARDS

by

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13. ABSTRACT (*Maximum 200 words*)

This report provides an assessment and methodology for determining the impact of agricultural levees on computed flood elevations. By accounting for flood hydrograph stage, flood hydrograph volume, and the conveyance and storage of floodwaters in the protected area behind the levee system, the effect of agricultural levees on floods of a magnitude greater than the levee design can be determined. A dendritic, one-dimensional dynamic wave model was used to compute the hydraulic routing characteristics for the flooding simulations. The methodology was applied to determine these effects specifically along the Missouri River from River Miles 187 through 235.

Site-specific results for this application indicate that the level of flood protection (based upon the top of levee elevation profile with no allowance for freeboard) provided by the existing agricultural levee system is less than the 10-year flood. Individual reaches of the existing agricultural levee system exceed the computed 100-year flood elevations; however, the levee

(Continued)

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systems taken as a whole do not provide a consistent level of protection. Overtopping of the existing levee system fills floodplain storage over the duration of the simulated flood hydrographs. Computed flood elevations for floods of magnitude greater than the levee design profile are not affected by the temporary loss of overbank storage and conveyance.

The sensitivity of flood elevations to levee structural integrity was analyzed by computing flood elevation profiles assuming that the levees breach upon incipient overtopping. Levee breaching increased the rate that the floodwaters entered the overbank area; however, overbank storage was filled by the time of peak discharge in the river channel and overbank water-surface elevations were equivalent to river water-surface elevations within the study area. Peak water-surface profiles throughout the study area were equivalent for both breached and nonbreached levee conditions.

Flood elevations were computed for three levee alignments with levee profiles set to the 10-, 25-, 50-, and 100-year recurrence interval flood. The levee alignments were collinear with the channel bank line, the existing alignment, and the Regulatory Floodway boundary specified on the Flood Hazard Boundary Maps of the study area. The results indicate that computed flood elevations are more sensitive to the amount of overbank conveyance area between the main river channel and the levee than to the levee elevation profile. The results are consistent with the current practice of the National Flood Insurance Program of limiting structural floodplain encroachment.

PREFACE

The agricultural levee impact study, reported herein, was conducted at the US Army Engineer Waterways Experiment Station (WES) at the request of the US Federal Emergency Management Agency (FEMA) under Interagency Agreement No. EMW-89-E-3049, dated 11 August 1989.

This investigation was conducted during the period August 1989 to July 1990 in the Hydraulics Laboratory of WES, under the direction of Mr. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory; Mr. Marden B. Boyd, Chief of the Waterways Division, Hydraulics Laboratory; and Mr. Michael J. Trawle, Chief of the Math Modeling Branch, Waterways Division. The Project Engineer for this study was Mr. Brad R. Hall, Math Modeling Branch, who also prepared this report. Ms. Lisa G. Porter, Math Modeling Branch, provided technician support throughout the course of this study. Ms. Marsha C. Gay, Information Technology Laboratory, WES, provided editorial support.

Dr. Frank Tsai was the Project Officer at FEMA in Washington, DC. His assistance in the execution of this contract and desire to analyze the problem addressed in this report are gratefully acknowledged. Topographical maps, levee surveys, and cross-section and hydrologic data were provided by personnel from the US Army Engineer District, Kansas City (CEMRK). CEMRK personnel who provided this invaluable information were Mr. Lloyd Wisdom, Ms. Margy Debrot, and Mr. Dave Monnig, all of the CEMRK District Office, and Mr. Chuck Duncan of the CEMRK Jefferson City Project Office.

The Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
miles (US statute)	1.609344	kilometres

IMPACT OF AGRICULTURAL LEVEES ON FLOOD HAZARDS

PART I: INTRODUCTION

Background

1. Agricultural levees are used in many low-lying areas to protect farmlands from floods. The US Army Corps of Engineers defines agricultural levees as "levees that provide protection from flooding in lands used for agricultural purposes" (Headquarters, US Army Corps of Engineers (HQUSACE), 1978). The levees are often constructed, maintained, and improved on an ad hoc basis by local landowners organized into levee districts or with the assistance of Government flood protection programs. The levee design profile is oftentimes not uniform throughout the levee system, and also is generally less than the 100-year flood recurrence interval (RI). Since these levees are often located within the regulated floodway designated on a community's Flood Insurance Rate Map, a significant conflict may exist between local agricultural interests and the objectives, as defined in Sections 60.3 and 65.10 of the National Flood Insurance Program (NFIP) (Federal Emergency Management Agency 1987), of maintaining a Regulatory Floodway to limit floodplain encroachment and increases in regulatory flood elevation.

2. Extensive construction of agricultural levees along the Missouri River in central Missouri has occurred. Federal and local floodplain management agencies have expressed concern about the impact of these levees on flood elevations, providing the impetus for this study. The study area extends from Jefferson City, MO, located at River Mile (RM) 144 to Waverly, MO, at RM 294. The detailed study area in which hydraulic simulation of levee overtopping and computation of floodplain hydraulics was conducted extends from the Interstate 70 Highway Bridge at RM 185 to Glasgow, MO, at RM 235. A location map and cross-sectional layout along the detailed study area are shown in Figure 1.

3. Channel and overbank cross sections are located at approximately 0.5- to 1.0-mile* intervals along the main river channel. Existing levee

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

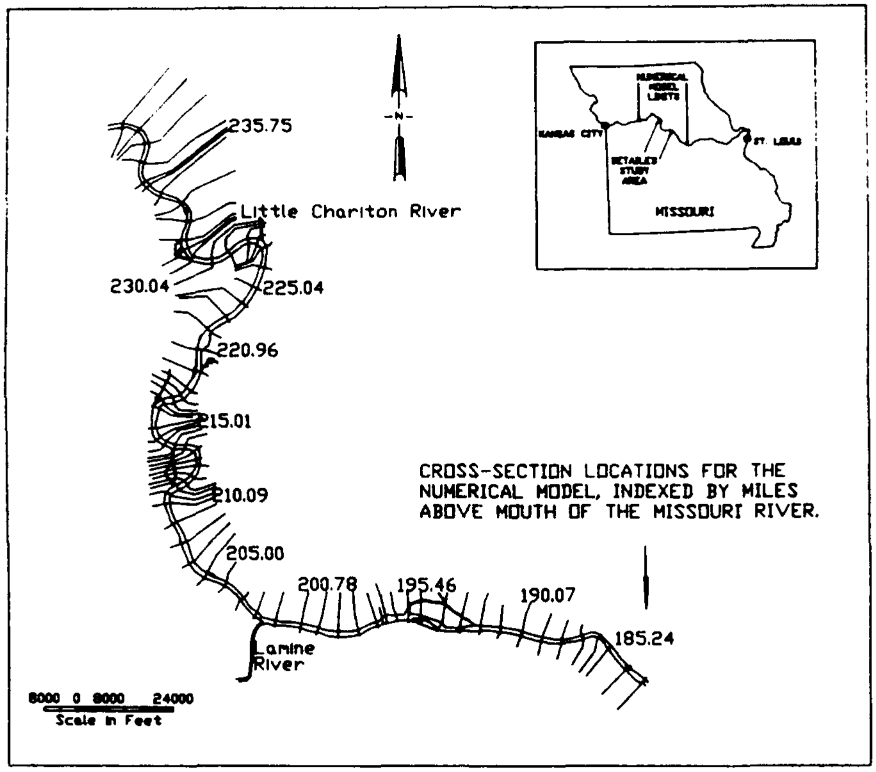

Figure 1. Location map and cross-section layout of study area

elevation profiles used for this study were developed from ongoing US Army Corps of Engineers levee repair eligibility surveys and cross-section survey plots. These top of levee profiles were developed from the best available information at the time of this study. Actual levee elevations may differ due to ongoing levee rehabilitation, repair, and embankment settlement.

4. Agricultural levees protect the majority of the floodplain in the study area. In addition, within the study area there are Federally constructed levees on the left bank of the Missouri River upstream of Glasgow, MO, extending from RM 227 to RM 239. Agricultural levee locations within the detailed study area are plotted in Figures 2 through 5. Regulatory Floodway boundaries have been developed for the detailed study area (US Army Engineer District, Kansas City, 1981b) and are also plotted in Figures 2 through 5.

Purpose and Scope of Report

5. At the request of the Federal Emergency Management Agency (FEMA), the Hydraulics Laboratory at the US Army Engineer Waterways Experiment Station

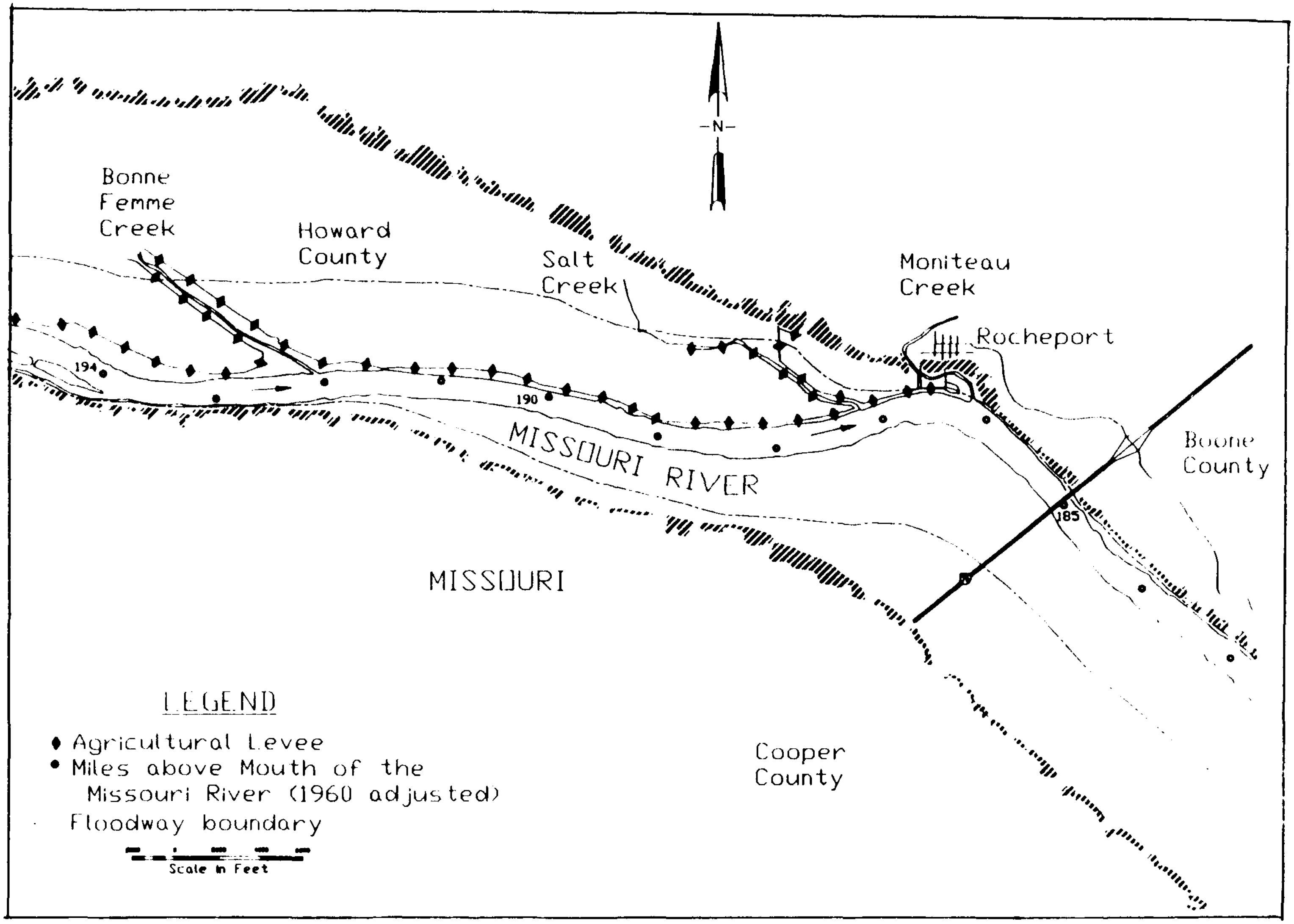

Figure 2. Agricultural levee location map, RM 183 to 195

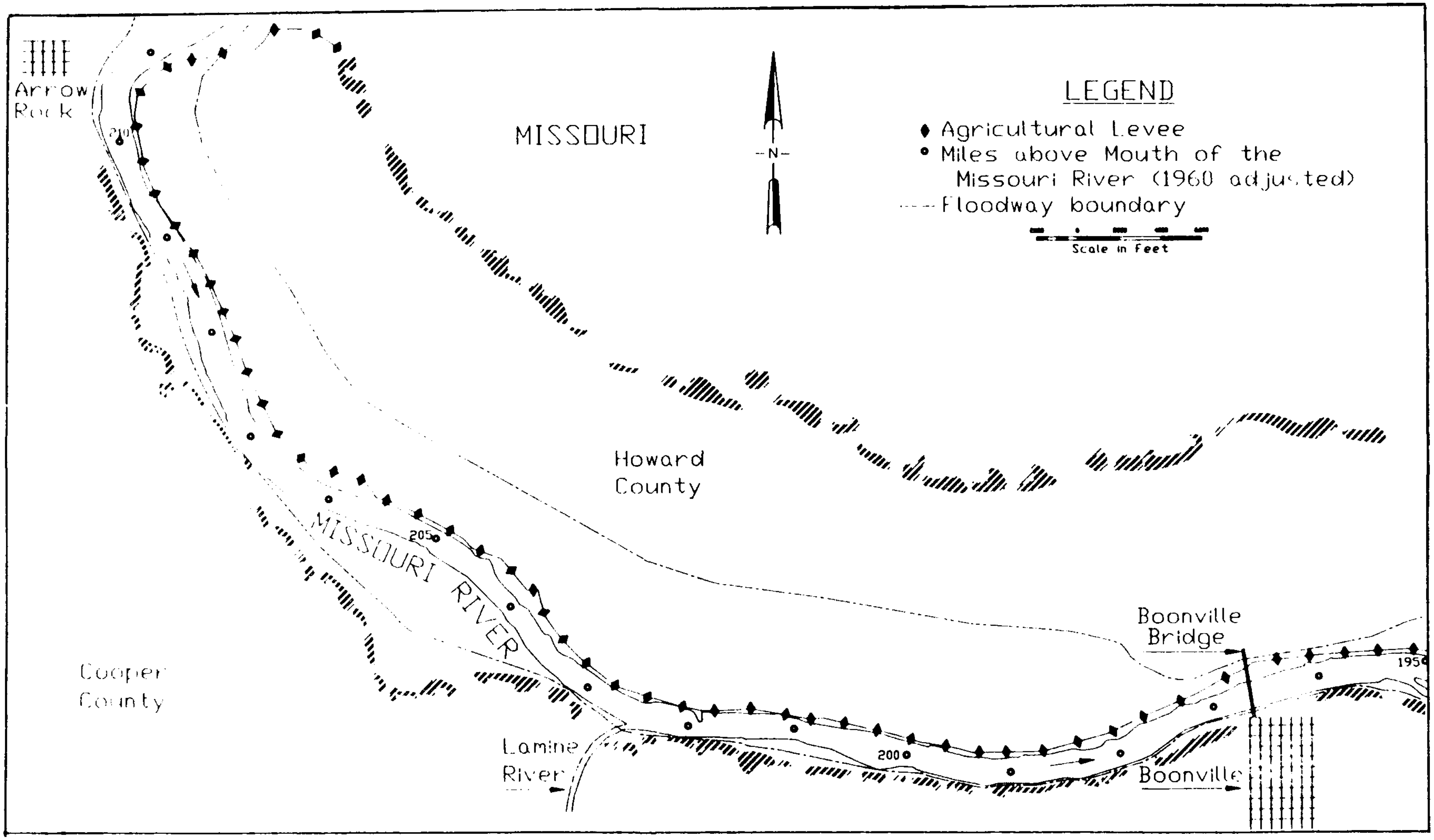

Figure 3. Agricultural levee location map, RM 195 to 211

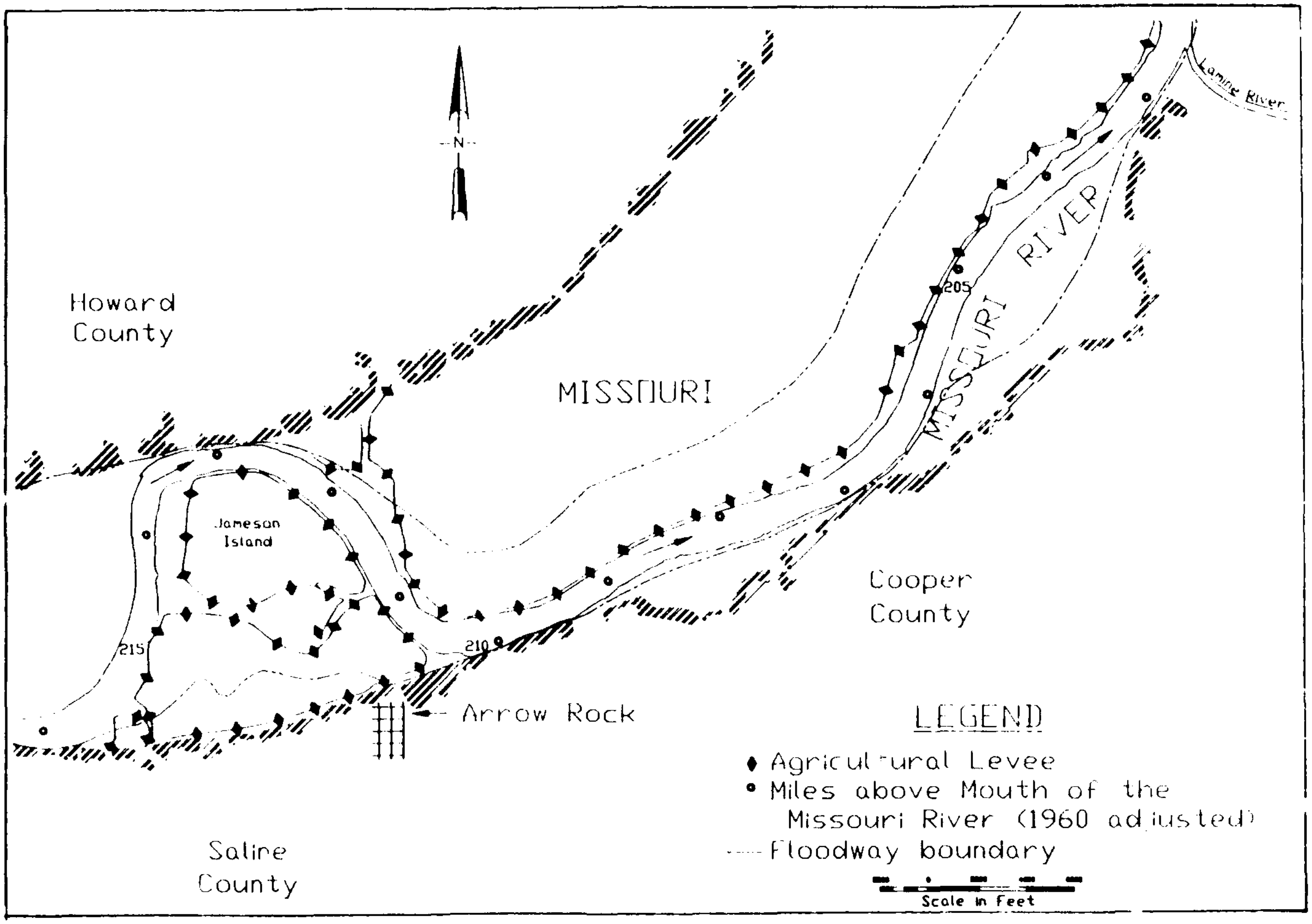

Figure 4. Agricultural levee location map, RM 203 to 216

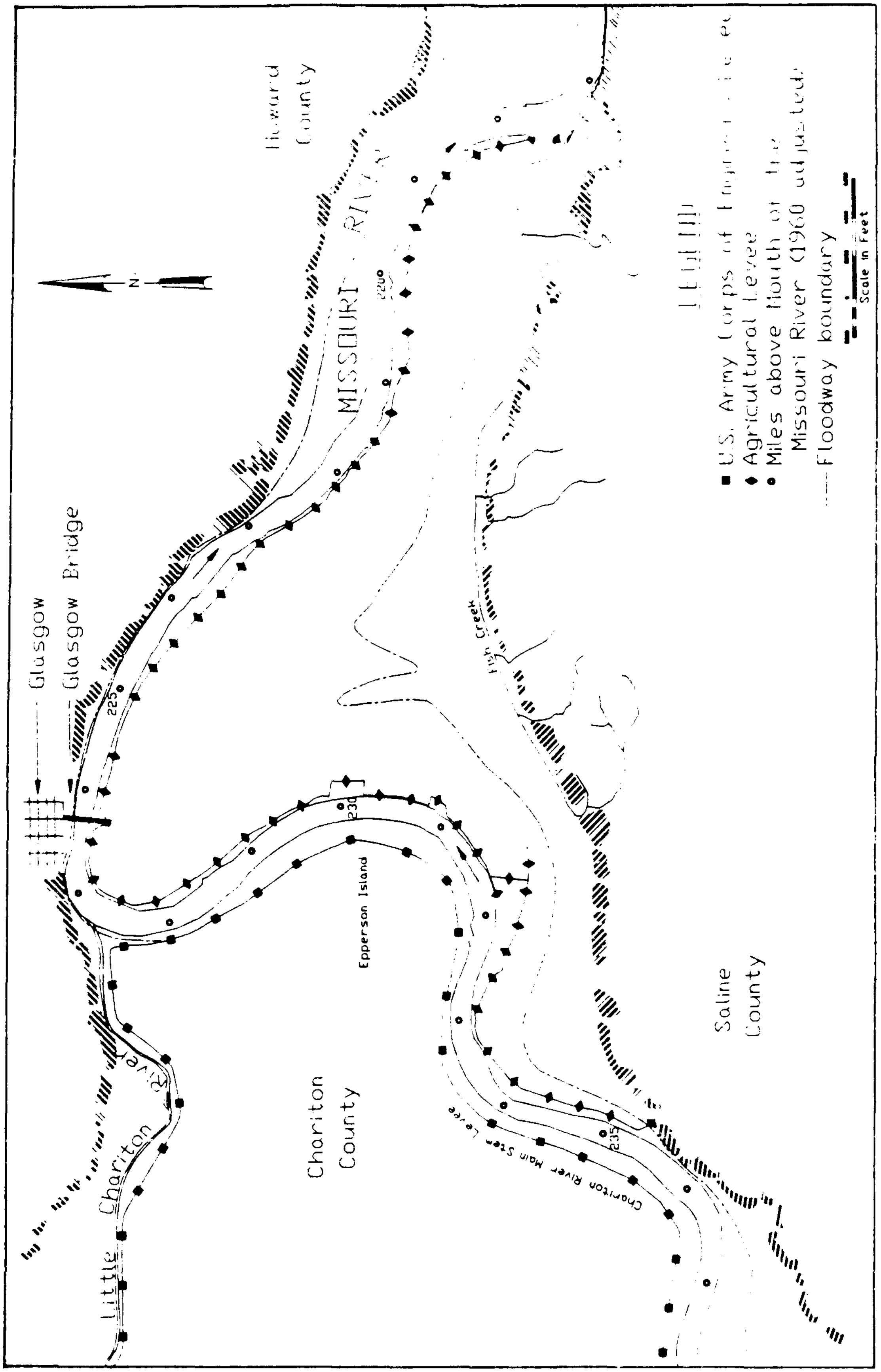

Figure 5. Agricultural levee location map, RM 216 to 238

studied the impact of agricultural levees on flood hazard. To compute the interaction between flood wave passage and levee overtopping and breaching, and the interaction between the timing and the volume of water that leaves the active conveyance of the main river channel and enters overbank storage behind the agricultural levees, a numerical one-dimensional dynamic simulation model was developed. The model assesses the impact of various levels of conveyance and floodplain storage reduction due to the presence of agricultural levees on water-surface elevations for a range of flood magnitudes. This report describes the study approach and results, and provides recommendations on assessing the severity of agricultural levee impact on flood hazards.

PART II: REGULATORY GUIDELINES

6. FEMA has defined the Regulatory Floodway as that portion of the floodplain that must be reserved from encroachment in order to pass the 100-year-RI flood without increasing the water-surface elevation more than 1 ft, providing hazardous velocities are not produced. Regulatory Floodways are usually determined by steady flow hydraulic analysis of floodplain encroachment. Overbank conveyance reduction is specified for determining the amount of encroachment on the right bank and left bank floodplains. Example methods of determining the amount of encroachment on the right and left overbank floodplains are equal conveyance reduction or conveyance reduction in proportion to existing condition overbank conveyance.

7. Levee construction has the potential to increase the flood elevation profile of a river by affecting two hydraulic processes. Eliminating overbank conveyance through levee construction alters the stage-discharge rating curve, and flood wave attenuation is reduced due to the elimination of overbank storage. The degree of flood elevation increase due to the construction of levees will vary depending upon the flood frequency. Levees will have the greatest impact on flood elevations for floods that do not overtop the levee. As the degree of levee overtopping and floodplain flow increase (i.e., flood RI and magnitude increase), the effects of the levee on flood elevations will decrease. Since regulations of the NFIP are based on the 100-year-RI flood risk and agricultural levees are generally constructed to a flood profile less than the 100-year RI, there is a need to identify a methodology to determine under what conditions agricultural levees adversely impact the 100-year flood profile.

8. FEMA has minimum standards for assuring flood protection. As stated in the previous paragraph, these standards for levee design were adopted for evaluating flood risk associated with the 100-year-RI flood (FEMA 1987). Two primary considerations in the NFIP regulations are a freeboard allowance and embankment erosion protection. NFIP regulations require a minimum freeboard allowance of 3 ft above the 100-year-RI flood to consider the protected area excluded from 100-year flood risk. For situations in which a high degree of certainty in the 100-year-RI water-surface profile exists, the NFIP regulations allow a freeboard allowance of 2 ft above the 100-year-RI profile. In addition, the NFIP regulations require levee embankment erosion protection in

accordance with guidelines set forth in the Engineer Manual, "Hydraulic Design of Flood Control Channels" (HQUSACE 1991) for assurance of levee integrity during the 100-year-RI flood.

9. The Corps of Engineers provides assistance to State, county, and local flood control districts for levee repair through the Public Law (PL) 84-99 Program. Many of the levees repaired under the PL 84-99 Program can be classified as agricultural levees. Minimum design and construction standards for the levees are required for Federal repair eligibility. These requirements are documented in Engineer Regulation 500-1-1, Change 1 (HQUSACE 1987). The minimum top of levee elevation profile for acceptable performance under the PL 84-99 Program is the 10-year-RI flood profile plus 3 ft of freeboard. In addition, minimum design standards for levee stability, seepage prevention, and erosion protection are required for Federal repair assistance under the PL 84-99 Program. Floodplain management guidelines are an important consideration in the PL 84-99 Program, and levee repairs are completed with the goal of not increasing the elevation of future floods. The Corps of Engineers will not provide assistance for repair of secondary levee systems on the river side of the main levee system. Modification of levee systems to increase the degree of protection or to provide protection to a larger area is not authorized under the PL 84-99 Program.

10. The US Department of Agriculture, Soil Conservation Service, has the authority to undertake emergency measures for flood control under Section 403 of PL 95-334. Minimum design standards for freeboard, erosion protection, embankment stability, and seepage prevention are provided in the *National Engineering Handbook* (US Department of Agriculture 1982). This document specifically states the need to avoid increases in flood profile elevations due to levee construction.

PART III: NUMERICAL MODELING APPROACH

11. The one-dimensional dynamic wave simulation model DWOPER (Fread 1987) was used for simulating the channel and floodplain hydraulics. The numerical model computes the time-varying flow rate and water-surface elevation in branched and looped channel networks based on an implicit numerical approximation of the St. Venant equations (Henderson 1966). Cross sections are partitioned into active conveyance, inactive conveyance, and overbank flow channels. A schematic cross section that indicates the geometrical properties as discretized in the DWOPER model is shown in Figure 6.

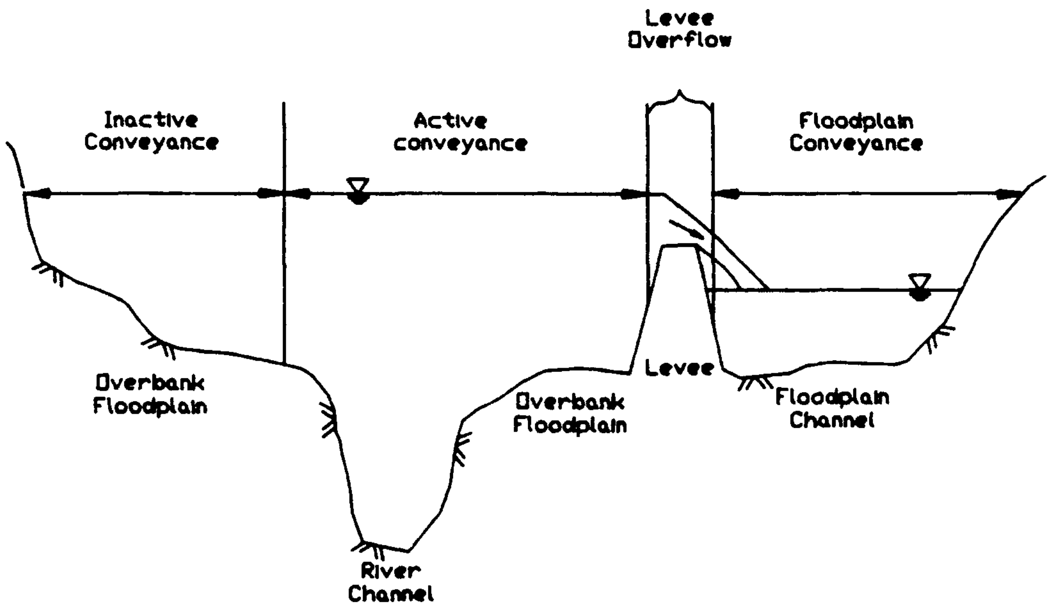

Figure 6. Schematic cross-sectional properties as discretized in the DWOPER model

12. A computational network of the study area was developed. The computational network is represented by cross sections and reach lengths between cross sections. Lateral flow due to levee overtopping allows for exchange of flow between floodplain conveyance and the river channel. The DWOPER model computational network for the detailed study area is shown in Figure 7. Figure 7 indicates cross-section locations for both main channel and floodplain conveyance cross sections and reaches in which levee overtopping may occur.

13. Boundary conditions are required for DWOPER model computations. The DWOPER model developed for this study used a stage-discharge rating curve at the Jefferson City gage for the downstream boundary condition and discharge

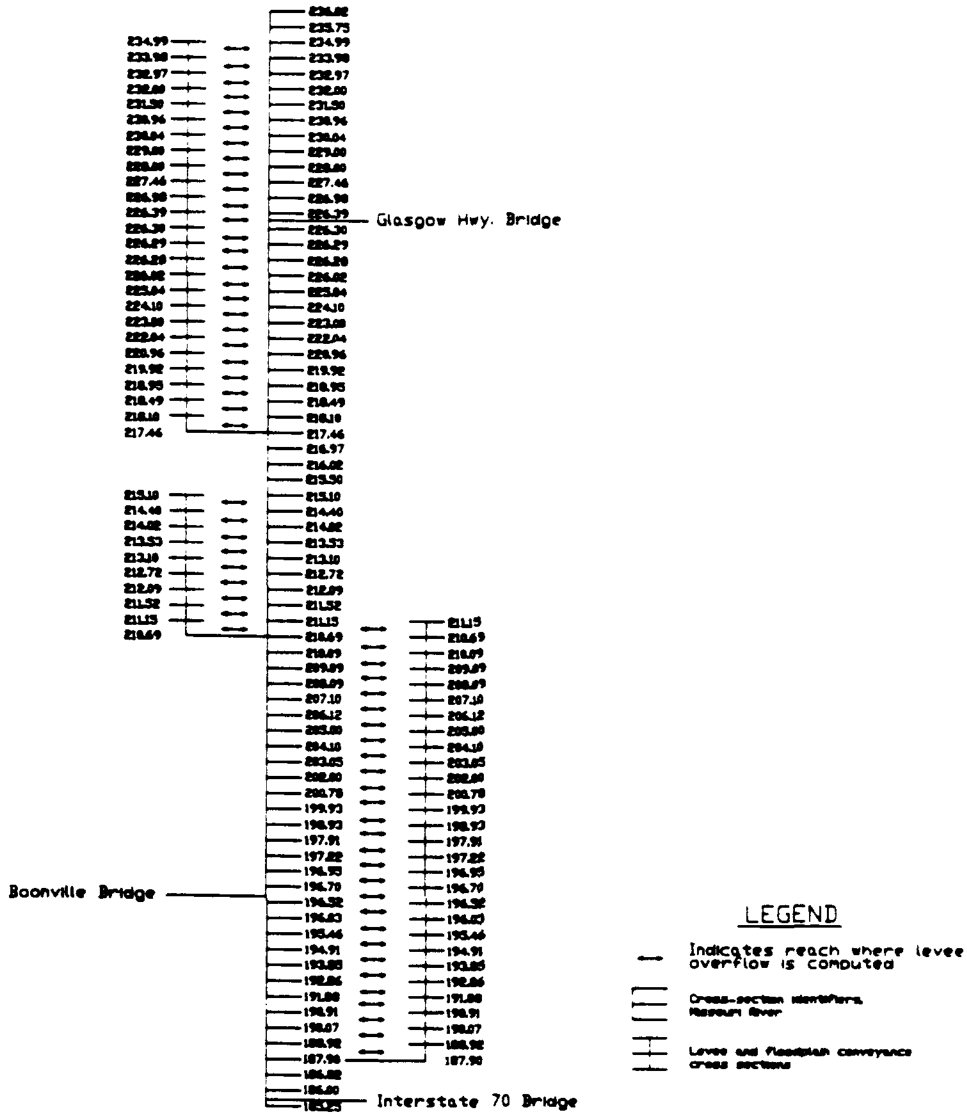

Figure 7. Computational network of levee overtopping area

boundary conditions at the upstream boundary at Waverly as well as discharge boundary conditions for the three major lateral inflow points along the study reach area. The three lateral inflow rivers along the study reach are the Lamine River, the Chariton River, and the Grand River. A schematic of the boundary conditions specified for the DWOPER model is shown in Figure 8.

Levee Overtopping and Breach Parameters

14. Floodwaters enter the overbank areas protected by agricultural levees by overtopping and breaching of the levee structure. The rate of levee

overflow is computed by the broad-crested weir relationship:

$$Q_{weir} = C * K_s * L_{weir} * (H_{river} - H_{weir})^{1.5} \quad (1)$$

where

- Q_{weir} = levee overflow flow rate, cfs
- C = weir coefficient, $ft^{0.5}/sec$
- K_s = correction factor for tailwater submergence
- L_{weir} = length of the levee being overtopped, ft
- H_{river} = water-surface elevation of the river at the location of overtopping, ft
- H_{weir} = elevation of the weir crest, ft

The weir coefficient can vary between 2.6 and 3.1 depending on levee cross-sectional characteristics (Skogerboe and Hyatt 1967). The broad-crested weir coefficient was set at 2.6 for all levee overflow computations. The tailwater submergence correction factor K_s is defined by:

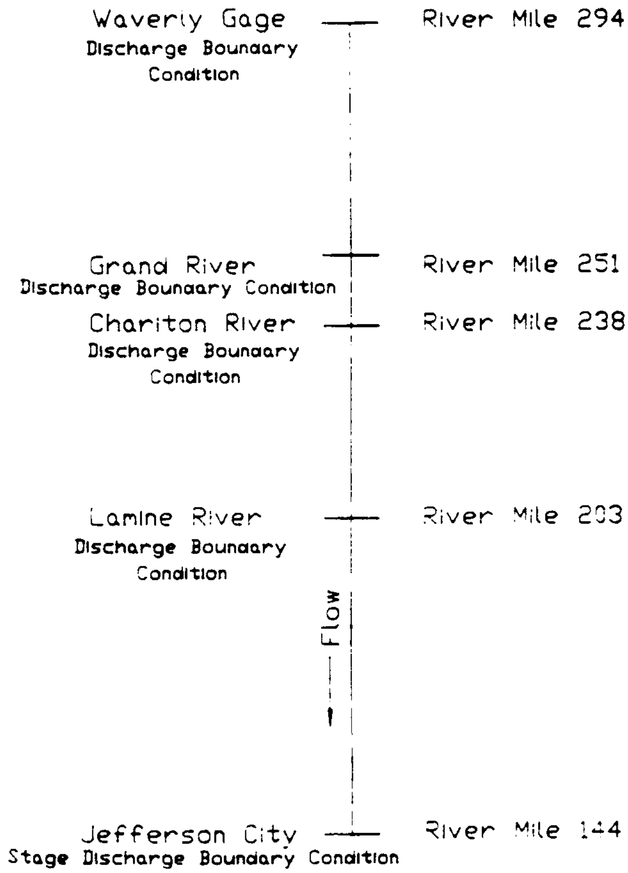

Figure 8. Boundary condition schematic for DWOPER model

$$K_s = 1.0 \text{ , for } \frac{H_{tail} - H_{weir}}{H_{river} - H_{weir}} \leq 0.67 \quad (2)$$

$$K_s = 1.0 - 27.8 \left(\frac{H_{tail} - H_{weir}}{H_{river} - H_{weir}} - 0.67 \right)^3 \text{ for } \frac{H_{tail} - H_{weir}}{H_{river} - H_{weir}} > 0.67 \quad (3)$$

where H_{tail} is the water-surface elevation in the weir tailwater, ft.

15. The DWOPER model has the capability to compute flow through breached levees. Input parameters are the length of the levee breach, the depth of levee overflow required to initiate levee erosion, the final depth of breach erosion in the levee, and the time period required for the specified breach erosion depth to occur. Unfortunately, these parameters are difficult

to specify even under highly controlled laboratory conditions. The American Society of Civil Engineers Task Committee for the Mechanics of Overflow Erosion on Embankments has summarized several laboratory and field studies of dam, levee, and highway embankment erosion (Powledge et al. 1989a, 1989b). Their work documents observed levee and highway embankment failures. A levee erosion rate of 1 ft/hr is within the range of observed levee and highway embankment erosion rates reported in their work.

16. Extensive overtopping and breaching of levees occurred throughout the study area of the Missouri River during the October 1986 flood.* However, levee erosion rates and breach lengths were not documented. Levee breach lengths of ten times the levee height have been used in floodplain studies by the US Army Corps of Engineers (US Army Engineer District, Seattle, 1987). Based upon the limited amount of design guidance on levee erosion parameters, levee erosion rates of 1 ft/hr and breach lengths of ten times the levee height were adopted for computing flow through breached levees.

Numerical Model Adjustment and Verification

17. The numerical model was adjusted using two separate hydraulic criteria. The model was initially adjusted to reproduce computed steady-flow water-surface profiles developed for the Federal Flood Insurance Program (US Army Engineer District, Kansas City, 1981a). An additional check on model adjustment was performed by checking peak water-surface elevations observed during the October 1986 flood by simulating a dynamic 30-day reconstruction of the flood event. Adjustment parameters were the delineation of the active and inactive conveyance, the composite Manning's roughness coefficient for the active conveyance section, and channel expansion and contraction coefficients.

18. The lateral distribution of active conveyance for each cross section was specified as the main channel and the portion of the overbank area between the main channel and the existing agricultural levees. The initial estimate of the composite Manning's *n* was computed as a function of stage with the computer program "Geometric Elements from Cross-Section Coordinates," GEDA (US Army Engineer Hydrologic Engineering Center 1981). Cross-sectional

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* Personal Communication, 1989, Margy Debrot, US Army Engineer District, Kansas City.

coordinates and the lateral distribution of Manning's n as specified from the steady-flow water-surface profiles computed by the Kansas City District were used as input to GEDA. GEDA determines the composite Manning's n as a function of the lateral distribution of Manning's n , the wetted perimeter, and the water-surface elevation for each cross section. Final adjustment of the Manning's n values was accomplished by comparing water-surface profiles computed by the steady-flow DWOPER model with the steady-flow profiles published for the study area (US Army Engineer District, Kansas City, 1981a) for the 10-year and 100-year peak flow discharges. The adjusted values of composite Manning's n for the DWOPER model varied between 0.025 and 0.030 for all river cross sections. The floodplain channels behind the levee system were assigned a Manning's n value of 0.07. Comparisons of the computed water-surface profiles within the detailed study area for the 10-year-RI and 100-year-RI floods are shown in Figures 9 and 10, respectively.

19. The October 1986 flood was used as the hydrologic data base for verifying the DWOPER model. Peak water-surface profiles measured within the study area (US Army Engineer District, Kansas City, 1987) provided the data for verifying the dynamic stage-discharge prediction capability of the DWOPER model. The Missouri River discharge hydrograph was measured by the US Geological Survey during the October 1986 flood at the gaging station located at the Missouri, Kansas, and Texas Railroad bridge at Boonville, MO. Comparing measured and computed flood hydrographs at the gage provided a means of verifying the flood routing capabilities of the DWOPER model. Boundary conditions of the DWOPER model, adjusted to match the steady-flow 10-year and 100-year flood profiles, were specified to match observed discharge hydrographs for the time period of 20 September 1986 to 20 October 1986. Twenty-four-hour time-steps were used for this and all other dynamic simulations of the DWOPER model. The measured peak water-surface profile and the computed DWOPER peak water-surface profile for 1986 flood conditions are shown in Figure 11. The measured and computed discharge hydrographs at the Missouri River at the Boonville gage (RM 196.7) are plotted in Figure 12.

Flood Hydrographs

20. The DWOPER model boundary condition schematic shown in Figure 8 indicates that flood hydrographs for the Missouri River at Waverly, MO, the

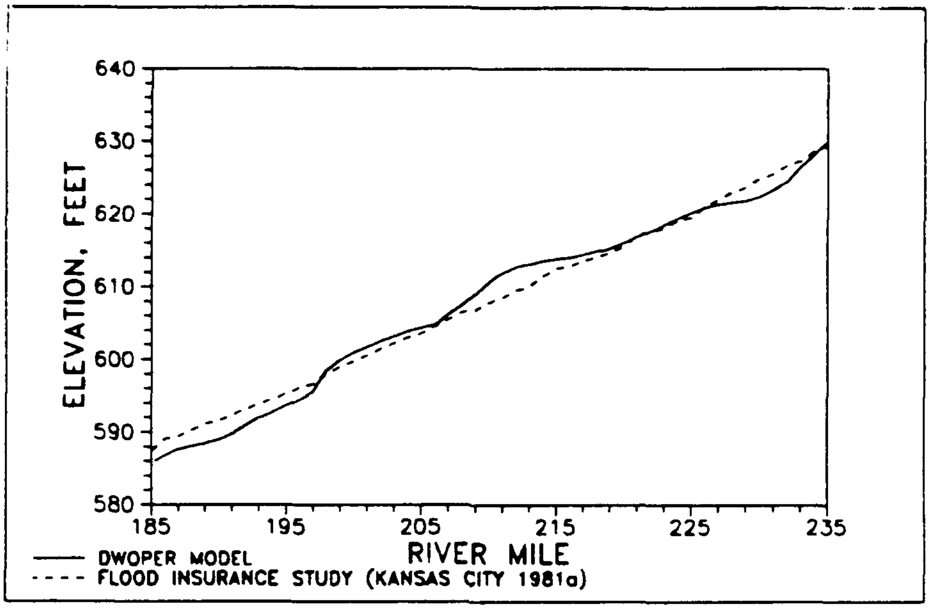

Figure 9. Comparison of computed water-surface profiles, 10-year-RI flood

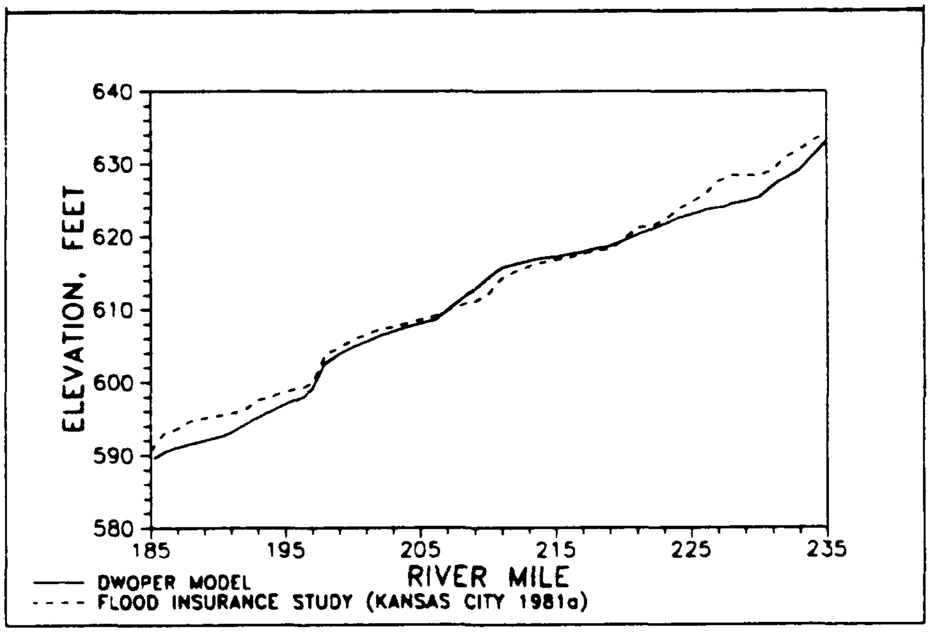

Figure 10. Comparison of computed water-surface profiles, 100-year-RI flood

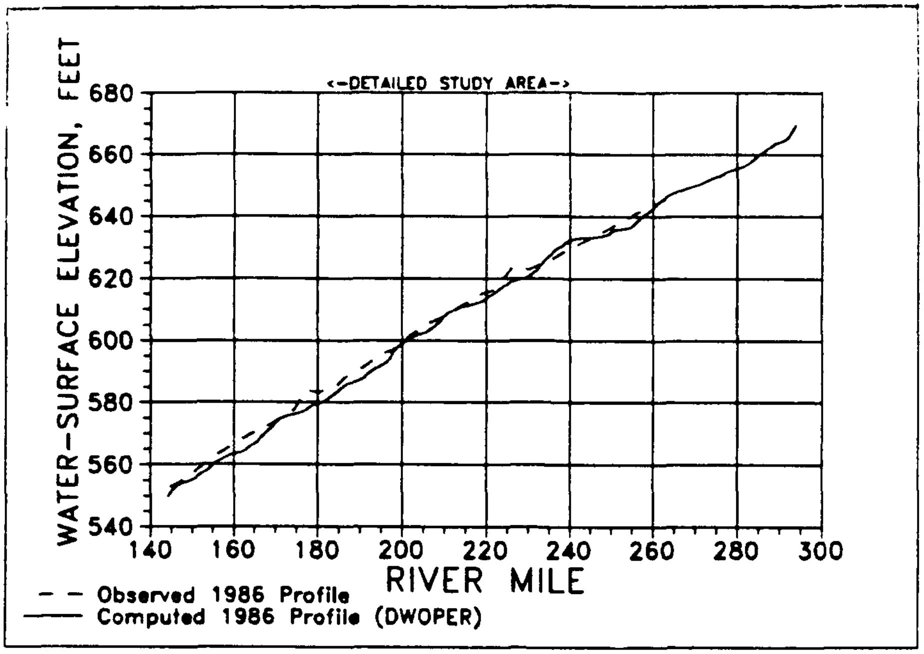

Figure 11. Comparison of computed and observed high-water profiles, October 1986 flood

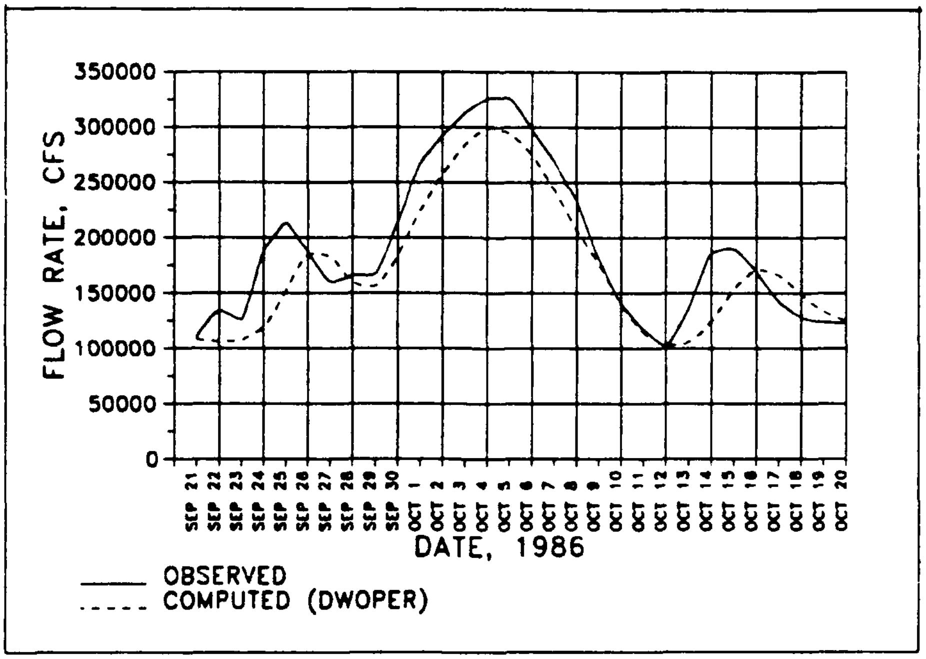

Figure 12. Comparison of computed and observed flood hydrograph, Missouri River at Boonville, MO, October 1986 flood

Grand River at Missouri RM 251, the Chariton River at Missouri RM 238, and the Lamine River at Missouri RM 203 are required for the dynamic analysis of levee overtopping in the study area. These flood hydrographs were developed for 10-year-, 25-year-, 50-year-, and 100-year-RI floods from historical flow rate-duration-frequency statistics and peak discharge-frequency statistics used for NFIP studies of the study area. The peak discharge of the hydrograph was set equal to the discharge used for the steady-flow water-surface profiles of the study area. Discharge-duration-frequency relationships were developed from daily discharge records of the Missouri River at the Waverly gage (USGS gage No. 06895500) using Log-Pearson Type III statistics (US Water Resources Council 1982). The period of record used in the analysis was 1 January 1952 to 31 December 1987. The resultant discharge-duration-frequency statistics are listed in the following tabulation:

Recurrence	Flow rate, cfs, for Duration			
Interval	30-day	10-day	7-day	1-day Peak
10-year	161,000	203,000	216,000	285,000
25-year	192,000	245,000	260,000	350,000
50-year	213,000	275,000	291,000	395,000
100-year	234,000	305,000	321,000	445,000

21. Daily discharge data for the Lamine, Chariton, and Grand Rivers at their confluences with the Missouri River are not available. Peak flow-frequency statistics for these rivers are available from the steady-flow water-surface profiles published for the study area. Discharge-duration-frequency statistics for these rivers were developed by multiplying the discharge-duration-frequency values developed for the Missouri River at Waverly (RM 294) by the ratio of the peak discharge of the tributary river over the peak discharge of the Missouri River at Waverly. The resultant flood hydrographs used for DWOPER model boundary conditions for computing the effects of agricultural levees on flood elevations in the study area are plotted in Figures 13-16. The timing of the flood peaks on the tributaries was lagged 2 days from the upstream boundary condition hydrograph (Missouri River at Waverly) to allow for flood wave travel time and for tributary flood peaks to be coincident with the peak discharge on the Missouri River at their confluences. The flood hydrographs used for simulation incorporate the best available information, as obtained from the existing NFIP studies and measured

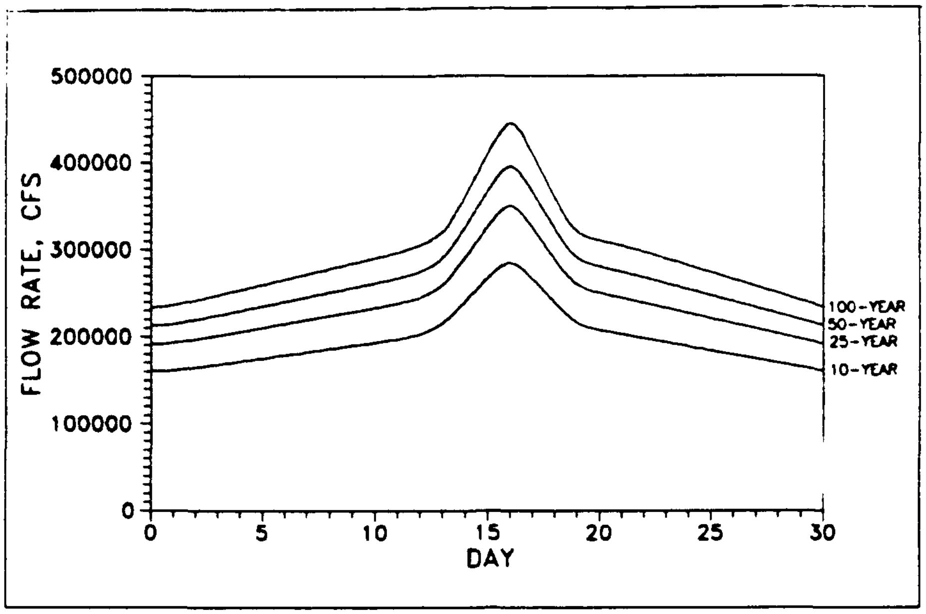

Figure 13. Flood hydrograph boundary condition, Missouri River at Waverly

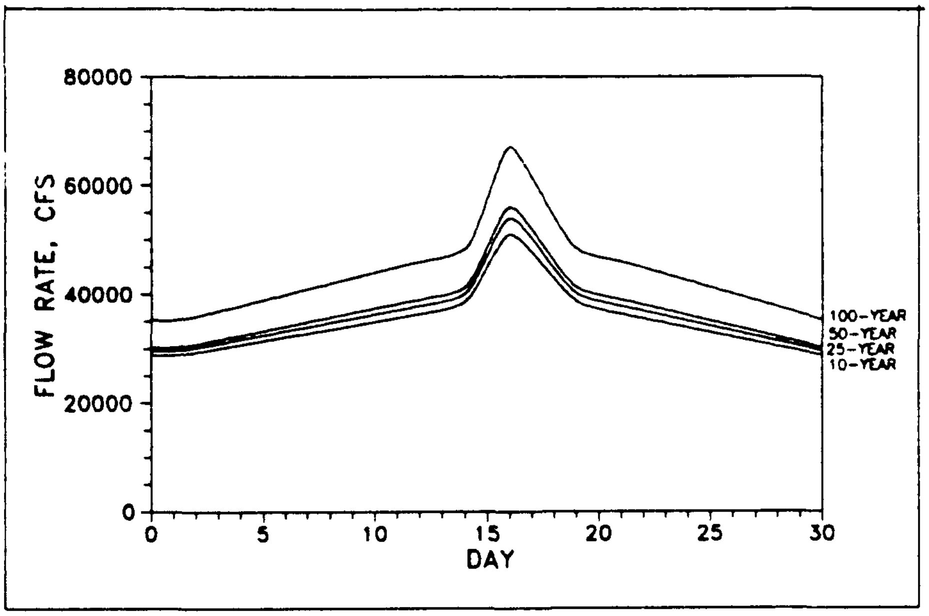

Figure 14. Flood hydrograph boundary condition, Grand River at confluence with the Missouri River

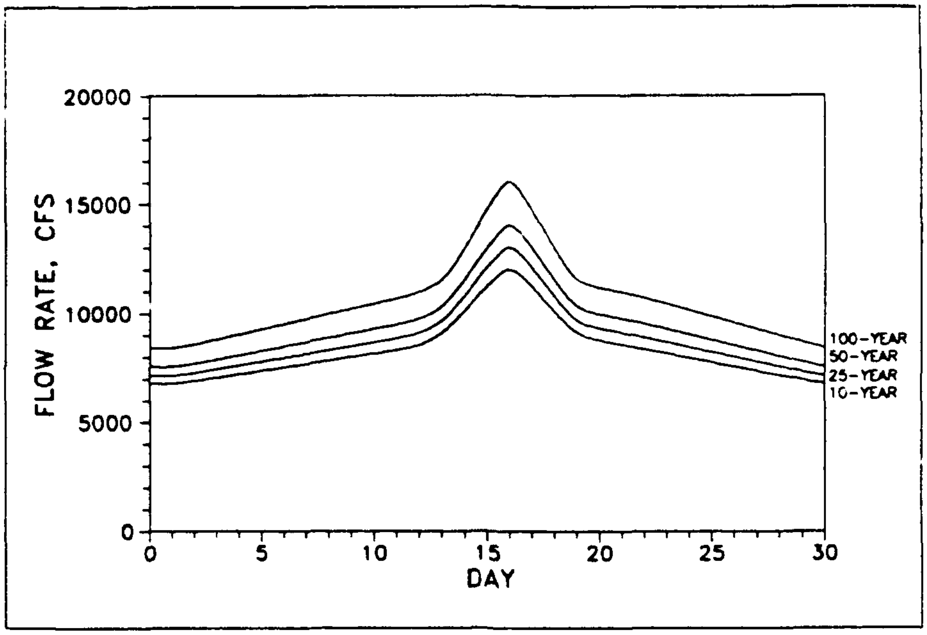

Figure 15. Flood hydrograph boundary condition, Chariton River at confluence with the Missouri River

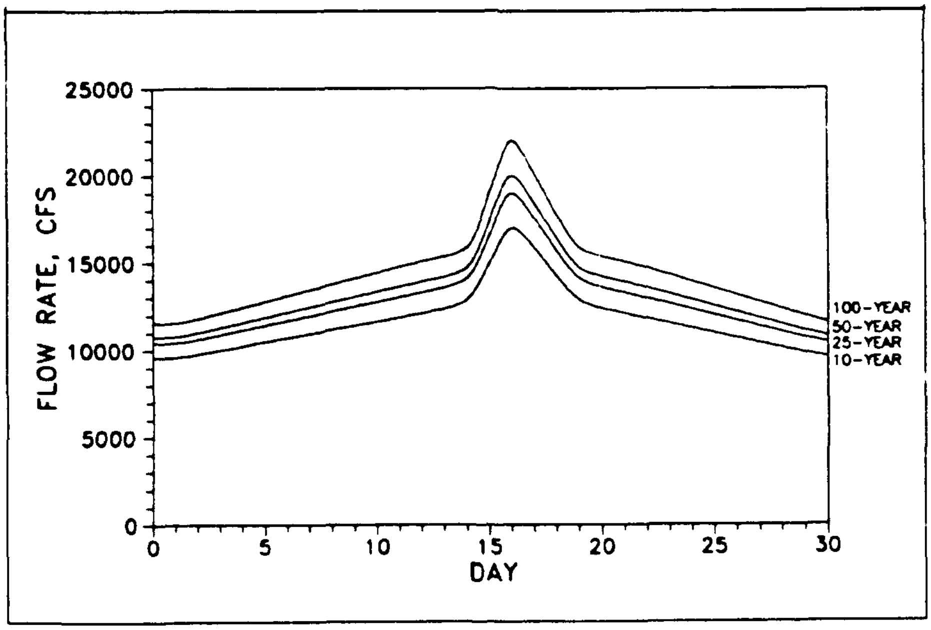

Figure 16. Flood hydrograph boundary condition, Lamine River at confluence with the Missouri River

daily streamflow discharges, for determining flood hydrograph peak discharges and flood hydrograph volumes. The flood hydrograph analysis does not incorporate a detailed analysis of flood hydrograph ascension and recession rates, nor does it incorporate a detailed operational study of the effects of the main-stem Missouri River and tributary river flood control reservoirs on flood hydrograph characteristics.

PART IV: NUMERICAL MODEL APPLICATION

22 The sensitivity of computed flood elevations to variation of several levee parameters was tested. Levee parameters included the top elevation profile, the areal extent of floodplain protection, and breaching of levee embankments during the flood event. A levee freeboard allowance was not considered for all the flood hydrograph-levee profile combinations analyzed. Levee overtopping was assumed to commence when computed river water-surface elevations exceeded the specified levee elevation. Depending on the desired conditions, levee embankment elevations were specified as either the existing levee elevation or a specific design RI water-surface elevation.

Existing Levee Impacts on Flood Elevations

23. The impact of the existing agricultural levees on the peak water-surface profile for the 10-year-, 25-year-, 50-year-, and 100-year-RI flood hydrographs was determined. Peak water-surface profiles in the detailed study area are plotted with top of levee profiles for the existing levee conditions in Figures 17-19. The results of the existing condition analysis indicate that the existing levee system provides an inconsistent level of flood protection within the detailed study area. Overtopping occurs at several locations on each levee system. Floodplain storage is completely filled for each of the events, and hence overbank flood elevations are equivalent to the peak flood elevation in the river channel.

Levee Encroachment Impacts on Flood Elevations

24. Peak water-surface elevations were determined for the entire model limits for the 10-, 25-, 50-, and 100-year-RI floods for three alignments of agricultural levees within the detailed study area. These alignments are the existing agricultural levee alignment, an alignment immediately adjacent to the river bank, and an alignment along the Regulatory Floodway boundary. The existing agricultural levee alignment varies between a 100- to 500-ft setback from the top of the riverbank. The alignment adjacent to the riverbank represents the maximum amount of floodplain encroachment by agricultural levees, and thus the maximum flood stage impact for levee relocation. The alignment

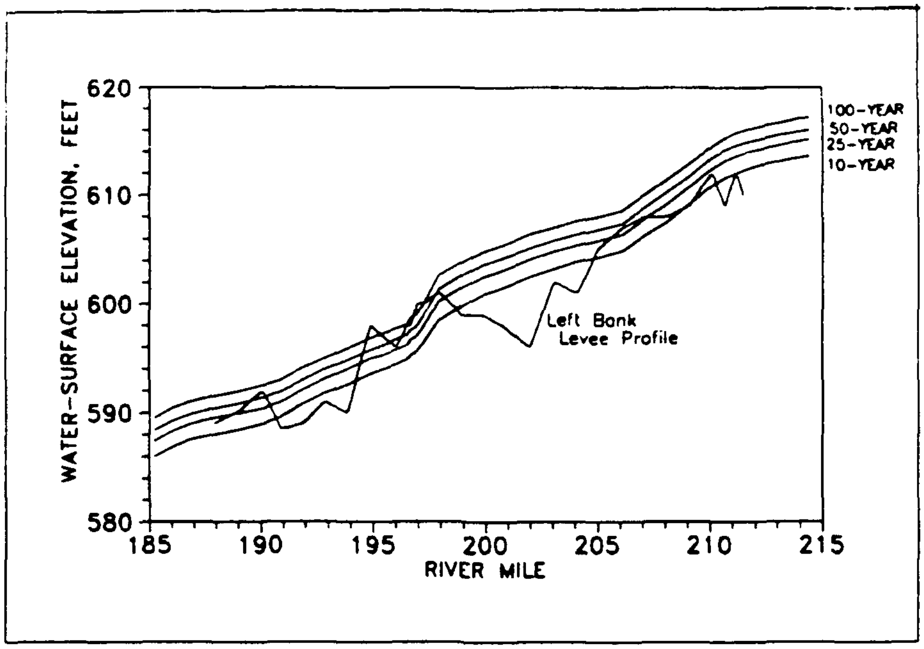

Figure 17. High water profiles with existing levees for 10-, 25-, 50-, and 100-year-RI flood, RM 185 to 215

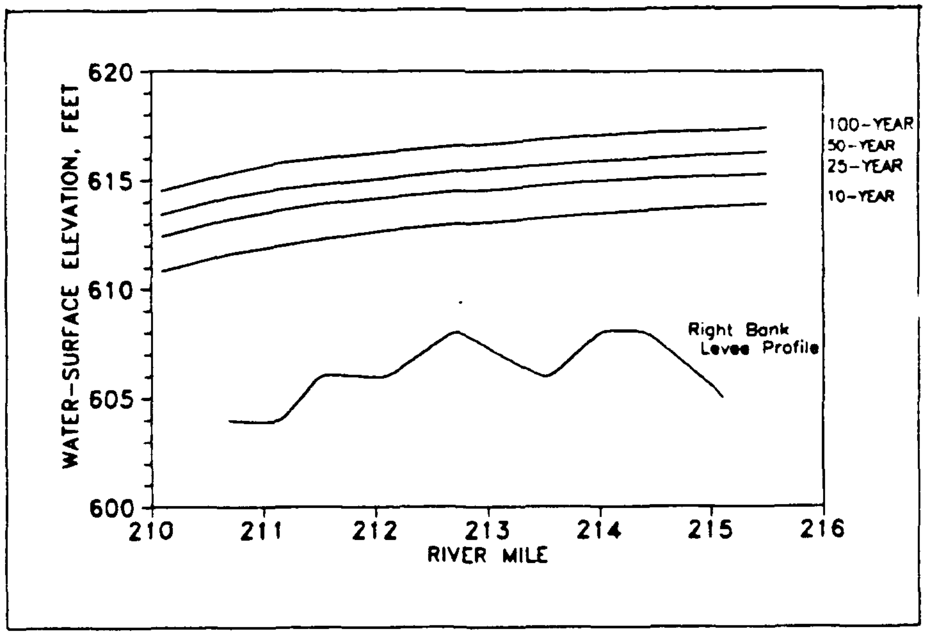

Figure 18. High water profiles with existing levees for 10-, 25-, 50-, and 100-year-RI flood, RM 210 to 216

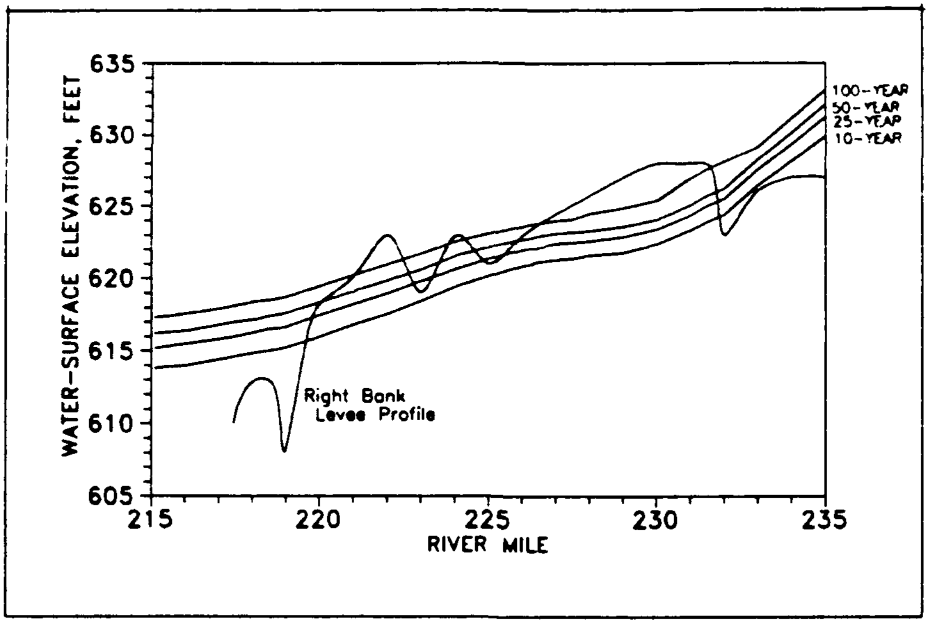

Figure 19. High water profiles with existing levees for 10-, 25-, 50-, and 100-year-RI flood, RM 215 to 235

following the Regulatory Floodway boundary helps to identify what level of flood stage relief could be gained by increasing the overbank conveyance within the floodplain. Levee overtopping was not permitted during these simulations and the flood was assumed to be completely contained by the levee system; thus the simulations identify the maximum impact that levee construction to specific design RI's would have on the flood RI of interest.

25. Computed water-surface profiles for the 10-, 25-, 50-, and 100-year-RI floods are plotted in Figures 20-23, respectively. The longitudinal extent of the detailed study area is also shown in the figures. The figures graphically indicate the amount of flood stage reduction that could be gained by setback of the existing levee alignment to the Regulatory Floodway boundary. Conversely, the figures also show the flood stage increase that would occur if the existing agricultural levee alignment was moved to the channel bank. The effects of conveyance change through the detailed study area cause changes in water-surface elevation (namely, increases the peak water-surface profile for the bank line levee alignment and decreases the peak water-surface profile for the Regulatory Floodway levee alignment) for a distance of approximately 20 miles upstream. Differences in flood elevations rapidly dissipate downstream of the detailed study area due to channel and overbank storage effects. Average differences within the detailed study area

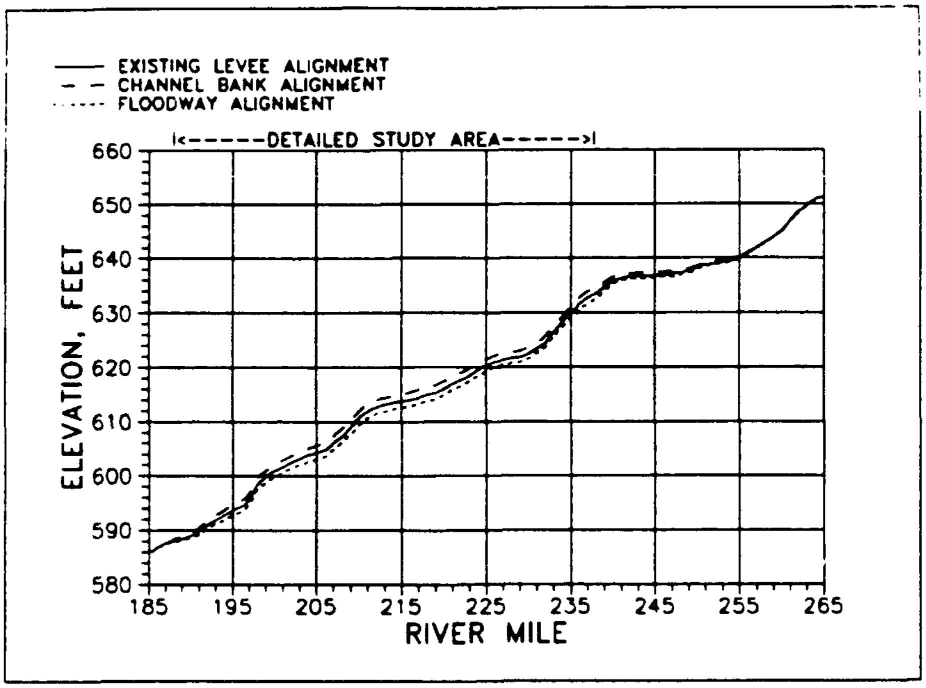

Figure 20. Effects of levee encroachment on peak water-surface elevations, 10-year-RI flood

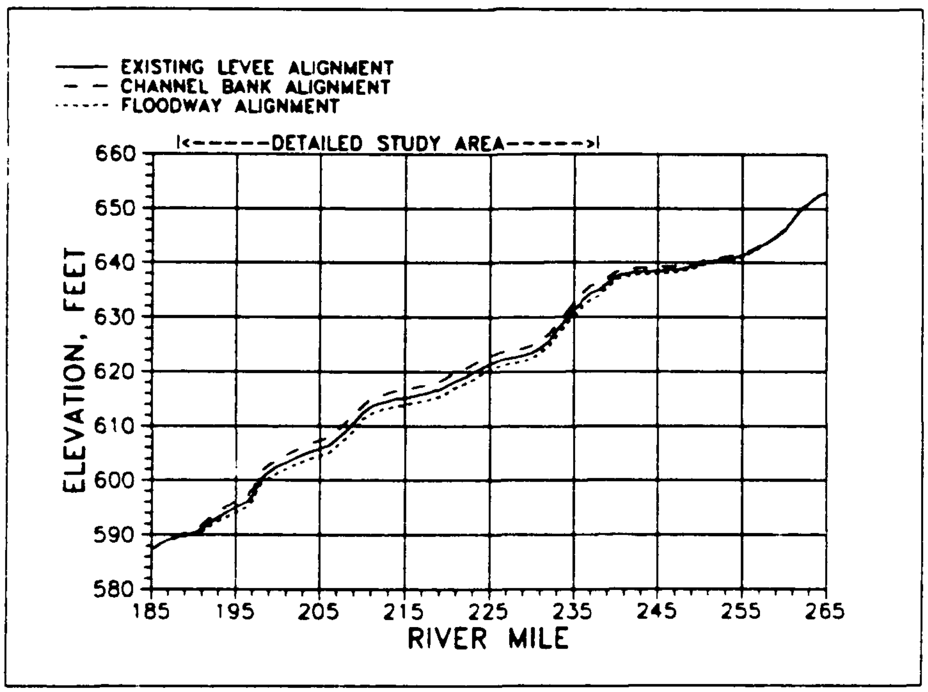

Figure 21. Effects of levee encroachment on peak water-surface elevations, 25-year-RI flood

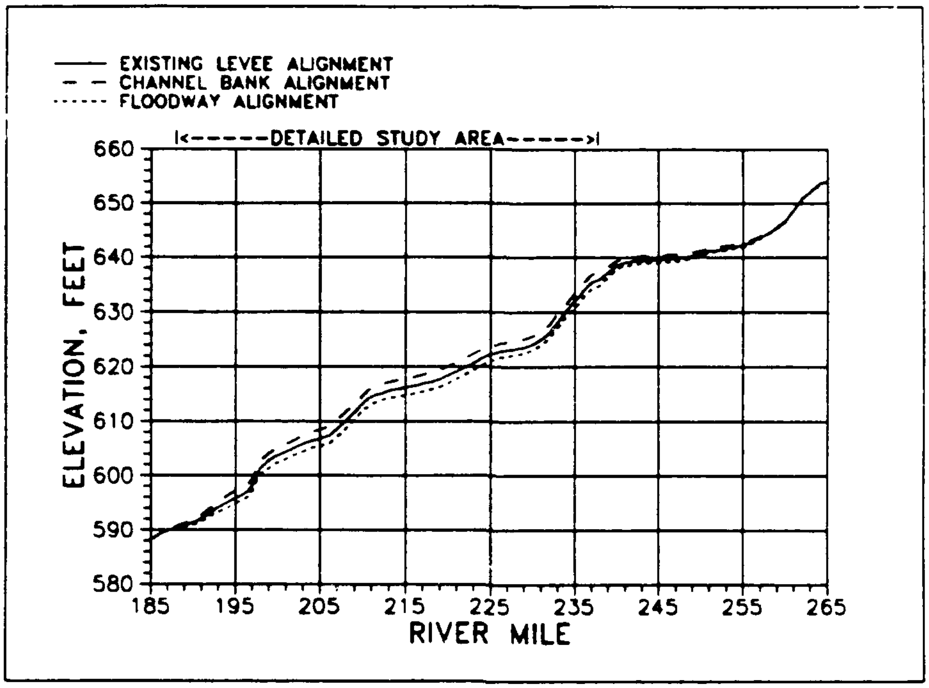

Figure 22. Effects of levee encroachment on peak water-surface elevations, 50-year-RI flood

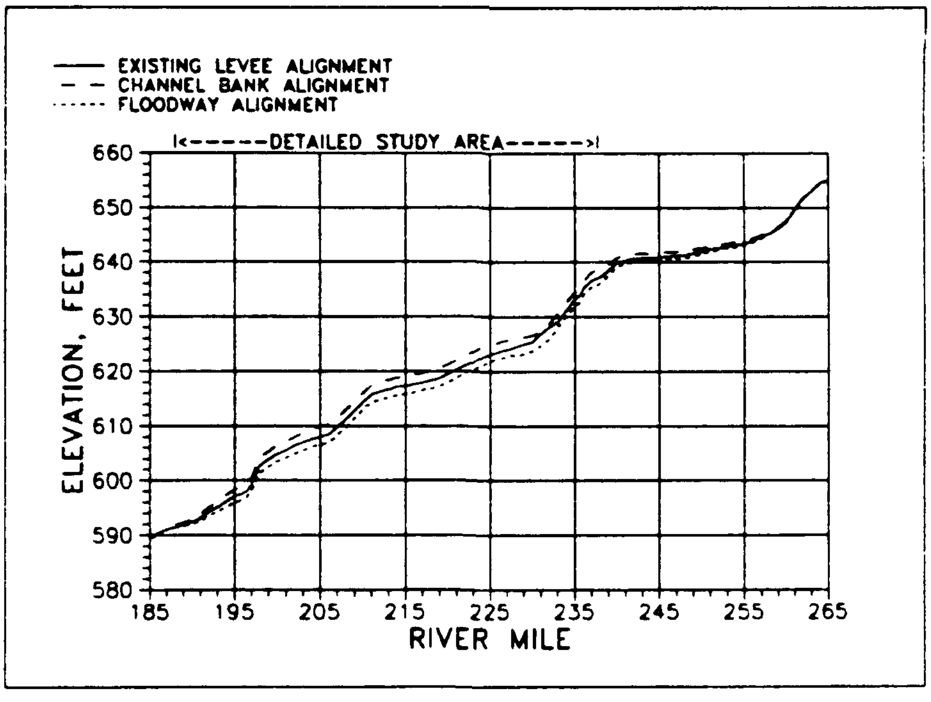

Figure 23. Effects of levee encroachment on peak water-surface elevations, 100-year-RI flood

between the water-surface elevation of the existing levee alignment and the water-surface elevation for the channel bank and Regulatory Floodway levee alignment are given in the following tabulation:

Recurrence Interval, years	Average Water-Surface Elevation Difference, ft, Within the Detailed Study Area of the Existing Levee Alignment Water-Surface Elevation and the Floodway Alignment	Bank Line Alignment
10	-1.16	0.97
25	-1.30	1.07
50	-1.39	1.14
100	-1.50	1.32

Levee Overtopping Simulations

26. Additional simulations that incorporate levee overtopping calculations were completed to identify the impact of agricultural levees on floods of a magnitude greater than the design RI of the levee system. The following combinations of levee design RI and flood RI were investigated:

a. Levee profiles set at the 10-, 25-, and 50-year-RI flood profile overtopped by the 100-year-RI flood.

b. Levee profiles set at the 10- and 25-year-RI flood profile overtopped by the 50-year-RI flood.

c. Levee profiles set at the 10-year-RI flood profile overtopped by the 25-year flood.

27. The simulations were repeated for the three levee alignments described in the previous section. Conceptually, the magnitude of the overtopping depth and the duration of overtopping decrease as the design profile of the agricultural levee system approaches the flood profile. As the design level of the agricultural levee system increases, the potential for impacting and increasing flood elevations for floods greater than the levee design profile increases.

28. Computed levee overtopping depths of the agricultural levee system within the detailed study area for the levee profile design RI-overtopping flood RI combinations described previously for the existing levee alignment, the Regulatory Floodway levee alignment, and the channel bank levee alignment are plotted in Figures 24-26, respectively. Maximum overtopping depths exceed 0.8 ft in all cases.

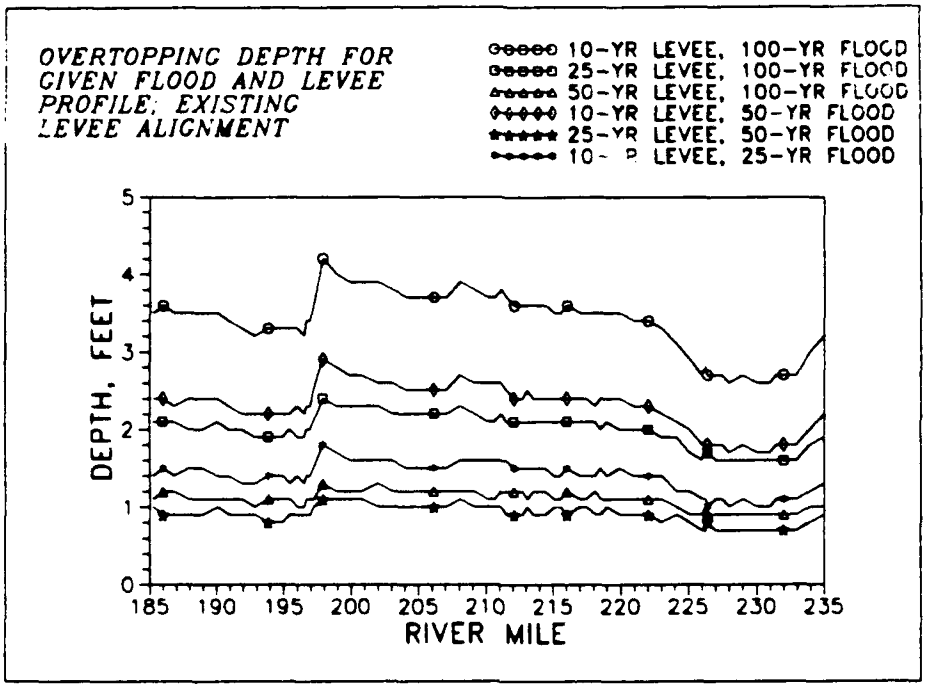

Figure 24. Overtopping depth for given flood and levee profile, existing levee alignment

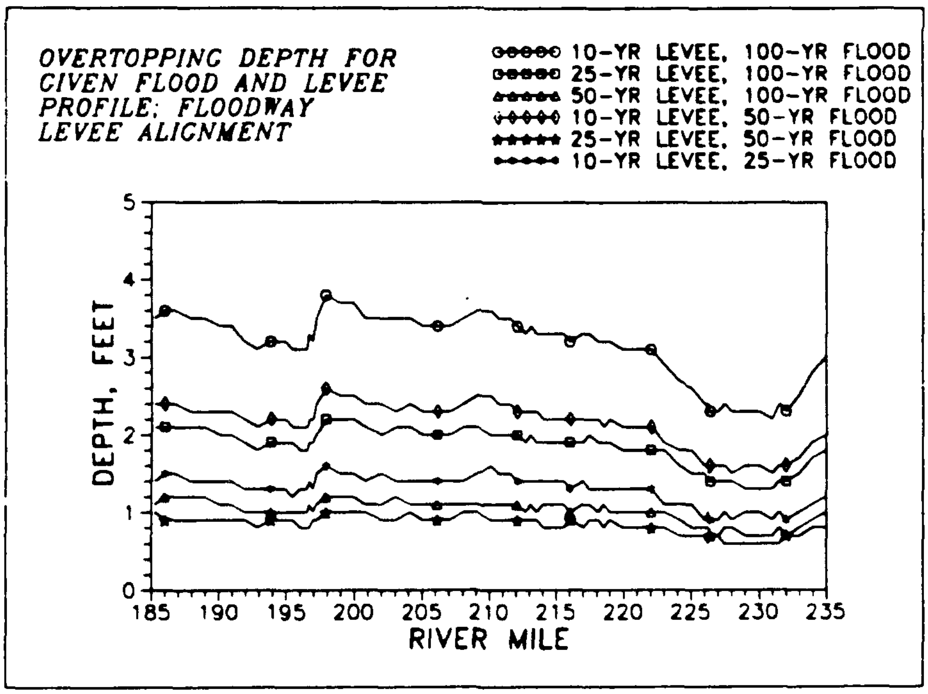

Figure 25. Overtopping depth for given flood and levee profile, floodway levee alignment

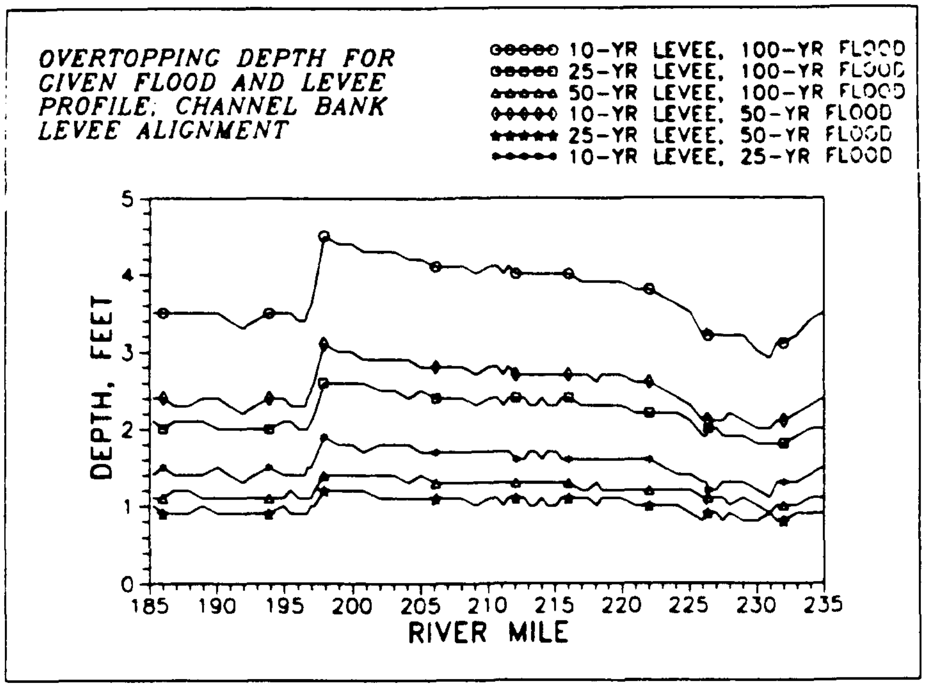

Figure 26. Overtopping depth for given flood and levee profile, channel bank levee alignment

29. The resultant flood profiles for the three levee alignments and for the four flood RI's are summarized in Tables 1-10. The peak water-surface elevations indicate that conveyance on the river side of the levee structure appears to be the most significant parameter affecting peak water-surface elevations.

30. This dependence on conveyance apparently causes the computed peak water-surface elevations for all RI's for the floodway alignment levee profiles to be lower than the existing condition flood elevations. This results from the existing condition numerical model adjustment. The numerical model was adjusted and verified by assigning the floodplain channel Manning's n behind the agricultural levee system a value of 0.07, and assigning the channel Manning's n (which includes the main river channel and the entire floodplain up to the agricultural levee) a value of 0.025 to 0.03.

31. An alternative way to characterize the variation in flood risk for the combinations of flood magnitude, levee profile, and levee alignment is shown in Tables 11-13. Since the water-surface profiles for the 10-year levee floodway alignment are the lowest for any given combination of flood magnitude and top of levee profile, the computed water-surface profiles for this condition are used as base conditions. The difference between the base condition

and computed water-surface elevations for all other levee alignments and top of levee profiles is illustrated.

PART V: RECOMMENDATIONS FOR FLOODPLAIN MANAGEMENT

32. Floodplain managers must consider two aspects of agricultural levee parameters and their impact on flood elevations: (a) the location of the levee system on the floodplain and the amount of floodplain conveyance removed and (b) the elevation of the levee profile. The site-specific results computed from this study indicate that the levee location has the greatest effect on flood elevations. This result reinforces the basic premise of the Regulatory Floodway concept, namely, maintenance of an unobstructed conveyance corridor for passage of floods.

33. For a given levee alignment, the top of levee profile also affects the computed flood elevation. For the 100-year flood, computed flood elevations are equivalent for levee profiles constructed to the 10- and 25-year flood elevations. This indicates that at this location, floodplain regulations based on 100-year flood risk could allow agricultural levee profiles to be built up to the 25-year flood profile, with no allowance for freeboard.

PART VI: IMPACT ASSESSMENT SUMMARY

34. The effects of agricultural levees on computed flood stage of the Missouri River from RM 187 to RM 235 have been documented in this report. The important hydraulic parameters that this study investigated and their effect on computed flood elevations are summarized in the following paragraphs.

a. 100-year flood impacts: The results indicate that for the existing levee alignment, increasing the levee profile to fully confine the 100-year-RI flood increases the flood stage less than 0.4 ft over the flood stage computed with the existing levee system. Increasing the levee profile in this alignment to the 50-year-RI flood induces less than 0.1 ft of flood stage increase, and levees constructed to the 25-year-RI and less have no impact on computed 100-year-RI flood profiles. For the channel bank line levee alignment, 100-year-RI levees would increase the flood stage a maximum of 2.2 ft over the existing condition 100-year flood profile. Levees with a 10-year-RI profile built along the channel bank line would increase 100-year-RI flood profiles a maximum of 1.7 ft. Conversely, relocation of the levee alignment to the Regulatory Floodway boundary and removal of the existing agricultural levee system indicate a reduction in computed 100-year-RI flood elevations for all levee profiles tested.

b. Floodplain conveyance: Overbank conveyance appears to be the most significant controlling effect of the parameters tested on peak flood elevations within this study area. Confining levees were used to compute the maximum impact on flood elevation for the three levee alignments tested. Relocation of the agricultural levee system alignment to the Regulatory Floodway boundary and removal of the existing agricultural levee alignment throughout the detailed study area reduced the peak water-surface elevation on an average from 1.16 ft for the 10-year-RI flood to 1.50 ft for the 100-year-RI flood. Conversely, relocation of the agricultural levee system to the river bank line increased the peak water-surface elevation on an average from 0.97 ft for the 10-year-RI flood to 1.32 ft for the 100-year-RI flood. Propagation of backwater reduction or augmentation upstream of the detailed study area was computed approximately 18 miles upstream of the detailed study area to RM 255. Channel and overbank attenuation of flood stage reductions or augmentations nullifies the effects of the conveyance loss within a distance of approximately 2 miles downstream of the detailed study area to RM 185.

c. Magnitude and duration of stage exceedence: For this application, overtopping stage exceeded 0.8 ft for all levee alignment and flood frequency-levee design profiles tested, and the resultant overtopping duration exceeded 2 days for all flood and levee combinations tested. Computed water-surface elevations in the floodplain area behind the agricultural levee system indicate that these areas fill rapidly. These computations used the submerged weir equation for exchange of floodwaters between the main river channel and the floodplain area behind the levees. Floods in this reach of the Missouri River are characterized by a long duration of high discharge, providing ample time period for overtopping of levee systems and filling of floodplain storage. Due to the long duration of levee overtopping computed in this study, computed flood elevations were not affected by levee breaches in the agricultural levees. An example of a leveed area's peak flood elevations being less than the peak river water-surface elevations can be found in flood hazard studies where extremely high diurnal tides cause the peak river water-surface profiles (US Army Engineer District, Seattle, 1987).

d. Levee freeboard: This analysis ignores the need for freeboard in levee elevation to assure a given level of flood protection. Freeboard allowances are provided in levees to allow for uncertainty in the computed stage-discharge relationship, and the flow-frequency relationship. The statistical estimates of discharge are based on the unbiased best estimator of the discharge-duration-frequency relationship (US Water Resources Council 1982). Statistically, there is a 50 percent chance that the true RI of interest discharge is greater than the RI of interest discharge used in the analysis. Similarly, there is a 50 percent chance that the true RI of interest discharge is less than the RI of interest discharge used in the analysis. Since the consequences of levee overtopping can be severe, levee design practices traditionally incorporate a freeboard allowance to reduce the threat of overtopping. Flood hazard studies commonly ignore the freeboard allowance when determining the level of protection for a given levee system.

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Table 1

Peak Water-Surface Elevation, ft

100-Year Flood, Existing Levee Alignment

	Levee Profile				
RM	Existing*	100-year	50-year	25-year	10-year
240.50	639.95	640.10	639.98	639.95	639.95
234.99	632.80	633.10	632.86	632.80	632.80
230.04	624.70	625.00	624.76	624.70	624.70
225.04	622.78	623.10	622.84	622.78	622.78
219.92	619.03	619.40	619.10	619.03	619.03
215.10	616.95	617.30	617.02	616.95	616.95
210.09	614.18	614.50	614.24	614.18	614.18
205.00	607.63	608.00	607.70	607.63	607.63
199.93	604.48	604.80	604.54	604.48	604.48
596.65	596.90	596.70	596.65	596.65	596.65
190.07	592.40	592.50	592.42	592.40	592.40
185.25	589.50	589.50	589.50	589.50	589.50

* Existing levee alignment and profile.

Table 2

Peak Water-Surface Elevation, ft

100-Year Flood, Bank Line Levee Alignment

	Levee Profile				
RM	Existing*	100-year	50-year	25-year	10-year
240.50	639.95	641.10	640.90	640.85	640.85
234.99	632.80	634.40	634.14	634.08	634.08
230.04	624.70	626.60	626.28	626.20	626.20
225.04	622.78	624.90	624.54	624.45	624.45
219.92	619.03	621.20	620.84	620.75	620.75
215.10	616.95	619.10	618.74	618.65	618.65
210.09	614.18	616.10	615.78	615.70	615.70
205.00	607.63	609.80	609.44	609.35	609.35
199.93	604.48	606.40	606.08	606.00	606.00
194.91	596.65	598.20	597.94	597.88	597.88
190.07	592.40	593.00	592.90	592.88	592.88
185.25	589.50	589.50	589.50	589.50	589.50

* Existing levee alignment and profile.

Table 3

Peak Water-Surface Elevation, ft

100-Year Flood, Floodway Levee Alignment

RM	Levee Profile Existing*	100-year	50-year	25-year	10-year
240.50	639.95	639.50	639.35	639.30	639.30
234.99	632.80	631.90	631.60	631.50	631.50
230.04	624.70	623.80	623.50	623.40	623.40
225.04	622.78	621.80	621.47	621.37	621.37
219.92	619.03	617.90	617.53	617.40	617.40
215.10	616.95	615.90	615.55	615.43	615.43
210.09	614.18	613.20	612.88	612.7[illegible]	612.77
205.00	607.63	606.50	606.13	606.00	606.00
199.93	604.48	603.50	603.18	603.07	603.07
194.91	596.65	595.90	595.65	595.57	595.57
190.07	592.40	592.10	592.00	591.97	591.97
185.25	589.50	589.50	589.50	589.50	589.50

* Existing levee alignment and profile.

Table 4

Peak Water-Surface Elevation, ft

50-Year Flood, Existing Levee Alignment

RM	Levee Profile Existing*	50-year	25-year	10-year
240.50	638.75	638.90	638.78	638.75
234.99	631.80	632.10	631.86	631.80
230.04	623.85	624.10	623.90	623.85
225.04	621.90	622.20	621.96	621.90
219.92	617.95	618.30	618.02	617.95
215.10	615.85	616.20	615.92	615.85
210.09	613.08	613.40	613.14	613.08
205.00	606.45	606.80	606.52	606.45
199.93	603.28	603.60	603.34	603.28
194.91	595.57	595.80	595.62	595.57
190.07	591.30	591.40	591.32	591.30
185.25	588.40	588.40	588.40	588.40

* Existing levee alignment and profile.

Table 5

Peak Water-Surface Elevation, ft

50-Year Flood, Bank Line Levee Alignment

RM	Levee Profile			
	Existing*	50-year	25-year	10-year
240.50	638.75	639.70	639.54	639.50
234.99	631.80	633.30	633.06	633.00
230.04	623.85	625.60	625.30	625.23
225.04	621.90	623.70	623.40	623.33
219.92	617.95	620.00	619.66	619.58
215.10	615.85	617.80	617.48	617.40
210.09	613.08	614.80	614.52	614.45
205.00	606.45	608.40	608.08	608.00
199.93	603.28	605.00	604.72	604.65
194.91	595.57	597.10	596.84	596.78
190.07	591.30	591.90	591.80	591.78
185.25	588.40	588.40	588.40	588.40

* Existing levee alignment and profile.

Table 6

Peak Water-Surface Elevation, ft

50-Year Flood, Floodway Levee Alignment

RM	Levee Profile			
	Existing*	50-year	25-year	10-year
240.50	638.75	638.30	638.15	638.10
234.99	631.80	630.90	630.60	630.50
230.04	623.85	623.10	622.85	622.77
225.04	621.90	621.00	620.70	620.60
219.92	617.95	616.90	616.55	616.43
215.10	615.85	614.80	614.45	614.33
210.09	613.08	612.10	611.78	611.67
205.00	606.45	605.40	605.05	604.93
199.93	603.28	602.30	601.97	601.87
194.91	595.57	594.90	594.68	594.60
190.07	591.30	591.00	590.90	590.87
185.25	588.40	588.40	588.40	588.40

* Existing levee alignment and profile.

Table 7

Peak Water-Surface Elevation, ft

25-Year Flood, Existing Levee Alignment

RM	Levee Profile Existing*	25-year	10-year
240.50	637.65	637.80	637.68
234.99	630.93	631.20	630.98
230.04	623.18	623.40	623.22
225.04	621.13	621.40	621.18
219.92	617.08	617.40	617.14
215.10	614.90	615.20	614.96
210.09	612.10	612.40	612.16
205.00	605.48	605.80	605.54
199.93	602.20	602.50	602.26
194.91	594.75	595.00	594.80
190.07	590.33	590.40	590.34
185.25	587.40	587.40	587.40

* Existing levee alignment and profile.

Table 8

Peak Water-Surface Elevation, ft

25-Year Flood, Bank Line Levee Alignment

RM	Levee Profile Existing*	25-year	10-year
240.50	637.65	638.60	638.44
234.99	630.93	632.40	632.16
230.04	623.18	624.80	624.52
225.04	621.13	622.80	622.52
219.92	617.08	618.90	618.60
215.10	614.90	616.80	616.48
210.09	612.10	613.70	613.44
205.00	605.48	607.30	607.00
199.93	602.20	603.80	603.54
194.91	594.75	596.10	595.88
190.07	590.33	591.00	590.88
185.25	587.40	587.40	587.40

* Existing levee alignment and profile.

Table 9

Peak Water-Surface Elevation, ft

25-Year Flood, Floodway Levee Alignment

RM	Levee Profile Existing*	 25-year	 10-year
240.50	637.65	637.20	637.00
234.99	630.93	630.10	629.73
230.04	623.18	622.50	622.20
225.04	621.13	620.30	619.93
219.92	617.08	616.10	615.67
215.10	614.90	614.00	613.60
210.09	612.10	611.20	610.80
205.00	605.48	604.50	604.07
199.93	602.20	601.30	600.90
194.91	594.75	594.00	593.67
190.07	590.33	590.10	590.00
185.25	587.40	587.40	587.40

* Existing levee alignment and profile.

Table 10

Peak Water-Surface Elevation, ft

10-Year Flood, All Levee Alignments

RM	Levee Profile Existing*	 Existing Agricul-tural Levee	 Adjacent to Riverbank	 Regulatory Floodway
240.50	635.98	636.10	636.80	635.60
234.99	629.65	629.90	630.90	628.90
230.04	622.18	622.40	623.60	621.50
225.04	619.95	620.20	621.40	619.20
219.92	615.63	615.90	617.30	614.80
215.10	613.50	613.80	615.10	612.60
210.09	610.50	610.80	612.00	609.60
205.00	604.00	604.30	605.60	603.10
199.93	600.63	600.90	602.00	599.80
194.91	593.38	593.60	594.70	592.70
190.07	588.93	589.00	589.50	588.70
185.25	586.00	586.00	586.00	586.00

* Existing levee alignment and profile.

Table 11

Difference Between Tabulated Elevation and Base Condition Flood Elevation, 100-Year Flood

		Floodway Alignment Top of Levee Elevation				Existing Alignment Top of Levee Elevation				Bank Line Alignment Top of Levee Elevation			
RM	Base Condition Elevation, ft	10-Year	25-Year	50-Year	100-Year	10-Year	25-Year	50-Year	100-Year	10-Year	25-Year	50-Year	100-Year
240.50	639.30	0.0	0.0	0.05	0.20	0.65	0.65	0.68	0.80	1.55	1.55	1.60	1.80
230.04	623.40	0.0	0.0	0.10	0.40	1.30	1.30	1.36	1.60	2.80	2.80	2.88	3.20
219.92	617.40	0.0	0.0	0.13	0.50	1.63	1.63	1.70	2.00	3.35	3.35	3.44	3.80
210.09	612.77	0.0	0.0	0.11	0.43	1.41	1.41	1.47	1.73	2.93	2.93	3.01	3.33
199.93	603.07	0.0	0.0	0.11	0.43	1.41	1.41	1.47	1.73	2.93	2.93	3.01	3.33
190.07	591.97	0.0	0.0	0.03	0.13	0.43	0.43	0.45	0.53	0.91	0.91	0.93	1.05

Table 12

Difference Between Tabulated Elevation and Base Condition Flood Elevation, 50-Year Flood

		Floodway Alignment Top of Levee Elevation			Existing Alignment Top of Levee Elevation			Bank Line Alignment Top of Levee Elevation		
RM	Base Condition Elevation, ft	10-Year	25-Year	50-Year	10-Year	25-Year	50-Year	10-Year	25-Year	50-Year
240.50	638.10	0.0	0.05	0.20	0.65	0.68	0.80	1.40	1.44	1.60
230.04	622.77	0.0	0.08	0.33	1.08	1.13	1.33	2.46	2.60	2.83
219.92	616.43	0.0	0.12	0.47	1.52	1.59	1.87	3.15	3.23	3.57
210.09	611.67	0.0	0.11	0.49	1.41	1.47	1.73	2.78	2.85	3.13
199.93	601.87	0.0	0.10	0.49	1.41	1.47	1.73	2.78	2.85	3.13
190.07	590.87	0.0	0.03	0.13	0.43	0.45	0.53	0.91	0.93	1.03

Table 13

Difference Between Tabulated Elevation and Base Condition Flood Elevation, 25-Year Flood

		Floodway Alignment Top of Levee Elevation		Existing Alignment Top of Levee Elevation		Bank Line Alignment Top of Levee Elevation	
RM	Base Condition Elevation, ft	10-Year	25-Year	10-Year	25-Year	10-Year	25-Year
240.50	637.00	0.0	0.20	0.68	0.80	1.44	1.60
230.04	622.20	0.0	0.30	0.96	1.14	2.32	2.60
219.92	615.67	0.0	0.43	1.47	1.63	2.93	3.23
210.09	610.80	0.0	0.40	1.36	1.60	2.64	2.90
199.93	600.90	0.0	0.40	1.36	1.60	2.64	2.90
190.07	590.00	0.0	0.10	0.34	0.40	0.88	1.00